Comparing the merits of integrated power modules versus discrete regulators

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Modern integration technologies have brought about improvements to the modular "DC/DC power module" voltage regulator.

Time to market, cost, size constraints, reliability, and design capabilities are among the motivating factors in choosing modular power versus a traditional controller plus external components design. Each approach has its advantages and disadvantages. And often times, it is not possible to predict which choice will better satisfy the list of design criteria until the design process has been completed for each approach.

What is a modular voltage regulator?

The basic building blocks of a simple, non-isolated DC-DC switching voltage regulator can be seen in the schematics shown in **Figure 1**. PWM control, current switching, inductance, and capacitance for storing energy are all required. The power module integrates the current switches and inductor while these are separate entities in a discrete design. Since the values of the energy-storing capacitors tend to be well over 1 µf, they are integrated less often into a monolithic package.

How to choose between discrete and modular power

Typically, the tradeoff is between cost of ownership, design effort, and performance.

The cost of ownership is the bill of materials (BOM) cost in addition to power designer labor fees plus test, potential redesign labor fees, and finally manufacturing/assembly costs. Other potential costs can include those associated with quality issues with an improperly designed supply.

Clearly, the design effort behind using a fully integrated power module is less than that of a discrete supply. But within the discrete regulator designs available, there exists a range of integration. For example, some regulators have built-in FET switches that remove the task of choosing the FETs and gate drive considerations. Controller ICs are the most flexible of choices but require a more expert level of design capability. Should one decide to tackle a non-modular approach, they should further investigate how "discretely" they wish to dive into the design. Fortunately, there are excellent tools available such as TI's WEBENCH® online design tool, that allow novice power supply designers to easily assemble discrete supply designs.

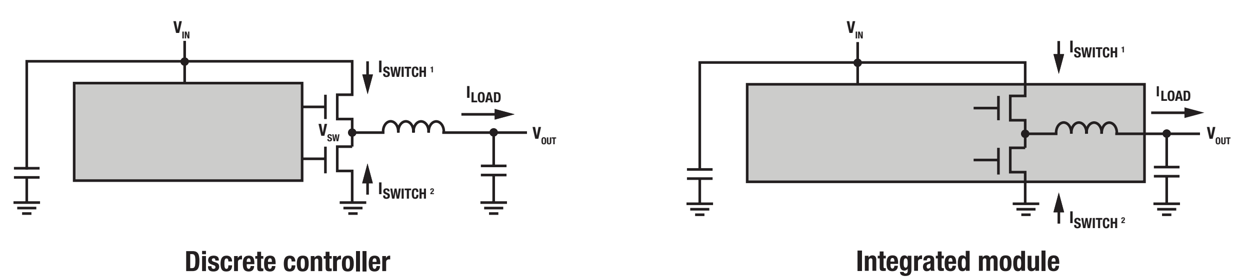


Figure 1. DC-DC buck regulator integration levels.

Integrated modules streamline design and layout challenges but do not completely eliminate the process. At a minimum, the designer must evaluate the power specifi cation of the design; this includes assessing requirements of input and output voltage, current, allowed temperature rise, noise issues, safety and emissions, and possibly other considerations. Even the simplest modular solution is not exempt from careful planning.

Circuit performance is multifaceted and application dependent. Where output noise might be most critical in an RF circuit supply, temperature rise and size of the circuit can be the driving specifications in a hearing aid.

Design example

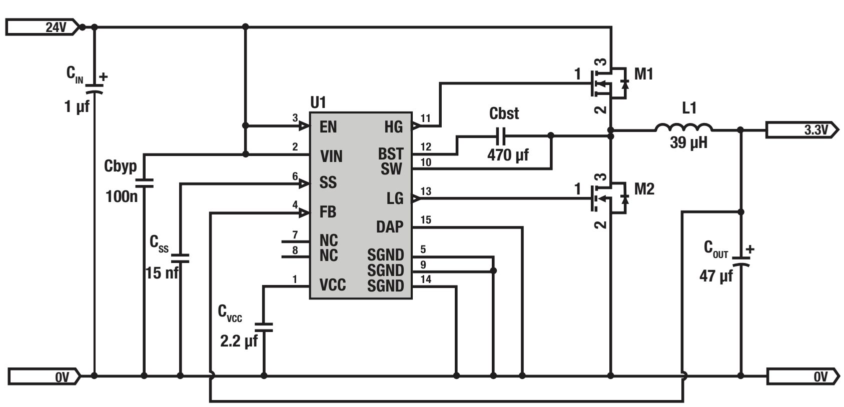
It would be impossible to examine the pros and cons of each approach with all possible values of voltage and current, but the following design analysis will expose the benefits and drawbacks of a modular design versus a design with a discrete controller IC for a common set of parameters. The design specifications will be the same between the two approaches:

- V_{IN} = 24 V
- V_{OUT} = 3.3 V
- Output current = 3.0 A maximum
- Ambient temperature = 55°C

To demonstrate the relative ease of design between the two approaches, TI's WEBENCH design tool will be used to design circuits around the LM3152 3.3V SIMPLE SWITCHER® controller and LMZ14203 SIMPLE SWITCHER power module. The easy-to-use WEBENCH tool offers too large a complement of design tools to highlight at this time, but it can be thoroughly examined online at TI.com/webench. The desired output will focus on the schematic, BOM costs, component land area of the PCB, output noise analysis, efficiencies, and thermal simulation.

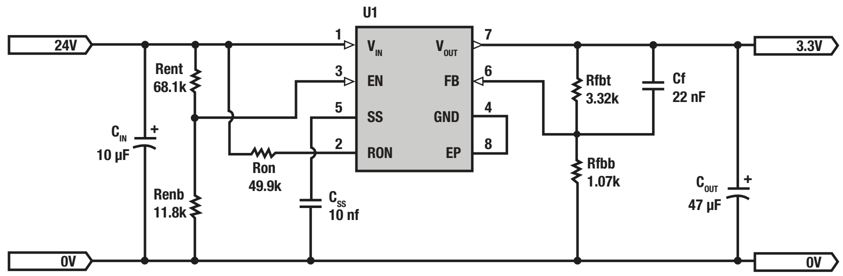
Schematics and bill of materials

Figure 2 shows the discrete design using the LM3152 3.3 V controller. This design was accomplished using the WEBENCH tool and took about 30 minutes, including a few part changes to optimize for cost savings and some design simulation to verify proper operation. Design without the aid of a CAD program might take anywhere from a couple of hours to an entire day for circuit calculations and component searches.



Part	Attribute	Price
Cbst	470 nF/16 V	$ 0.02
Cbyp	100 nF/50 V	$ 0.01
C_{IN}	1 µF/50 V	$ 0.05
C_{OUT}	47 µF/16 V	$ 0.41
C_{SS}	15 nF/50 V	$ 0.01
C_{VCC}	2.2 µF/10 V	$ 0.02
L1	10 µH/4 A	$ 0.54
M1	80 V/30 mΩ	$ 0.39
M2	80 V/30 mΩ	$ 0.39
U1	LM3152MH-3.3	$ 2.30
	Total BOM	$ 4.14

***Figure 2**. Discrete design—LM3152 3.3V controller and bill of materials.*



Part	Attribute	Price
Cf	22 nF/50 V	$ 0.01
C_{IN}	10 µF/50 V	$ 0.43
C_{OUT}	47 µF/6.3 V	$ 0.18
C_{SS}	10 nF/50 V	$ 0.02
Renb	11.8 KΩ	$ 0.01
Rent	68.1 KΩ	$ 0.01
Rfbb	1.07 KΩ	$ 0.01
Rfbt	3.32 KΩ	$ 0.01
Ron	49.9 KΩ	$ 0.01
U1	LMZ14203	$ 9.50
	Total BOM	$ 10.19

