

# ON Semiconductor

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## Charge Pump Based Multiple LED Driver

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### APPLICATION NOTE

#### Abstract

This application note describes a multi-functional system, capable of generating and controlling the power needed to utilize three features available in modern cellular phones. In addition to larger displays, with full color capability, flash and torch features have now been added to support the embedded camera and the night path finder. These features are made possible by using an ultra bright LED powered by standard battery cells.

#### BASIC CIRCUIT DESCRIPTION

Since the LED have a forward drop voltage ranging from 3 V to 4.5 V, depending upon the forward current, a straightforward connection to a standard battery is not feasible as depicted Figure 1. A boost structure must be used to make the power supply voltage compatible with the LED.

On the other hand, combining three functions in the same system creates a special case since the converter must be capable of driving the wide current load needed for the different functions. The typical currents used to drive the LED, summarized in Table 1, range from a low 1 mA to 350 mA when the flash is activated. Moreover, unlike the xenon photo flash, the LED system must have a relatively long pulse of light to properly illuminate the scene. Typically, a xenon pulse has a 1 ms flash duration, the LED system being in the 100 ms to 200 ms range. Consequently, the converter must be designed to support such a large demand.

High powered LED capable to sustaining up to 800 mA are under development and drivers for these devices should be available within a few months.

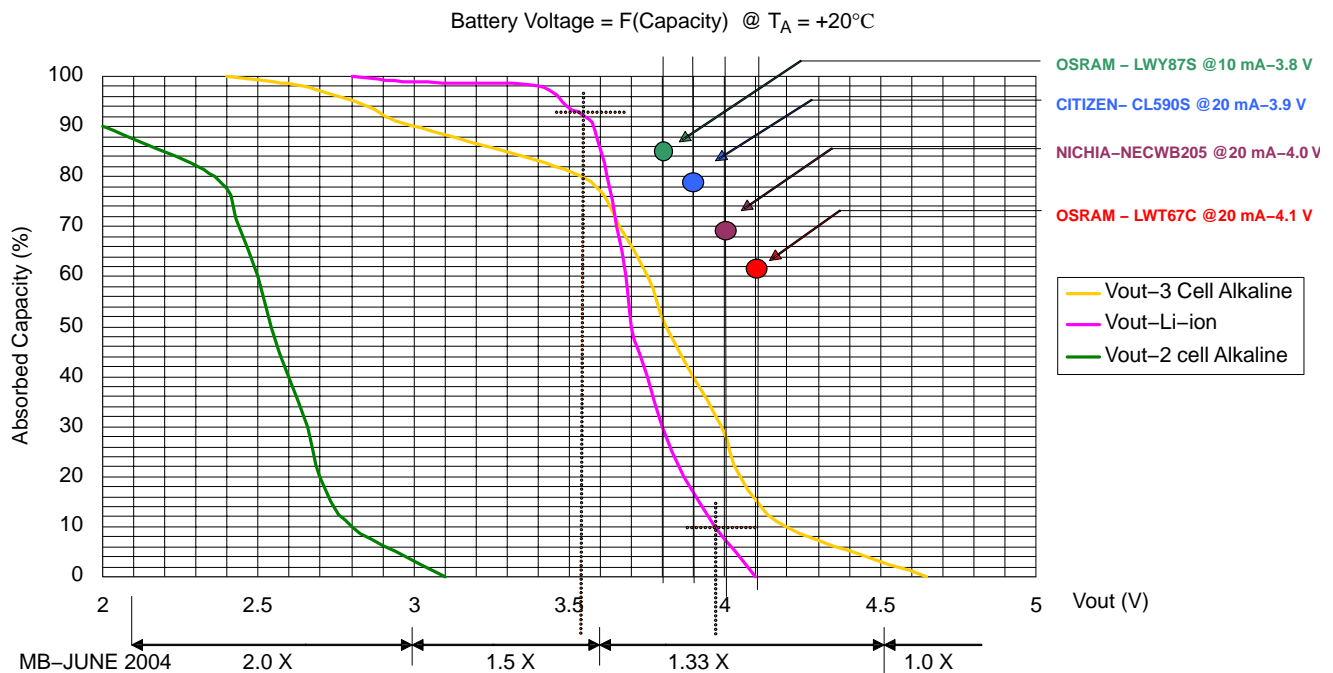


Figure 1. Typical Lithium-Ion Battery Voltage and White LED

Table 1. White LED Typical Applications

| LED              | Backlight    | Torch  | Flash  |
|------------------|--------------|--------|--------|
| OSRAM LWY85S     | 1 mA – 10 mA |        |        |
| OSRAM – LWT67C   | 1 mA – 20 mA |        |        |
| OSRAM            |              | 100 mA |        |
| OSRAM – LWW5SG   |              |        | 350 mA |
| CITIZEN – CL590S | 1 mA – 20 mA |        |        |
| NICHIA–NECWB205  | 1 mA – 20 mA |        |        |
| LUMILED          |              |        | 800 mA |

Along with the amount of current the converter provides, it is worthwhile to note the thermal behavior of both the silicon and the power LED.

