A Dollar Store Boost Mode Converter for LED Bulbs

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My article in the November/December 2011 issue of the AMRAD newsletter showed how easy it is to change the 5Vdc output from a dollar store cell phone car adapter. The adapter uses the very common and versatile MC34063[1] switch-mode regulator chip in the step-down or “buck” configuration. A buck converter produces an output voltage that is always lower than the input voltage. In this mode it is similar to a linear voltage regulator like the LM317 but is more efficient. The magic of the switch-mode converter really shines when configured in the step-up or “boost” mode that produces an output voltage higher than the input. Boost mode is useful, for example, when if you want to power a 15 Volt circuit from a 5 Volt source such as a USB port. Another example is powering a 5V USB device from a 3-volt battery pack.

An opportunity to build a boost mode converter came up when I saw a broken 120Vac LED light bulb on the shelf at Home Depot. Here was a chance to tear it apart and find out what was inside. After explaining why I was willing to buy a broken bulb, the agent at the customer service desk gave it to me for free.

Figure 1 EcoSmart LED Bulb

Figure 1 shows the broken bulb. A portion of the diffuser is broken out revealing a hint of the LED array inside the bulb. Surprisingly, the diffuser is frosted glass like a common incandescent bulb. I expected plastic. The bulb is a “40 Watt equivalent” rated at 8.6W by EcoSmart, a Home Depot house brand and sells for less than $10. The bulb produces 429 lumens at a very pleasing color temperature of at 3000°K. I have some of these bulbs in my kitchen and they are an improvement over incandescents and are much better than CFLs in my application. I have noticed some radio frequency interference when placed close to my FM radio.

The first step in the tear down was to cover the bulb with a cloth and gently smash the rest of the glass difuser. It takes some effort to remove the glass shards at the base as they are held in by a very tenacious and resilient elastomer.

Figure 2 is a close-up of the LED array. There are 16 chips mounted to an aluminum plate 32 mm in diameter. The LED chips are surface mount devices connected in two parallel strings of eight series diodes. It took a hot iron to unsolder the two leads from the LED array because the sink is very effective in dissipating the heat. The base contains the electronics to match the 120Vac line to the LED array and is completely potted inside an insulating tube. It probably contains a high power factor switched rectifier followed by a buck converter.

Figure 2 LED Array

In order to find the voltage and current used by the LED array I remounted the LED array to the heat sink and connected a dc voltmeter and ammeter to the circuit. Although the array seems to be electrically isolated from the line, to be on the safe side, I fed the bulb through an isolation transformer and used a Variac to adjust the input voltage from 0 to 125Vac.

With 120Vac input the LED array drew 280mA at 24.6Vdc for 6.9W. This is the design condition for our boost converter.

Figure 3 shows the current-voltage curve for the array. As is typical for LEDs the I-V curve is very steep after reaching the forward "turn on" voltage. At 24.6Vdc the dynamic resistance of the 16-LED array is 2.7 Ohms. A change of ±0.1V (4%), as might happen due to fluctuation of diode temperature, will change the current by ±37mA (13%). We really should use a constant current driver such as the NCP3063[2]. But the DSU has nearly all the parts we need mounted on a very small printed circuit board for one US dollar.

