

# High Efficiency DC/DC Power Converters Reduce System Costs in Telecommunication Systems

*High efficiency power converters are now available for telecommunications applications. These help reduce the system cost over its lifetime through better reliability, higher MTBF, less thermal management and less conducted EMI. Initial higher cost for the modules is outweighed by the many technical benefits that lead to an overall lower system cost.*

## High Efficiency DC/DC Power Converters

### 1.1 The History of Power

Power supplies have been manufactured in quantity since the early 1920s. These were called linear supplies (see Section 1.2) and were used to power radios. These supplies used voltage regulator tubes (similar to a zener diode) to produce a stable output. The output set point was determined by rotating certain control knobs on the supply. An unfortunate effect of this method was that the tube tended to get very hot due to the large power dissipation in the device. In those days, happily, one cared not for such things as long as the element did not melt or the plates glowed red.

With the introduction of semiconductors in the 1950s the high power dissipation in power supplies became important as designers wished to avail of this new technology (significant space saving and tighter design tolerance). Early products using these transistors were limited to low input voltage models and low power levels for reliability reasons. High power applications still needed a vacuum tube or (in the 1950s and '60s) magnetic amplifiers. It was also around this time that the switching power supply was invented. However, the applications of this technology were limited due to the audible whistle developed as a result of the low switch frequencies (50Hz) employed.

The energy crisis of the 1970s spurred on efforts to develop more efficient methods of power conversion. The development of low loss ferrite cores and high-speed bipolar transistors at around this time allowed the design of high-frequency (20kHz) SMPSs that were now inaudible. Higher operating frequencies also have the beneficial effect of allowing more compact (smaller) power supply designs.

The 1980s saw improvements in MOSFET technology that allowed operating frequencies of 100kHz and higher. This led to further reductions in the size of PSUs.

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### 1.2 Linear versus Switching Power Supplies

As previously noted, the first power supply topologies were linear rather than switchmode. Both linear and switched power supplies regulate their output voltage over a given current range. However, the method by which the output voltage is regulated differs. This is, in fact, the major disadvantage with the linear power supply. Any excess input power is dissipated as heat and this drastically reduces the operating efficiency. A typical efficiency figure for a linear power supply is 40%.

The operating principle of the linear power supply can be explained by considering the simple electronic circuit in Figure 1. The 12V zener, CR1, clamps the output voltage,  $V_{out}$ , to  $12V - 0.7V^* = 11.3V$ . Assume, for this example, that the output is connected to a constant current load,  $I_L$ , of 1A. If the input voltage,  $V_{in}$ , is increased then the voltage drop across R also increases since  $V_r = V_{in} - (11.3V + 0.5V^\dagger)$ . Therefore, the power dissipated in the resistor is  $V_r \times I_L$  which increases as  $V_r$  (or  $V_{in}$ ) increases.

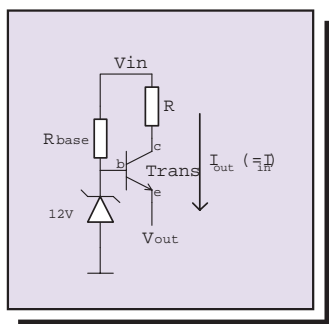


Figure 1 - Simple Linear Supply

This high power dissipation is undesirable because it requires more input power from the source for a given output power. From Equation 1 it is clear that the linear supply's efficiency decreases as the input power increases. In order to have high efficiency one must

ensure that  $P_{in}$  is as close as possible to  $P_{out}$ .

$$\text{Efficiency(\%)} = \frac{P_{out}}{P_{in}} \times 100$$

Equation 1

To show how the efficiency of the linear supply is affected by changes in input voltage, consider three inputs: 18V, 24V and 36V. Calculate the efficiency of the supply using Equation 2 when the output current is 1A (remembering that, in this case, output current = input current) and the output voltage is 11.3V. The results for each input voltage is shown in Table 1 where it is clear that the linear supply's efficiency drops very quickly as the input voltage increases.

