Discrete Design of a Low-Cost Isolated 3.3V-to-5V DC-DC Converter

While isolated DC-DC converter modules for 3.3V-to3.3V and 5V-to-5V conversion are readily available on the market, 3.3V-to-5V converters in integrated form are still hard to find. Even if your search proves successful, these specific type of converters, in particular those with regulated outputs, often possess long lead times, are relative expensive, and usually limited to certain isolation voltages.

Isolated 3.3V-to-5V converters are often required in long distance data transmission networks, where the bus node controller is operating from a 3.3V supply to conserve power, while the bus voltage is 5V to maintain signal integrity and to provide high drive capability over long distances.

A discrete design can be a low-cost alternative to integrated modules if your application requires higher isolation voltages than 2 kV, or converter efficiency higher than 60 %, or reliable availability of standard components.

The drawbacks of designing your own, discrete, dc-dc converter are, you must be willing to put some serious elbow grease into the design, which includes choosing a stable oscillator structure and break-before-make circuit as well as selecting good MOSFETs that can be driven efficiently by standard logic gates. You will have to perform temperature tests and long term reliability tests by yourself. This entire effort cost time and money.

Therefore, before rushing into *your do-it-yourself converter design* consider the following:

Integrated modules have usually passed temperature tests and other industrial qualifications. These modules not only represent the most reliable solution, but also provide you with a fast time-to-market.

With regards to pricing, however, it seems of course a bit odd, that converters with unregulated output are priced at around $4.50 to $5.00 per 1000 units, while converters with regulated output often cost twice as much, approximately $10.00 and more. Thus, it seems more common-sense to purchase a converter with unregulated output and either buffer the output with some serious bulk capacitance, or feed it into a low-cost, low-dropout regulator, such as the TPS76650 at $0.50 / 1ku.

Now, the DIY enthusiast to whom life is nothing without a challenge might evaluate the discrete DC-DC converter design in Figure 1. This circuit uses readily available, standard components only, such as logic ICs and MOSFETs for the transformer drive and a low-dropout regulator for a regulated output voltage.

