AND9797/D

Reduced Power Dissipation of Relay Loads

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APPLICATION NOTE

Integrated circuit driver circuits often use relay loads in their application. Output drivers are a source of power dissipation on the IC. Latching relays can be used to keep sustaining load current at a minimum by engaging and removing drive current, but a PWM system can also preserve reduced power conditions by engaging and reducing duty cycle using standard type relays.

By considering the Maximum Turn−On Voltage and Minimum Turn−Off Voltage specifications typically quoted in the relay electrical specification, your system design can utilize a signal to pull−in and activate the relay followed by a reduced power PWM sustaining signal.

The only inconvenience here is doing your calculations for the two states (pull−in current and drop−out current) and adding an external clamping diode to account for the additional clamping action of the system.

Table 1 below highlights a recent view of current electrical specifications of automotive relays for Maximum Turn−On Voltage, Minimum Turn−Off Voltage and Coil Current. These are all the attributes we need to formulate usage of standard relays in a PWM mode for reduced power conditions.

Shaded row indicates a device used in calculations further in this document.

Table 1 represents a majority of automotive low−voltage (Turn−on Voltage) relays which allows us to calculate a single solution PWM value (as an example) for the group using the average ratio in the table of 6.5. Power savings would of course be dependent on the Coil Impedance and Coil Current in the application.

Table 2 below highlights a second group of similar relay devices falling into a 2^{nd} category of devices with a higher ratio of Coil Current to Sustaining Current.

Table 1. GROUP 1 OF AUTOMOTIVE RELAYS WITH SIMILAR RATIO OF COIL CURRENT TO SUSTAINING CURRENT

Turn−On Voltage (max)	Turn−Off Voltage (min)	Coil Current (mA)	Coil Impedance (Ω)	Sustaining Current (mA)	Ratio of Coil Current to Sustaining Current
4.7	0.7	71.4	65.8	10.6	6.7
5.5	0.8	53.3	103.2	7.8	6.9
5.5	0.8	92.3	59.6	13.4	6.9
6.3	0.9	53.3	118.2	7.6	7.0
6.5	1	66.7	97.5	10.3	6.5
6.9	1	83.3	82.8	12.1	6.9
6.9	1.2	133	51.9	23.1	5.8
6.9	1.2	240	28.8	41.7	5.8
6.9	1.2	288	24.0	50.1	5.8
				average	6.5

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December, 2018 − Rev. 0

Table 2. GROUP 2 OF AUTOMOTIVE RELAYS WITH SIMILAR RATIO OF COIL CURRENT TO SUSTAINING CURRENT

Turn−On Voltage (max)	Turn−Off Voltage (min)	Coil Current (mA)	Coil Impedance (Ohms)	Sustaining Current (mA)	Ratio of Coil Current to Sustaining Current
6.2	0.5	117	53.0	9.4	12.4
6.6	0.6	57	115.8	5.2	11.0
7	0.6	84	83.3	7.2	11.7
7	0.6	117	59.8	10.0	11.7
7.2	0.6	100	72.0	8.3	12.0
7.2	0.6	167	43.1	13.9	12.0
8	0.6	150	53.3	11.3	13.3
				average	12.0

Shaded row indicates a device used in calculations further in this document.

While Table 1 and Table 2 incorporate the majority of automotive relay devices, it should be pointed out there are additional production relays which fall out of these two categories. These are represented in Table 3 below. This stresses the point of the requirement for calculations for each individual application.

Table 3. GROUP 3 OUTLIER GROUP OF AUTOMOTIVE RELAYS

Turn−On Voltage (max)	Turn−Off Voltage (min)	Coil Current (mA)	Coil Impedance (Ω)	Sustaining Current (mA)	Ratio of Coil Current to Sustaining Current
5.7	1.25	55	103.6	12.1	4.6
6.9	1.5	47.2	146.2	10.3	4.6
8.5	1	77.2	110.1	9.1	8.5

DUTY CYCLE

Let’s use examples from Group 1 and Group 2. The first example uses of a 97.5 Ω Coil Impedance Relay with a ratio of 6.5 for the Coil Current to the Sustaining Current. First we will calculate the power in the load under DC conditions, and then review the power savings when the device is operated in a PWM fashion creating the 6.5 ratio.