According to the OSRAM's data sheet, the Dragon LED (LWW5SG) should have a maximum 4.5 V forward drop with 350 mA current. The power absorbed by the load will be 1.57 W and, assuming a 75% efficiency of the DC/DC converter, will translate to almost 2 W of input power. Consequently, some 400 mW will be dissipated as heat into the silicon and, according to the NCP5603 data sheet, the chip temperature will increase by  $R_{\theta JA} \times P_{in} = 85 \times 0.4 = 34^{\circ}\Delta C$ . Such a temperature increase is acceptable since, even under the worst case +85°C ambient temperature, the junction will be below the maximum rating defined for this chip.

However, we must take into account the low battery situation: in this case, the efficiency of the converter can decrease and we end up with 60% efficiency, yielding almost 54°C temperature increases. At this point, the silicon can rise above 125°C, under extreme high ambient temperature, and the global long-term reliability of the chip will be impaired. This can be avoided by either reducing the thermal resistance (using a heatsink by means of the PCB layer) or by ensuring the duty cycle is short enough to properly cool off the chip between pulses.

Generally speaking, the High Intensity LED are power limited and care must be observed to avoid any thermal run out during normal operation. This is particularly true for the flash mode in which, as depicted above, nearly 1.6 W are dissipated into the LED junctions. Because the junction to ambient thermal resistance is limited by the packaging of the

LED, a good thermal contact to a dedicated layer on the printed board is essential. The LWW5SG specifications give a maximum 9°C/W junction-to-case thermal resistance, capable of limiting the temperature of the silicon to the 100°C maximum specified in the OSRAM data sheet. After dissipating 1.6 W, the maximum thermal to air resistance acceptable by the chip can be calculated as:

$$R_{\theta JA} = \frac{T_{jmax} - T_{amb}}{P_{chip}}$$

$$R_{\theta JA} = \frac{100 - 85}{1.6} = 9.37^{\circ}C/W$$

Since the  $R_{\theta JC}$  is 9°C/W, it is practically impossible to achieve a 0.38°C/W case to ambient thermal resistance and the only alternative is to limit the operating ambient temperature.

Assuming  $T_{amb} = 60^{\circ}C$ , then  $R_{\theta JA} = (100-60) / 1.6 = 25^{\circ}C/W$ .

In this case, the case-to-ambient thermal resistance is  $25 - 9 = 16^{\circ}C/W$ , a value more realistic, although not so easy to achieve with a room limited PCB.

NCP5603 operates without special treatment in terms of thermal sinking and a simple copper flag is built underneath the QFN package as depicted Figure 3.

The schematic of the multiple application, Figure 2, illustrates the three functions:

- Backlight → four LED in parallel, dimming capability.
- Torch → one LED, no output adjustment.
- Flash → one power LED, pulse width adjustable.

