Strategic Briefing Report on Battery Chargers and External Power Supplies

February 2008

Content

1 Background

The electrical grid supplies power to homes, businesses and factories in the form of high voltage alternating current (AC). Yet an increasing proportion of electrical equipment found in these buildings actually operates on low voltage direct current (DC). This includes virtually all products using rechargeable batteries, digital displays and screens of various types, remote controls, touch screen controls, transmitters, receivers, timers, light emitting diodes (LEDs), audio amplifiers, microprocessors, memory, or variable speed DC motors. All of these devices require power supplies to convert high voltage AC to low voltage DC at the front end of these products.

In the US, it has been estimated that on average each person owns about five external power supplies. The total electricity flowing through all types of power supplies has been estimated at 6% of the US national electricity consumption.

External power supplies (EPS) and battery chargers (BC) are mainly supplied alongside other OEM products such as laptops, mobile phones, printers, power tools, etc. The OEMs tend to source the EPS / BC based on the power requirements of the main appliance - the energy efficiency is a lesser concern. The user does not have any influence over the energy consumption of the EPS / BC, apart from to disconnect the device when not in use. Power supplies which are left connected to the mains continue to draw power, even when not connected to a device.

In view of this the European Commission decided to address EPS and BC within the EuP Directive and intends to introduce EcoDesign requirements to improve the energy efficiency and environmental performance of all EPS and BC. The justification for applying EcoDesign requirements directly to EPS / BC is because they are products which are "placed on the market and/or put into service as individual parts for end-users and of which the environmental performance can be assessed independently."

In January 2008, the Commission published a draft Implementing Measure which proposes EcoDesign requirements for EPS. The preparatory study concluded that the potential for improving the use phase energy performance of BC is not cost effective, and so BC are not included in the scope if this Implementing Measure.

The efficiency of an EPS varies widely from less than 15% to more than 90% - the remainder is wasted as heat. The efficiency and manufacturing cost of the EPS is dependant on the choice of technology used. The efficiency of an EPS is measured by applying a load on the output (DC) side of the unit. Because an EPS needs to power a product while the product is doing a wide range of tasks, the power supply normally operates at a range of loads. For example, a computer power supply needs to provide more power when the user is running complicated software programmes, compared to when the user leaves the computer idle. As the load on the power supply changes, so does the efficiency of the power supply. For most supplies, the efficiency is measured at 25%, 50%, 75% and 100% of the maximum allowable load, as well as a no load measurement. Another consideration is the output power and output voltage of the power supply. In general, higher wattage power supplies are able to achieve higher efficiencies. For example, a 50 W power supply operating at full load will be more efficient than a 25 W power supply operating at full load. Likewise, higher output voltages generally yield higher efficiencies than low output voltages. So, a power supply rated 25 W at 12 V will tend to be more efficient than a power supply rated 25 W at 3.3 V. However, at any given output power and voltage there is a range of efficiencies. For example, for power supplies with less than 20 W of output power, average efficiencies can be as low as 20% and as high as 80%.

2 Proposed EcoDesign requirements for external power supplies

2.1 Scope

The draft Implementing Measure applies to all external power supplies which have a nameplate output power of less than 250W (i.e. rated power output specified by the manufacturer of less than 250W). It sets EcoDesign requirements both for EPS sold together with the “primary load” (e.g. notebook, monitor, modem, etc) and sold separately. The EcoDesign requirements are closely related to US legislation, the Energy Star EPS programme and Chinese legislation (which is also based on Energy Star).

Halogen lighting convertors (operating low voltage halogen lamps) are covered by scope and the Implementing Measure sets separate EcoDesign requirements and measurement methods for these.

Battery chargers are not in scope of this Implementing Measure. The preparatory study concluded that the potential for improving the use phase energy performance of BC is not cost effective, and that their contribution to the total use phase energy consumption of EPS and BC is less than 5%. This will be reviewed in future revisions to the Implementing Measure.