Calculating the minimum supply operating voltage required to engage the relay (6.5 V across the relay coil) for example 1. This is a direct current calculation.

$$\text{Vbat} - \text{Voutx} = 6.5\ \text{V} \qquad \text{(eq. 1)}$$

$$\text{Voutx} = \text{Vbat} \times \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}} \qquad \text{(eq. 2)}$$

$$\text{Vbat} - \left(\text{Vbat} \times \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right) = 6.5\ \text{V} \qquad \text{(eq. 3)}$$

$$\text{Vbat} \times \left(1 - \left(\frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right)\right) = 6.5\ \text{V} \qquad \text{(eq. 4)}$$

$$\text{Vbat} = \frac{6.5}{\left(1 - \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right)} \qquad \text{(eq. 5)}$$

$$\text{Vbat} = \frac{6.5}{\left(1 - \frac{1.5}{1.5 + 97.5}\right)} = 6.6\ \text{V} \qquad \text{(eq. 6)}$$

For minimum Duty Cycle, the average voltage across the coil must be 1 V.

$$\left(\text{Vbat} - \left(\text{Vbat} \times \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right)\right) \times \text{DC} = 1\ \text{V} \qquad \text{(eq. 7)}$$

$$\left(6.6 - \left(6.6 \times \frac{1.5}{1.5 + 97.5}\right)\right) \times \text{DC} = 1\ \text{V} \qquad \text{(eq. 8)}$$

$$\text{DC} = \frac{1}{6.5} = 15.4\% \qquad \text{(eq. 9)}$$

Similarly the Duty Cycle for Group 2 (ratio = 12) assumes operation of the circuit at the Turn−on Voltage (7.2 V across the relay coil).

$$\text{Vbat} - \text{Voutx} = 7.2\ \text{V} \qquad \text{(eq. 10)}$$

$$\text{Voutx} = \text{Vbat} \times \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}} \qquad \text{(eq. 11)}$$

$$\text{Vbat} - \left(\text{Vbat} \times \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right) = 7.2\ \text{V} \qquad \text{(eq. 12)}$$

$$\text{Vbat} \times \left(1 - \left(\frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right)\right) = 7.2\ \text{V} \qquad \text{(eq. 13)}$$

$$\text{Vbat} = \frac{7.2}{\left(1 - \frac{\text{Rdson}}{\text{Rdson} + \text{Rcoil}}\right)} \qquad \text{(eq. 14)}$$

$$\text{Vbat} = \frac{7.2}{\left(1 - \frac{0.8}{0.8 + 43.1}\right)} = 7.33\ \text{V} \qquad \text{(eq. 15)}$$

For minimum Duty Cycle, the average voltage across the coil must be 0.6 V.

$$\left(\mathrm{Vbat} - \left(\mathrm{Vbat} \times \frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right) \times \mathrm{DC} = 0.6\ \mathrm{V} \qquad \text{(eq. 16)}$$

$$\left(7.33 - \left(7.33 \times \frac{0.8}{0.8 + 43.1}\right)\right) \times \mathrm{DC} = 0.6\ \mathrm{V} \qquad \text{(eq. 17)}$$

$$\mathrm{DC} = \frac{0.6}{7.46} = 8.04\% \qquad \text{(eq. 18)}$$

These Duty Cycle calculations use the absolute limit numbers included in the relay datasheets. Good engineering practice would dictate the duty cycle be increased higher for production than the calculated values resulting in a good margin.

POWER SAVINGS

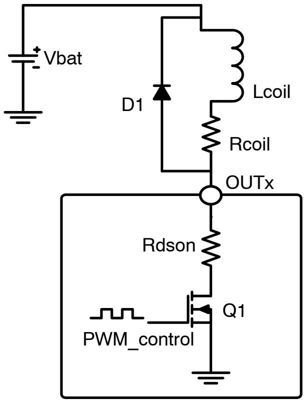


Figure 1. Output Drive

We will now compare the power dissipation (1 output) under conditions using the most prevalent relay selections (Group 1 and Group 2) for 15.4 % and 8.04% duty cycle in comparison to a DC 100% duty cycle. The 1st 4 examples rely on the release time of the relay and ignore the spikes caused by the flyback event (i.e. the power dissipation on the I_C attributed to the flyback conditions are assigned to be zero).

