Non-Isolated AC/DC Power Supply Design and Implementation based on Power Integrations LNK3205

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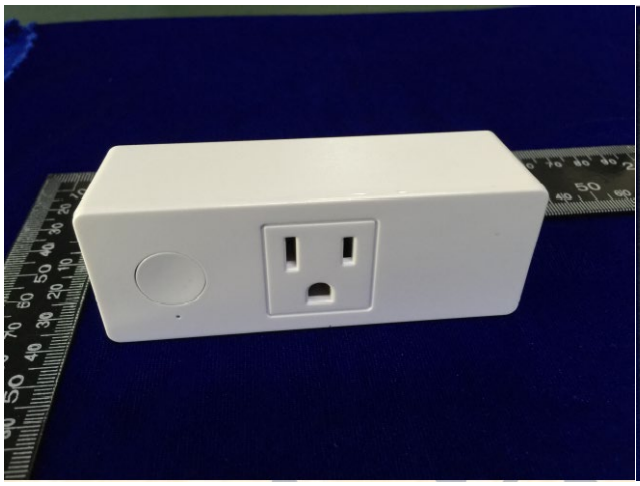
Part I: Project Background

On 11-Oct-2017, my company planned to design a Plug-In Relay (On/Off) product for our IEEE 802.15.4 based smart home application. The project was accomplished, and the product got its FCC and UL certifications, recently. As a person who involved in every detail of hardware design and manufacturing. I have to say based on my personal working experience, if the RF related design is the first most important thing for the product, the AC/DC should take the place just behand the RF design. The communication range and quality are defined by the RF design which may affect the user experience since the first time they are using the product. However, to a certain extent, the product's life span is defined by the AC/DC design which may affect the manufacturer to define the warranty time. Especially, the AC/DC circuit is the only module in our product which contains electrolytic capacitors. For a well-designed product, electrolytic capacitor is the one of main causes of product failure.

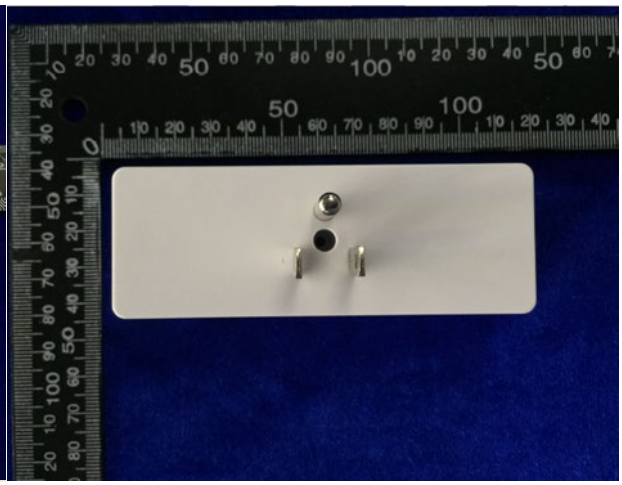
Let us focus on AC/DC design, the first thing needs to be cleared is why using Non-Isolated AC/DC. I designed a satisfied 3.3VDC isolated AC/DC solution based on the Power Integrations LNK363DN for our previous projects. Those projects already got FCC and UL certifications. Therefore, in the very beginning, I preferred to reuse the mature solution for this project, but after a little bit research I realized that the isolated solution may rise the BOM cost significantly due to HLW8032 high-precision energy metering IC. HLW8032 requires a 5VDC Non-Isolated AC/DC. So, an additional small footprint 5VDC Non-Isolated AC/DC must be used even the 3.3VDC isolated AC/DC is already at there for powering up the SOC. Digital Isolators also need to be added for the communication between the SOC and HLW8032. According to the consideration of the product's size, reliability and the BOM cost, I

decided to design a new 5VDC Non-Isolated AC/DC based on Power Integrations LNK3205 which has capability to power up the whole product.