2.2 Definitions

The draft Implementing Measure contains the following definitions:

1. "External power supply" means a device which
    - is designed to convert alternating current (AC) power input from the mains power source input into lower voltage direct current (DC) or AC output;
    - and is able to convert to only one DC or AC output voltage at a time;
    - and is intended to be used with a separate device that constitutes the primary load;
    - and is contained in a physical enclosure separate from the device that constitutes the primary load;
    - and is connected to the device that constitutes the primary load via a removable or hard-wired male/female electrical connection, cable, cord or other wiring;
    - and has nameplate output power not exceeding 250 Watts
2. "Nameplate output power", in the following denoted by PO, means the output power as specified by the manufacturer (also called rated output power).
3. “Halogen lighting convertor" means an external power supply used with extra low voltage tungsten halogen lamps covered in IEC 60357.
4. “No load” means the condition in which the input of an external power supply is connected to the mains power source, but the output is not connected to any primary load. The “no load” condition is identical to the “off-mode” condition as defined in the draft Implementing Measure for Standby and Off-mode Losses. However, the term “no load” is used here for the sake of international harmonisation.
5. "Active mode" means a condition in which the input of an external power supply is connected to the mains power source, and the output is connected to a load.
6. “Active mode efficiency” means the ratio of the power produced by an external power supply in active mode, to the input power required to produce it.

7. "Average active efficiency" means the average of the active mode efficiencies at 25%, 50%, 75% and 100% of the nameplate output power.

Other expressions used in this implementing measure shall have the same meaning as in Directive 2005/32/EC.

2.3 EcoDesign Requirements

The draft Implementing Measure proposes measurable limits for no-load power consumption and average active energy efficiency. The requirements have been chosen to harmonise with US legislation, the Energy Star programme and the European Code of Conduct for EPS.

The preparatory study showed that the energy efficiency levels which can be achieved by implementing EcoDesign options which represent Least Life Cycle Cost to industry, are better than the levels contained in the US Energy Bill. The US Energy Bill, which is based on the California Energy Commission Phase 2 standards for EPS, sets energy efficiency levels which become mandatory from 1 July 2008. Even though these levels are lower than can currently be achieved by industry, the first phase of the draft Implementing Measure adopts the same levels as the US Energy Bill.

The second phase of the draft Implementing Measure is harmonised against the energy efficiency levels in the Energy Star programme and European Code of Conduct for external power supplies (both coming into force in 2008). The reasons for this are:

- The market penetration of products applying new technologies yielding better energy efficiency levels is expected to grow and become cost-effective by 2011
- The Phase 2 levels provide a clear roadmap with sufficiently long transition periods for product design, both for manufacturers of external power supplies, and for the manufacturers of the “primary load” products
- Harmonisation with the Energy Star and EU Code of Conduct benchmarks provides coherence with further international initiatives;
- This approach is dynamic

The draft Implementing Measure sets separate energy efficiency levels for halogen lighting convertors because lighting convertors are usually operated at full load. Therefore, using an average of efficiencies at several point loads, as done for the other external power supplies, is not appropriate. The suggested levels correspond to the levels the preparatory study identified could be achieved by implementing EcoDesign options which represent Least Life Cycle Cost to industry.

The preparatory study identified that lifetime extension, multiple use and reuse of external power supplies (EPS) and battery chargers (BC) offer significant environmental gains, particularly when combined with the EcoDesign options discussed in the later sections of this report. However in order to achieve this it would be necessary to standardise the connection interfaces between the EPS / BC and the application devices, and to develop groups of devices where the chemical systems of the batteries and the voltage and capacity requirements of the devices can be standardised. This is the subject of an ISO standardisation programme[1] and was considered outside of the scope of the EuP Directive.

[1] COPOLCO 42/2006: An International Standard for Harmonisation for Interfaces for Battery Chargers and Consumer Goods powered by Rechargeable Batteries, October 2006.

2.3.1 Limits for External Power Supplies

a) Six months after this implementing measure has come into force:

No load

- The no load power consumption shall not exceed 0.50 Watt

Average active efficiency

The average active efficiency shall be not less than:

- 0.50 x PO, for PO < 1.0 Watt
- 0.09 x ln(PO) + 0.50, for 1.0 Watt ≤ PO ≤ 51.0 Watts
- 0.85, for PO > 51.0 Watts

b) Two years after this implementing measure has come into force:

No load

- 0.30 Watt, for PO < 50.0 Watts
- 0.50 Watt, for PO ≥ 50.0 Watts

Average active efficiency

The average active efficiency shall be not less than:

- 0.50 x PO, for PO < 1.0 Watt
- 0.08 x ln(PO) + 0.585, for 1.0 Watt ≤ PO ≤ 36.0 Watts
- 0.87, for PO ≥ 36.0 Watts

The no load power consumption and the active average efficiency referred to in paragraphs a) and b) above shall be measured according to the procedure in "Test Method for Calculating the Energy Efficiency of Single-Voltage External Ac-Dc and Ac-Ac Power Supplies", Chris Calwell et al, August 11, 2004

