# Why use a wall adapter for ac input power?

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## Introduction

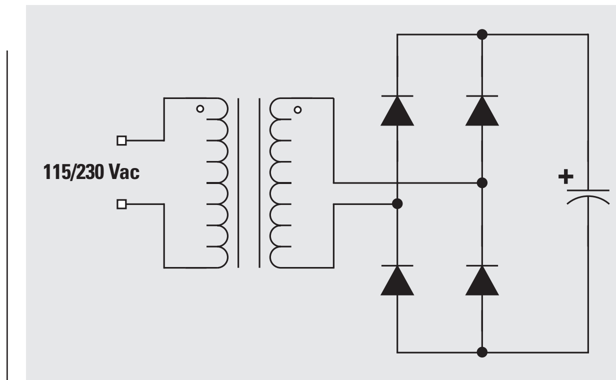
A DSL modem was chosen to examine the tradeoffs of using a wall adapter versus using an offline power supply. DSL modems are being widely deployed, with the number of new subscribers expected to grow at greater than a 50% compounded annual rate over the next four years. The number of new subscribers is expected to grow from 7 million this year to over 25 million in 2004. Because the DSL modem is a consumer product, cost is a very sensitive issue in its design; this cost ripples down into the power supply architecture selection. Designers are faced with two popular choices. In the first, a 50/60-Hz transformer, rectifier, and filter generate a low dc voltage that is then converted to well regulated outputs. In the second, ac input power is rectified and filtered, and a high-frequency switcher converts the resulting high-voltage dc to regulated voltages for the DSL electronics. While the second approach is generally cheaper in high-volume applications, it significantly complicates the modem design. The power supply is typically implemented on the same circuit card as the remainder of the electronics, and the high dc voltage introduces issues of agency approvals, noise, and size.

Table 1 presents typical VoIP DSL modem power supply requirements. Modems are generally required to run from ac wall power that has a wide voltage and frequency range. As with many modern systems, a number of low voltages power various analog and digital functions. In addition, two higher negative voltages power a telephony interface. The –24-V output provides power for the loop current while the telephone is in use. A –72-V output powers the phone ringing circuitry. As contrasted with the lower voltages, these outputs have widely varying load ranges, from essentially no load when the phone system is not in use, to full load on either output depending on whether the line is in use or simply ringing. Efficiency is generally not a critical issue as long as the heat can be removed; consequently, low-cost linear regulators are widely used.

**Table 1. Typical VoIP DSL modem power supply requirements**

| PARAMETER | REQUIREMENTS | | | |
|---|---|---|---|---|
| Input voltage(s) | 115/230 Vac, 50/60 Hz | | | |
| Output power | 9.7 W max | | | |
| Output parameters | **Voltage (V)** | **Max Current (A)** | **Max Ripple ($mV_{pp}$)** | **Regulation (%)** |
| | +5 | 0.65 | 50 | ±5 |
| | +3.3 | 0.75 | 30 | ±3 |
| | +1.8 | 0.40 | 30 | ±3 |
| | +1.5 | 0.40 | 30 | ±3 |
| | –28 | 0.05 | 500 | ±15 |
| | –72 | 0.02 | 1000 | ±15 |
| Efficiency | Very system-dependent from 50 to 85% | | | |

**Figure 1. A simple ac-to-dc unregulated wall adapter**




## What is an ac/dc wall adapter?

A wall adapter's function is to step down the raw 115/230-Vac line voltage into a safer, lower-voltage dc output that can be readily accepted by either the end use equipment or another power supply input. The output voltage tolerance over which the equipment being powered can operate determines whether additional voltage regulation is required. Some circuits, such as battery chargers, may not require a tightly regulated input voltage, and an unregulated dc input voltage may work just fine. In this case, the simplest way to generate that voltage is shown in Figure 1.

This circuit generates one output voltage; but multiple well regulated outputs are often needed. The most common ways to generate these voltages are with switching regulators, linear regulators, or a combination of both. If the unregulated input voltage is higher than the output voltages, multiple buck converters and/or linear regulators are often the best solution. Linear regulators would be used if the output current is not large so that excessive power is not dissipated in the device. In the case where only a single regulated output is needed, the switching converter can be placed either inside the ac/dc wall adapter, making this the entire power supply, or added as part of the end-use circuit. Depending on the goals of the overall product, either choice may be used. For example, if a smaller or lighter product is desired, then a regulated wall adapter would be used. If aesthetics, integration, or heavy loading are important goals, then putting the switcher with the end-use circuit would be the best solution.