Figure 1 shows the composition of the outputs. All the outputs are low−side drive (pins OUTx). We are using 2 different sized outputs. The two different sized outputs (Rdson = 1.5 Ω, 0.8 Ω) will be used in the proceeding examples. An added external flyback diode (D1) is added to enhance the flyback capability of the system. Typical clamp specification has 2M cycles. This setup in practice will most likely exceed 2M cycles resulting in the need for an external diode.

Power dissipation is concentrated in the output driver (Q1). Current into the Q1 is set by Vbat and the two series resistors Rcoil and Rdson.

Examples and actual applications should define the PWM timing signals such that any delays in turn−on / turn−off times are insignificant and flyback events are minimized.

POWER CALCULATION EXAMPLES

Example 1 (Group 1)

Rcoil = 97.5 Ω
Rdson = 1.5 Ω
Vbat = 6.6 V

$$\mathrm{Idrain(Q1)} = \frac{\mathrm{Vbat}}{\mathrm{Rcoil} + \mathrm{Rdson}} = \frac{6.6}{97.5 + 1.5} = 66.7\ \mathrm{mA} \qquad \text{(eq. 19)}$$

100% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \qquad \text{(eq. 20)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 21)}$$

$$\mathrm{Power} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 22)}$$

$$\mathrm{Power} = \frac{6.6 \times 1.5 \times 0.0667}{1.5 + 97.5} = \frac{0.660}{99} = 6.67\ \mathrm{mW} \qquad \text{(eq. 23)}$$

15.4% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle} \qquad \text{(eq. 24)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 25)}$$

$$\mathrm{P} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 26)}$$

$$\mathrm{Power} = \frac{6.6 \times 1.5 \times 0.0667 \times 0.154}{1.5 + 97.5} = \frac{0.102}{99} = 1.03\ \mathrm{mW} \qquad \text{(eq. 27)}$$

Example 2 (Group 2)

Rcoil = 43.1 Ω
Rdson = 0.8 Ω
Vbat = 7.33 V

$$\mathrm{Idrain(Q1)} = \frac{\mathrm{Vbat}}{\mathrm{Rcoil} + \mathrm{Rdson}} = \frac{7.33}{43.1 + 1.5} = 164\ \mathrm{mA} \qquad \text{(eq. 28)}$$

100% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \qquad \text{(eq. 29)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 30)}$$

$$\mathrm{Power} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 31)}$$

$$\mathrm{Power} = \frac{7.33 \times 0.8 \times 0.164}{0.8 + 43.1} = \frac{0.962}{43.9} = 21.9\ \mathrm{mW} \qquad \text{(eq. 32)}$$

8.04% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle} \qquad \text{(eq. 33)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 34)}$$

$$\mathrm{P} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 35)}$$

$$\mathrm{Power} = \frac{7.33 \times 0.8 \times 0.164 \times 0.0804}{0.8 + 43.1} = \frac{0.0773}{43.9} = 1.76\ \mathrm{mW} \qquad \text{(eq. 36)}$$

14 V Automotive Battery Examples

Typical automotive applications operate with Vbat = 14 V.

We continue the examples here with the same loads as Example 1 and Example 2, but now modified with Vbat = 14 V.

Operating at 14 V improves the Duty Cycle Example Requirements.

Example 3 Duty Cycle

$$\mathrm{TurnOff\ Voltage} = 1\ \mathrm{V} \qquad \text{(eq. 37)}$$

$$(\mathrm{Vbat} - \mathrm{Vout}) \times \mathrm{DC} = 1\ \mathrm{V} \qquad \text{(eq. 38)}$$

$$\mathrm{Vout} = \mathrm{Vbat} \times \frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 39)}$$

$$\left(\mathrm{Vbat} - \left(\mathrm{Vbat} \times \frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right) \times \mathrm{DC} = 1\ \mathrm{V} \qquad \text{(eq. 40)}$$

$$\mathrm{Vbat} \times \left(1 - \left(\frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right) \times \mathrm{DC} = 1\ \mathrm{V} \qquad \text{(eq. 41)}$$

$$\mathrm{DC} = \frac{1}{\mathrm{Vbat} \times \left(1 - \left(\frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right)} \qquad \text{(eq. 42)}$$

$$\mathrm{DC} = \frac{1}{14 \times \left(1 - \left(\frac{1.5}{1.5 + 97.5}\right)\right)} = 7.25\% \qquad \text{(eq. 43)}$$