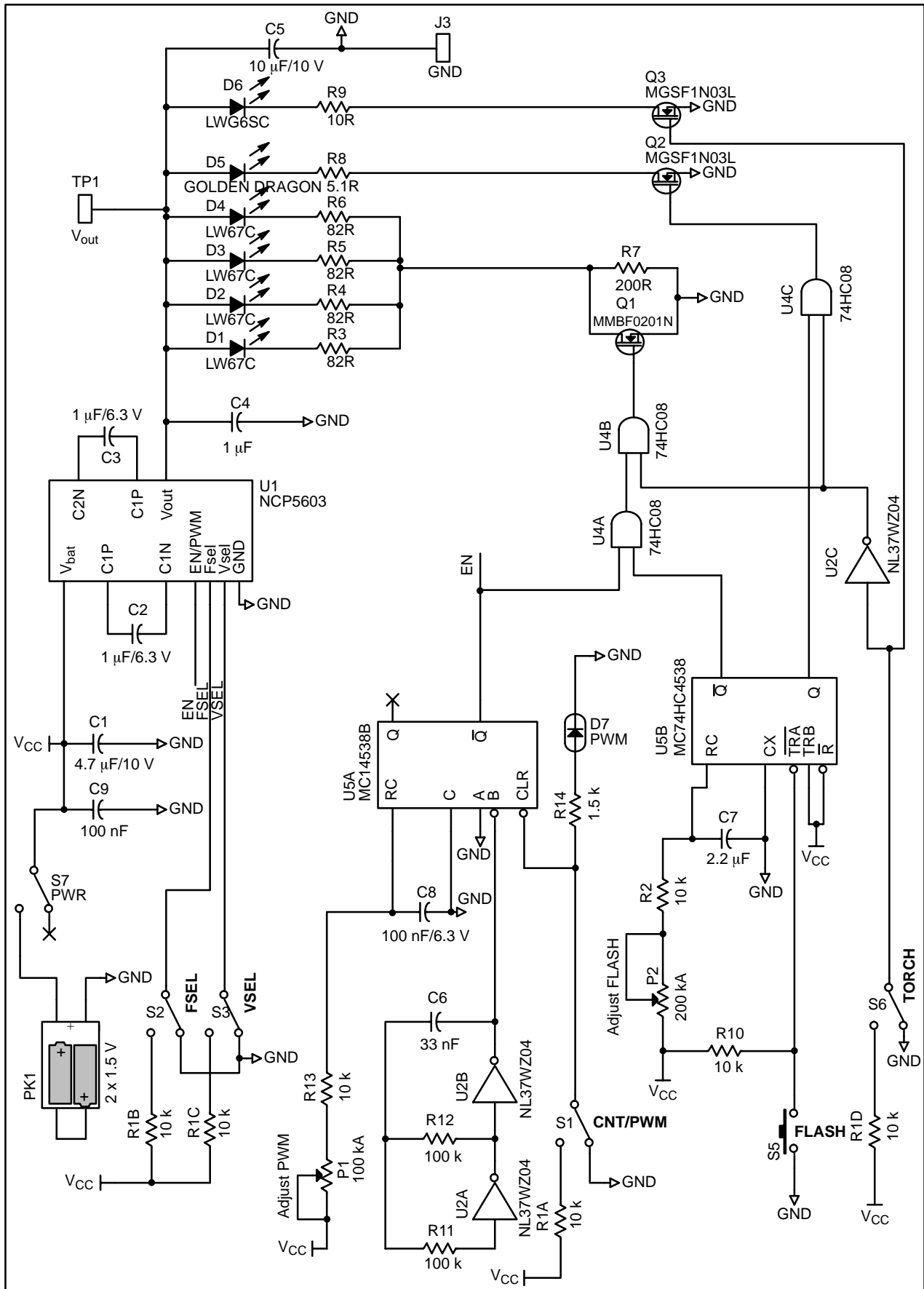
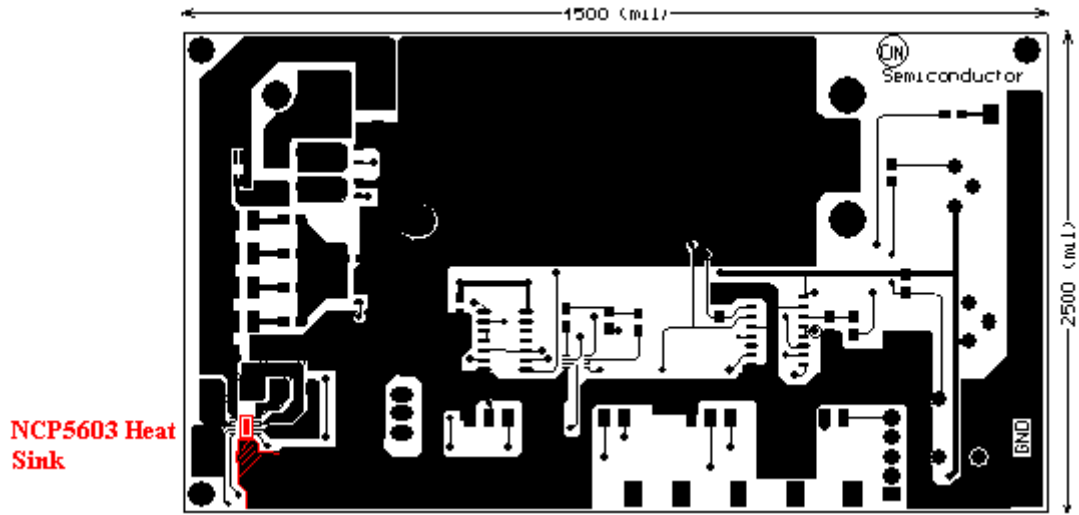
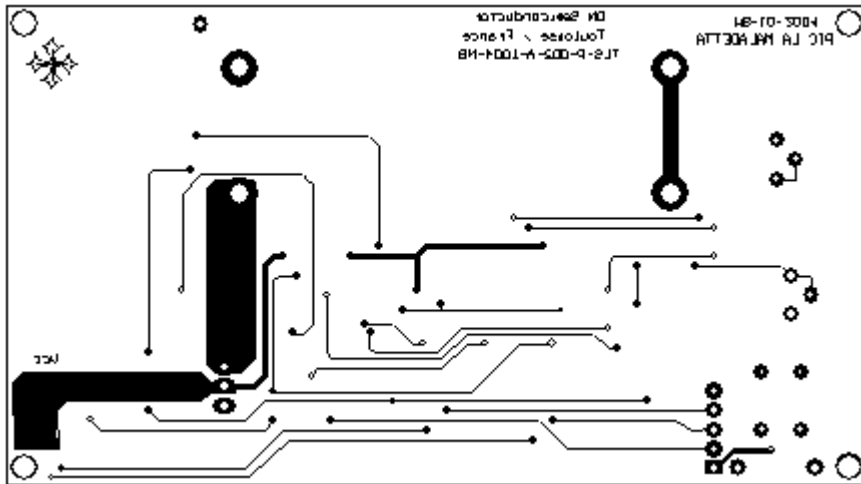