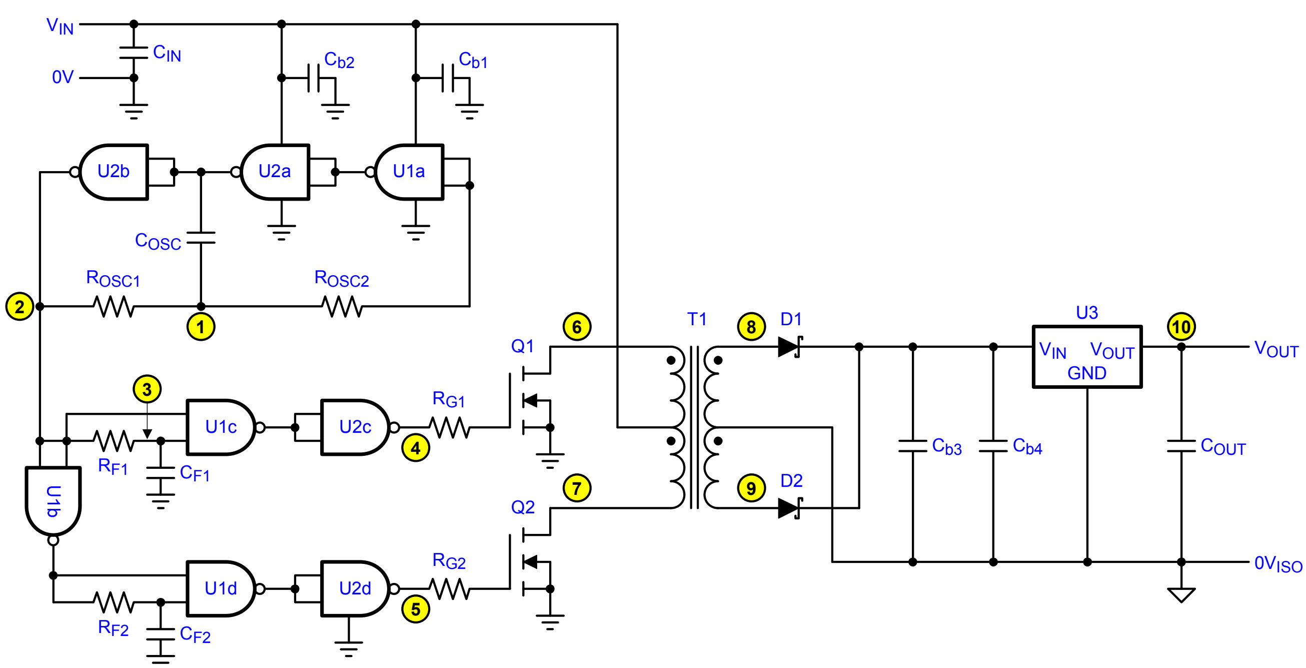

Figure 1. Isolated 3.3V-to-5V Push-Pull Converter

While this circuit has been prototyped using through-hole components, thus making its form factor larger than that of integrated modules, the board space can be drastically reduced by using Little-Logic™ components from Texas Instruments.

The main benefits of this design are the free choice of the isolation transformer for isolation voltages from 1kV to 6kV, and its low bill-of-material (BOM).

The goal is to offer a low-cost alternative to fully integrated DC-DC converters with regulated outputs, and to stand-alone transformer drivers, usually priced around $1.80 per 1ku, by making the transformer-driver stage as inexpensive as possible.

Operation Principle

Low-cost, isolated DC-DC converters are commonly of the push-pull driver type. The operation principle is fairly simple. A square wave oscillator with a push-pull output stage drives a center-tapped transformer, whose output is rectified and made available in regulated or unregulated DC-form. An important, functional requirement is that the square wave has a 50 % duty cycle to assure symmetrical magnetization of the transformer core.

Another requirement is that the product of magnetizing voltage and magnetizing time, known as the ET product and measured in Vµs, does not exceed the transformer's characteristic ET-product, specified by the transformer manufacturer.

Finally, a break-before-make circuit following the oscillator must be implemented to prevent the two legs of the push-pull output stage from conducting simultaneously and causing a circuit failure.

The Final Design

The well-known three-inverter-gate oscillator, consisting of U1a, U2a and U2b, is said to be stable over supply variation. Its nominal frequency is set to 330 kHz through a 100 pF ceramic capacitor (C_{OSC}) and two 10 kΩ resistors (R_{OSC1} and R_{OSC2}). The oscillator possesses a duty cycle of close to 50% and a maximum frequency variation of less than ± 1.5% across a 3.0V to 3.6V variation in supply voltage.

Figure 2 shows the waveforms at the summing point of R_{OSC1} and R_{OSC2} (TP2) and at the oscillator output (TP1).

A test point (TP) is indicated through a yellow circle, its voltage measured with respect to circuit ground.