Figure 2 shows the output voltage variation with an unregulated wall adapter. When loaded lightly, the output voltage is at its maximum because the output capacitor peak detects the transformer secondary. The capacitor stays fully charged during the entire line period due to low current draw. As the load is increased, the dc output voltage starts to droop. A large amount of primary winding resistance and leakage inductance is designed into the transformer to limit energy in a fault condition. A large portion of the leakage inductance is due to the separation between the primary and secondary windings required for UL approval. This can be in the form of either a split bobbin with the primary and secondary windings on opposite halves of the core or a large amount of insulating tape between the layer stacks. With increasing load current, a larger share of the transformer's voltage drops across the winding resistance and leakage inductance, reducing the output voltage. Since the output diodes only conduct when the secondary voltage on the transformer exceeds the voltage on the output capacitor, the output capacitor provides the load current during a large portion of the line period. The larger the load becomes, the more voltage droop there will be across the output capacitor, since it must support the load entirely. Eventually, as the load is increased beyond its design limits, the output diodes and/or the transformer windings will overheat and fail as open circuits, reducing the output to zero volts. This failure does not usually happen instantly; and, as Figure 3 shows, peak output powers of approximately 150% of maximum power can be obtained for a duration of several seconds. However, this peak power occurs at voltages significantly lower than nominal.

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**Figure 2. A 9-V/1.2-A ac/dc unregulated wall adapter output voltage**

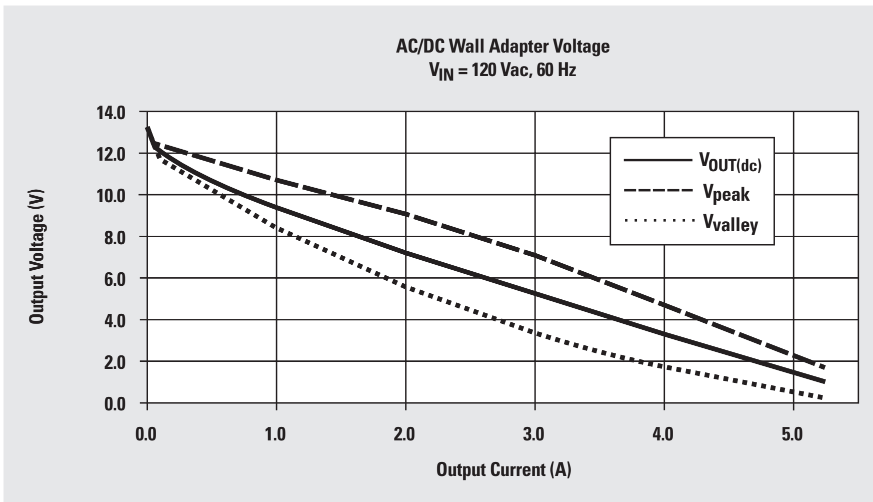
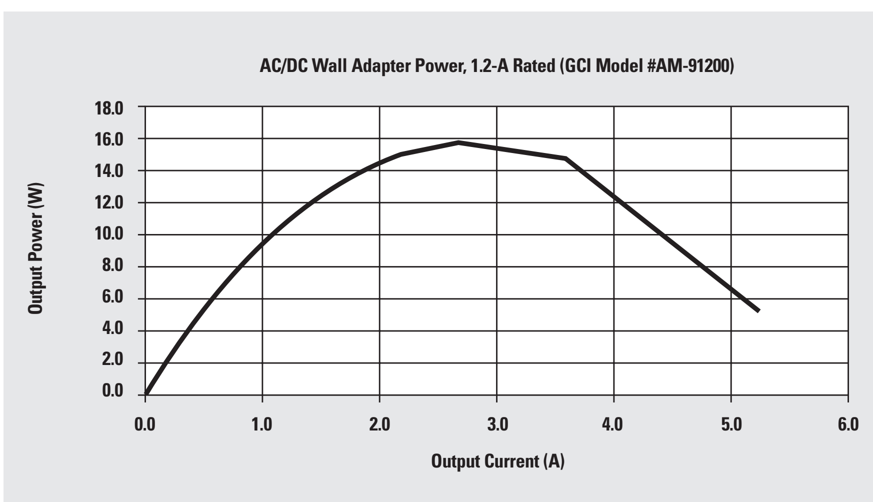