$$\text{Efficiency(\%)} = \frac{V_{out} I_{out}}{V_{in} I_{in}} \times 100$$

Equation 2

Input Line Voltage	Efficiency
18V	62.8%
24V	47.1%
36V	31.4%

Table 1 - Linear Supply Efficiency Over Input Line Voltage

This situation is greatly improved by using a switching topology, Figure 2. What happens in this case is that a control signal tells the switch, S, when it needs to turn on and off so that the correct amount of energy is transferred to the output. The principle used is called PWM - pulse width modulation.

\* The voltage drop across the transistor base-emitter junction is 0.7V.

† The voltage across the collector-emitter junction is typically 0.5V.

With PWM the input signal is chopped into pulses. These are then averaged to give a rectified dc level. The longer the on time of the pulse with respect to its off time the higher is the regulated dc voltage.

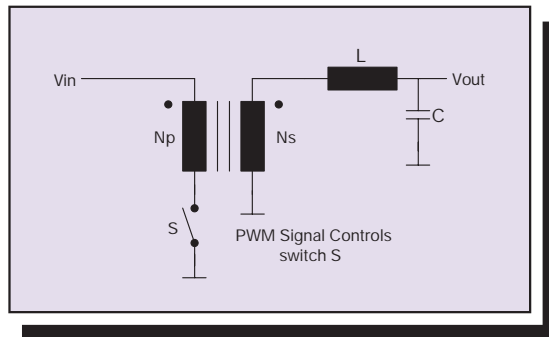


Figure 2 - Switching Topology

Note that the switched converter in Figure 2 requires an output filter, L and C, to smooth out the pulsed waveform produced by the switching action. The filter averages the pulse waveform to produce a low-noise, rectified output signal. This filter is not required for the linear supply because the waveform is not chopped, see Figure 1, and this means that linear supplies will generally be better than switched supplies for applications that require very low levels of noise on the output voltage waveform.

The difference between linear and switched power supplies can now be explained using Equation 3.

$$\text{On time of switch} \propto \frac{1}{V_{in}}$$

Equation 3

This equation tells us that the on-time of the switch increases as the input voltage decreases and vice versa.

This controlled turning on and off of the power switch

saves a lot of input energy normally lost in a linear power supply and is the primary reason for the increased efficiency of switch-mode power converters over linear supplies. Continuous improvements in components and power converter topologies have allowed greater efficiency figures than ever before but the fundamentals remain the same.

### 1.3 Nomenclature

There is some confusion regarding what constitutes a high efficiency converter and what is standard. This confusion is a result of the way power conversion has developed, see Section 1.1. When switch-mode power supplies were first used in competition with linear supplies they were touted as being high efficiency converters. Of course this was true - the average linear power supply was only 40% efficient unless the input voltage was close to  $V_{out}$ , see example in Table 1, whereas the early switching supplies were almost twice this value.

However, when switch-mode power supplies replaced linear supplies as the industry norm, efficiency figures of 80% and greater became increasingly regarded as standard.

A new generation of power supplies has emerged in the past number of years that make use of superior components and techniques such as synchronous rectification and advanced topologies to drive efficiency figures up to 90% and beyond. These are sometimes called ultra high efficiency units but, with shifts in attitude on what an acceptable efficiency benchmark is, these are now more correctly described as high efficiency power converters.

## High Efficiency DC/DC Power Converters

### 1.4 Introduction

This document intends to highlight the very real economic benefit to the customer of using high efficiency switch-mode power supplies in his system. The analysis will start with listing the attributes associated with high efficiency power supplies. The next section will be devoted to analysing each of these attributes so that the reader may understand the why they are beneficial. A glossary of terms used throughout the paper is included in Section 7 to assist those not familiar with power supply nomenclature.