Figure 2. Multiple LED Driver Application

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TOP Layer



BOTTOM Layer

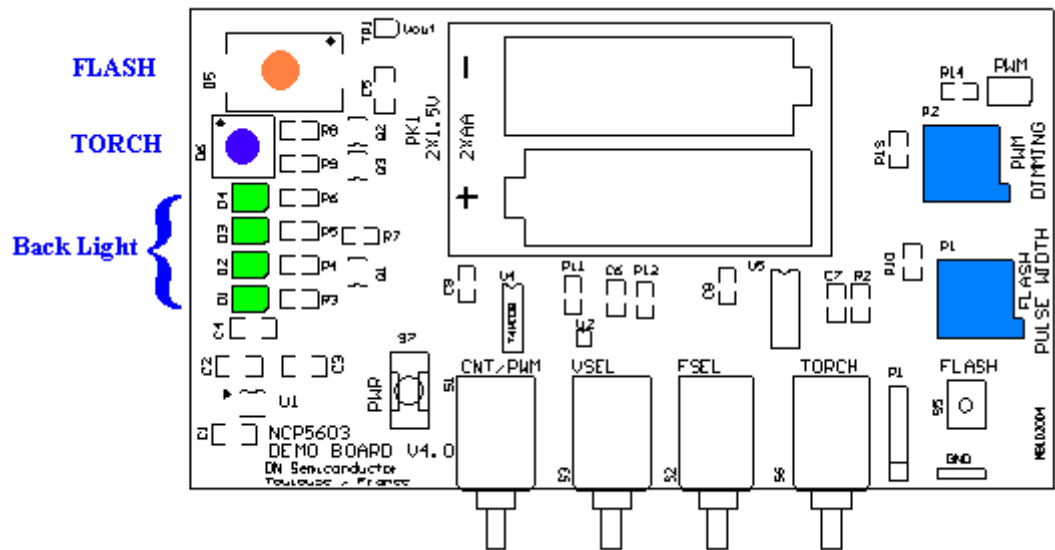


Figure 3. Printer Circuit Board GERBER Files (scale 1:1)

The system is powered by two AA cells in series, assembled in a standard battery holder, the operating mode being selected by the S1, S5 and S6 switches. Since the total current is limited by the DC/DC converter, the backlights LEDs are automatically deactivated when either the Torch or the Flash are selected. Moreover, the Flash is not available while the Torch is running.