2.3.2 Limits for Halogen lighting convertors

One year after this implementing measure has come into force:

No load

- The no load power consumption shall not exceed 0.50 Watt

Active efficiency

- The active efficiency shall not be less than 0.925
- The no load power consumption shall be measured according to IEC/EN 62301 (revised version)
- The active efficiency shall be measured according to the procedure in the "Australian/New Zealand Standard on the Performance of transformers and electronic step-down convertors for ELV lamps"

3 Status of the proposed EcoDesign Requirements

The draft Implementing Measure for EPS will be discussed at the Consultation Forum meeting on 22 February 2008. An impact assessment is also underway with a completion target of February 2008. This must also be completed before the Consultation Forum can be held.

3.1 Consultation Forum

The Consultation Forum comprises a group of 60 experts including one representative from each Member State and acceding country (in the case of the UK, an official from Defra). It is also open for observers from candidate and EEA countries. The Consultation Forum reports to the Regulatory Committee, which has the final decision on implementation of the EcoDesign requirements.

DEFRA leads on the transposition of the Directive into UK legislation and on EcoDesign requirements for particular product groups such as EPS and BC, working closely with BERR and industry stakeholders.

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On 29 January DEFRA e-mailed the details of the draft Implementing Measure to stakeholders and asked for comments to be returned by Thursday 14th February. The Market Transformation Programme will assist the UK Government in managing this consultation process and any comments should be sent to info@mtprog.com.

To be added to the mailing list for details of this and other stakeholder meetings send an e-mail to sustainability@berr.gsi.gov.uk

3.2 Regulatory Committee

The next step after the Consultation Forum meeting will be submit the Implementing Measure for approval by the EU Regulatory Committee which consists of the Commission and the 27 Member States.

It is anticipated that the EU Regulatory Committee will meet to vote on the Implementing Measure for EPS and BC in July 2008. DEFRA will aim to hold a consultation meeting to discuss the draft Implementing Measure in advance of this EU Regulatory Committee meeting.

If the vote is successful, the Implementing Measure would be submitted for adoption by the European Commission and European Parliament later in 2008. This can take about 5 months to prepare the written procedure and complete the necessary translations.

The final Implementing Measure will specify:

- The products covered
- Application dates
- Generic and specific EcoDesign requirements
- Measurement standards/methods
- Conformity assessment procedures
- Information requirements

Manufacturers' obligations under the Implementing Measure will include:

- Designing the product in compliance with eco-design requirements
- Carrying out conformity assessment - generally by self assessment
- Affixing the CE mark and issuing an EC Declaration of Conformity

4 EcoDesign Options for external power supplies and battery chargers

The January 2007 preparatory study for power supplies and battery chargers analysed a wide range of potential EcoDesign options and assessed which of these would represent the Least Life Cycle Cost for the industry to implement.

Based on this analysis, designers should consider the following EcoDesign options to improve the energy efficiency of power supplies to meet the levels specified in the draft Implementing Measure:

- Replacing linear power supplies by more efficient switched-mode power supplies
- Improving the efficiency of switched-mode power supplies by
  - Reducing rectification losses at low output voltage and high output current through use of Schottky diodes or synchronous rectification
  - Reducing switching losses at high switching frequencies through use of resonant technology
  - Reducing losses from integrated circuits and magnetics at low loads
- Improving the power factor for switched-mode power supplies by
  - Passive power factor correction or
  - Active power factor correction, possibly also including low load switch-off of power factor correction

Lifetime extension, multiple use and reuse of external power supplies (EPS) and battery chargers (BC) offer significant environmental gains, particularly when combined with the EcoDesign options outlined. However in order to achieve this it would be necessary to standardise the connection interfaces between the EPS / BC and the application devices, and to develop groups of devices where the chemical systems of the batteries and the voltage and capacity requirements of the devices can be standardised. This is the subject of an ISO standardisation programme[2] which may well impact the industry in the future.

5 Comparison of linear and switched-mode power supplies

There are two main types of power supply designs: linear and switched-mode. In addition, switched mode power supplies can be sub-divided into two categories depending on whether the switching is carried out by using pulse width modulation (PWM) or resonant/quasi resonant technology. The efficiency, weight / size and inherent electrical noise of these power supplies is summarised in Table 1.

Table 1. Comparison of main types of power supply

Characteristic	Linear power supply	Switched-mode power supply with pulse width modulation (PWM)	Switched-mode power supply with resonant/quasi resonant switching
Weight / size	High	Medium	Low
Electrical noise	Low	High	Medium
Efficiency	30 – 50%	65 – 85%	75 – 95%

The reasons why the industry is moving towards choosing switched-mode power supplies and the issues associated with this can be summarised as follows.