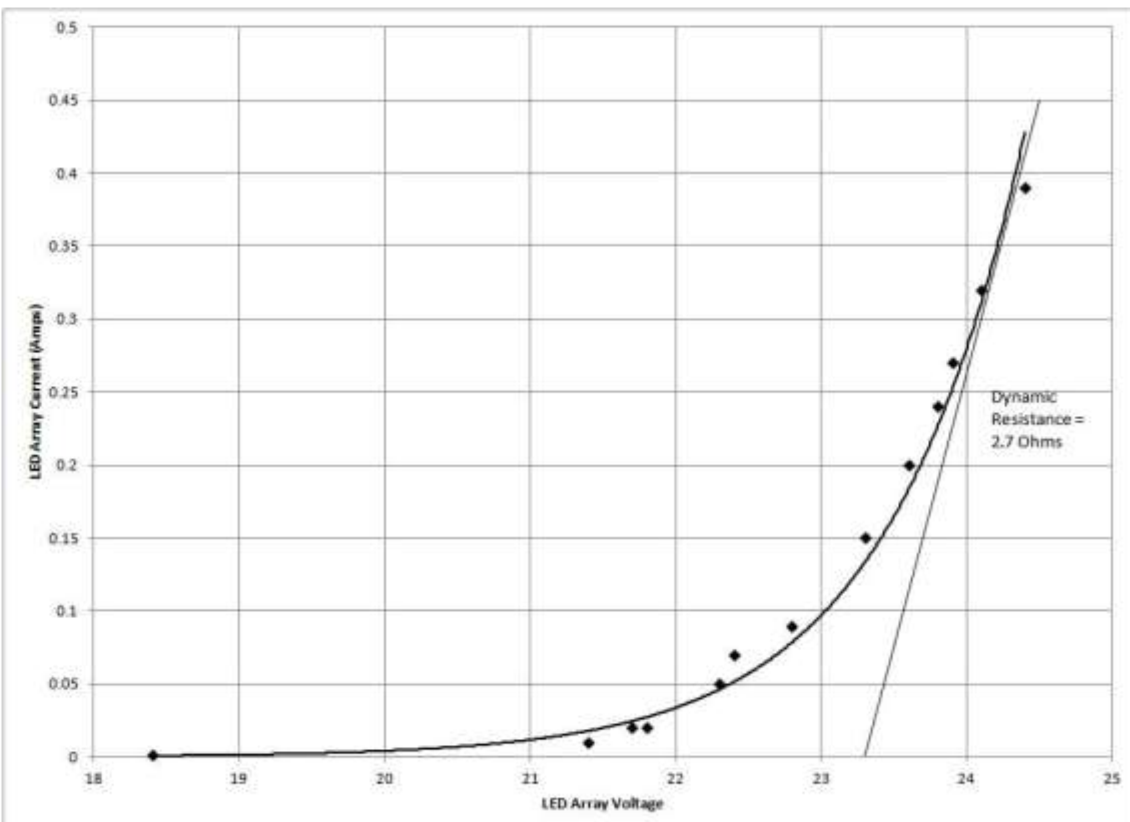

Figure 3 LED Array V-I Curve

Design parameters:

V_{out}	24.6Vdc	
I_{out}	0.28Adc	
V_{in}	11Vdc	This is the low end of a 12V lead acid battery.
f	100kHz	I picked this value before I noticed that the datasheet says the limit is 30kHz.
V_F	0.3Vdc	Schottky diode forward voltage drop at 0.28A.
V_{sat}	0.6dc	Transistor switch saturation voltage in the non-Darlington connection from the data sheet at 1.3A.

Let's work through the design equations for the 34063 chip in the boost configuration:

Find the On-to-Off ratio:

$$t_{on}/t_{off} = \frac{V_{out} + V_F - V_{in}}{V_{in} - V_{sat}} = \frac{24.6 + 0.3 - 11}{11 - 0.6} = 1.33$$

The period of the switching cycle is the reciprocal of the frequency. Let's choose 100kHz as the switching frequency then find the ON and OFF times:

$$t_{on} + t_{off} = \frac{1}{f} = \frac{1}{100{,}000Hz} = 10\mu s$$

$$t_{off} = \frac{t_{on} + t_{off}}{t_{on}/t_{off} + 1} = \frac{10}{1.33 + 1} = 4.3\mu s$$

$$t_{on} = \left(t_{on} + t_{off}\right) - t_{off} = 10 - 4.3 = 5.7\mu s$$

Find the timing capacitor:

$$C_T = 4x10^{-5} t_{on} = 4x10^{-5} \cdot 6.1x10^{-6} = 228pF\ use\ 220pF$$

$$I_{pk(switch)} = 2I_{out}\left({}^{t_{on}}/_{t_{off}} + 1\right) = 2 \cdot 0.28(1.33 + 1) = 1.3A$$

$$R_{SC} = {}^{0.3}/_{I_{pk(switch)}} = {}^{0.3}/_{1.3} = 0.23\Omega\ use\ the\ 0.22\Omega\ in\ the\ DSU$$

$$L_{min} = \frac{V_{in} - V_{sat}}{I_{pk(switch)}} t_{ON} = \frac{11 - 0.6}{1.3} 5.7 = 46\mu H\ use\ the\ 260\mu H\ in\ the\ DSU$$

$$\frac{R_2}{R_1} = \frac{V_{out}}{1.25} - 1 = \frac{24.6}{1.25} - 1 = 18.7$$

The DSU uses 1.2K for R1 so R2 will be 22K.

