AN2108

LED PPFC quick guide

This design guide is intended to help solve problems thatz occur when designing a RediSem Passive Power Factor LED driver. Before beginning a design, either use RediSem's Component Calculator spreadsheet or request RediSem to provide the initial design and use this guide to help when fine-tuning and fault finding. Please use the following schematic for component references used throughout this document:

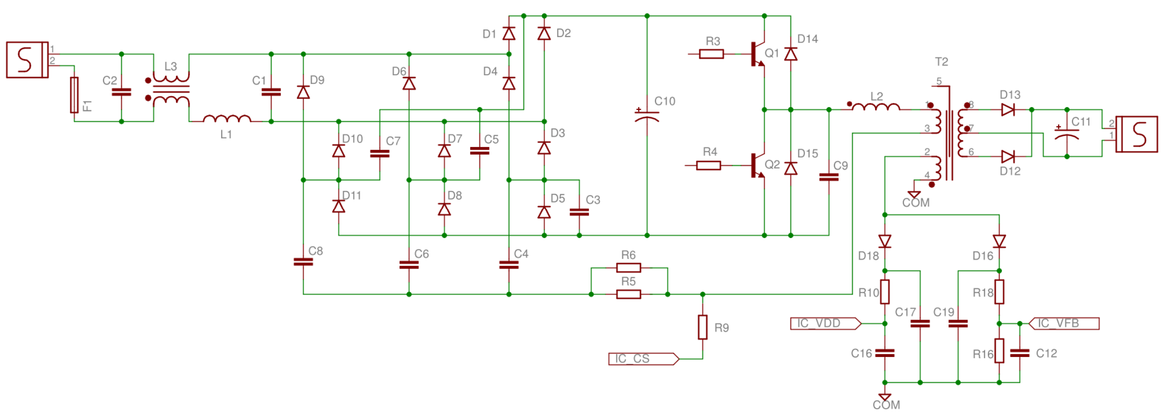

Figure 1: RediSem driver key component reference schematic

Creating the PCB

There are a few key areas that are important to layout correctly in order to have a good design. Please follow these guidelines:

- Position the RC components near the RC pin of the IC. Keep the tracks as short and thin as possible
- Keep the track connected to the VFB and Comp pins(R18, R16, C12) as short as possible
- Put the capacitors as close to the pins as possible
- Use a ground plane around the IC's inputs (pins 1, 2, 5, 8) wherever possible
- Treat both ends of the CS resistors (R5, R6) as star connections. Position the CS resistors (R5,R6) close to the IC
- Do not have high currents flowing under the IC. Make sure that the main load current is not flowing in the IC GND
- Keep the IC's Aux power loop small. Track D18 and C17 directly back to the transformer GND
- Keep the base drive tracks short – watch out for Q2 because this also connects to HT-
- Keep the "Noisy" tracks short. These are the switched node of the transistors both before and after the base drive winding & tracks to the main inductor L2
- Keep these "Noisy" tracks away from the IC and small signal tracks
- Make sure that the main inductor L2 is polarized so that the noisy end which is connected to Q1,Q2 is on the inside of the winding
- Keep the CM inductor and input connector as far away from the noisy tracks as possible – this helps EMI
- Keep the "Noisy" nodes away from the secondary circuit – this helps EMI
- If a transformer screen winding is to be used, connect it directly to the quiet side of the CM inductor (junction of C1 and L3) using a separate track
- Make sure that the base drive windings are all correct - this is a very common problem for the driver not starting

Choosing the correct components

Even though the PPFC components are low cost and commonly available, care should still be taken to choose the correct components. This section aims to help customers select the right components.

Choose PC44 core material or better

A major disadvantage of flyback transformers is that they need a large ferrite core volume to avoid saturation problems. However, as the flyback topology only uses half of the available flux swing, a low-grade material such as PC40 gives acceptable core loss.