Example 4 Duty Cycle

$$\mathrm{TurnOff\ Voltage} = 0.6\ \mathrm{V} \qquad \text{(eq. 44)}$$

$$(\mathrm{Vbat} - \mathrm{Vout}) \times \mathrm{DC} = 0.6\ \mathrm{V} \qquad \text{(eq. 45)}$$

$$\mathrm{Vout} = \mathrm{Vbat} \times \frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 46)}$$

$$\left(\mathrm{Vbat} - \left(\mathrm{Vbat} \times \frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right) \times \mathrm{DC} = 0.6\ \mathrm{V} \qquad \text{(eq. 47)}$$

$$\mathrm{Vbat} \times \left(1 - \left(\frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right) \times \mathrm{DC} = 0.6\ \mathrm{V} \qquad \text{(eq. 48)}$$

$$\mathrm{DC} = \frac{0.6}{\mathrm{Vbat} \times \left(1 - \left(\frac{\mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}}\right)\right)} \qquad \text{(eq. 49)}$$

$$\mathrm{DC} = \frac{0.6}{14 \times \left(1 - \left(\frac{0.8}{0.8 + 43.1}\right)\right)} = 4.37\% \qquad \text{(eq. 50)}$$

Example 3 (Group 1)

Rcoil = 97.5 Ω
Rdson = 1.5 Ω
Vbat = 14 V

$$\mathrm{Idrain(Q1)} = \frac{\mathrm{Vbat}}{\mathrm{Rcoil} + \mathrm{Rdson}} = \frac{14}{97.5 + 1.5} = 141\ \mathrm{mA} \qquad \text{(eq. 51)}$$

100% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \qquad \text{(eq. 52)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 53)}$$

$$\mathrm{Power} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 54)}$$

$$\mathrm{Power} = \frac{1.4 \times 1.5 \times 0.141}{1.5 + 97.5} = \frac{2.96}{99} = 29.9\ \mathrm{mW} \qquad \text{(eq. 55)}$$

7.25% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\mathrm{Power} = \mathrm{Vout} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle} \qquad \text{(eq. 56)}$$

$$\mathrm{VOUTx} = \frac{\mathrm{Vbat} \times \mathrm{Rdson}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 57)}$$

$$\mathrm{P} = \frac{\mathrm{Vbat} \times \mathrm{Rdson} \times \mathrm{Idrain} \times \mathrm{Duty\ Cycle}}{\mathrm{Rdson} + \mathrm{Rcoil}} \qquad \text{(eq. 58)}$$

$$\mathrm{Power} = \frac{14 \times 1.5 \times 0.141 \times 0.0725}{1.5 + 97.5} = \frac{0.215}{99} = 2.17\ \mathrm{mW} \qquad \text{(eq. 59)}$$

Example 4 (Group 2)

Rcoil = 43.1 Ω
Rdson = 0.8 Ω
Vbat = 14 V

$$\text{Idrain(Q1)} = \frac{\text{Vbat}}{\text{Rcoil} + \text{Rdson}} = \frac{14}{43.1 + 1.5} = 314\ \text{mA} \quad \text{(eq. 60)}$$

100% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\text{Power} = \text{Vout} \times \text{Idrain} \quad \text{(eq. 61)}$$

$$\text{VOUTx} = \frac{\text{Vbat} \times \text{Rdson}}{\text{Rdson} + \text{Rcoil}} \quad \text{(eq. 62)}$$

$$\text{Power} = \frac{\text{Vbat} \times \text{Rdson} \times \text{Idrain}}{\text{Rdson} + \text{Rcoil}} \quad \text{(eq. 63)}$$

$$\text{Power} = \frac{14 \times 0.8 \times 0.314}{0.8 + 43.1} = \frac{0.352}{43.9} = 80.1\ \text{mW} \quad \text{(eq. 64)}$$

4.37% Duty Cycle Power Dissipation

Power = Power contribution from one output load.