5.1 Size and weight

Linear power supplies use a transformer operating at the mains frequency of 50/60 Hz. This linear transformer is several times larger and heavier than the corresponding transformer in a switched-mode power supply, which runs at a much higher frequency (usually between 50 kHz and 400 kHz).

5.2 Efficiency

Linear power supplies regulate their output by using a higher voltage in the initial stages and then wasting excess voltage or current as heat, which is very inefficient (typically around 30 – 50%). This power loss is a necessary part of how the circuit operates. The power loss can be reduced by improving the design, but never eliminated, even using ideal components. Switched-mode power supplies draw current at full voltage based on a variable duty cycle, and can increase or decrease their power consumption to regulate the load as required. A switched-mode power supply will regulate using Pulse Width Modulation or, at power ratings below 30W, ON/OFF control. In all switched-mode power supplies, the transistors are always fully on or fully off. The only heat generated is from switching losses in the main switching transistors, non-zero resistance in the "on" state, and rectifier voltage drop. By optimising the design, a switched-mode power supply can have an efficiency of more than 95%.

[2] COPOLCO 42/2006: An International Standard for Harmonisation for Interfaces for Battery Chargers and Consumer Goods powered by Rechargeable Batteries, October 2006.

5.3 Radio frequency interference

The currents in a switched-mode power supply are switched at a high frequency which can generate undesirable electromagnetic interference (EMI). EMI filters and RF shielding are needed to reduce this. Linear power supplies generally do not produce EMI.

5.4 Power factor

The current drawn by a simple switched-mode power supply is non-sinusoidal and does not follow the input voltage waveform. Power factor correction circuits are commonly used to improve the power factor. In 2001 the EU implemented the standard IEC/EN61000-3-2 which places limits on the power factor of equipment with an output power of more than 75W. The standard defines four classes of equipment depending on its type and current waveform. The most rigorous limits (class D) are established for personal computers, computer monitors and TV receivers. In order to comply with these requirements all modern switched-mode power supplies with output power of more than 75W include at least passive power factor correction. Improving the power factor for linear power supplies is not as problematic as for switched-mode power supplies.

6 Manufacturing costs and market uptake of switched-mode power supplies

The changeover from linear to switched-mode power supplies at the low power output range is driven primarily by cost, particularly the cost of raw materials. The higher the output power for a linear mode power supply, the more material is required for the transformer coils (ferrite core and copper windings) and also for the housing (due to larger transformers). These raw material costs have become a significant part of the overall product costs. For example, the price of copper has increased by more than 300% since 2000.

At the same time as material costs for linear power supplies have increased, the component costs for switched-mode power supplies have continued to decrease due to greater economies of scale from increased market penetration. There is a break-even point where the materials and component costs for linear power supplies become more expensive than for switched-mode power supplies. Currently this break-even point is somewhere in the range of 15 – 20 W for most applications. For some applications such as mobile phones, this break even point can be even lower (3-4 W) because of mass scale production.

Comparing the resource consumption for two mobile phone external power supplies from the same manufacturer, one using a linear design and the other switched-mode, shows that

- The number of electronic components is higher for switched-mode design but due to the bulkiness of the linear designs, the total weight of the switched-mode power supply is about 50% less;
- Total energy consumed in the manufacture of the switched-mode power supply is about 30% of the energy consumed in the manufacture of the liner power supply.

Even among switched-mode designs, the Bill-of-Materials can vary widely in a given market segment. This depends on several technical aspects such as:

- Circuit layout: including specific measures such as resonant / quasi-resonant switching, primary-side controlled units.
- Level of integration: replacement of discrete components by integration on an ASIC which results in less components and overall smaller size, as well as lower no-load losses and increased efficiency.

- Assembly technology: Surface-mount technology uses smaller but usually more expensive components compared to through-hole technology.

Other factors influencing the shift towards switched-mode power supplies include:

- A trend towards higher power applications
- More mobile applications which require miniaturised power supplies.

Switched-mode power supplies are already available on the market for common power ranges. As such, changing from a linear to a switched-mode power supply does not require a redesign of external power supplies. Switched-mode power supplies can meet the required specifications for almost all AC-DC applications, apart from stationary audio products where the linear design provides a significant advantage through lower noise. A few products run fully on AC (e.g. fairy lights) and in this case a change from an AC-AC linear power supply to an AC-DC switched-mode unit does not make sense.