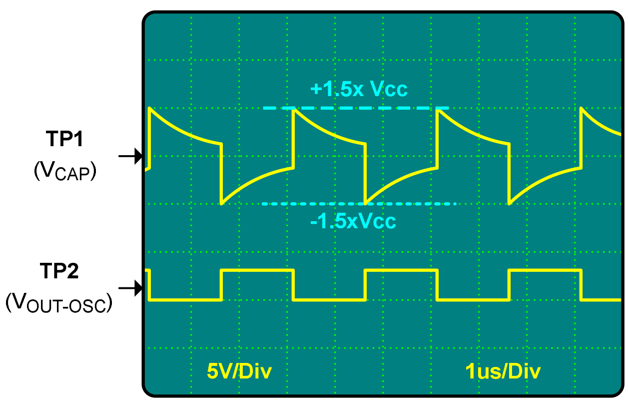

Figure 2. Oscillator Waveforms

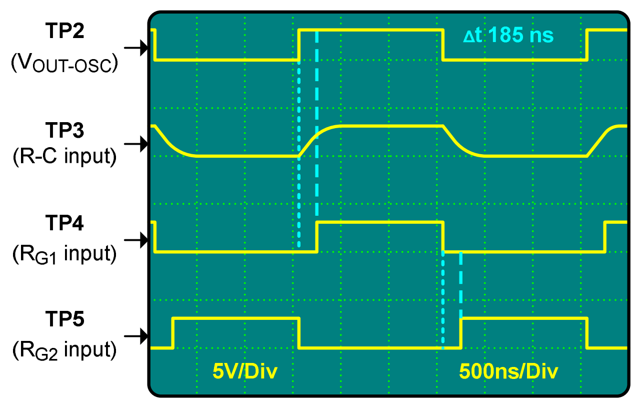

Figure 3. Break-Before-Make Waveforms

Two schmitt-trigger NAND gates (U1c, U1d) perform a break-before-make function to avoid overlapping of the MOSFET's conducting phases. Another two NAND gates (U2c, U2d) are configured as inverting buffers, generating the correct signal polarity necessary to drive the N-channel MOSFETs (Q1, Q2). The complete break-before-make action is shown in Figure 3.

The MOSFETs have been selected based on their relative low total charge and their fast response times to accommodate the limited drive capability of standard logic gates.

The isolation transformer (T1) has a secondary-to-primary winding ratio of 2:1, a primary inductance of 0.9 mH, and a guaranteed isolation voltage of 3 kV. The input and output waveforms of the transformer are shown in Figure 4.

The two diodes (D1, D2) are fast Schottky rectifiers performing a full-wave rectification while providing low forward voltage at full load current (V_{FW} < 0.4V @ 200 mA).

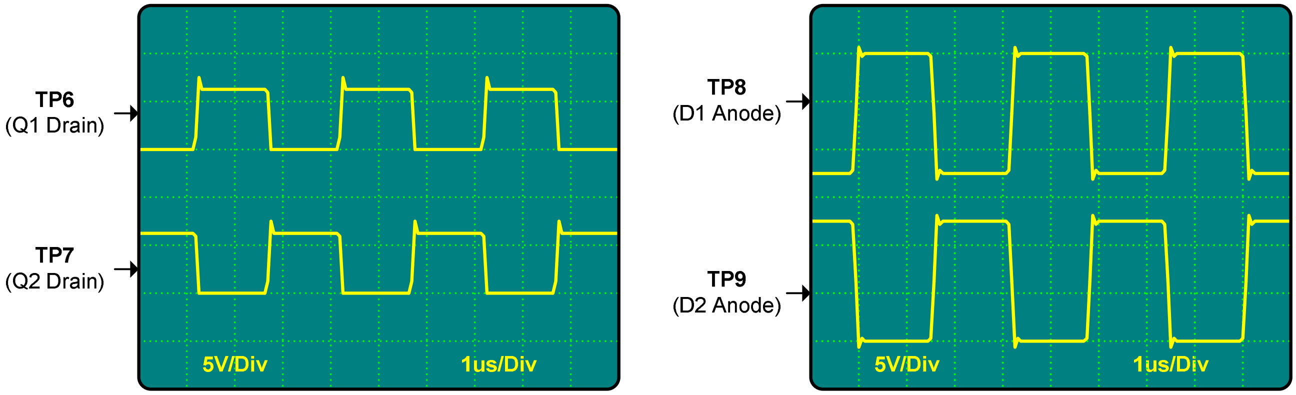

Figure 4. Transformer Input Waveforms (left) and Output Waveforms (right)

It is possible to take the output voltage right from a bulk capacitor (Cb3) following the diodes. In this case the output is unregulated but provides the maximum efficiency of the dc-dc converter. However, caution must be applied not to exceed the maximum supply of the affected circuitry, which can easily occur under low-load, or open-circuit conditions. If the unregulated output voltage under minimum load proves to be too high, it is necessary to use a linear regulator after the full-wave rectifier to provide a stable output supply.

The main benefit of a linear regulator is the low-ripple output. Further benefits include short-circuit protection and over-temperature shutdown. The main drawback, however, is a significantly reduced efficiency.

Figure 5 shows the ripple of the circuit in Figure 1 at an output voltage of V_{OUT} = 4.93V, and Figure 6 compares its efficiency with the one of an integrated DC-DC module with regulated output.