In particular, the potential cost saving in using high efficiency rather than standard efficiency converters will be alluded to in each section. A case study in Section 4 will look at a hypothetical situation in which a system designer has a choice of a standard efficiency dc/dc converter or a higher efficiency one which costs slightly more.

The emphasis on cost is deliberate and important. It may seem prudent to a procurement specialist to buy standard efficiency units for his system, especially for high volume orders, rather than more expensive high efficiency counterparts as can be seen in Table 2. This paper will prove the fallacy of this thinking.

The choice facing the consumer is whether to buy unit LOW\_EFF, a standard efficiency (75%) 40W 2.5V output device, or unit HI\_EFF, a high efficiency (86%) 40W 2.5V output device which costs \$2.5 more. Unit HI\_EFF could, for example, be a trimmed down EXA40 48S2V75 available from Artesyn technologies.

Unit HI_EFF price (\$)	47.5
Unit LOW_EFF price (\$)	45
Price difference (\$)	2.5
Units per system	30
Saving per system (\$)	75
Number of systems	10,000
Overall cost saving (\$)	750,000

*Table 2 - Initial Cost Saved by Procuring Standard Efficiency Converters*

The assumed costs for these hypothetical devices are typical of what one may expect of 40W dc/dc converters in quantities of 10k and more. The perceived customer has an application that requires systems containing thirty 40W dc/dc power supplies and ten thousand such systems are required worldwide. The systems are each powered by a front-end ac/dc power supply. The impact of choosing a high efficiency solution rather than the cheaper standard efficiency products will be investigated and the impact to the customer highlighted at every opportunity.

## 2 Attributes Associated with a High Efficiency PSU Design

A high efficiency dc/dc converter will exhibit enhanced performance when compared to one of standard efficiency. The attributes associated with high efficiency are listed below and explained in greater detail further on.

High efficiency units:

- Require less input power.
- Have lower P<sub>diss</sub>.
- Are cooler.
- Have increased reliability/MTBF.
- Can potentially have smaller components and higher power density.

- Have less input filtering (cheaper and more space efficient).
- Cost less to run - lower utility bills.
- Enable efficient low Vout designs.
- Allow the end user reduce system costs over the product lifetime.

### 3 Benefits

In the following subsections each parameter listed in Section 2 is explained and its impact on the end-user highlighted.

A hypothetical case study in Section 4 will demonstrate how much can be saved over the product lifetime. The paradigm of lower cost with better performance and reliability is now available to the system designer.

#### 3.1 Lower Power Dissipated

The efficiency of a power supply was defined in Equation 1 but, for this section, it is better to re-write the equation as in Equation 4.

$$\text{Efficiency (\%)} = \frac{P_{\text{out}}}{P_{\text{out}} + P_{\text{diss}}} \times 100$$

Equation 4

It is immediately obvious that a high efficiency converter has lower P<sub>diss</sub> than a standard efficiency converter if they both have the same P<sub>out</sub>. Lower power dissipation means that there is less heat to remove from the unit and thermal management is easier.

If the efficiency of a 40W power supply is increased from 75% to 86%, as in the later case study, the unit's P<sub>diss</sub> decreases by a staggering 4.4W! The lower the P<sub>diss</sub>, the cooler the power supply. Lower operating temperatures impact the design in a number of ways:

- Higher MTBF and a lower failure rate.
- Can use a smaller component, e.g. smaller switching FET, because its P<sub>diss</sub> is lower.
- Can therefore design a smaller power supply - increased power density
- If a heatsink was required to ensure a SOT for the device then this may not now be required or a smaller heatsink may do.
- If component temperatures are sufficiently reduced the designer may opt for open-frame products (no case or potting) and realise the benefits thereof<sup>[1]</sup>. The cost can be further reduced if a metal baseplate can be avoided in favour of FR4.
- When the power supply runs cooler the product can be used in higher ambient temperature environments.
- Alternatively, one may run the unit at the same ambient and take advantage of:
  - i. Increased thermal de-rating
  - ii. Increased output power capability
  - iii. Higher MTBF

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### 3.2 Increased Reliability Means Lower Overall System Cost

A device's reliability increases as its operating temperature is reduced, as mentioned in Section 3.1 above. When calculating the MTBF of the power supply the lower thermal stress on the high efficiency unit will yield a higher MTBF. For example, a part's MTBF may double if its operating temperature is reduced by 20°C. This means less frequent field failures compared to a standard efficiency unit.