In 2000, switched-mode power supplies represented 54% of the North American market by number of units sold. In 2005 this had increased to 75% and by 2010 it is predicted to reach 84%.

7 Linear power supply design

The linear power supply is most often used with low-cost, low power consumer products. These linear power supplies, in their most elementary form, step down AC voltage with a transformer, rectify the AC voltage into DC, and convert the resulting variable DC voltage to a linear DC voltage. A simplified diagram of a linear power supply is shown in Figure 1. Although the input transformer can be very efficient, the majority of the losses are in the linear regulator. The linear regulator functions by using a transistor as a series resistance that changes value with changes in load. The current remains relatively constant through the regulator, and so the power drop from the difference in voltage between the output of the transformer and the load is simply 'thrown away' as heat. Consequently, the overall linear power supply is inherently inefficient, typically 45% for a 5 V design.

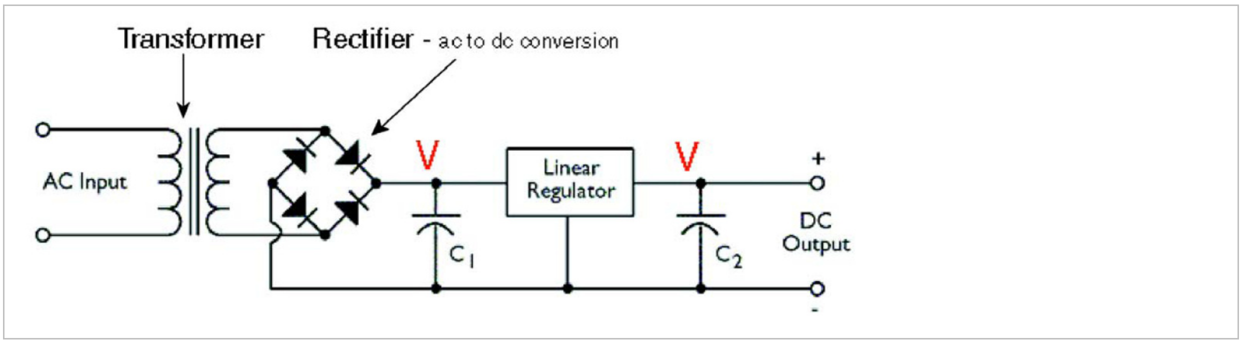

Figure 1. Typical linear power supply circuit

While simplicity and lower inherent noise are attractive advantages of the linear power supply, the maximum achievable efficiency is limited by the fact that the difference between the voltage input to the regulator (rectified DC, V_{in}) and the DC voltage out of the regulator (V_{out}) results in voltage drop across the linear regulator. The power loss within the regulator is the product of the voltage drop and the current flow. In general, the efficiency of the linear power supply can not be higher than the ratio of V_{out} / V_{in}.

So why not make a linear power supply more efficient by choosing an input transformer that results in V_{in} as close as possible to V_{out}? In theory this can be done. However, in practice the variation in voltage supplied by the electrical grid must be taken into account. For the linear regulator to work the voltage from the electrical grid must not drop below a certain minimum level above V_{out}.

Linear transformers use relatively large iron cores and require many turns of copper wire to convert regular 50/60 Hz AC. As a result they are large and bulky. Moreover, linear power supplies do not incorporate smart technology to recognise the standby or sleep mode of the appliance and cut back the consumption accordingly. As a result, they consume much more power than necessary. Transformers in linear power supplies will produce heat and waste power even if there is no low voltage load connected to their output.

8 Switched-mode power supply design

Switched-mode power supplies have a fundamentally different way of converting the high-voltage variable DC to a low-voltage DC. Instead of positioning the transistor as a variable series resistance (as in the linear power supply), the transistor can be used as a switch. With the switch on, energy is transferred to the load. Thus the average energy can be controlled by varying the proportion of time for which the switch is on or off (duty cycle). When combined with an energy storage device such as a capacitor, the on/off pulses are smoothed and the load sees only the average energy. The width of the on time (or pulse width) can be modulated to provide an optimum current and voltage (i.e. power) to the load. This is a switched-mode power supply with pulse width modulation.

Because the PWM method does not have a limit on DC input voltage, there is no need for an input transformer to convert the high voltage AC to a lower voltage AC. A simplified diagram of a typical switched-mode power supply with pulse width modulation is shown in Figure 2.