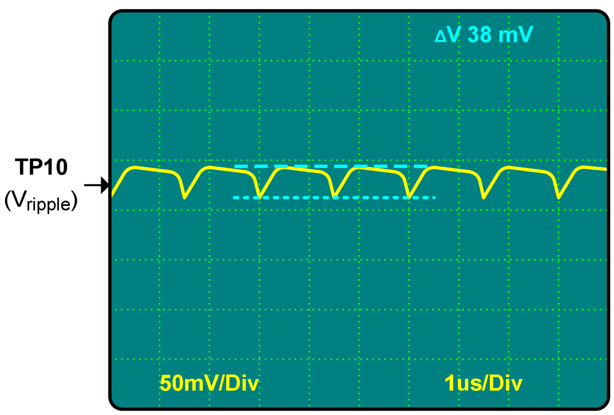

Figure 5. Output Ripple at V_{OUT} = 4.93V

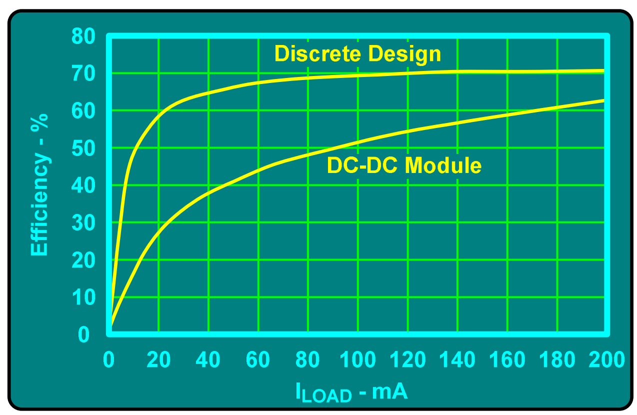

Figure 6. Efficiency Comparison

Bypass Capacitors

Note that the values of the bypass capacitors are larger than the 10 nF commonly implemented in low-speed application. This is because high-speed CMOS technologies, such as AHC, AC and LVC, possess high dynamic loading, and the values for bypass capacitors must be 0.1 μF or higher to assure proper operation. This is of particular importance for the inverter buffers performing the gate drives of the MOSFETs, where the bypass capacitor was determined with 0.68 μF.

Finally the following Table 1 provides an approximate bill of material.

Table 1. Bill of Material

Name	Value	Function	1ku Price / $	Qty	Converter BOM / $	XFMR Driver
U1	SN74AHC132	Quad schmitt trigger NAND	0.17	1	0.17	0.17
U2	SN74AC00	Quad NAND	0.17	1	0.17	0.17
U3	TPS76650	250mA LDO	0.53	1	0.53	-
Q1, Q2	FDN335	N-ch Power MOSFET	0.105	2	0.21	0.21
R_{OSC1}, R_{OSC2}	10k	OSC resistor	0.04	2	0.07	0.07
R_{F1}, R_{F2}	1.54k	Delay resistor	0.035	2	0.07	0.07
R_{G1}, R_{G2}	150	Gate drive resistor	0.035	2	0.07	0.07
C_{OSC}	100pF	Oscillator capacitor	0.04	1	0.04	0.04
C_{F1}, C_{F2}	47pF	Delay capacitor	0.04	2	0.08	0.08
C_{b1}	0.1uF	Bypass capacitor	0.02	3	0.06	0.02
C_{b2}	0.68uF	Bypass capacitor	0.03	1	0.03	0.03
C_{b3}	0.1uF	LDO input capacitor	0.02	1	0.02	-
C_{IN}, C_{b4}, C_{OUT}	4.7uF	Bulk capacitor	0.12	3	0.36	0.12
D1, D2	MBR0520L	Schottky diode	0.045	2	0.09	-
T1	TGRTI-360NARL	1:2 Transformer, 3kV	2.31	1	2.31	-
Total					**4.28**	**1.09**

Conclusion

Where board space constraints are not imminent, the discrete design of an isolated 3.3V-to-5V dc-dc converter with regulated output can present a viable low-cost alternative to an integrated dc-dc module with regulated output. A major benefit of the discrete design is the free choice of isolation transformer, allowing to comply with varying isolation voltage requirements.

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