DESIGNING HIGH-PERFORMANCE ISOLATED DC/DC POWER STAGES WITH DISCRETE COMPONENTS

Accelerate your development with
RECOM's isolated power supply building blocks.

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Introduction

Adding in-circuit isolated power just got more flexible. RECOM now offers its power supply components in discrete form as well as fully integrated modules. The “build vs buy” decision is always part of a complex power supply design: engineers must decide which systems or subsystems are available off the shelf and which require custom implementation using discrete components.

For over 50 years, RECOM has offered a broad selection of PC board-mounted isolated power supply modules. Now, with the addition of discrete versions, engineers gain greater flexibility to tailor solutions to their specific design requirements.

Isolated DC/DC power supplies are a mainstay of today’s complex electronics systems. Industrial automation, robotics, commercial communications, and other complex applications often include subsystems for communication, sensing, and control that operate at different voltage levels than the main DC rail. These subsystems frequently require galvanic isolation and benefit from precise, stable regulation within the circuit to ensure reliable performance.

Traditionally, designers of these systems have had little choice but to include a pre-built module to satisfy this need.
The module approach offers the following advantages:

- Preassembled ready-to-use solution
- Reduced design-in time
- Full supporting documentation and certifications
- Lower TCO in smaller quantities

However, a discrete solution is a better option in higher volumes (typically above 50K units) or when facing critical and non-standard requirements.

A custom design offers more options for input, output, and isolation, including multiple output options and greater PCB layout flexibility. This paper covers the key considerations required once the decision has been made to design your own isolated power section using RECOM’s discrete power supply components.

The Build vs. Buy Decision

Small isolated DC/DC power supplies are an important part of most complex designs. Isolation breaks ground loops, reducing system noise, and protects the whole application from system failure if a fault develops in a single subsystem. For example, sensor inputs are often isolated so that external voltages or electrical noise are not injected into the application. In addition, isolation may be a safety requirement to protect the user from electric shock should an input cable or sensor come in contact with a hazardous voltage.

Until recently, the most common design solution was a completely isolated supply module. However, modules occupy a fixed space, cost more in higher volumes generally above 50K units, and may require a secondary assembly operation. Now that RECOM offers its individual power ICs and SMD transformers in discrete form and a fast custom transformer design and manufacturing service, adding an isolated DC/DC supply directly into the design is a viable option.

The discrete approach gives engineers more PCB space, lower cost at higher volumes, and greater customization flexibility. Discrete solutions can deliver multiple output voltages, different voltage levels, and higher current capability, as well as PCB layout flexibility not possible with a pre-built module.

Key Power Supply Design Factors

One of the first decisions is to select a power supply topology. Let’s explore the three most common choices: push-pull, full-bridge, and flyback.

Push-Pull

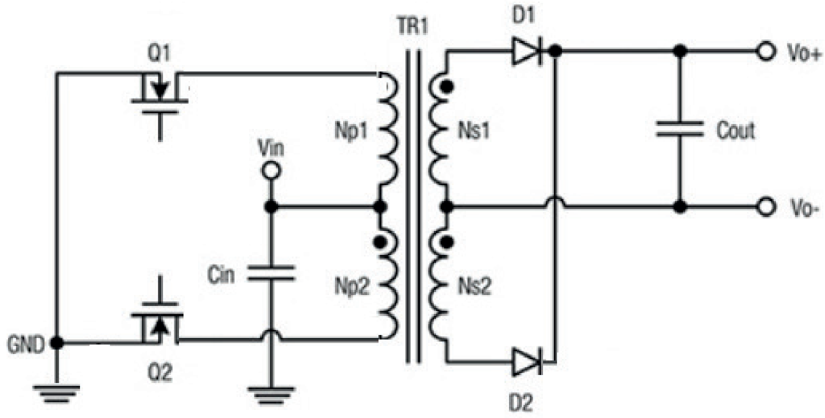

Figure 1: Typical push-pull schematic

A push-pull supply is well-suited to lower voltages and higher current applications because push-pull transistors switch half the average current at the full input voltage. Conversion losses are lower than they are with other topologies because the input current is shared and full core magnetisation is utilised; therefore, push-pull is a highly efficient option. Because the IC design requires only two transistors, the IC cost is lower. However, the transformer requires a primary-side center-tap, so the transformer may be more expensive to manufacture.