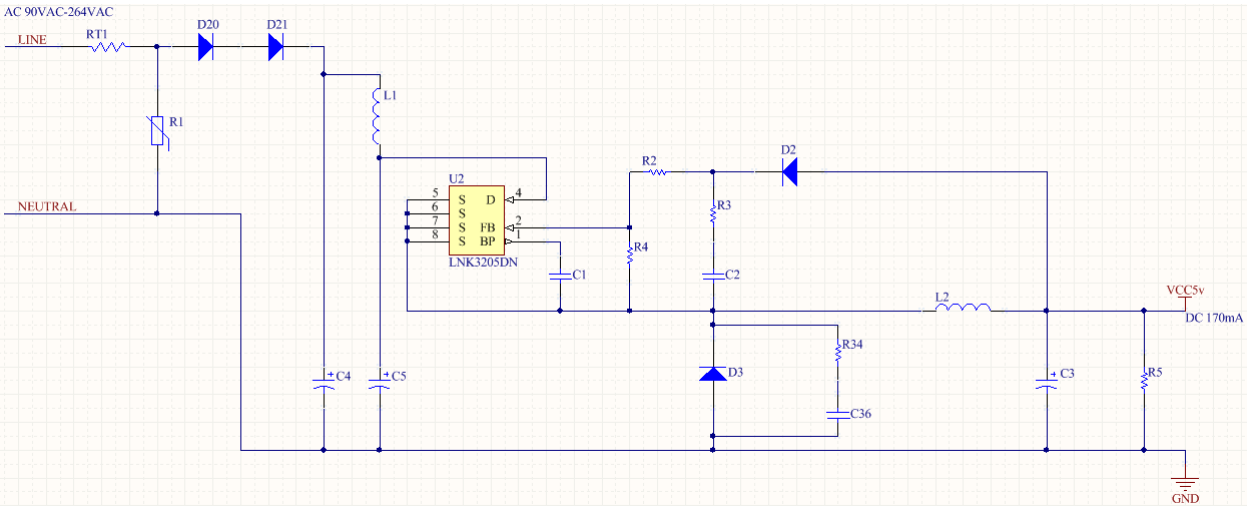
Part II: Theoretical Analysis and Calculation



Front view of product



Back view of product



5VDC Non-Isolated AC/DC Schematic

Design Requirements:

90VAC-264VAC Input, 5VDC 170mA Output. LNK3205's operation frequency is 66kHz (fsw).

1. Inductor L2
   Calculation of the Inductance Value

According to the design requirements, $VIN_{min} = 90VAC$ multiply by 1.41 as the peak voltage and take a 20% margin. Thus,

$VIN_{min} = 90VAC * 1.41 * 0.8 = 101V$

$$Duty(max) = \frac{V_o}{VIN_{min}} = \frac{5VDC}{101V} = 0.0495$$

$$t_{on}(max) = \frac{Duty(max)}{fsw(min)} = \frac{0.0495}{66kHz} = 0.75us$$

$Io(max)$ takes a margin of about 20%, $Io(max) = 170mA * 1.2 = 0.204A$

$L = t_{on}(max) * \frac{VIN_{min} - V_o}{I_p}$ (Where the critical point (peak) $I_p = Io(max) * 2 = 0.408A$)

$= 0.75us * \frac{101VDC - 5VDC}{0.408A} = 176.47uH$ => the inductor should be larger than 177uH

So, I selected 680uH (required by datasheet and widely available in the supply chain)

Calculation of the Inductor's Current Rating

Assume that the minimum ON time at the maximum input voltage 264VAC is

$$t_{on}(min) = \frac{\left(\frac{5VDC}{264VAC * 1.41}\right)}{66kHz} = 0.2us$$

Thus, $IL_{peak} = t_{on}(min) * \frac{VIN_{max} - V_o}{L} = 0.2us * \frac{264VAC * 1.41 - 5VDC}{680uH} = 0.108A$

=> the inductor's current rating should be larger than 0.2A.