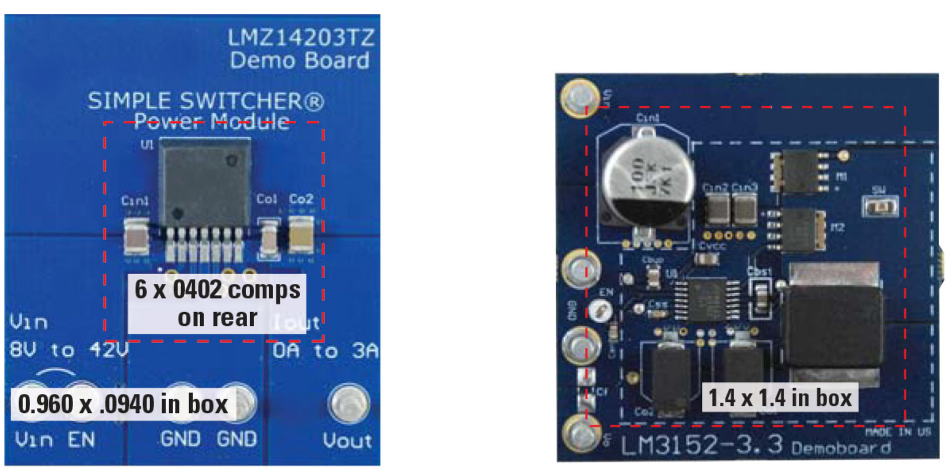
***Figure 3**. Modular design—LMZ14203 integrated power module and bill of materials.*

Figure 3 shows the schematic of the modular design using the LMZ14203 integrated power module. With fewer design choices to make, and limited opportunities for error, the design process is almost instantaneous with the WEBENCH design tool. The data sheet provides instruction on choosing the capacitors and resistors. The task of searching through catalogs for the FETs and the inductor is eliminated.

Comparing the BOM cost between the two designs, there is clearly a cost benefi t to the discrete design. Note that the power module price is based on a 500-piece list price, whereas the controller price is based on a 1000-quantity list price. All costs shown are generated by the WEBENCH tool and are published catalog prices, typically at 1000-unit or cut-tape quantities.

Simplicity of PCB layout

Figure 4 shows evaluation boards that represent the current design examples. The "art" of laying out a switching regulator lies in reducing the length and size of the high-current, high-frequency nodes, as well as properly managing the paths of the return currents. Any PCB CAD operator can put together a "working" supply. Ensuring the supply is robust and operating with minimal noise emissions requires careful planning and knowledge of the circuit operation. It should be intuitively obvious that the modular design is far less prone to layout mistakes.



Integrated power module **Discrete controller**

***Figure 4**. Evaluation boards for modular and discrete solutions.*

Design type	WEBENCH® footprint (single-side layout)	50% packing factor	Eval board comparison (single-side layout)
Discrete	526 mm² / 0.815 in²	1.22 in²	1.4 in²
Modular	374 mm² / 0.58 in²	0.87 in²	0.902 in²

***Figure 5**. Component land area comparison table.*

Another advantage of the PCB layout for some modular designs is the ability to route an unbroken top copper plane underneath the die. Maximum heat conduction between the die and the top copper plane is always an important goal to keep the junction temperatures as cool as possible. In the case of TI's LMZ family of power modules, a large-geometry exposed pad of ground potential is spatially separated from the other signal pins. The LMZ14203 evaluation board in **Figure 4** illustrates the ease of providing unbroken top copper to the exposed pad underneath the module.

Component land area

Component PCB "footprint" is given in units of mm2 by the WEBENCH tool. It includes a 1 mm per-side margin to allow for clearance. The table in **Figure 5** summarizes the total component footprint and adds an additional 50% packing factor to include traces and open spaces. All dimensions are for single-side layout.

Efficiency and thermal simulation

The WEBENCH thermal simulator outputs represent operating conditions of 24 V_{IN}, 3.3 V_{OUT}, 3 A output current, 55°C ambient temperature, no fan, and 1.5 oz copper on both sides. Thermal graphs show a generic layout and do not represent the maximum packing density possible.

It is clear from the efficiency plots and the thermal images in **Figures 6** and **7** that the discrete design is more effi cient and will operate with less heat dissipation compared to the modular design. Of course, this is just one operating point.

An advantage of the discrete design is the ability to optimize the FET selection for the specifi ed operating voltage and output current. Also, it is important to remember that these temperatures are at 55°C raised ambient. With a maximum Tj of 125°C, there remains an additional 38°C of safety buffer for the modular design.