- Best for low voltage (3.3V, 5V), higher current
- RECOM's new driver chips: RVP6501, RVP010

Full-Bridge

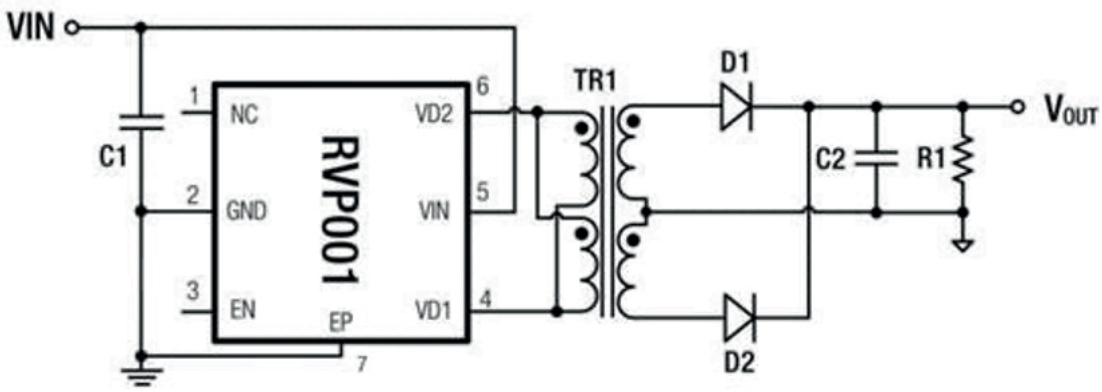

Figure 2: Typical full-bridge schematic

The full-bridge primary IC requires four internal transistors, making it more costly than a push-pull IC. However, the full-bridge transformer does not require a primary-side center-tap. Therefore, it is less expensive, all other parameters being equal. Transformers typically cost more than driver ICs.

- Best for lower current, higher voltage (12V,15V, 24V)
- RECOM's new driver chips: RVP001, RVP003, RVP003S, RVP005

Flyback

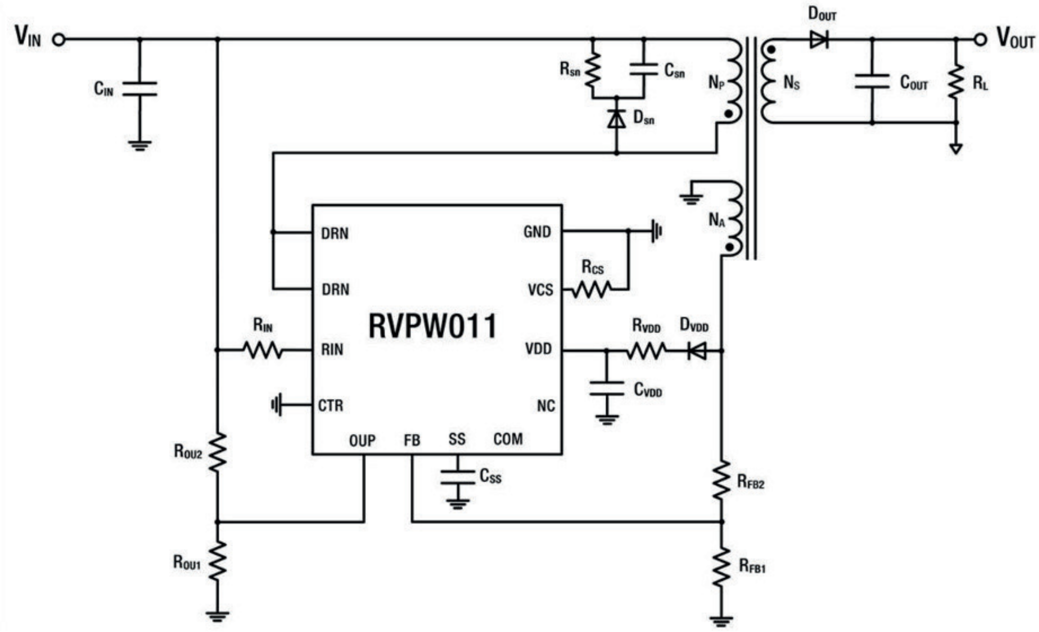

Figure 3: Typical flyback schematic

Flyback topology is typically used when a regulated output, a wider input voltage range, or higher output power (5W to 30W) is required.