$$\text{Power} = \text{Vout} \times \text{Idrain} \times \text{Duty Cycle} \quad \text{(eq. 65)}$$

$$\text{VOUTx} = \frac{\text{Vbat} \times \text{Rdson}}{\text{Rdson} + \text{Rcoil}} \quad \text{(eq. 66)}$$

$$\text{P} = \frac{\text{Vbat} \times \text{Rdson} \times \text{Idrain} \times \text{Duty Cycle}}{\text{Rdson} + \text{Rcoil}} \quad \text{(eq. 67)}$$

$$\text{Power} = \frac{14 \times 0.8 \times 0.314 \times 0.0437}{0.8 + 43.1} = \frac{0.154}{43.9} = 3.51\ \text{mW} \quad \text{(eq. 68)}$$

SUMMARY

Using a PWM technique and the Turn−On (max) and Turn−Off (min) characteristics of standard relays we are able to reduce the on−chip power dissipation substantially as compared to the standard DC drive supplied to engage relays. Please note any power attributed to flyback events due to the inductive load have been ignored for this presentation.

Table 4. POWER DISSIPATION SUMMARY

	Group 1	Group 2	Group 3	Group 4
V_{BAT}	6.5 V	7.2 V	14 V	14 V
Coil Impedance	47.5 Ω	43.1 Ω	97.5 Ω	43.1 Ω
R_{dson}	1.5 Ω	0.8 Ω	1.5 Ω	0.8 Ω
Coil Turnoff Voltage	1 V	0.6 V	1 V	0.6 V
100% Power duty cycle	6.67 mW	21.9 mW	29.9 mW	80.1 mW
Reduced Duty Cycle (for reduced power dissipation)	1.03 mW (15.4% DC)	1.76 mW (8.04% DC)	2.17 mW (7.25% DC)	3.51 mW (4.37% DC)
% Reduction in Power	84.6%	92.0%	92.7%	95.6%

Worst case numbers calculated at a supply voltage equal to the turn on voltage of the relay were 84.6% and 92.0%. These numbers were further improved with an increase in supply voltage to a standard automotive battery voltage of 14 V to 92.7% and 95.6%.

IN PRACTICE

The previous examples rely on the release time to maintain the engagement of the relay. This approach uses a mechanical mechanism which may not be considered the best approach. Additionally the method requires a minimum release time specification which may not be available in the relay specification. The release time specification is usually detailed as a maximum only.

An alternative approach using a PWM continuous current control method eliminates the mechanical minimum release time specification and relies on all electrical parameters.

Here are waveforms (Figure 2) similar to what you can expect when driving a relay in a pwm method as in Figure 1. The test being run has the relay engaged. The 1st waveform (blue) (C3) is the input driver control waveform “PWM_control”. In this case the driver used is the NCV7240 so the input control pin is INx. The NCV7240 does not need the external flyback diode D1 because the NCV7240 has internal clamping but it is included here to simplify the equations needed to calculate power.

The 2nd waveform (yellow) (C1) is OUTx voltage and clamps to 1V above the supply voltage (Vbat = 14 V) at 15 V.

The 3rd waveform (green) (C4) is the current through the coil. You can see the continuous current through the coil 1st in one direction (increasing) as Q1 energizes Lcoil and then in the other direction (decreasing) as the energy in the coil is dissipated through D1 when Q1 turns off.

Figures 4 and 5 are simply zoomed in scope captures of the same setup.

Note the "jumps" or "skips" in current during the transitions in both directions decreasing to increasing, and increasing to decreasing. This is caused by an internal resistor in the relay across the coil commonly used in relay manufacturers for de−spiking. In this case we can measure the resistor value to be at a common value of 600 Ω. (15 V/25 mA).