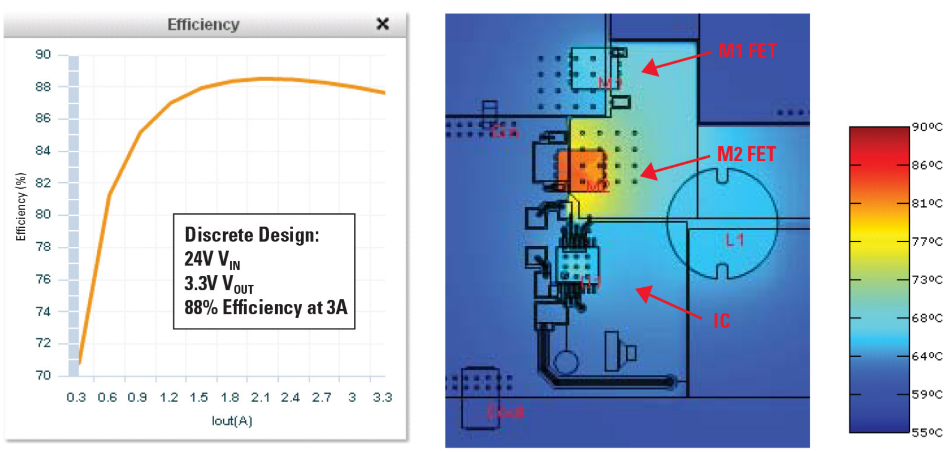


***Figure 6**. WEBENCH simulation output for a discrete design.*

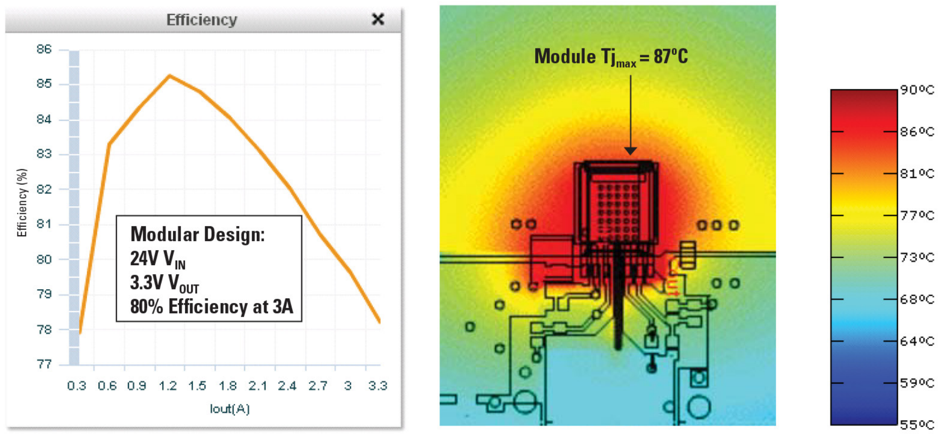


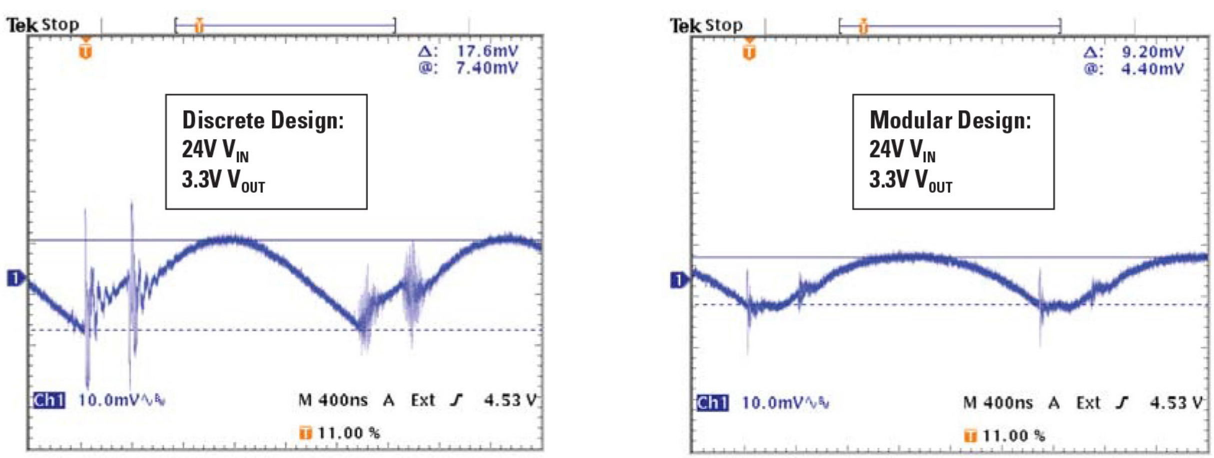
Figure 7. WEBENCH simulation output for a modular design.