- Best for wider input range and higher power (5W to 30W)
- RECOM's new driver chips: RVPW011, RVPW012, RVPW014, RVPW015, RVPW016

Key Components of an Isolated DC/DC Power Supply

All three topologies require three key components: a DC/DC transformer driver chip, a transformer, and a rectifier or rectifier/regulator. In functional terminology, a supply with a lower output than input voltage is called a buck converter. A supply that increases voltage is called a boost converter, and a supply that can perform both functions is referred to as a boost/buck converter.

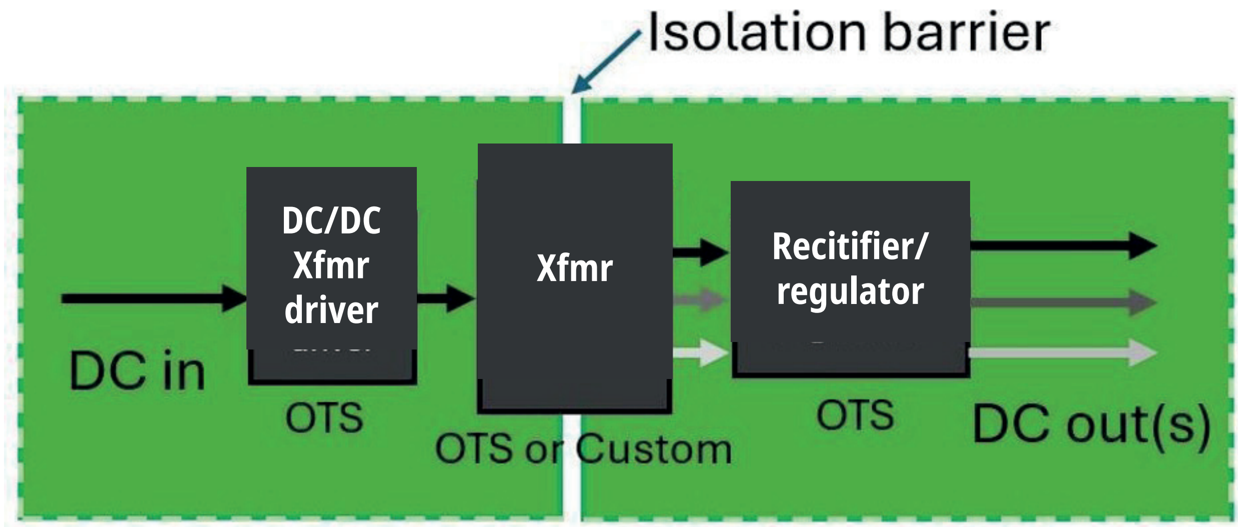

Figure 4: Key components of DC/DC isolated supply

The transformer driver chip sets the topology and essential operating parameters. It is an oscillator that creates an AC-like signal suitable for transformer/inductor management. The oscillating signal may be ground-referenced or floating.

The transformer determines the output voltage or voltages and provides an isolation barrier. To maintain separation, ground planes are not directly connected between the primary and secondary winding sides. Some circuit designs may bridge isolation using capacitors or resistors to manage high- or low-frequency isolation, or for ground-loop management.

The secondary IC is a rectifier or rectifier/regulator that converts the transformer's alternating output into DC and, when needed, stabilizes the output voltage. Passive components in the isolated DC/DC supply include capacitors for signal conditioning and resistors for current limiting.

Transformer Driver Chip Selection Considerations

RECOM offers transformer driver chips in all three topologies. The chips are used in RECOM's line of DC/DC converter power modules and are therefore field-tested with a long track record of successful deployment.

Spotlight on the RVP6501

One of the most popular isolated DC/DC designs is based on the industry standard 6501 power IC. The chip has a long history and provides reliable operation, but it has some limitations. RECOM recently introduced an updated pin-compatible replacement part, the RVP6501, which improves on the legacy part.