Increased product lifetime is very significant in systems where reliable operation is paramount and where systems are in remote/inaccessible regions.

### 3.3 Component Size/Rating

A high efficiency power supply will have less  $P_{diss}$  in the power train - FET, transformer, output diodes, output inductor - than a standard efficiency converter. Power components will therefore run cooler (better thermal de-rating) in a high efficiency converter.

Rather than take advantage of better thermal de-rating the designer may take advantage of lower  $P_{diss}$  to reduce the size of some of the larger power components such as the transformer and the switching FET. This would result in a converter with a higher power density ( $W/m^3$ ) than before and take up less space on the application's layout. The converter's weight would also be reduced. This would make mounting on vertical racks easier and may eliminate the need for holding clamps.

In certain cases the designer may be able to combine obtaining a higher power density with lower thermals - a win-win situation!

### 3.4 Input Filtering

Input power reduces as converter efficiency increases if  $P_{out}$  remains constant (Equation 1).

It is for this reason that the power dissipation in the input filter inductor, the main switch and the transformer reduces as the converter efficiency increases. The dissipated heat in these components will reduce by  $\Delta I_{rms}^2 R$  where  $\Delta I_{rms}$  is the change in rms input current due to higher efficiency.

Another benefit of having lower input currents is that the reflected EMI is reduced. A more efficient device will therefore need less filtering than a standard efficiency converter.

Consider the rms input current requirements of unit LOW\_EFF and unit HI\_EFF, see Table 3. The input current was calculated for the worst case input condition - lowest acceptable input voltage, 36V.

The input voltage ripple will also decrease with the input current demand if the switching frequency remains constant. This means that less bulk capacitance is required than in the standard efficiency converter. How this impacts cost is discussed below.

	Efficiency (%)	$I_{in}$ (A)	$I_{in}^2$ (A)	$\Delta P_{in}$ (%)
Unit LOW_EFF	75	1.481	2.193	N/A
Unit HI_EFF	86	1.292	1.699	23.9

Table 3 - Input Current Requirements

The size of the filter inductor is affected by the input current demand - higher current means more copper and a higher saturation limit. This means that filter inductors

for high efficiency converters are, in general, smaller and cheaper than those required for standard devices.

The external filter required by the standard efficiency converter (Unit LOW\_EFF) to conform to Class B conducted emission standards consists of eight 1812 470nF 100V ceramic capacitors and a 22mm x 22mm 47µH inductor. The cost of the filter is summarised in Table 4 below.

The external filter required by the high efficiency converter (Unit HI\_EFF) for conformance to conducted EMI class B is the same as for the standard converter but with six capacitors, not eight. Therefore, as seen in Table 4, the high efficiency converter costs 22¢ less per unit to filter than the standard efficiency unit. The cost benefit would be greater if the reduction in input current was sufficient to allow a smaller filter inductor.

Component	Cost (\$)
1812 capacitor	0.11
22mm <sup>2</sup> inductor	0.36
Unit LOW_EFF filter cost	1.24
Unit HI_EFF filter cost	1.02

*Table 4 - Input Filter Costs*

Table 4 shows that each time Unit HI\_EFF rather than Unit LOW\_EFF is bought for a system requiring Class B filtering, such as that in our case study in Section 6, \$0.22 per unit is saved on the end user's total cost of ownership. In this case study the total cost saved with regard to dc/dc filtering alone is \$66,000.