2. Output Capacitor C3

Assume that the output ripple voltage (ΔVpp) is 100mV

$Z_{C3} < \frac{\Delta Vpp}{IL_{peak}} = \frac{0.1V}{0.108A} = 0.926\ Ohm\ @\ 66kHz\ (fsw(min))$

Convert $Z_{C3}$from 66kHz to 100kHz

$$Z_{C3} < 0.926\ Ohm\ * \frac{66}{100} = 0.611\ Ohm\ @\ 100kHz$$

The ripple current $I_s(rms)$:

$$I_s(rms)\ =\ IL_{spk} * \sqrt{\frac{1}{3}} = 0.108A * \sqrt{\frac{1}{3}} = 0.06235A$$

Voltage Rating of Capacitor C3 is $V_o * 2 = 5V * 2 = 10V$

3. Output Diode D3
   Since the output rectifier diode turns on and off at the switching frequency, it uses a fast recovery diode that can switch at high speed (66kHz or above).

   The reverse voltage applied to the output diode should be less than or equal to the margin:
   $V_{dr} = \frac{VIN_{max}}{0.7} = \frac{264*1.41}{0.7} = \frac{372}{0.7} = 531V$ => select 600V products
   Diode losses are approximate, but are:
   $P_d = V_F * I_{out} = 1V * 0.17A = 0.17W$
   $V_F$means diode's forward voltage.

4. R_{BIAS}(R4) and R_{FB} (R2)
   The value of R_{BIAS}(R4) and R_{FB} (R2) are selected such that, at the regulated output voltage, the voltage on the FEEDBACK pin(V_{FB}) is 2.0V. This voltage is specified for a FEEDBACK pin current (I_{FB}) of 49uA.

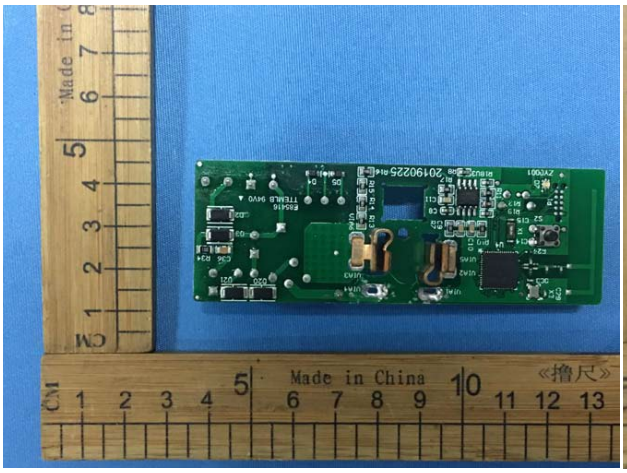
   Let the value of R_{BIAS}(R4) =2.49 kOhm; this bias the feedback network at amount of ~0.8mA

   Hence the value of R_{FB} (R2) is given by

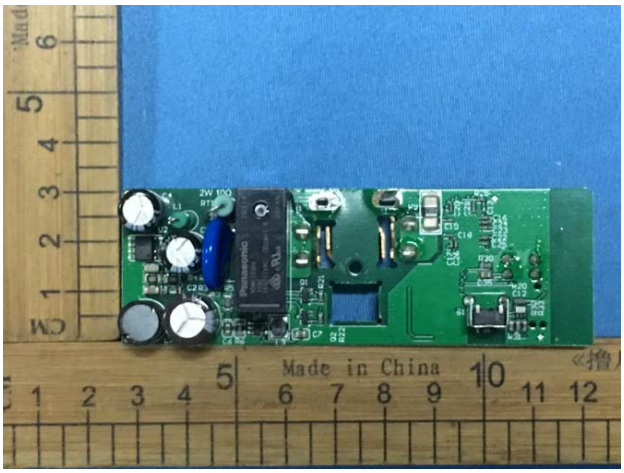
$$R_{FB} = \frac{V_o - V_{FB}}{\frac{V_{FB}}{R_{BIAS}} + I_{FB}} = \frac{(V_o - V_{FB}) * R_{BIAS}}{V_{FB} + (I_{FB} * R_{BIAS})}$$
$$= \frac{(5VDC - 2VDC) * 2.49kOhm}{2V + (49uA * 2.49kOhm)}$$
$$= 3520.25\ Ohm$$ =>3.48 kOhm