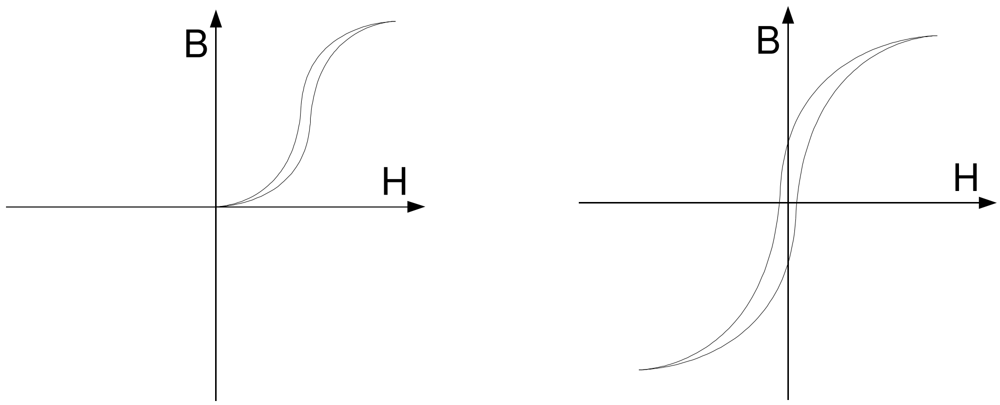

Figure 2: Flyback compared to LLC transformer Flux Density swing

Resonant full-wave forward transformers (such as the LLC) are much more compact than flyback transformers because they utilize both halves of the B-H curve, and this results in a higher relative core loss when compared to flyback transformers. Because LLC ferrite volume is small, total core loss will not be high, but core material selection will have a significant effect. This can often mean that using a more expensive, higher grade core material can result in a smaller (and cheaper) transformer.

Low loss core materials are readily available. Comparing the material choices from TDK, the older PC40 has the highest losses and most of the modern core materials will reduce the power loss by approximately 25% when the core operates at 100˚C. Below shows a table of TDK power ferrites. For RediSem resonant converter products, we recommend the use of PC44 or better.

Material			PC95	PC90	PC47	PC44	PC40
Initial permeability	μ_i	25 °C	3300±25%	2200±25%	2400±25%	2400±25%	2300±25%
Core loss volume density		25 °C	350.0	680	600	600	600
at 100kHz, 200mT		60 °C	290.0	470	400	400	450
Typical Values	P_{cv}(kW/m^3)	80 °C	280.0	380	300	320	400
		100 °C	290.0	320	270	300	410
		120 °C	350.0	400	360	380	500

Figure 3: TDK core loss specifications

Use NPO material for C9

C9 is a high voltage capacitor and can usually be bought in both X7R and NPO materials. X7R material has a much higher series resistance which can lead to a significant reduction in efficiency. If you are not sure which type of capacitor you have in your design, make sure that the capacitor is not getting hot.

Use polypropylene resonant capacitors

C3 to C8 should all be low loss type polypropylene capacitors otherwise there might be reliability issues. You can tell which type of capacitors you have by running the driver and checking that the capacitors do not become hot.

Boost diodes (D1-D11) should be RS1J
RS1J diodes have a reverse recovery time (t_{rr}) of 250ns, whereas RS1M diodes have a t_{rr} of 500ns. The combination of low forward voltage drop and reasonable speed make RS1J's a very good choice. Do not try to use slow rectifier diodes otherwise efficiency, THD and EMI can be bad. Using faster diodes is ok, but this usually results in a higher forward voltage drop and possibly also changes the EMI result.

Characteristic	Symbol	RS1A	RS1B	RS1D	RS1G	RS1J	RS1K	RS1M	UNITS
Maximum instantaneous forward voltage at1.0 A	V_F	1.30							V
Maximum reverse current @T_A=25℃ at rated DC blocking voltage @T_A=125℃	I_R	5.0 50.0							μ A
Typical reverse recovery time (Note1)	t_{rr}	150				250	500		ns

Figure 4: RS1J reverse recovery time is 250, not 500ns (Galaxy Microelectronics)

Keep Output Capacitor small
Do not use a large output capacitor. This is not necessary and can prevent the driver from starting up correctly. Flicker is not affected significantly with a larger output capacitor. If it is necessary to filter out the high frequency, use a small inductor on the output.

Transistor Choice
At first, please use the transistors that RediSem recommends. When selecting other transistors, choose transistors with low fall time (t_f) and low storage times (t_s). Also, do not use transistors that are too big as larger transistors typically have higher switching losses. RediSem typically chooses transistors with a continuous collector current rating that is 2-3 times higher than the peak primary current.