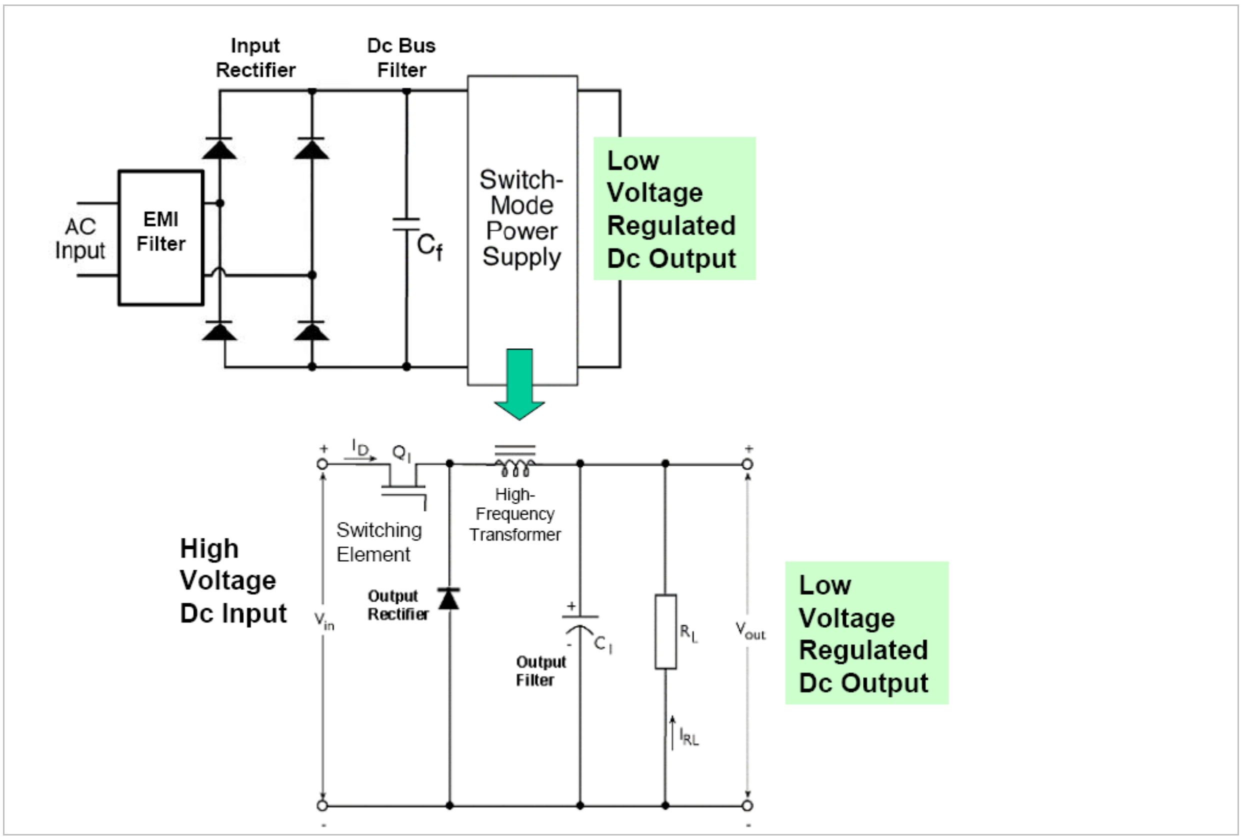

Figure 2. Typical linear power supply circuit

9 Improving the efficiency of switched-mode power supplies

At full load, more than 80% of the losses in a switch-mode power supply arise from the output rectifier and the switching element.

9.1 Rectification losses at low output voltage and high output current

The losses in the output rectifier are due to the forward voltage drop of the diode. The power loss in the diode is the product of the voltage drop multiplied by the current through the diode. Thus, reducing the voltage drop of the diode will increase the efficiency of the power supply.

For output voltages above 10 V or so, ordinary silicon diodes are commonly used, which have a typical forward voltage drop of about 0.7 V. Depending on the current from the output transformer, the efficiency losses of silicon diodes can be up to a few W. For lower output voltages, Schottky diodes are used exclusively as these have a lower forward voltage drop of 0.25 V. A Schottky diode uses a metal-semiconductor junction instead of a semiconductor-semiconductor junction as in conventional diodes. This creates a higher current density which provides the advantages of faster recovery times than silicon diodes (allowing low-loss operation at higher frequencies) and a lower forward voltage drop.