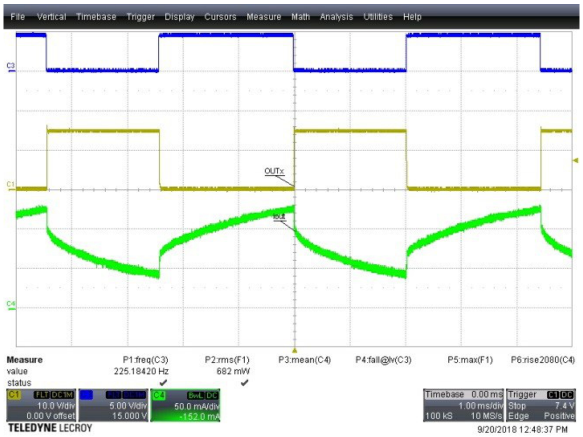


Figure 2. Typical Relay Coil Waveforms

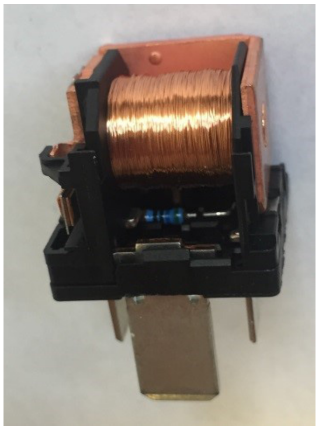


Figure 3. Relay Showing Internal Resistor across the Coil

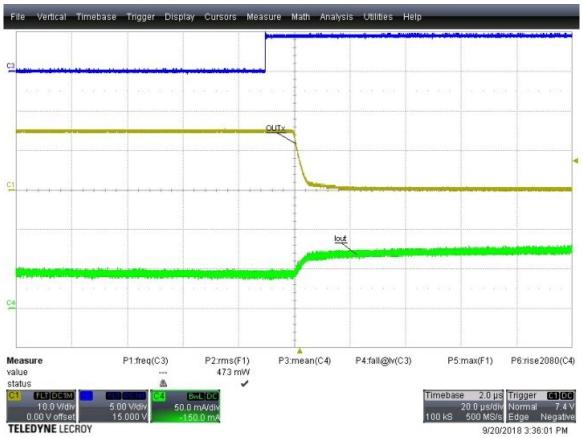


Figure 4. Zoom1 Typical Relay Drive Waveforms

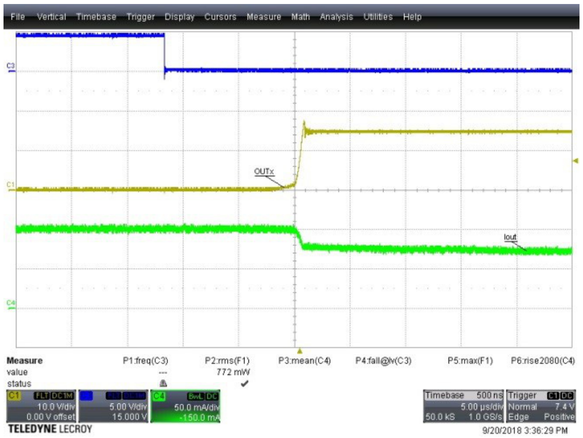


Figure 5. Zoom2 Typical Relay Drive Waveforms

Calculations for engaging the relay require the average current as shown in Figure 2 because this is the power needed to keep the relay energized. It is not the power on the IC. The power on the IC is only a portion of this cycle (while the FET is turned on). While the current through the resistor does not contribute to engaging the relay it is built into the relay specification and must be included if there is a resistor present. So this includes 25 mA of current to sustain the relay. In our examples we will assume the resistor is NOT present (for simplicity).

As with the previous examples (1−4) with the relay release times, the relay is assumed to have been previously engaged and we will focus on the release mechanism function.

Our baseline 100% duty cycle power calculations from example 3 and example 4 will apply here. This assumes a 14 V automotive battery application.

Table 5.

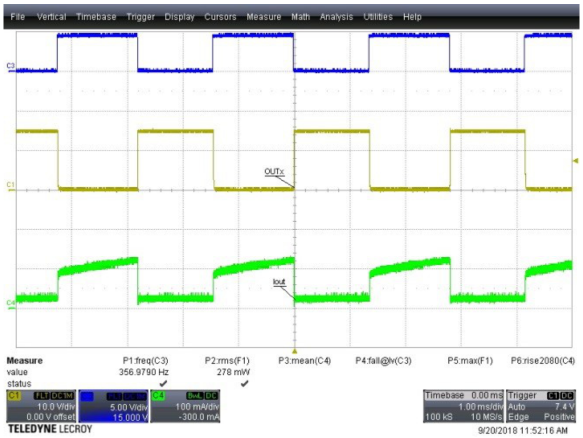
14 V Car Battery Application	100% Duty Cycle	Relay Sustaining Current
Example 3 (97.5 Ω coil)	29.9 mW	10.3 mA
Example 4 (43.1 Ω coil)	80.1 mW	13.9 mA

Power Calculations using PWM Sustaining Current Boundary Conditions

We are concerned here with the power being dissipated on the IC. The current through Q1 is displayed in the scope capture below. Reviewing the current waveform below (Figure 6), highlights that it is ½ of the current “triangle” waveform of Figure 2. This is explained by the fact current is flowing in the IC when Q1 is turned on while it energizes Lcoil and current in the coil continues to flow after Q1 is turned off and flows through D1.