The new RVP6501 is a logical successor and second source to the established 6501 push-pull transformer driver. While a 6501-type is a common choice for power supply design given its ubiquity and longevity, the new RVP6501 offers full compatibility with key improvements. The RECOM chip operates from a 2.8V to 6V supply and tolerates input transients up to 10V. It delivers a consistent 500mA across its entire operating range, outperforming the legacy 6501-type, which provides 300mA at 5V and only 150mA at 3.3V.

RECOM RVP6501	Industry standard 6501
New design	Older design introduced in 2012
Short-circuit protection	No short-circuit protection
Actively prevents core saturation	Minimal core saturation mitigation
Over-temperature protection	No over-temperature protection
500mA through the voltage range	300mA at 5V and 150mA at 3.3V

Table 1: Comparison of RVP6501 vs. industry standard 6501

The RVP6501 features make-before-break switching and includes the ability to detect gate voltages. This feature adjusts the dead time spacing and automatically compensates for thermal, load current, and aging drift in the gate threshold voltage. Transistor current monitoring provides continuous short-circuit and overload protection. These features avoid the risk of core saturation due to imbalances in the magnetizing and relaxation magnetic flux in each cycle sometimes called flux walking, thus mitigating one of the main disadvantages of push-pull topology. The RVP6501 is cost optimized to deliver a no compromise solution at a lower price than the legacy 6501-type.

Transformer Selection

Figure 5: RECOM DC/DC isolation power supply transformers

While suitable transformers may be available as off-the-shelf products, building your own mains power supply also allows you to develop a custom transformer that meets specific requirements. With a custom transformer and a homemade AC power supply, the primary circuit does not have to be adapted to a fixed selection of power supply modules. A custom power supply can provide additional taps, multiple voltages, or non-standard voltage and current parameters.

When selecting a transformer, the key parameters to consider include topology, input voltage, output voltage or voltages, isolation voltage requirements, PCB space, pick-and-place assembly capability, and assembly reflow temperature tolerance.

Transformer Design

If no off-the-shelf transformer meets the required specifications, a custom unit must be designed — either by a design engineer or by RECOM.
Transformers operate based on the principle of electromagnetic induction. They typically consist of a primary coil, a magnetic core, and a secondary coil. As the voltage changes in the primary coil, a magnetic field is induced in the core. This magnetic field induces a current in the secondary winding. If the voltage is constant, the magnetic field stabilizes and no longer induces current in the secondary coil; therefore, transformers require AC to operate.

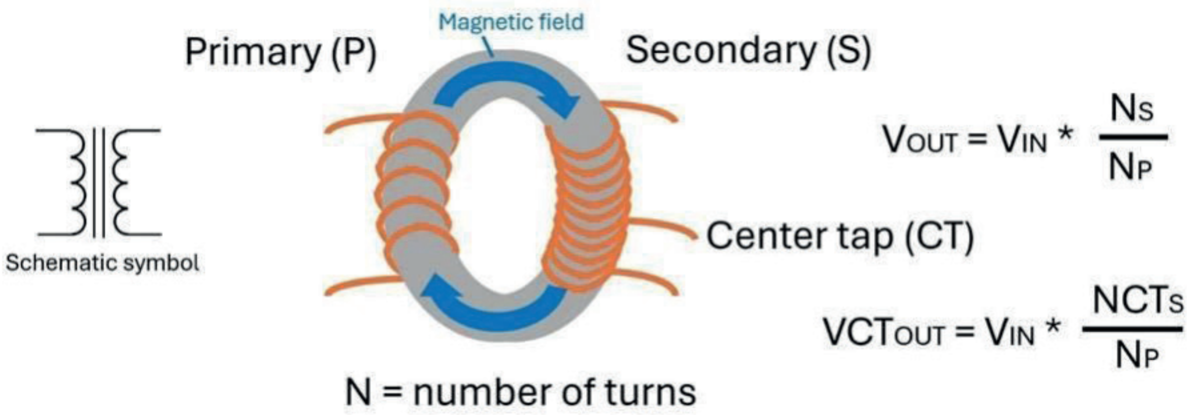

Figure 6: Basic transformer construction, with a 2X primary-to-secondary winding ratio and a center tap