5. Verification
   $$solve\left(\frac{(x-2)\cdot 2490}{2 + (49\cdot 10^{-6}\cdot 2490)} = 3480, x\right)$$
   x = 4.9657 VDC

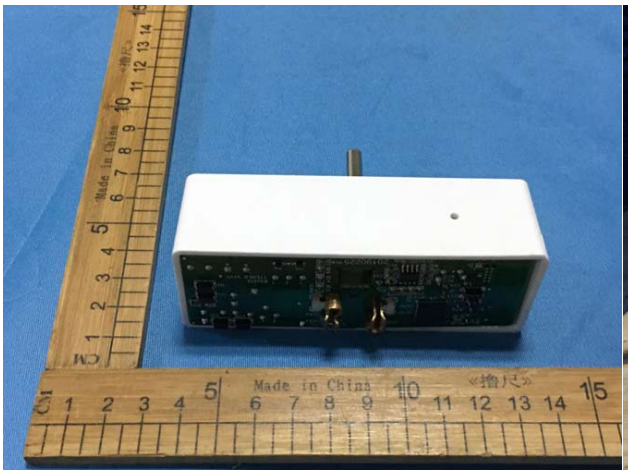
Part III: Circuit Implementation



Internal Photo 1



Internal Photo 2



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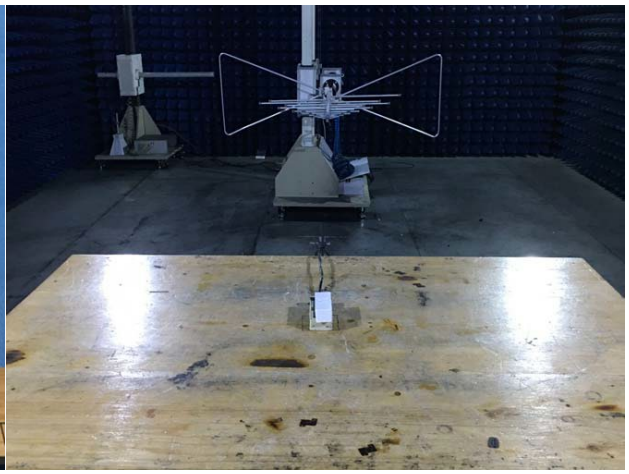
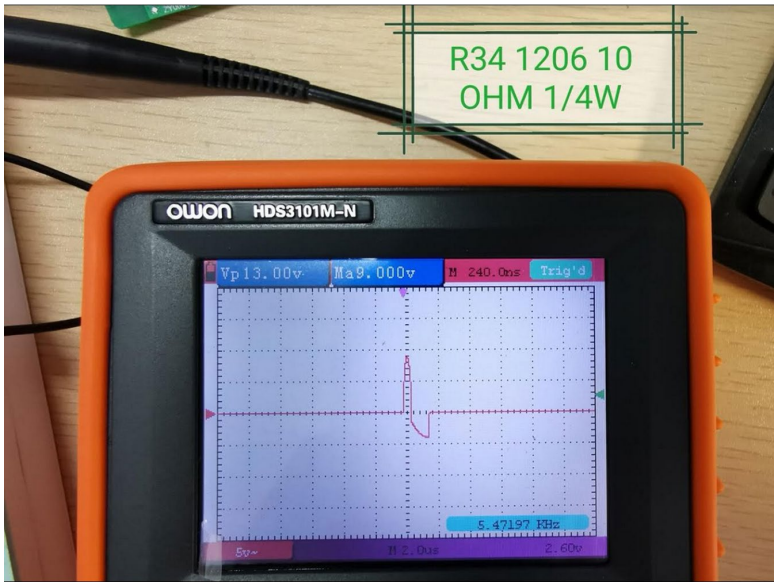