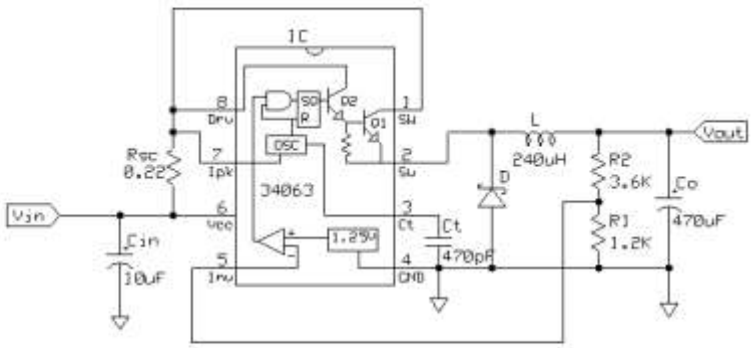

Figure 4 DSU Circuit - Buck Mode

Reconfiguring the board from buck mode to boost mode took some careful work with a motor tool and some creative relocation of the inductor and Schottky diode. I changed the timing capacitor and R2. We really don't care about output voltage ripple because the human eye cannot see the 100kHz flicker of the LED but I put a 22µF 50Vdc electrolytic from my junk box in place of the 10V unit on the DSU. Maybe it will help control the radio frequency interference noted from the stock unit.

I also cut off the part of the board that mounts the USB connector. The final board is 30mm long by 15mm wide and 15mm high. Sadly, it is just a fraction too big to fit inside the bulb base so I put it in the feed line to the bulb and covered it with shrink tubing.

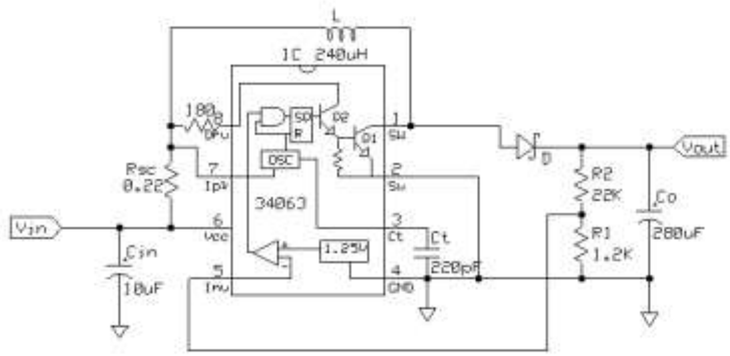

Figure 5 DSU Reconfigured as Boost Mode

The completed bulb works fine and produces useful area lighting with less than 600mA at 12Vdc – perfect for EMCOMM or portable operation. The efficiency is nearly 75% at 12Vdc. The measured performance and efficiency curves are shown in Figure 6. Despite designing the circuit for a minimum input voltage it actually works quite well down to 3 Volts.

MC34063 Boost Mode Design Equations

No.	Description	Parameter	Calculation
1	On-to-off ratio	$\left(t_{on}/t_{off}\right)$	$\frac{V_{out} + V_F - V_{in}}{V_{in} - V_{sat}}$
2	Cycle period	$\left(t_{on} + t_{off}\right)$	$\frac{1}{f}$
3	Off time	t_{off}	$\frac{\left(t_{on} + t_{off}\right)}{\left(t_{on}/t_{off}\right) + 1}$
4	On time	t_{on}	$\left(t_{on} + t_{off}\right) - t_{off}$
5	Timing capacitor	C_T	$4.0\ x\ 10^{-5} t_{on}$