**Figure 3. 50% additional peak power is available for short durations**



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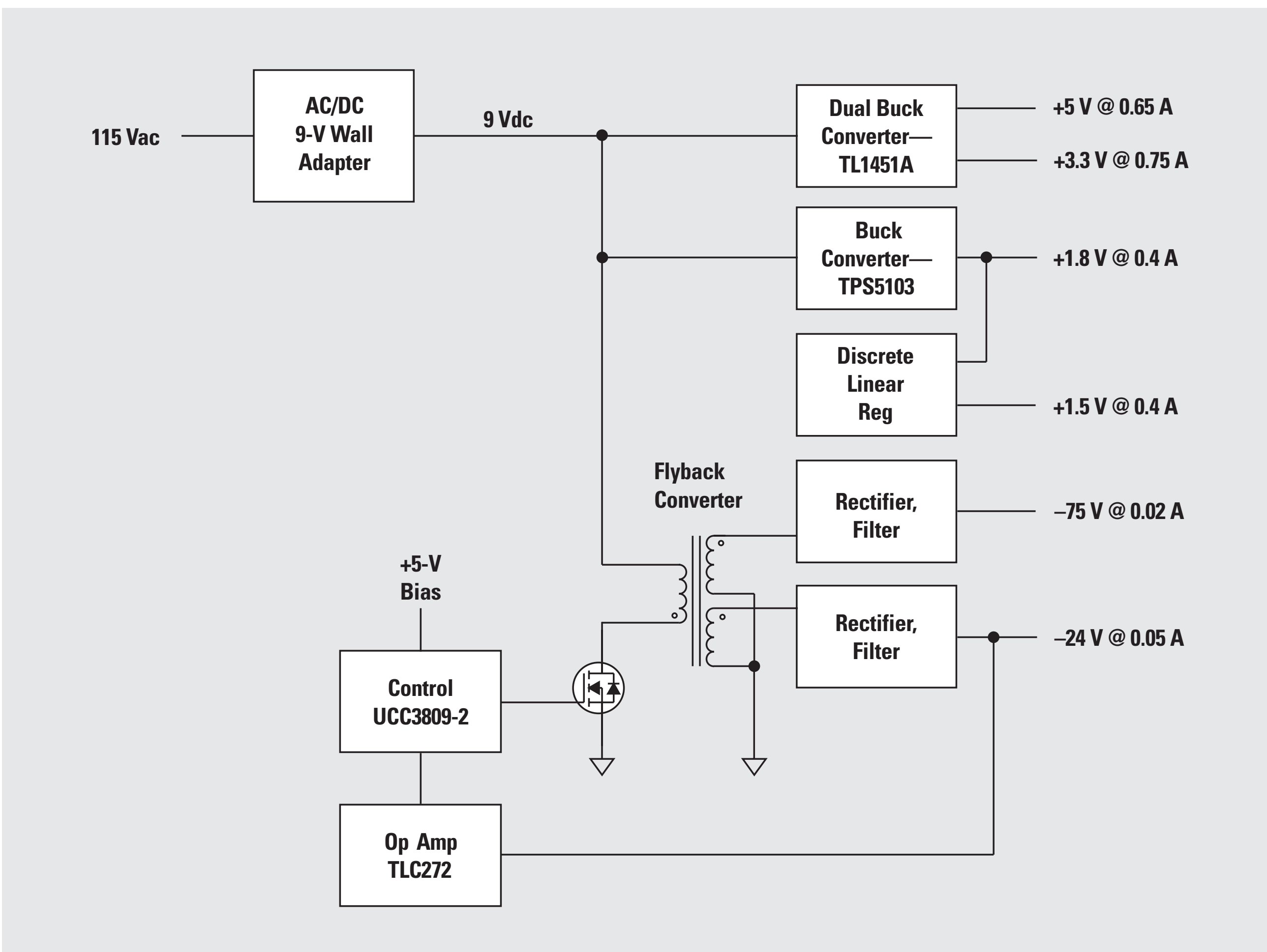
## What's the wall adapter approach?

Figure 4 shows a sample design of a DSL modem powered by a wall adapter. A wall adapter converts wall power to an unregulated 9 Vdc. With load ranges from 0 to 100% and input voltage tolerances of greater than ±10%, the 9-V output can have a variation of over 6 to 15 V. Since the wall adapter is outside the modem and isolated, the 9-V input to the product does not represent a safety issue and can be simply routed within the modem. The 9-V input then drives multiple power stages to provide the user voltages. Buck converters and linear regulators generate the lower voltages for the digital and analog circuits, while a flyback power supply feeds the telephony interface circuits.