Checking before turning on
Once the driver has been assembled, please make these simple checks to avoid wasting unnecessary time:

- Check input connection and input fuse
- Check output terminal +LED and –LED
- Check the direction of all diodes
- Check the voltage rating of output Schottky diode – in a half bridge it should be twice the max rated output voltage plus a margin
- Check Transistor pinout is correct, ECB, BCE
- Check base drive winding direction, orientation and connections are correct
- Ensure that the transformer does not have an airgap – measure the primary winding inductance
- Check all Ecap polarity

Start the driver using 230Vac with full load applied, preferably an LED load. It should operate well with correct component values. If it cannot startup, please follow the steps below to debug it:

Fault-finding - No output
If there is no output, or only a small amount of oscillating before the driver switches off again, then check the following:

- Check HT cap (C10) voltage. If there is a high voltage, discharge it and do some more checking
- Check base drive connections. Follow a RediSem schematic to check.
- Check to see if IC has power (3 to 3.6V) – Check startup resistor and RC capacitor connection
- Check the BJT 's are in the correct way round – bae, collector, emitter
- Check main transformer phase of secondary winding – a half bridge should have two out-of-phase windings. If the windings are incorrectly in phase, the output current is normally low.

If all are correct, input AC mains again and look at some useful signals

- Measure the base of the bottom transistor Q2. Are there start pulses and oscillations?
- Measure the collector of the bottom transistor. Does it swing from HT+ to HT- as it should?
- Measure the current through the main inductor. Is it the correct magnitude?
- Measure the IC's Vdd and RC pin. Is Vdd reaching 3.6V so that the IC can turn on? Is the IC oscillating at the correct frequency?

Fault-finding - Repeated start-up (LED flashing)

A driver may repeatedly start-up in follow cases:

- Bad E-load. Check by using an LED load. Some E-loads are slow to respond so the IC senses an OVP and protects
- In case of a bad E-load, set it to the minimum LED voltage and turn on again or use an LED
- Incorrect Cvdd (C16) value – make it large and try again
- Incorrect oscillator cap value (too high frequency/ too low frequency) – look at the RC pin and make sure it starts at the frequency you expect: 50-100kHz
- Aux winding or aux diode D18 is broken (No Aux power)
- Aux resistor R10 is too large, so Aux power is not enough. Reduce it to 1k and try again
- Current sensing resistors R5 & R6 are incorrect – check that the current in the resonant inductor is as expected
- Aux sensing resistors R16 & R18 ratio is wrong. If Vfb is too low or too high, then the IC will protect and shut down. Check that the voltage on Vfb rises quickly above 100mV and remains below 1.2V. It should remain below 1.1V in normal operation
- Too large output capacitance will keep Vfb voltage low for too long - Reduce the output capacitance and try again

Quick Design Tests

After building the first sample or after changing the design, these are some quick tests to check that the design is probably ok before doing a complete design validation:

- 11^{th} harmonic at full load
- THD at minimum load voltage
- HT cap (C10) voltage at 264VAC minimum load voltage
- Ripple at full load, 202VAC (high frequency can be filtered by a small output choke)
- Thermal test at 264VAC minimum load, 198VAC full load
- Low temperature startup at 198VAC full load
- Check when the unit will restart with higher output voltage (one extra LED)
- Reduce output voltage until the unit shuts down (min voltage protection)
- Apply 264VAC and full load, then disconnect the load: Check the maximum output voltage is SELV and will not damage the output diodes D12, D13
- Apply 264VAC and a short circuit load then check the voltage of the HT bus is below the rating of C16
- Does the LEDs flash / flicker during startup or power off?

Fine-tuning the design

It is sometimes necessary to fine-tune some parameters around the IC to optimise the design:

- Fine-tune the CS resistor (R5, R6) to set an accurate output current. Note that resistors have a positive temperature coefficient, so it might be necessary to set the current slightly high at room temperature
- Note: before replacing the CS resistor, discharge the HT capacitor properly otherwise you will destroy the IC
- Raux (R10) sets the turn-off output voltage. A higher value of Raux (R10) will cause the driver to shut off at a higher voltage. Select R10 to cope with high temperature and IC spread
- Rfb1:Rfb2 (R16:R18) ratio selects open load voltage of the driver. Select a VFB pin voltage of approximately 1.1V at full load voltage output
- Efficiency of the unit might reduce if a low quality C9 is used, poor diodes or polypropylene capacitors are used
- To reduce the switching frequency output current it is best to add a small inductor in series with Vout+

THD and Harmonic Tuning

RediSem's designs should provide reasonable THD and harmonic performance, but some additional tuning might be required for an optimised design. As a general principle: more boosting gives better THD, less boosting gives better efficiency.