No.	Description	Parameter	Calculation
6	Peak switch current	$I_{pk(switch)}$	$2I_{out}\left(\left({t_{on}}/{t_{off}}\right)+1\right)$
7	Current sense R	R_{SC}	$\frac{0.3}{I_{pk(switch)}}$
8	Minimum inductance	L_{min}	$\left(\frac{V_{in}-V_{sat}}{I_{pk(switch)}}\right)t_{on}$
9	Output capacitor	C_O	$9\frac{I_{out}t_{on}}{V_{ripple}}$
10	Voltage divider ratio	$\left({R_2}/{R_1}\right)$	$\frac{V_{out}}{1.25}-1$

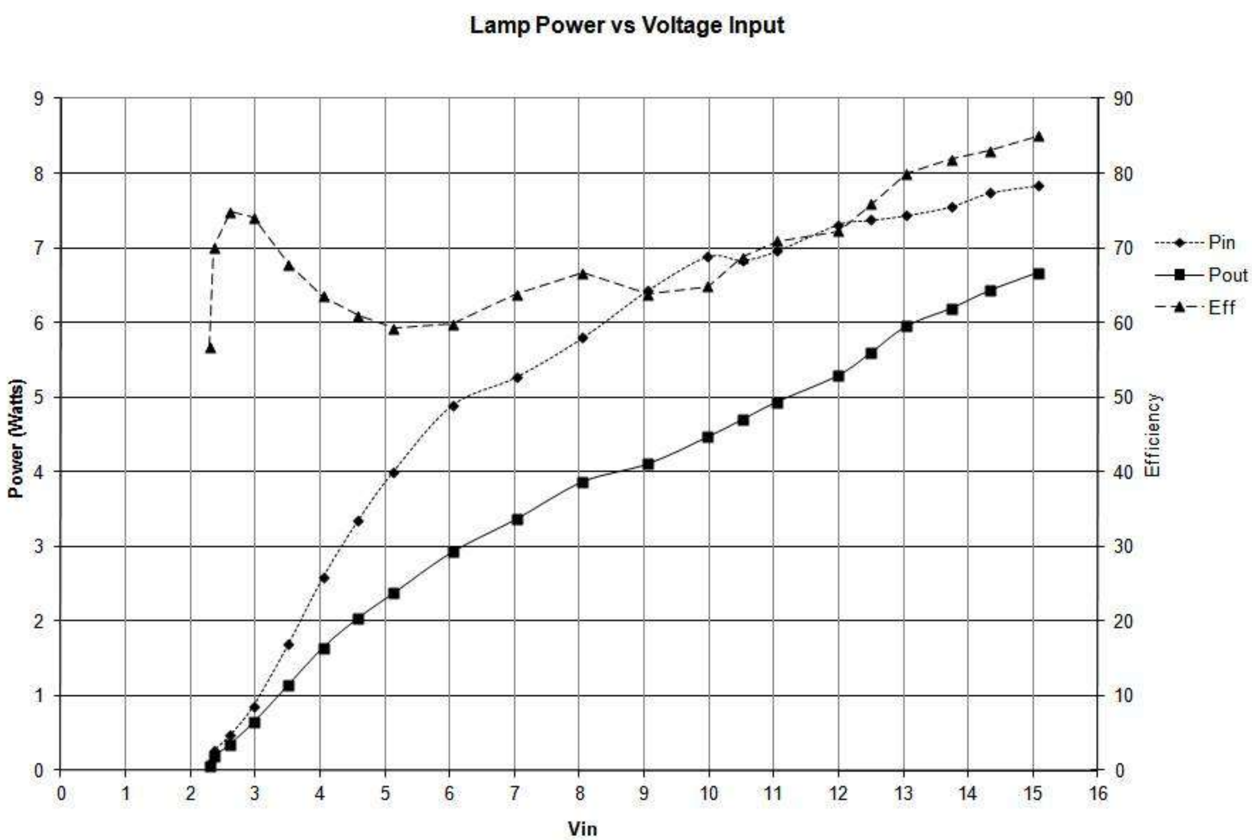

Figure 6 As-Built Measurements

REFERENCES:

1. MC34063 datasheet, ON Semiconductor, http://www.onsemi.com/pub_link/Collateral/MC34063A-D.PDF
2. NCP3063 product information, ON Semiconductor, http://www.onsemi.com/PowerSolutions/product.do?id=NCP3063