An extra feature, backlight dimming, is provided by switch S1 is associated with potentiometer P1. When the switch is connected to ground, the NCP5603 enabling pin EN is high and the brightness is maximized. When the

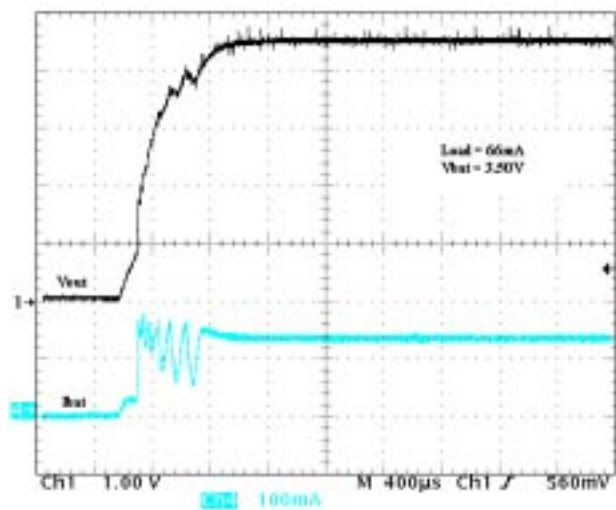
switch S1 is flipped to the Vcc position, the RESET of U5A is released and the EN pin is clocked High / Low by the clock generated by U2A / U2B. Simultaneously, diode LED D7 turns ON to identify the PWM mode of operation. The duty cycle of the U5A /  $\bar{Q}$  output is manually adjusted by potentiometer P1 to set the brightness of the four associated LED.

The efficiency of the system has been evaluated at room temperature (see Table 2), the results being fully within the NCP5603 data sheet specifications.

**Table 2. Demo Board Efficiency**

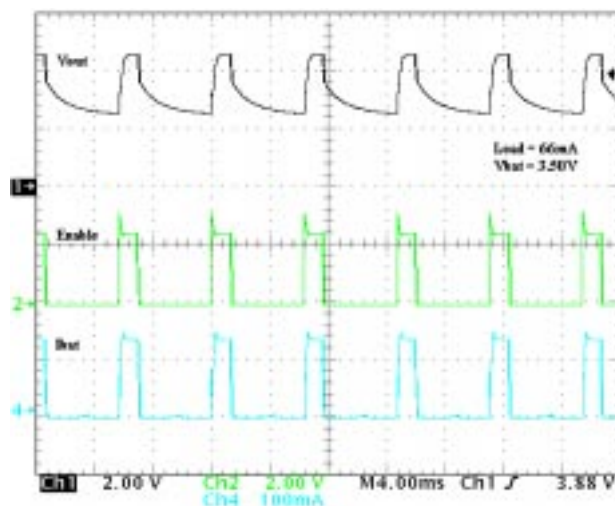
| V <sub>bat</sub> | I <sub>bat</sub> | V <sub>out</sub> | I <sub>out/LED</sub> | I <sub>out Total</sub> | Yield  | Comments        |
|------------------|------------------|------------------|----------------------|------------------------|--------|-----------------|
| 3.50 V           | 2.3 mA           | 0 V              | 0 mA                 | 0 mA                   | –      | No Load         |
| 3.50 V           | 132 mA           | 4.42 V           | 16.5 mA              | 66 mA                  | 63.14% |                 |
| 3.50 V           | 170 mA           | 4.92 V           | 21.4 mA              | 85.6 mA                | 70.78% |                 |
| 3.10 V           | 131 mA           | 4.42 V           | 16.5 mA              | 66 mA                  | 71.83% |                 |
| 3.10 V           | 169 mA           | 4.92 V           | 21.4 mA              | 85.6 mA                | 80.38% |                 |
| 3.10 V           | 300 mA           | 4.92 V           | 142 mA               | 142 mA                 | 75.12% | Torch operation |

The inrush current is internally limited by the chip, as depicted Figure 4, and no uncontrolled current takes place when the system starts up from scratch.