### 3.5 Running Costs

A higher efficiency PSU will draw less current from its supply (battery or dc rail). This results in longer battery lifetimes, if the batteries are on, or smaller utility bills - an ongoing saving over the full product lifetime.

The battery lifetime increases because less current drain allows the battery hold up longer than in the standard efficiency case where the current drain is higher. This means that there is less recharging required per year than would be the case with the less efficient system. The utility savings are also non-trivial as determined in the case study, Section 4.

The higher MTBF figures and superior reliability mean less replacement modules are needed over the system lifetime. Typically, a high efficiency unit with sufficient derating to double its MTBF with respect to the standard efficiency device would need only half as many replacements over the product lifetime compared to the standard efficiency unit. The cost of sending out personnel to repair/replace the unit must also be included in the total cost of the power supply in the system.

The space and cost savings realised by designing units with a higher power density, Section 3.1, may help to reduce the size of the customer's application racks or increase the electronics density on the existing racks.

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### 3.6 Low Vout Possible

One of the prevailing trends in electronics is the continuing proliferation of ICs requiring lower supply voltages at high power. Whereas five years ago most telecom ICs required 5V supplies there is an increasing shift towards 3.3V, 2.5V and even lower voltages.

Power suppliers must follow this trend with units offering low voltages at varying power levels. Artesyn Technologies' EXA40 48S1V8 delivers 8A at 1.8V for just such applications. The unit has an external trim pin that allows the output voltage to be user-adjusted  $\pm 10\%$  if this is required.

If a standard efficiency topology was used to design such a low voltage output converter, using schottky diodes in the output stage, the voltage drop across the diodes would account for too much  $P_{diss}$ . For example, if a 0.4V schottky is used in a 1.8V 8A PSU one would see a power dissipation of  $0.4V \times 8A = 3.2W$  in the output diodes alone! This  $P_{diss}$  is highly undesirable as it represents 22% of the 14.4W output power. This means that the unit is already limited to 82%\* efficiency before all the other losses are included. This is unacceptable.

The solution is to use a high efficiency output arrangement in which synchronous rectifiers replace the schottky diodes. A typical resistance for SRs is  $14m\Omega$  (IRL3103D1S). The power loss in the 1.8V 8A converter with this component is now only 0.896W or 6% of the output power - a clear improvement. Even better SRs such as the IRL3803S with an  $R_{ds(on)}$  of  $6m\Omega$  are available if the budget allows.

It is quite clear that the very low output voltage PSUs required for the new generation of low voltage ICs would be very inefficient, with all the disadvantages associated with inefficiency, were it not for the availability of high efficiency design techniques.

A solution preferred by some system designers is to continue using traditional 5V or 3V3 output supplies and employ one of the myriad post-regulators available from several IC manufacturers. There is an efficiency penalty associated with this approach. Consider a standard efficiency (85%) 3V3 output converter with a 3V3-to-1V8 post-regulator attached. A good post-regulator will deliver 90% efficient power. Therefore the efficiency of the 1V8 output referred to the input of the standard efficiency 3V3 PSU is 77% - far less than the EXA40 48S1V8 (84%). Some cost implications of employing a discrete post-regulator will be discussed in Section 4.3.

## 4 Case Study - How High Efficiency Units Reduce Total System Cost

This paper is primarily concerned with demonstrating the very real benefits accrued when high efficiency converters are used in high reliability, cost-competitive systems. A procurement specialist will often balk at paying premium prices for such converters and will save on the transaction (see Table 2) in the belief that he has reduced the system cost. The argument, on the face of it, is compelling because the buyer in the introduction has saved \$750,000.

\* Calculate using Equation 4.

However, the power supplies will continue to cost his company money through maintenance, installment costs, external filter components and replacement costs as discussed in previous sections.

In this case study many of the costs accrued to a system owner of using a power supply in an application will be analysed for both high efficiency and standard efficiency units. The case study will highlight the cost benefit to the system owner of buying the more expensive high efficiency product.