The secondary winding voltage (VS) is calculated based on the primary voltage (VP) and the ratio of primary to secondary turns. For example, a transformer with four times as many secondary turns as primary will yield a 4X boost in voltage: 3Vin becomes 12Vout. The same applies in reverse. Four times the number of primary coils compared to secondary will result in a factor of four drop: 12V becomes 3V. A center tap allows for multiple output voltages or full operation on different voltage cycle phases. Figures 1, 2, and 3 illustrate the primary and secondary winding construction as used in the three power supply topologies.
In practice, the winding ratio must also account for the forward voltage drop from the rectifier, as well as any other significant losses

expected in the system prior to the load.

$$V_S = V_{OUT\_min} + V_F + F_L$$

Where VOUT $_{\_min}$ is the minimum output voltage after rectification, VF is the forward voltage drop of the rectifier, and VL represents any other cumulative losses.
The exact transformer winding formula depends on the power supply topology. Other parameters, such as power and current capacity, also have an impact. Therefore, the transformer selection section of the transformer driver chip datasheet must be consulted.

Rectifier, Rectifier/Regulator

The rectifier may use multiple configurations, such as discrete diodes, bridge rectifiers, intelligent rectifier chips, regulated rectifier/regulator chips, or synchronous rectifier chips. Synchronous rectifiers replace diodes with MOSFETs to reduce losses. Under many conditions, the transformer with a well-regulated input provides sufficiently regulated output. If not, the rectifier stage must include voltage regulation circuitry.

Output Capacitor

An output capacitor is required to reduce ripple and provide power during switching gaps. Individual driver chips may have specific requirements, so the part's data sheet should be consulted. In general, the component should be a low ESR ceramic capacitor in the range of 4.7µF to 10µF.

Design, Integration, and Layout Considerations

Fortunately, small isolated DC/DC supplies typically do not require complex schematic design or layout techniques. The layout does present some standard issues associated with a mix of small and large components. Airflow and component positioning can affect solderability. Trace length should be considered to minimize losses, noise, and transients. Overall, the power section design is straightforward.

Circuit Traces

Keep the PCB traces between the driver and transformer primary as short as possible to minimize I^2R copper losses and reduce ringing caused by parasitic inductance and capacitance. The same guideline applies to the transformer's secondary winding and the rectifier stage (diodes or a synchronous rectifier IC). The driver's input capacitor should be positioned as close as possible to the IC's power pins to ensure stable operation and limit supply ripple.

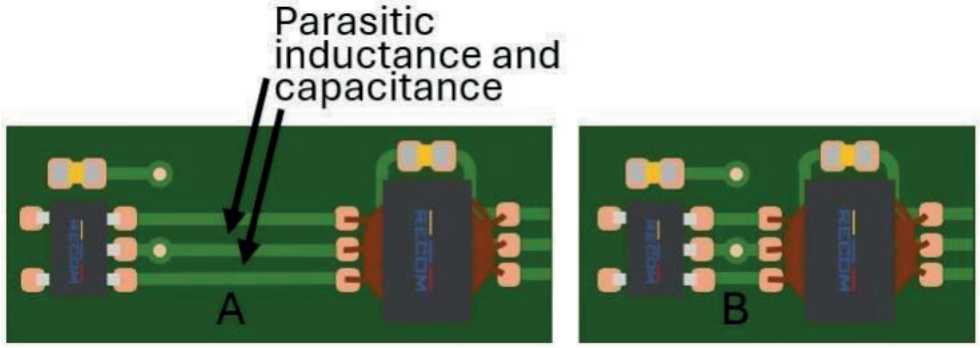

Figure 7: Long traces (A, left) begin to act as a capacitor and or inductor. Short traces (B, right) minimize the effect

The transformer and driver chip should be located as close together on the PCB as component courtyard and mechanical constraints allow, as shown in Figure 7B.

Parasitic capacitance and inductance caused by longer traces can smooth the primary side AC waveform. This reduces transformer performance or can cause resonance, adding noise to the system. Ringing occurs when the magnetic field from the transformer induces current in the input traces. Shorter traces (B) reduce the amount of copper affected by the magnetic field.