Output noise and emissions

Since there are many ways to quantify noise generated from switching supplies, this discussion will be limited to comparing the output voltage noise between the two designs. In addition, it would be an erroneous assumption to say that one approach is always noisier than the other. Factors such as inductor size, input voltage, switching frequency, and capacitor Equivalent Series Resistance (ESR) play dominant roles in the resultant output voltage ripple.

There is, however, a distinct advantage in modular designs since the circuit traces connecting the regulator components are minimized far more than is possible in a discrete design.

The LMZ family of integrated modules utilizes a threedimensional stack of silicon and shielded inductor to minimize trace length and inductance. Scope plots of the output voltages are shown in **Figure 8**.



Note: AC-coupled output noise. BW = 150 MHz. Very low inductance probe across output capacitors.

Figure 8. Output ripple noise measurement taken from evaluation boards.

For both of these outputs, it is possible to realize even lower voltage ripple by lowering the total capacitor ESR. This can be achieved by obtaining a more expensive capacitor or adding more capacitance in parallel. The difference to notice is the amount of very-high-frequency noise "spikes" that appear in the discrete design. All of the additional parasitic inductance and capacitance of the trace elements create high-frequency spikes that occur in the output and also as conducted and radiated noise that can fail noise emissions tests.

Reliability considerations

Circuit failures of a working power supply design can be grouped into three categories—initial assembly errors, lack of protection against misuse (overloaded outputs, excessive input voltages, etc.), and shortened lifetime component failures. Both discrete and modular designs are subject to all three categories, but it is often the case where the modular design incorporates a more extensively thought-out set of protection mechanisms since the entire circuit is "planned" by a designer and the module manufacturer will subject the circuit to a much more rigorous set of testing than the typical end user will expose to their supply.

Modular designs have a significant advantage when it comes to comparing the likelihood of assembly errors such as incorrect components, unstuffed components, and bad solder joints. The modules are always tested before they are sold for assembly into a printed circuit board.

Summary

The pros and cons of discrete versus modular voltage regulator design for the previous design example are summarized in the following table. This "scorecard" will generally hold true for many DC-DC regulator applications. Exceptions to this example will occur often, especially since design specifi cations often deviate from common voltage and current ranges.

	Consideration	Modular approach	Discrete approach	Comments
Costs	Cost of design		x	Initial cost much less for discrete design Time to market might offset differences significantly
	Reliability of design	x		Assembly errors greatly reduced in modular design Modular design subject to higher levels of testing
	Cost of ownership	Depends upon factors such as quantities, quality of assembly line, and purchasing consistency		
Ease of design	Design simplicity	x		Always easier, especially if CAD tool unavailable
	Simplicity of PCB layout	x		Always easier, diffi cult to make mistakes
	Design effort	Schematic, parts sourcing, and PCB layout are all easier		
Performance	Design size	x		Usually smaller with modular design
	Thermal advantages		x	Ability to optimize components allows flexibility in design
	Output noise, ripple	x	x	For this design, modular was quieter, but there is control over ripple noise with choice of component value
	Output voltage, RF	x		Modular designs are inherently quieter due to small node length/size
	RF emissions / compliance	x		As above, TI's SIMPLE SWITCHER power modules are predesigned to pass EN55022 and equivalent compliance testing
	Circuit performance	More performance metrics available, but not listed above; extremely application dependent		

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