The hypothetical system described in the introduction will be used in the case study. The system requires -48V power with 40W capability at each of 30 cards in a system. Class B filtering is required for all inputs in order to conform to EMI requirements. An AC/DC front end with N+1 redundancy powers each system and has EN55022 Class B filtering to the mains.

The AC/DC front end is a standard efficiency device and the procurement specialist's choice is whether to use a high efficiency dc/dc converter or a cheaper standard efficiency device. The following subsections will each describe the cost involved in running the system over 10 years and these costs will be compared in order to determine which option costs less over time.

An extension to the case study involves a system designer using a -48V input, +5V output standard efficiency converter with a post-regulator circuit to achieve a 40W 2.5V supply. This extension is important because many system designers are loath to qualify new components for their system because of the high cost of such programmes and the time it takes to perform them.

The case study will show that the one-stage high efficiency conversion offered by Unit HI\_EFF is a much better option for many reasons. Only those parameters of interest in this paper will be discussed in detail but a complete analysis of on-board power solutions versus high efficiency modular PSU solutions will be presented in a future publication.

#### 4.1 Standard Efficiency Solution

The standard efficiency device is 75% efficient and, at \$45, costs \$2.5 less than the high efficiency device. Using Equation 1 the input power,  $P_{in}$ , required by each dc/dc converter is 53.3W. Therefore the total demand on the system's front-end ac/dc is 1599W. If a 20% de-rating guideline is used for the ac/dc the front-end solution needs to be rated for 1918.8W. Four 85% 500W ac/dc supplies with a fifth supply providing N+1 redundancy would provide this. If we assume a cost of 20¢/Watt then the front-end solution costs \$500 per system. The ac/dc front end, in turn, requires 1,881W from the mains (or battery) supply.

Each dc/dc requires a filter costing \$1.24 for Class B operation at a system cost of \$37.20. In a typical ac/dc front-end the filter is in-built and therefore covered by the cost/watt quotation above.

The total cost of the solution is summarised in Table 5. This information will be compared with that in Table 6, Section 4.2. Note that the cost of on-going inspection, testing, installation etc. have not been covered in this paper as they are not efficiency-dependant. This paper is only concerned with costs that are directly related to the efficiency of the power supplies chosen to power the system.

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Item	Cost
30 x 40W dc/dc	1,350
30 x dc/dc filter	37.20
5 x 500W ac/dc	500
Total system cost (\$)	1,887.20
No. of systems globally	10,000
Total cost of ownership (\$)	18,872,000

Table 5 - Cost of Standard Efficiency Solution

### 4.2 High Efficiency Solution

The high efficiency device is 86% efficient and, at \$47.5, costs \$2.5 more than the standard efficiency device. The total demand on the system's front-end ac/dc is now 1395W. Again, assuming a 20% de-rating guideline on the ac/dc front end the required output rating is 1674W. This is supplied by 3 x 550W ac/dc (1650W) with an extra unit providing N+1 redundancy. A 1650W front-end means 18% de-rating which is fine. Again, assuming a cost of 20¢/Watt, the front-end solution costs \$440 per system - less than the standard efficiency solution.

Each dc/dc requires a filter costing \$1.02 for Class B operation at a system cost of \$30.60. The ac/dc product, as mentioned in Section 4.1, has an in-built EMI filter.

The total cost of the solution is summarised in Table 6.

Item	Cost
30 x 40W dc/dc	1,425
30 x dc/dc filter	30.60
4 x 550W ac/dc	440
Total system cost (\$)	1,895.60
No. of systems globally	10,000
Total cost of ownership (\$)	18,956,000

Table 6 - Cost of High Efficiency Solution

### 4.3 On-board Power Solution

The supply voltages for today's telecom ICs are dropping from 5V a few years ago to 3.3V and lower. Sometimes a system owner will choose to add a post-regulator to the output of the qualified dc/dc converter rather than take the time to qualify a new part in his system.

