RediSem APFC & LLC LED design guide

Overview

RediSem's controller IC's can be used alongside an Active PFC stage in a 2-stage converter. The aim of this design guide is to explain how to design the LED driver and how to use RediSem's APFC controller IC's. Resonant converters, such as the LLC and LCC converters offer lower EMI, smaller size and higher efficiency than the equivalent Flyback converter. RediSem's patented Controlled Self-Oscillating Converter (CSOC) technology for bipolar transistor half-bridge converters combined with our patented Primary Sensing Regulation (PSR) method offers a very low BOM cost for converters ranging in power from 20W up to 300W. In summary the key features and benefits are:

- Soft-start to minimize component cost
- Small size because of high frequency – full wave resonant operation
- High efficiency because of the bipolar transistors in a resonant half-bridge
- Low EMI due to the resonant technology
- Low cost, high reliability Bipolar transistor half-bridge
- Primary-Side Regulation (PSR) +/-5% (secondary side regulation also possible)
- On-Chip protection for open-circuit, short-circuit and overtemperature

It is recommended you always use one of RediSem's example designs as a starting point for new designs. Please check with us regularly for updates and additional information. As RediSem develops more LED driver IC's and example designs, this Design Guide will be continually updated.

Top-level Design Notes

Resonant Half-Bridge

The series-resonant half-bridge is ideally suited to LED Driver applications, because it provides excellent efficiency and has inherently good immunity and low-noise characteristics to make EMC compliance very easy. RediSem's LED Driver Controller IC's are specifically designed to use resonant topologies for LED Drivers. Typical resonant converter technologies used for CC power conversion is an LC or LCC converter which requires a capacitor and inductor in series with the isolation transformer primary winding.

RediSem's controller ICs are unique in that they combine a self-oscillating bipolar converter (CSOC) topology with a simple half-bridge control scheme using bipolar switching devices, which are both lower cost and more robust than MOSFET alternatives. Furthermore, the self-oscillating design is inherently immune to running in capacitive mode, which is a considerable problem for MOSFET-based solutions. [Please see AN2113 for more information about RediSem's bipolar transistor and CSOC drive technology.]

Using CSOC with Active Power Factor Correction (APFC)

For some applications, such as those with very wide input/output voltage requirements, it may be necessary to use Active Power Factor Correction (APFC). RediSem's LED controller IC's may be easily combined with a PFC regulator design, as shown in Figure 1.

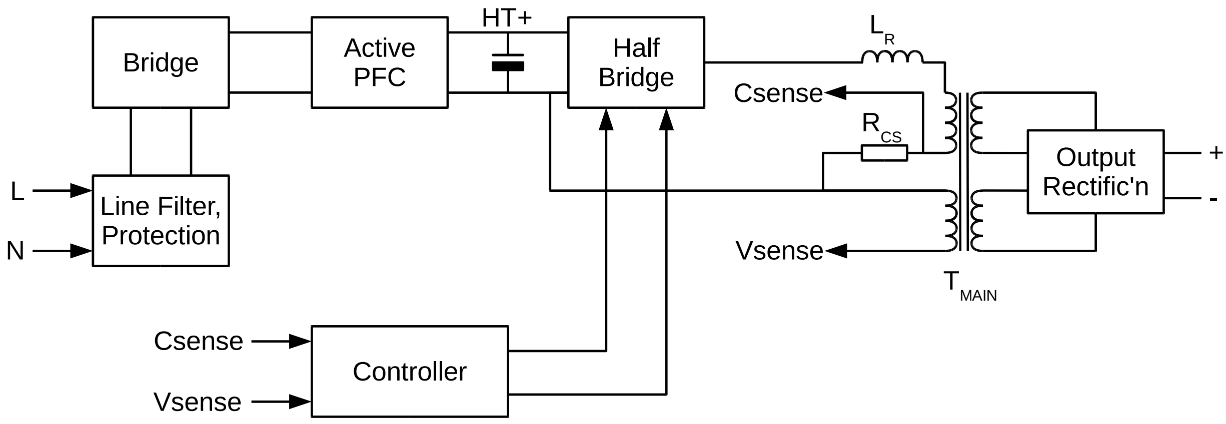

Figure 1: CSOC with APFC (simplified schematic)

Component selection

RediSem provide a component calculator tool to assist with the design process. Please check for updates from time to time. The guidelines below should be considered as a starting point.

The LED driver is intended to run super-resonantly, ie the tank resonant frequency should be lower than the minimum operating frequency. Please refer to the schematic given in figure 2.