For low output voltage and high output current, one of the ways that manufacturers are improving efficiency is by using a relatively new technique called synchronous rectification, which replaces a passive diode with an active switch such as a MOSFET transistor. Compared to Schottky diodes, MOSFETs have even lower "on"-state voltage drops and can switch at even faster speeds. Synchronous rectifiers based on MOSFET transistors are now widely used in electronic power supply units designed for very low output voltages (where the voltage drop in an ordinary rectifier would represent an unacceptable fraction of the total output voltage). As microprocessor voltages continue to move from 5 V to 3.3 V, 2 V and even lower, the use of synchronous rectification will become essential to making power supplies which are more than 80% efficient.

At light load, the losses in the power supply arise mainly from integrated control circuits and magnetics (transformers and inductors). For products which spend considerable amounts of time under light load then these losses can be significant. To minimise losses at light load, designers will often employ technologies such as digital control, frequency scaling, low-loss capacitors and inductors, non-shunt current sensing, and better packaging of discrete components.

While synchronous rectification is essential to improving efficiency in high output power/low voltage power supplies, it can reduce the efficiency of very low wattage power supplies (<10 W). This is because the use of synchronous rectification requires additional fixed losses, such as for the gate driver, which are not present with diodes. While this additional power requirement is much lower than the efficiency gain due to reduced diode losses at high power, it becomes significant at low output power levels.

Some advanced designs incorporate a hybrid where diode-based technology is used for the low power mode and at higher loads a frequency scaling technology is used to run a MOSFET power switch instead.

9.2 Switching losses at high switching frequencies

The maximum efficiency attainable by a switched-mode power supply with pulse width modulation (PWM) is related to the switching frequency of the power switch, which generally falls in the 10 to 100 kHz range. In the last decade, switching frequencies have begun to increase, as manufacturers push to make supplies fit smaller form factors. Smaller designs are usually more efficient. Higher switching frequency also provides a faster dynamic response. However, increasing the switching frequency of PWM power supplies beyond 30 to 50 kHz typically increases switching losses.

Switching loss is the power dissipated by the switch as it changes state. Although today's switches are very fast, they nevertheless require some time to change from on to off. During this time, the voltage across the device increases while the current decreases. The sum of the instantaneous product of the voltage and the current is defined as the switch loss.

Improvement in switch design (from Bipolar to MOSFET) will result in lower turn-on and turn-off times, however it is impossible to make a switch with a zero turn-off and turn-on time. An alternative to overcoming switching losses is to use resonant switching. Resonant technology attempts to minimise the switching losses by shaping the voltage and/or current waveform to be as close to zero as possible during the time periods that switching occurs.

To do this, designers have developed a variety of configurations to take advantage of improvements in device characteristics. This generally involves some form of inductor and capacitor circuit to form a resonance that causes the reshaping of the waveform to enable zero voltage and/or zero current switching. Techniques include:

- Zero current switching (ZCS)
- Zero voltage switching (ZCS)
- Soft switching and phase controlled resonant inverters
- Quasi-resonant fly-back and push-pull invertors

Resonant technology by itself does not necessarily mean a higher efficiency than PWM designs. However, resonant technology allows operation of power supplies much more efficiently at higher switching frequencies.

10 Reducing radio frequency interference for switched-mode power supplies

Switched-mode power supplies generate inherent electromagnetic interference and require the incorporation of filters to limit the effect. The capacitors in these filters allow a small amount of leakage current to flow. The more effective the filter at suppressing the interference, the more leakage it is likely to produce. For a conventional switched-mode power supply with pulse width modulation there is therefore a trade-off between EMC performance and leakage current.

Electromagnetic noise increases with increasing switching frequencies. An alternative to overcoming increased electromagnetic noise at higher switching frequencies is to use resonant technology. In addition to reducing switching losses, resonant technology results in less inherent electromagnetic noise from the switched-mode power supply.

11 Power factor correction for switched-mode power supplies

The power factor of an AC electric circuit is defined as the ratio of the real power to the apparent power, and is a number between 0 and 1. Real power is the capacity for the circuit to perform work and is measured in Watts. Apparent power is the product of the current and voltage which is supplied to the circuit and is measured in volt-amperes. The significance of the power factor of a circuit is that utility companies supply customers with apparent power in volt-amperes, but bill them for Watts of real power used. Power factors below 1.0 require a utility company to generate more volt-amperes to supply the real power used by the customer. This increases generation and transmission costs. For example, for a circuit with a power factor of 1 to carry out work at a rate of 1 Watt requires the utility company to supply 1 kVA of apparent power to the circuit. For a circuit with a power factor of 0.2 to carry out work at a rate of 1 Watt requires the utility company to supply 5 kVA of apparent power to the circuit.

