Inexpensive analog isolation using a digital isolator

Michael Score - December 05, 2012

Isolation is needed now more than ever with applications like LED lighting, brushless motors, power monitoring, and many others that are a combination of direct offline power electronics with isolated control electronics. These applications typically use a very inexpensive analog voltage control for speed or intensity adjustments, whether through a potentiometer or with an analog interface like 0 to 10V.

An isolated operational amplifier (op amp) is too expensive for most of these high-volume applications. Digital isolation is more cost-effective, but typically requires an analog-to-digital converter (ADC) and multiple digital isolators. This article shows a cost-optimized solution for moving analog across the isolation barrier.

A digital isolator takes a digital input and isolates it, but cannot pass an analog signal. The output is either a 1 or a 0. The simplified digital isolator is just a logic level shifter that adds isolation. Typically a digital isolator is used in an application like this to first convert the analog signal to digital, and then send the digital signal using these isolators.

This method adds cost in the ADC and requires multiple digital isolators for the clock, data, chip select, and any other I/O required to control the ADC, which also adds cost. A single digital isolator can be used, if we can convert the analog data to logic level through a pulse-width-modulated (PWM) signal. The PWM represents a linear voltage by the percentage of time the waveform is in on versus off mode. Duty cycle is the percentage of on time to a given period of time.

The PWM is a cross between analog and digital because you are not sending true digital data like a typical parallel or serial interface, but the signal is either high or low with nothing in between. The PWM deals with timing instead of voltage so any common-mode voltage shift across the isolation barrier does not affect the signal. The PWM signal will be very robust to noise since it is either a 0 or a 1 instead of a small analog voltage.

A class-D amplifier is a very inexpensive way to convert analog to PWM. A class-D amplifier block diagram is shown in Figure 1. The class-D amplifier takes an analog voltage and outputs a pulse-width modulated signal. We choose the TPA2006D1 for this design because it is very inexpensive, small, and has very few external components. The class-D amplifier outputs 50 percent duty cycle for IN+ = IN-. The duty cycle is less than 50 percent for IN+ < IN- down to zero percent and greater than 50 percent for IN+ > IN- up to 100 percent.
Figure 1: Class-D amplifier block diagram.

**Figure 2 PWM signal**

**Figure 2** shows how a PWM signal is formed from the comparator (see comparator block in **Figure 1**). The analog input is compared to the 250-kHz triangle wave. When the analog input voltage is greater than the 250-kHz triangle wave voltage, the non-inverting class-D output is high. When the 250-kHz triangle wave is greater than the analog signal, the non-inverting comparator output is low. The inverting comparator output is low when the non-inverting comparator output is high, and high when the non-inverting comparator output is low. The average PWM non-inverting output voltage, $V_{OUT+}^{(AVG)}$, is the duty cycle times the supply voltage, where $D$ is the duty cycle, or on time, $t_{(ON)}$ / total period, $T$.

\[
V_{OUT+}^{(AVG)} = D \times V_{CC} \quad \text{(Eq. 1)}
\]

\[
D = \frac{t_{(ON)}}{T} \quad \text{(Eq. 2)}
\]

The duty cycle of the inverting output, $V_{OUT-}$, is one minus the duty cycle, or $1 - D$, of $V_{OUT+}$. If the input is at mid-supply, the duty cycle of $V_{OUT-}$ and $V_{OUT+}$ is 0.5. However, $V_{OUT-}$ is not used in this design since the design is single-ended for simplicity and lowest cost.
The class-D amplifier needs to have a wide enough bandwidth for the signal needed. If a DC waveform is desired, the class-D amplifier needs to be able to operate without input coupling caps. The TPA2006D1 is an example of a class-D amplifier with greater than 20 kHz bandwidth and can be DC-coupled so an AC or DC signal can be used. The gain is 300 k/Ri, where Ri is the input resistor, which is based on trimmed internal 150 kOhm front-end feedback resistors, and double the power-stage gain. The internal trimmed resistors with external input resistors make it convenient in setting the gain, depending on the input range.

The error in system output is due primarily to timing, since we are using a PWM. The class-D amplifier outputs a 250 kHz square wave with very accurate timing to minimize distortion and noise. However, the digital isolator needs to be much faster than 250 kHz. It must be able to switch fast enough for the rise and fall times to have as little effect as possible on the average output voltage and allow accurate low and high duty cycles. The digital isolator needs to have a propagation delay with rise and fall times much lower than the smallest desired on and off times, not just the period of PWM.

The rise and fall times, and prop delay low-to-high and high-to-low also should be close to the same. For example, if the rise time is much slower than the fall time, the output is shifted lower than intended because the output duty cycle is effectively reduced. This limitation is caused by using an optical-isolator in this solution. We chose the ISO721 for this design because the propagation delay for both low and high transition is 10 ns, and rise and fall times are equal at 1 ns. The ISO721 is only a single channel, but a dual, triple or quad channel from the ISO7xxx family can be used, if more isolated signals are needed.

**Figure 3 schematic of proposed solution**

See **Figure 3** for a schematic of the proposed solution.
Figure 3: Schematic of inexpensive analog isolation solution.

To test the solution, use a TPA2006D1EVM[1] with the OUT+ connected to the input of the ISO721EVM[2]. Short the input coupling capacitors to allow DC to be passed. Figure 4 shows the class-D output (pink) and the isolator output (cyan). The plot shows that the waveform still keeps accurate timing with the rise and fall times being fast and symmetrical. In this case use 5V as the supply for both the class-D amplifier and the digital isolator.

The plot shows that the mean of both outputs are at mid-supply and approximately equal. The mean of the class-D amplifier output is 2.51V and the mean of the digital isolator output is 2.6V. You can eliminate any error due to any peak-to-peak voltage difference from supply mismatch by adding a comparator after the digital isolator.

The comparator feeds a DSP or microprocessor logic input where the duty cycle is calculated and filtered into a voltage. Alternatively, the PWM out of the digital isolator is analog low-pass filtered to get a true isolated analog signal sampled by an ADC. In Figure 5 the analog input voltage (green) is being swept with a 20 kHz sawtooth waveform, showing the class-D output (pink) and isolated PWM output (cyan) duty cycle ranging from zero to 100 percent. Figure 5 also shows the design’s ability to respond to an AC waveform.

Figure 4: Oscilloscope plot of class-D output and digital isolator output.
Add the low-pass filter after the digital isolator, as shown in Figure 3. For low cost use a single resistor and capacitor for the low-pass filter. As shown in Figure 6 use a 1 k-Ohm resistor and a 68 nF capacitor to form a first order low-pass filter with a cut-off frequency of 2.3 kHz. Figure 6 shows that a 1 kHz sine wave was passed from input (green) to output (cyan) with a small phase-shift and minimal distortion. The simple RC filter leaves minimal ripple. You can increase the cutoff frequency for wider bandwidth at the expense of more ripple voltage. You can also use an active filter, if more ripple attenuation and higher bandwidth is needed.
Summary

A class-D amplifier and digital isolator plus RC low-pass filter makes a small and inexpensive analog isolation solution utilizing just a single inexpensive class-D amplifier and a single channel of digital isolation. This solution allows a traditional analog control signal to be used as these traditionally analog solutions are going digital and need isolation.

References


About the Author

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