Solderability

Passive components are subject to layout issues that are more prevalent in power supply design than in most other circuit sections. Tombstoning and cold solder joints occur when one solder pad of a small component receives less heat during solder reflow than the other. Smaller components are more susceptible than larger ones due to their lower mass. 0402 and smaller components are most susceptible. Uneven heating can occur due to disruptions in airflow during reflow. For example, an 0201 passive placed between two large electrolytic capacitors may not be sufficiently heated to form a reliable solder joint. Increasing reflow time or temperature to compensate may overheat and damage the electrolytics. Vapor phase reflow may mitigate the problem, but it is a more expensive process. The best option is to place the passives in areas with better airflow.

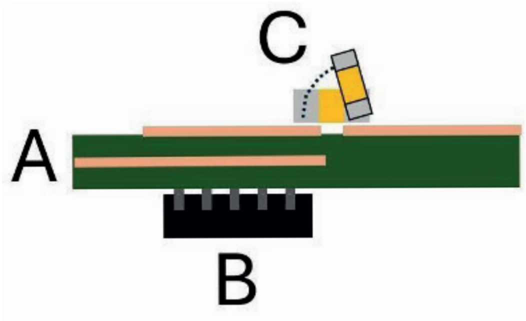

Figure 8: Inner layer (A) or heavy backside component (B) thermally impact half of a small passive component (C)

Inner copper layers (A), as shown in Figure 5, that cover one passive solder pad but not the other, or large components on the back side (B) that cover only one solder pad, can act as heat sinks and lead to a poor solder joint on a small component (C). Tombstoning (C) may result (C).

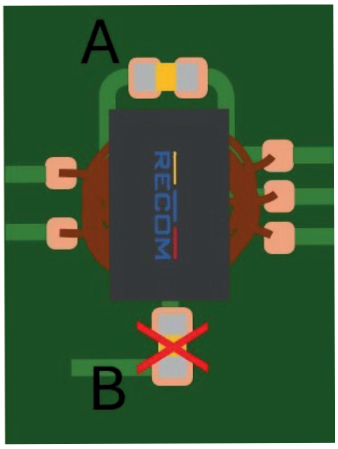

Figure 9: Pads on a small component must be parallel (A) to the heavy component, not perpendicular (B)

While capacitors and diodes often need to be placed as close as possible to a power component or transformer, thermal effects must be considered during placement. The heat soaking capability of larger components, especially transformers or power components with thermal pads, can significantly affect solderability. As shown in Figure 9, passives must be placed with both solder pads at the same distance, as in Figure 9A. Placing the parts perpendicular (B) may lead to tombstoning or cold solder joints.

Prototype Options, Long-Term Supply Chain, and Cost

RECOM offers design assistance and a 20-day evaluation prototype program. Under this program, if the required solution is not already covered by one of the available ex-stock discrete solution evaluation boards, RECOM will design and deliver a custom evaluation prototype based on any combination of standard ICs and standard transformers within 20 days. Full custom transformer solutions can also be considered, with MOQs applying. Another potential saving with a discrete design is that passive components may be shared with other sections of the overall design. This can reduce the bill of materials (BOM) line item count — a key factor in assembly cost.
If this is done, care must be taken to ensure that critical requirements such as ESR and precision are evaluated and, where they differ, the most critical circuit section requirements are followed.

RECOM estimates that the typical cut-off between a pre-built module being less expensive and a discrete solution being less expensive is approximately 50,000 units. Below that quantity, modules tend to be more economical; above that quantity, discrete solutions are more cost-effective. Other design and manufacturing parameters - such as design changes in the rest of the circuit to accommodate one approach or another, manual steps in the manufacturing process, and component overlaps - can shift the break-even point.

Summary

With RECOM making isolated DC/DC power module components available in discrete form, design engineers now have the flexibility to choose between using a pre-made DC/DC module or taking a DIY approach and designing the supply with discrete power ICs.

RECOM offers parts that utilize push-pull, full-bridge, and flyback power supply topologies. With the introduction of the RVP6501, RECOM provides a pin-compatible replacement for the legacy industry standard 6501 power IC. The new RVP6501 offers lower cost, improved performance, and updated technology.

RECOM can also assist with the most critical part, the transformer. RECOM's custom transformer program can deliver a fully custom transformer, giving engineers greater flexibility to meet specific design power requirements.
To learn more about RECOM's discrete component product line, visit recom-power/ic.

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