A typical switched-mode power supply first makes a DC bus, using a bridge rectifier or similar circuit. The output voltage is then derived from this DC bus. The problem with this is that the rectifier is a non-linear device, so the input current is highly non-linear. That means that the input current has energy at harmonics of the frequency of the voltage.

The high harmonics content of the input current for a switched-mode power supply without power factor correction results in a power factor of 0.55 to 0.65. In 2001 the EU implemented the standard IEC/EN61000-3-2 which sets limits on the harmonics of the AC input current up to the 40th harmonic for equipment with an output power of more than 75W. The standard defines four classes of equipment depending on its type and current waveform. The most rigorous limits (class D) are established for personal computers, computer monitors and TV receivers. In order to comply with these requirements all modern switched-mode power supplies with output power of more than 75W include at least passive power factor correction.

The simplest way of improving the power factor by controlling the harmonic current is to use a filter (so-called passive power factor correction). The filter is designed so that it passes current only at the frequency of the voltage (e.g. 50 or 60 Hz), and kills the harmonic current. The power factor can then be improved to about 0.7 to 0.75 using capacitors or inductors as required. However, this filter requires large-value high-current inductors, however, which are bulky and expensive.

An alternative is active power factor correction where a boost converter is inserted between the bridge rectifier and the main input capacitors. The boost converter attempts to maintain a constant DC bus voltage on its output while drawing a current which is always in phase with and at the same frequency as the line voltage. Another switch-mode converter inside the power supply produces the desired output voltage from the DC bus. With active power factor correction the power factor can be improved up to 0.99.

Active power factor correction requires additional semiconductor switches and control electronics, but permits cheaper and smaller passive components. Due to their very wide input voltage range, many switched-mode power supplies with active power factor correction can automatically adjust to operate on AC power from about 100 V (Japan) to 240 V (UK).

Active power factor correction requires an additional swiched-mode converter, which has its own power consumption. The power consumed by the additional swiched-mode converter can be significant under low load or no-load conditions. To combat these energy losses, some switched-mode power supplies incorporate additional controls which switch off the active power factor correction at low loads. This has been implemented by several manufacturers to comply with mandatory standards in California which require less than 0.75W no-load losses.

12 Action Plan

The major impact from a design viewpoint will be on the power supply manufacturers who will have to carefully consider the implications of the proposed EcoDesign requirements.

EPS manufacturers should asses the current energy efficiency of their units, and identify the most appropriate design options that will achieve the energy efficiency and power consumption limits. Manufacturers should then develop a plan for how the will implement these design options to comply with the power consumption restrictions by the deadline date.

Manufacturers of linear power supplies should consider and plan for a change to switched mode technologies, which already dominate the market. As mentioned above, the exception might be in AC/AC applications or for non-portable audio equipment where a linear power supply has significantly lower noise interference than a switched-mode power supply.

Manufacturers of switched-mode power supplies should consider how they will implement the required improvements in efficiency of their products to meet the limits in the draft Implementing

Measure. Manufacturers should also follow closely the trends in the end-use power requirements and newer technologies such as solar powered power supplies and chargers.

Regarding supply chain issues, none of the proposed EcoDesign requirements will require manufacturers to source any special or unusual components or materials. However, manufacturers will need to ensure that any new components or materials they use in their EPS / BC do comply with the RoHS materials restrictions so that they can be sold for use with a wide range of devices. Like all companies in the electronics sector, EPS / BC manufacturers will need to monitor the implementation of any future materials restrictions. These may arise from the review of the RoHS Directive in 2008 or from the implementation of the REACH Regulations.

In addition to the proposed EuP EcoDesign requirements, manufacturers should also track the development of the ISO standardization programme which is aiming to standardize the connection interfaces between EPS / BC and the application devices, and to develop groups of devices where the chemical systems of the batteries and the voltage and capacity requirements of the devices can be standardised.

Conformity assessment against the Implementing Measures will be based on self assessment. EPS manufacturers will be required to prepare a technical file or dossier containing a record of the design measures introduced, any harmonised standards used and any measurement or test data. The draft Implementing Measure specifies the measurement standards that must be used. The manufacturer can then sign an EC Declaration of Conformity with the implementing measure and affix the CE marking to the product. As it is likely that these products are already CE marked under product safety and EMC legislation then the manufacturer must integrate the new EcoDesign requirements into his CE marking regime without impinging on these other requirements.