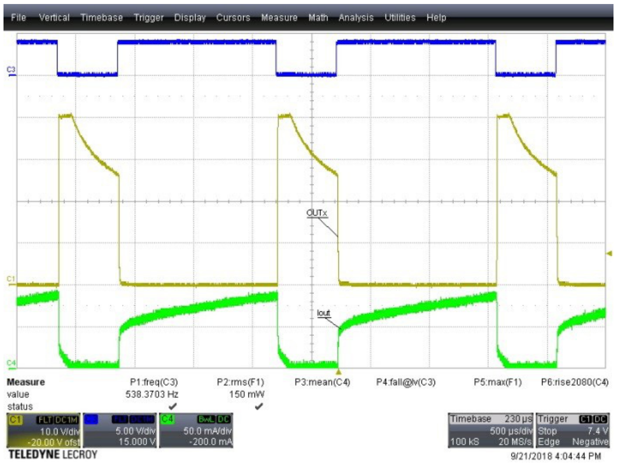
Instantaneous power can be calculated by the voltage on OUTx times the current. Including D1 as a flyback component makes for an easy calculation since the voltage clamp at a flat 15 V (1 V above Vbat).

Figure 7 shows the effect of removing D1. The voltage of the NCV7240 is now clamped at a much higher voltage (40 V) as compared to D1 (15 V) and the current (with the clamping) now is present on the IC instead of D1. So the 40 V clamp contributes more total energy to the IC.



Measure	P1:freq(C3)	P2:rms(F1)	P3:mean(C4)	P4:fall@lv(C3)	P5:max(F1)	P6:rise2080(C4)
value	356.9790 Hz	278 mW				
status	✓	✓				

Figure 6. IC FET Pull−down Current (Q1)



Measure	P1:freq(C3)	P2:rms(F1)	P3:mean(C4)	P4:fall@lv(C3)	P5:max(F1)	P6:rise2080(C4)
value	538.3703 Hz	150 mW				
status	✓	✓				

Figure 7. IC FET Pull−down Current (Q1) without D1

We need to predict what the current levels will be of the “triangle waveform”. Equations below can be used to predict these boundary conditions.

Calculate the Duty Cycle (DC) required for the sustaining current (Iavg) using the following equations should be used. I1 represents the energy storage of the coil inductor and I2 represents the energy discharge from the coil inductor through the diode. In these equations the diode is assumed to be ideal.

$$\mathrm{Iavg} = (\mathrm{I1} \times \mathrm{DC}) + (\mathrm{I2} \times (1 - \mathrm{DC})) \qquad \text{(eq. 69)}$$

$$\text{where} \quad \mathrm{I1} = \frac{V}{R}\left(1 - e^{\frac{-Rt}{L}}\right) \;\; \& \;\; \mathrm{I2} = I_o e^{\frac{-Rt}{L}} \qquad \text{(eq. 70)}$$

$$\mathrm{I1} = \frac{V_{BAT}}{\mathrm{Rcoil} + \mathrm{Rdson}}\left(1 - e^{\frac{-(\mathrm{Rcoil}+\mathrm{Rdson})t}{L}}\right) \qquad \text{(eq. 71)}$$

$$\mathrm{I2} = I_o e^{\frac{-\mathrm{Rcoil} \times t}{L}} \qquad \text{(eq. 72)}$$

A complex excel spreadsheet can yield similar results as presented in Table 4. The current equations do not lend themselves to a detailed presentation here as the peak and valley calculations must reach a steady state over multiple pulses for absolute values for power calculations.

As a comparison of 14 V operation, group 3 yields a 6.13% duty cycle versus the presented Table 4 value of 7.25%. An additional comparison of 14V operation with group 4 yields a 4.13% duty cycle versus 4.37% in the table.

CONCLUSION

Reduced operation power of relays can be accomplished through a PWM operation scheme. This has been shown here initially with calculations taken from relay manufactures datasheets and further confirmed using a complex spreadsheet with simple inductor/resistor timing equations.

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