**Figure 4. Typical Startup Timing**

With a startup time well below 1 ms (from zero to full V<sub>out</sub>, see Figure 4), the NCP5603 is fast enough to accommodate a flash application as shown in the demo board.




**Figure 5. Typical Digital Dimming**

Although there is no dedicated pin, the LED brightness can be dimmed by means of the EN digital control. The waveform captured in Figure 5 illustrate this behavior, the PWM being intentionally arranged out of the audio band for a portable system.

# AND8192/D

## NCP5603 – MULTIPLE DRIVE CIRCUIT – Bill Of Material

| QTY | Designator     | Description                           | Footprint    | Manufacturer     | Part Number                       |
|-----|----------------|---------------------------------------|--------------|------------------|-----------------------------------|
| 1   | R1             | 10 kΩ, pack four independent elements | SIP-5        | BOURNS           | 4605X series                      |
| 3   | R2, R10, R13   | 10 kΩ                                 | 0805         | Vishay Draloric  |                                   |
| 4   | R3, R4, R5, R6 | 82 Ω                                  | 0805         | Vishay Draloric  |                                   |
| 1   | R7             | 200 Ω                                 | 0805         | Vishay Draloric  |                                   |
| 1   | R8             | 1.2 Ω                                 | 0805         | Vishay Draloric  |                                   |
| 1   | R9             | 10 Ω                                  | 0805         | Vishay Draloric  |                                   |
| 2   | R11, R12       | 100 kΩ                                | 0805         | Vishay Draloric  |                                   |
| 1   | R14            | 1.5 kΩ                                | 0805         | Vishay Draloric  |                                   |
| 1   | P1             | 100 kΩ A Potentiometer                | VR4          | BOURNS           | 3386F-TW                          |
| 1   | P2             | 200 kΩ A Potentiometer                | VR4          | BOURNS           | 3386F-TW                          |
| 1   | C1             | 4.7 μF/10 V                           | 1206         | TDK              |                                   |
| 3   | C2, C3, C4     | 1 μF/6.3 V                            | 1206         | TDK              |                                   |
| 1   | C5             | 10 μF/10 V                            | 1206         | TDK              |                                   |
| 1   | C6             | 33 nF                                 | 0805         | KEMET            |                                   |
| 1   | C7             | 2.2 μF                                | 0805         | TDK              |                                   |
| 2   | C8, C9         | 100 nF                                | 0805         | KEMET            |                                   |
| 4   | D1, D2, D3, D4 | LW67C                                 | OSRAM_LED    | OSRAM            |                                   |
| 1   | D5             | GOLDEN DRAGON                         | OSRAM_DRAGON | OSRAM            | LWW5SG                            |
| 1   | D6             | LWG6SC                                | OSRAM_LWG    | OSRAM            |                                   |
| 1   | D7             | LED                                   | OSRAM_LED    | OSRAM            |                                   |
| 1   | Q1             | MMBF0201N                             | SOT_23A      | ON Semiconductor |                                   |
| 2   | Q2, Q3         | MGSF1N03L                             | SOT_23A      | ON Semiconductor |                                   |
| 1   | U1             | NCP5603                               | QFN10_COB    | ON Semiconductor |                                   |
| 1   | U2             | NL37WZ04                              | US8          | ON Semiconductor |                                   |
| 1   | U4             | 74HC08                                | SO-14        | ON Semiconductor |                                   |
| 1   | U5             | MC14538B                              | SO-16        | ON Semiconductor |                                   |
| 4   | S1, S2, S3, S6 | Toggle Switch                         | APEM_CMS     | APEM             | TL36WS84000                       |
| 1   | S5             | Push Button                           | PUSH_BUT_B   | CANNON ITT       | KSA 0M210                         |
| 1   | S7             | Toggle Switch                         | CKSWITCH_V   | C & K            | ET01MD1 CBE                       |
| 1   | TP1            | TEST POINT                            | TEST_POINT   | KEYSTONE         | 5005 (THM)                        |
| 1   | J3             | GND                                   | GND_TEST     | HARWIN           | D3082-01 (tin)<br>D3082-05 (gold) |
| 1   | PK1            | 2 x 1.5V<br>Battery holder, 2 x AA    | BPACK2       | KEYSTONE         | 2223                              |

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