## What's the offline approach?

Figure 5 represents the block diagram of an offline switcher for powering the DSL modem. The 115 Vac is rectified and filtered to provide an unregulated dc voltage of 240 Vdc to nearly 400 Vdc. This high voltage is switched by the flyback converter primary FET and rectified into dc on the secondary side. The main regulated output voltage is sensed and feedback to the primary side is used to maintain regulation over input line and output load variations. The telephony output voltages are unregulated and will vary some with line/load, while the lower voltage secondaries use linear regulators. The power transformer and the feedback optocoupler provide the required isolation between the primary input and secondary outputs. Care must be taken in the design of the power transformer to assure that proper spacing is maintained between primary and secondary windings to prevent arcing. Interwinding capacitances, improper grounding, and poor layouts can allow differential and common-mode currents to flow in the primary and/or secondaries and create noise voltages on the outputs as well as put EMI back into the source voltage. The input filter must be designed to suppress these currents to meet agency approvals. The designer must also be careful to use the proper voltage clearances between the optocoupler leads and between the transformer primary and secondary leads on the PWB itself, as well as between adjacent layers. The high voltage and isolation requirements present on the offline converter make the design somewhat more complicated than the wall adapter power supply.

**Figure 4. Wall adapter power supply block diagram**



## So which approach should you use?

Figure 6 shows the two approaches in approximately the same scale, and many of the differences are very apparent. The wall adapter is large since it must operate at line frequency; however, it is generally located outside the product and will not impact the product size. The adapter is very aesthetically unpleasing, as it can take up more than one slot on a power strip or hang from a wall plug. However, as you look further downstream, it becomes clear why so many products use the adapter. The wiring from it to the product is simpler due to lack of safety issues. The power supply in the product is simpler since it does not need to provide safety isolation or significant EMI filtering. As shown in the power supply in Figure 6b, EMI filter components and clearances can represent a third of the offline switcher board area. In addition, the offline power supply is another 20–30% larger since it has a transformer on board.

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**Figure 5. Offline power supply block diagram**

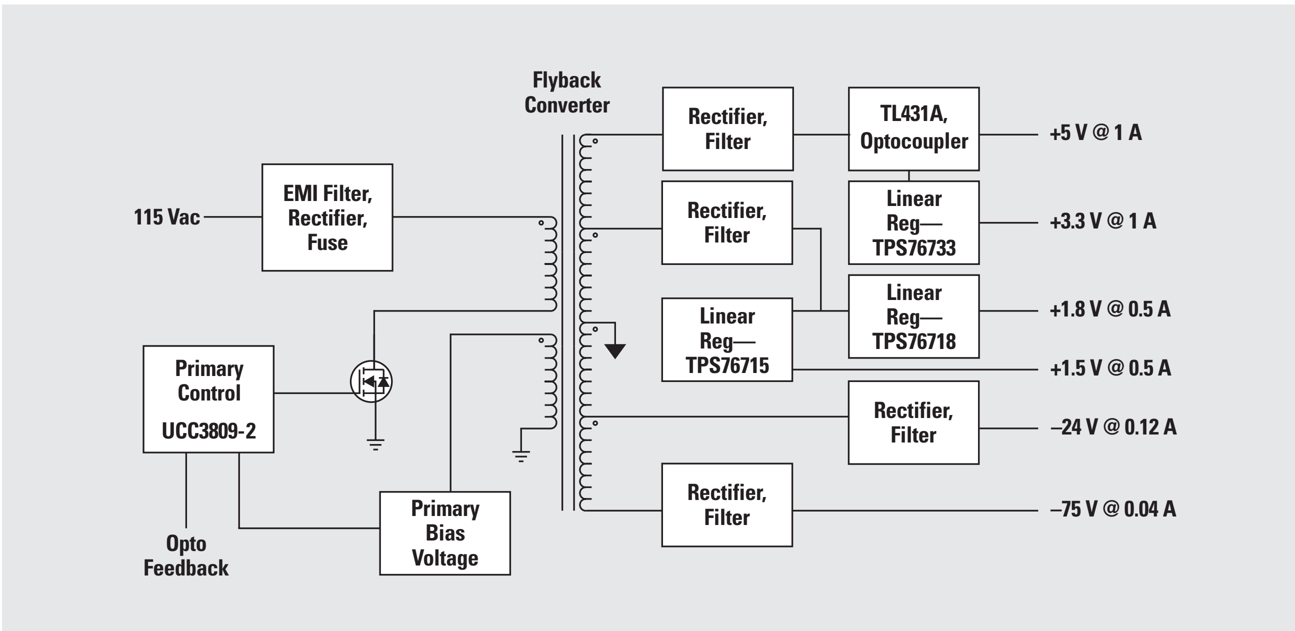
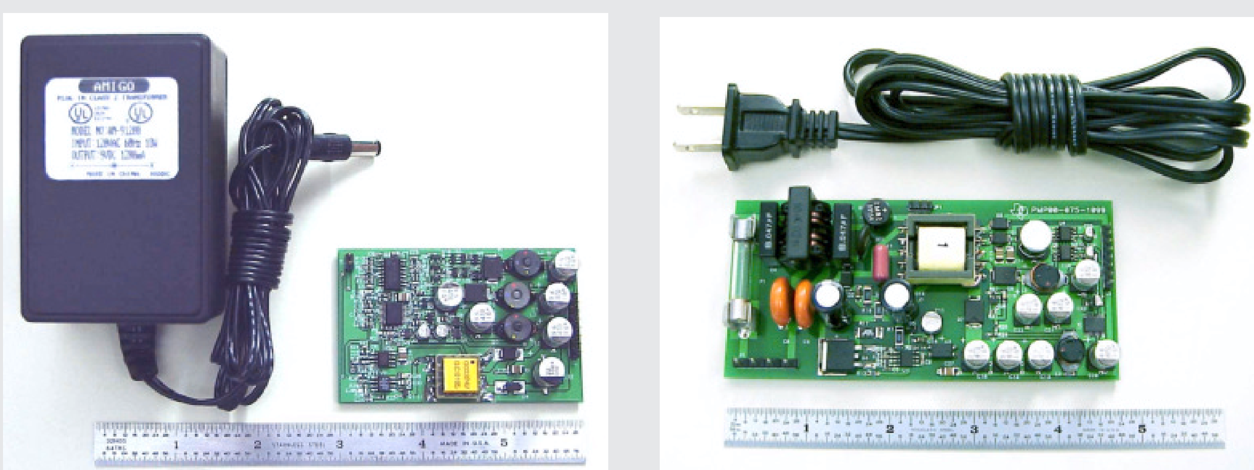