Some guidelines on tuning:

- Total resonance cap = C4+C6+C8. Larger value means more boosting
- Total boosting cap = C3+C5+C7. Smaller value means more boosting.
- The ratio of C3/C4 determines the shape of input current (helpful for full load 11^{th} Harmonic)
- The ratio of C5/C6 determines the shape of input current (helpful for light load THD, 3^{rd} Harmonic)
- The ratios of C7/C8 is advance tuning for high power unit wide range unit (>65W)
- Keep HT voltage as low as possible because it keeps resonant inductor small, the transistors cool and minimises the cost of the HT capacitor

After tuning, check:

- The 11^{th} harmonic at Full load and minimum required mains voltage (220 or 230VAC)
- The 3^{rd} Harmonic at Light load and maximum required mains voltage (230 or 240VAC)
- The HT voltage at Light load 264Vac

Thermals

Thermal management is always an issue for driver design. RediSem designs are intended for operation in the temperature range of -20°C to +50°C ambient when cased. Component temperatures should not rise much above 105°C except in special cases. If temperatures are high, then please try these suggestions below:

Transistors too hot at min load 264VAC

- It is most likely switching losses because of the high HT voltage and high frequency
- Check the base drive transformer is wound correctly – windings should be on top of each other
- Check the base drive has the correct inductance - Is the parallel inductor correct?
- Check that the anti-parallel diodes are good (D14,15) – Replace with TSC's HS1J to make sure
- Check that the BJT's are good – start with the transistors that RediSem recommends
- Check that the midpoint capacitor (C9) is positioned correctly and is of good quality – replace with a polypropylene capacitor to confirm. A higher value reduces switching losses.
- Replace with lower or higher current rating transistors. Transistors are typically operated at a peak of half of their rating current. Smaller transistors switch faster and larger transistors have better conduction losses.
- Reduce the switching frequency will help switching losses significantly
- Depending on the type of transistors used varying the base resistors can improve losses
- Check base capacitors are correct – increase and see if it improves
- Check the base drive transformer loops are not too long
- Midpoint capacitor C9 might be too small – increase and check again

Transistors too hot at 198V full load

- This is most likely conduction losses or capacitive mode problems
- Check for capacitive mode switching. The midpoint voltage (Collector of Q2) should always commutate before the current passes through zero. If not, reduce the inductance of the base drive transformer by lowering the value of the parallel inductor
- If it is switching capacitively, also reduce the size of the midpoint capacitor C9 and try again
- Increase the size of the transistors

Inductor too hot

- Is the transformer made using the correct material? Use PC44 as a minimum, PC47 is often a better choice. Resonant converters use both positive and negative flux density swing. It is therefore much more important to use better material in RediSem designs when compared to Flyback
- Check the design using the component calculator. Input the chosen material, wire diameter and turns into the calculator so that it can approximate the losses
- Because of skin and proximity effects in the wire, it is often better to use less copper rather than filling the bobbin. Check using the component calculator

Transformer too hot

- Use the calculator tool and follow the design
- It is often necessary to tweak the design in the calculator, optimizing the frequency and number of turns to minimize losses.

E-cap Ripple current

RediSem's designs make is possible to use small E-caps on both the HT bus (C10) and on the output (C11). This is good for space saving, but the designer needs to be cautious that the capacitor ripple current does not cause early E-cap failure. Use E-caps with a high ripple current rating for both the HT and output. Sometimes it might be necessary to use a higher value HT E-cap to ensure reliable operation. If this happens, it might also be possible to optimize the design further by selecting a higher turns ratio (more transformer primary turns) and re-tuning the boost capacitors. Choose the optimal configuration for C3, C5 & C7 to minimize E-cap Ripple by connecting some of these caps to HT+ and others to HT-. Be careful if you choose a large output capacitor because the IC will protect (driver starts briefly, then turns off) if the output capacitor is too large.

After a blow-up

Generally speaking, BJT drivers are incredibly robust, but we have all put the scope probe in the wrong places which can cause a bang. If the transistors are damaged, replace the control IC, transistors and base resistors. Also check the input circuit, such as the fuse. If this doesn't work, then look at the following components to find the damage.