The perception is that the cost of implementing the post-regulator is less than that of qualifying the new part. This approach has three faults:

- Power companies, such as Artesyn Technologies, are now pre-qualifying their new designs to the customer's standard. This allows the customers to use their devices in his application without a lengthy qualification process.
- The cost of the standard device plus post-regulator will probably be higher than that of the new supply.
- The customer needs experienced designers to properly implement the post-regulator. EMI from a switching post regulator, for example, may need to be filtered in case it interferes with the operation of the PSU, especially if the unit still has to supply its own output voltage to some parts of the circuit.

If the system owner buys a power solution from Artesyn Technologies he knows that the relevant qualification testing has been performed on the unit and he can immediately use the part as a fully qualified component. His choice now is whether to use a standard efficiency unit from his old system (standard efficiency is most likely because high efficiency topologies are only recently coming to the market) with an on-board post regulator or buy a high efficiency converter which performs the power conversion in one step.

This case study concentrates only on aspects of the OPB solution that relate to this paper. These are:

- Efficiency.
- Parts cost.
- Cost of filtering.
- Utility costs.
- Reliability.

In this case we will compare Unit HI\_EFF, the high efficiency 2.5V output power converter to an on-board solution consisting of a standard efficiency, say 84%, - 48V in, 5V out modular dc/dc converter with a 5V to 2V5 post regulator which is 90% efficient. The standard efficiency converter is from the same product family as Unit LOW\_EFF and so will cost the same. For simplicity we can also assume that the input filter will cost the same.

The post regulator would, typically, consist of a dedicated PWM IC with external components - FETs, capacitors, inductors, etc. Such a system is depicted in Figure 3. The PWM IC would be supplied by any of the leading manufacturers of such devices.

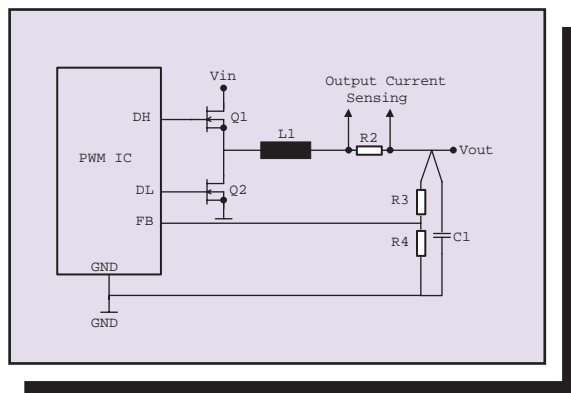


Figure 3 - Block Diagram of the OBP Post-Regulator

The post-regulator is also a 40W switching power supply and, as such, generates EMI which interferes with the output of the supply, in this case the 5V output PSU. This means that the input to the post-regulator may need to be filtered. Assume this is achieved using a similar filter (same cost) to that used for the standard efficiency converter (similar input power requirement).

The efficiency of the combined system, call it unit COMB, is 75.6% - very similar to that of unit LOW\_EFF. The running costs of this system are very similar to those of unit LOW\_EFF and are summarised in Table 7. Note that the AC/DC front-end requirement is the same as that for the system solution involving unit LOW\_EFF, see Table 5. A new line item is included in this cost summary - the cost of the components used in the OBP post-regulator circuit. This entry is calculated using typical estimates of each component's cost.

The OBP solution, with its higher efficiency, costs less than the solution with the standard efficiency converter, unit LOW\_EFF, but still costs much more than that with the high efficiency module, unit HI\_EFF. However, the cost of designing the OBP circuit has not been investigated in this paper. This, and other costs, may prove to be significant when OBP is investigated more fully in a future publication.