**Figure 6. Wall adapter approach (a) requires significantly less PWB area**




(a) (b)

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Table 2 presents a comparison of the two approaches. The first comparison is physical size. As shown in Figure 6, the wall adapter approach results in the smallest modem size, with an advantage of at least 4 $in^2$. The size of the design could be further reduced with the substitution of linear regulators for the buck power supplies. Component height favors the wall adapter approach also, as the input EMI filter components and power transformer of the offline approach drive its height 0.2 inches taller. Overall power supply weight favors the offline approach with its high-frequency transformer versus the very heavy line frequency transformer of the wall adapter approach.

Table 2 also includes relative costs of the two approaches. It includes product cost as well as engineering development time. In the very high-volume applications, where development cost does not represent a significant portion of the total cost, the offline approach has a slight cost advantage. Additionally, the offline inventory costs will be lower because a $0.25 line cord will be needed rather than a $2.00 wall adapter. However, in the lower-volume applications, the wall adapter has an advantage because it represents a simpler design with much lower qualification costs. Amortizing agency approvals over small production runs increases the costs of the offline approach. UL will take a much closer look at products with high voltage in them versus those where the high voltage is isolated within an approved wall adapter. The additional safety concerns will lengthen the time to market, necessitating additional time to make sure the design is correct before it is qualified. The DSL modems are also sensitive to power supply noise. The offline approach will switch 400 V on the primary that will have a higher likelihood of generating noise problems. All these factors raise the schedule risk of the offline approach, as the layout of the PWB will be more critical. Consequently, the offline approach will take a little more debug time.

So when is a wall adapter an appropriate choice? It is when production volumes are low, or when getting the product out quickly is key. It is typically not when production volumes are going to be high.

**Table 2. Offline approach is cheaper but carries higher risk**

| | AC/DC POWER SUPPLY | WALL ADAPTER AND DC/DC POWER SUPPLY |
|---|---|---|
| PWB area ($in^2$) | 10 | 6 |
| Component height (in) | 0.5 | 0.3 |
| Weight (lbs) | 0.4 | 1.6 |
| Aesthetics | Integrated in product | Big ugly tacky transformer |
| Relative cost (10K units) | 2.5 | 2.0 |
| Relative cost (1M units) | 1.0 | 1.1 |
| UL | HV in product | Simpler approval |
| Relative time to market | Additional 2–4 weeks | Baseline |
| Relative risk | Highest | Lowest |

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