- Check CS resistors, R5,6 - if it is open-circuit, then replace the IC again
- Check CS padding resistor (R9, usually 100Ω)
- Check the Aux diode and Aux resistor (D18, R10)
- Check that the inductor (L2) is not shorting out (one of the windings) – replace if concerned. If there is ever a sudden large change in current through this inductor, then a winding is shorting

Changing the number of boost stages

PPFC can be configured to have a single, double or triple boost stage. More than 3 boost stages are not very beneficial. To begin with, select the correct design to match your requirements by basing it on the RediSem design calculator; change it only when you have experience. Selecting the number of boost stages depends on a number of factors and the calculator produces designs that are chosen for the best price & performance combination. RediSem's resonant converter topology is best suited for narrow range designs. Narrow input and narrow output ranges result in a lower cost, higher performance unit that is smaller and more efficient, so choose wisely. The difference between a single, double and triple boost stage is described below:

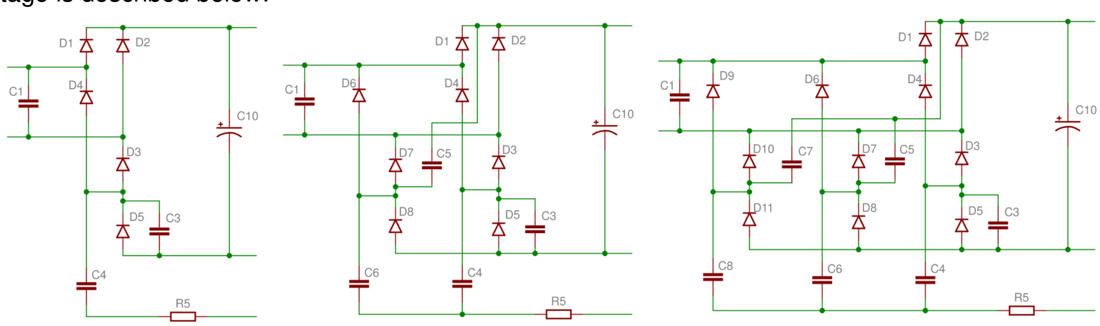

Figure 5: single, double and triple boost stages

Single boost stage

Lowest cost for low power designs. It is good in low power output <25W input power, where good harmonics are not required. It is also good enough where a narrow input or output voltage range is required. The HT bus voltage is the highest for the same THD performance.

Dual boost stage

This is a typical RediSem design. It is suitable for 25W~50W drivers with a wide output range (50%) or up to 70W with a narrower output voltage range of 70%~100%. The additional boost stage greatly helps to tune the THD, harmonics and HT bus voltage.

Triple boost stage

This has the highest component count, but as the components are all low cost, it can result in a lower cost BOM at higher powers as it reduces the stress on the large power components. It is mainly used in high output powers > 60W with wide range of 50%~100%, or >80W with a narrower output power range. It is also suitable for wider range input / output designs.

About RediSem

RediSem designs and supplies semiconductor ICs for energy efficient power management applications. RediSem uniquely combines extensive experience in power electronics with in-depth knowledge of IC design and manufacturing and works with the world's top suppliers and customers. RediSem's unique patented IC and converter technologies deliver maximum efficiency and performance, while reducing overall bill of materials cost through the use of bipolar transistors.

RediSem's range of LED control ICs can be used with RediSem's patented single stage LED control solution to provide very high efficiencies with low EMI – all with a single IC. When combined, these features deliver a low cost, high performance LED driver solution.

RediSem's fluorescent driver controller ICs achieve the advanced performance of MOSFET drivers by using bipolar transistors at a fraction of the BOM cost. RediSem's range of SMPS (Switched Mode Power Supply) control ICs enables low-cost LLC converters with bipolar transistors that deliver very high efficiencies already meeting DoE Level VI regulations, have low standby power and have much lower EMI compared to flyback converters.

All RediSem ICs are supported by comprehensive turn-key application designs enabling rapid time to market. For further information please use our contact details below

Contact Details

RediSem Ltd.
301-302 IC Development Centre
No 6 Science Park West Avenue
Hong Kong Science & Technology Park
Shatin, New Territories
Hong Kong

Tel. +852 2607 4141
Fax. +852 2607 4140
Email: info@redisem.com
Web: www.redisem.com

Disclaimer