Item	Cost
30 x 40W dc/dc	1,350
30 x dc/dc filter	37.20
5 x 500W ac/dc	500
30 x OBP component cost	139.80
30 x OBP filter	37.20
Total system cost (\$)	2,064.20
No. of systems globally	10,000
Total cost of ownership (\$)	20,642,000

Table 7 - Cost of OBP Solution

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Note also that, because the system efficiency is the same as for unit LOW\_EFF, the same  $P_{diss}$  must be extracted from the system. However, because each individual stage is more efficient than unit LOW\_EFF, it may be easier to manage the overall system thermals. However, the thermals will not be as good as in a system with Unit HI\_EFF. In fact, the benefit of having slightly cooler components in the system will probably be more than compensated by the lower MTBF due to the higher parts count.

Other disadvantages with OBP are:

- Each board evolution may require a redesign of the OBP section.
- Every time the OBP solution is used in a new system it has to be re-designed to meet the new system requirements.
- Each design cycle costs time and money. This cost is saved by using modular power supplies.

### 4.4 Utility Costs

The end user of the equipment will also benefit from lower utility costs - less power required by the equipment means less electricity need to run it over its lifetime. For example, for the standard efficiency system with Unit LOW\_EFF, the utility cost over the system's 10-year lifetime<sup>[2]</sup> is \$13,182.05 per system if the cost of a unit is 8¢.

The utility bill for the system using the higher efficiency power converters, Unit HI\_EFF, has a much lower utility bill - \$11,500 per system over ten years. This means a

saving of \$16.8M in utility costs to the end customer! The high efficiency power solution can now be seen to be much cheaper than the standard efficiency solution when the overall cost to the end customer is included and all this with the added technical benefit such as better MTBF, cheaper filtering.

Finally, the solution implementing an OBP post-regulator was seen to be 75.6% - very similar to Unit LOW\_EFF, and this means that its utility costs are also much the same. Adding the cost of extra components required for the system makes this slightly more expensive than the system with the standard efficiency solution. When one considers the added issue of lower MTBF due to a higher part count this solution seems to be the worst of the three for this case study.

### 4.5 Comparison

The end-user's total system running costs (including utility costs) are 16.8M cheaper when using the high efficiency solution even though the power converters cost \$750,000 more initially. The overall savings very much outweigh this initial outlay and one must also remember that with high efficiency units the amount of unit replacement, thermal management, filtering, etc. is less than in the standard efficiency system. This means cost savings for the equipment vendor as well as the system's end-user.

When comparing the costs in the simplified manner shown in Tables 5, 6 and 7 the hardware for the high efficiency system is \$84,000 dollars more expensive than the standard efficiency solution. However, the ongoing savings realised through lower maintenance, less need for fan cooling, better MTBF and, for the end user, lower utility bills more than compensate for this.

<sup>[2]</sup> Total system running costs including utility bills, components, maintenance costs, etc.

## 5 Conclusion

High efficiency power conversion is an essential element in cutting the running costs of a telecommunications system.

End users save cost over the product lifetime due to:

- Lower utility costs.
- Higher MTBF.
- Cheaper input filtering options.
- Less front-end power.

Less power dissipation in high efficiency converters means:

- Less heat for the system designer to extract.
- Less need for fans or heatsinks.
- Reduced converter weight. This helps eliminate the need for clamping units to the rack.
- Can run at a higher ambient.

High efficiency topologies enable the design of power converters with very low output voltages.

A high efficiency post-regulator combined with a standard efficiency converter is not as efficient as a high efficiency module.

## 6 References

[1] Open frame low to medium dc/dc converter modules. Design note 102 Rev. 02 - Feb 1999.

[http://www.artesyn.com/specs/dn\\_opendc\\_19990203.pdf](http://www.artesyn.com/specs/dn_opendc_19990203.pdf)

## 7 Glossary of Terms

OBP	=	On-board power
Pdiss	=	Power dissipated in the unit
Pin	=	Input power
Pout	=	Output power
PSU	=	Power supply unit
SOT	=	Safe operating temperature
SR	=	Synchronous rectifier