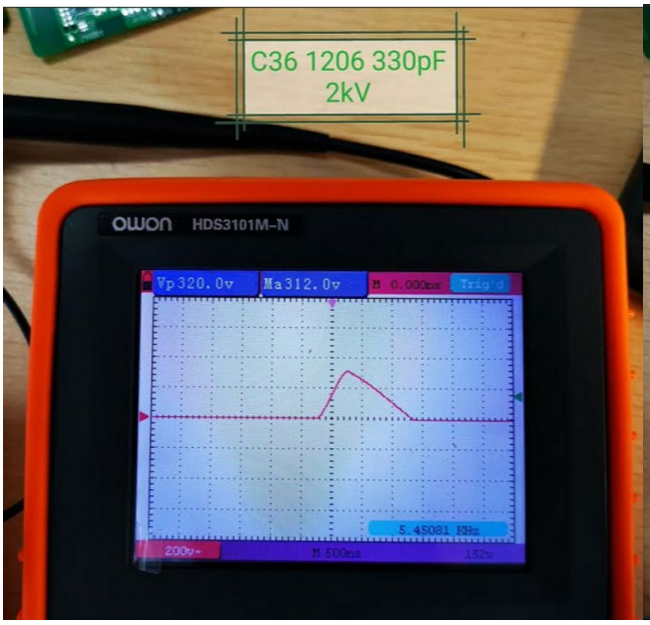
FCC Test Setup

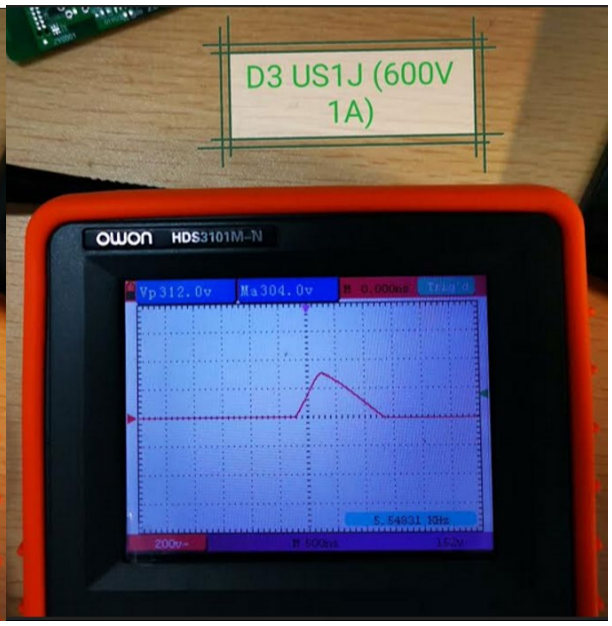
Components	Theoretical Calculations	Mfr. No
Inductor L2	680uH Current Rating > 0.2A	FH VLU0810-681KB
Capacitor C3	Less than 0.611 Ohm @ 100kHz Voltage Rating > 10V	NIPPON CHEMI-CON EKZE160ELL471MJC5S
Diode D3	Voltage Rating >= 600V Fast Recovery Diode that can switch at high speed (66kHz or above)	VISHAY US1J-E3/61T
R_{BIAS}(R4) and R_{FB} (R2)	R_{BIAS}(R4): 2.49 kOhm R_{FB} (R2): 3.48 kOhm	1206, 1/4W, 1%, -55°C ~ 155°C

C4, C5 and L1 are PI filter for EMI suppression. R34 and C36 in parallel to D3 are used to reduce spikes occurring ON/OFF.

Some measurement results when the input was 220VAC, 50Hz:



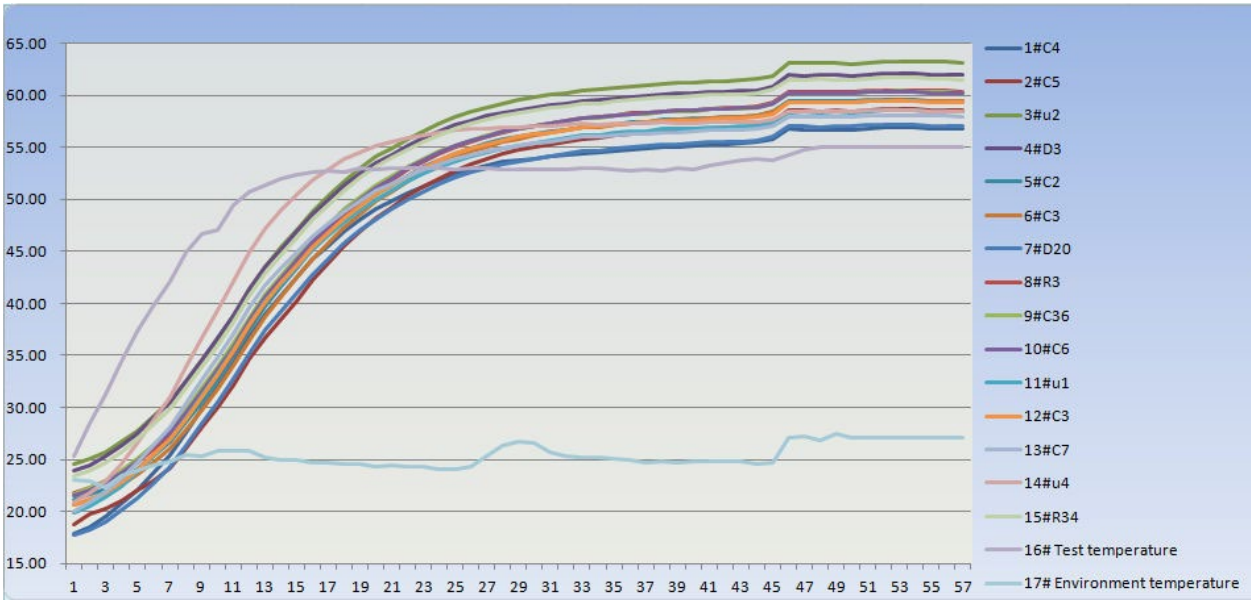




Part IV: Mean Time To Failure (MTTF) and Thermal Analysis

Test Contents:

NO	Testing item	Technical requirements	Results	Note
1	High and low temperature alternating heat and humidity tests	Ten samples are in series, connected with 120V power supply, a total of 4 groups. Test conditions: 1. Operate at high temperature and high humidity, with a temperature of 45℃ and a humidity of 95%, maintained for 7H. 2. Low temperature operation: -20℃ 7H operation 3. Temperature rise: 1℃/min to 45℃ humidity rises to 95% and remains for 7H; 4. First, bring the humidity to normal, and keep it at -20℃ for 7H; 5. Increase temperature by 1 degree/minute to 45 degrees, and keep humidity at 95% for 7H; 6. Repeat steps 4 and 5 for 3 cycles. The sample worked normally after the test。	qualified	/
2	High temperature aging life	Ten samples are in series, connected with 120V power supply, a total of 4 groups. Test conditions: When T=55±2°C, the test time was 450 hours. MTBF was calculated according to the test time after the test。	qualified	> 11.40 years



Component Temperature Rise Curve

Part V: Conclusion

The 5VDC Non-Isolated AC/DC based on Power Integrations LNK3205 was designed to meet all project's requirements successfully. It was integrated into the Plug-In Relay (On/Off) product which already got its FCC and UL certifications. According to the Mean Time To Failure Test above, the Plug-In Relay (On/Off) product's high temperature aging life was more than 11.4 years.

Part VI: References

[1] FCC Reports of Libre Home Inc Wireless Relay Control PRU. Retrieved Nov 15, 2019, from https://fccid.io/2AQXA-PRU