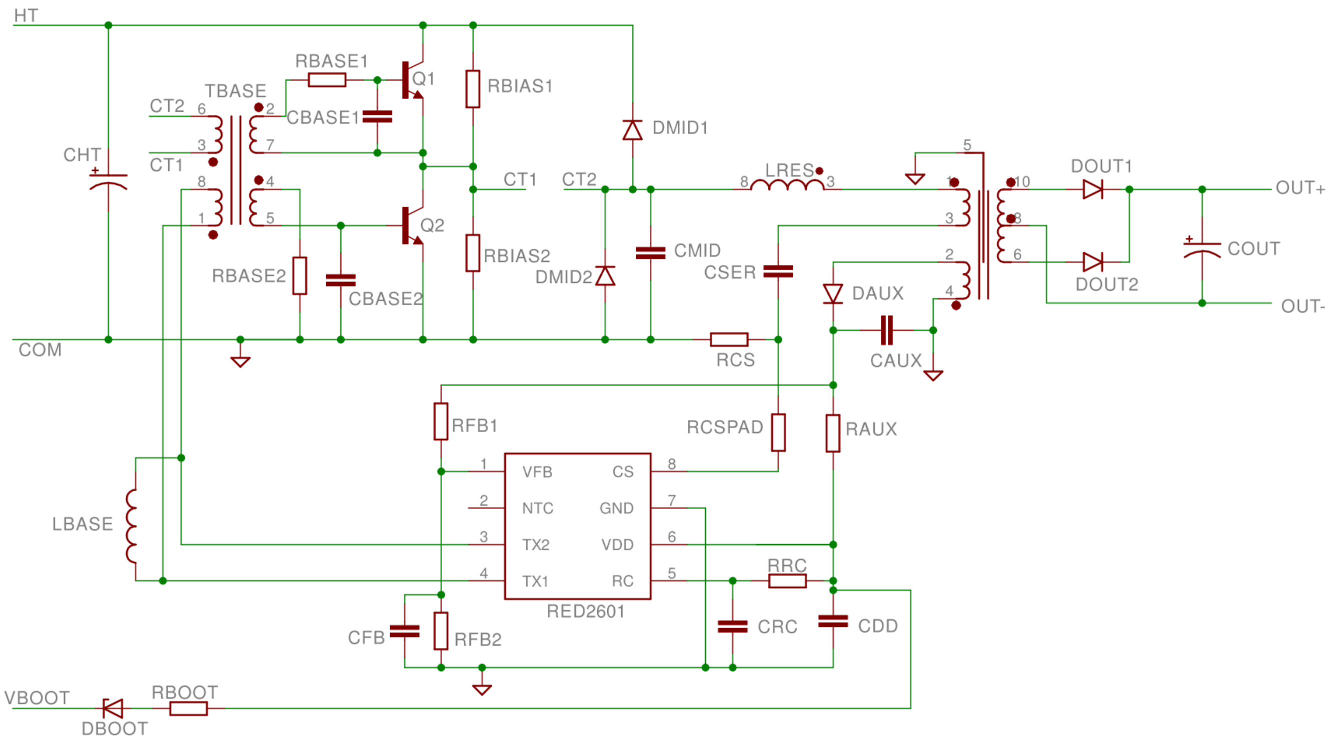

Figure 2: APFC LED Driver schematic

Power components

HT Capacitor

The minimum HT capacitor value is scaled at 0.33uF/W, which gives an acceptable amount of voltage ripple at low cost. So the approximate value of the HT capacitor is given by the equation:

$$C_{HT} = 0.33 \times V_{OUT} \times I_{OUT}$$

Inductor, Capacitors and Transformer

The recommended values for the turns ratio, series-resonant inductor, series-resonant capacitor and area products are given by the equations below:

$$N_{TURNS} = \frac{V_{HT}}{V_{RATIO} \times V_{OUT}}$$

$$L_{RES} = \frac{2.Q.V_{OUT}.N_{TURNS}^2}{\pi.F_{RES}.I_{OUT}}$$

$$C_{SER} = \frac{2.I_{OUT}}{\pi.F_{RES}.Q.V_{OUT}.N_{TURNS}^2}$$

$$\mathrm{L_{RES}}\ \text{Area Product} = AP_{LRES} \times I_{OUT} \times V_{OUT}$$

$$\mathrm{T}_{MAIN}\ \text{Area Product} = AP_{MAIN} \times I_{OUT} \times V_{OUT}$$

Where the parameter values are given below:

V_{OUT}	Maximum output voltage;
I_{OUT}	Maximum output current;
V_{HT}	Average HT voltage (from APFC stage)

The recommended starting values for Q, F_{RES}, V_{RATIO}, AP_{LRES} and AP_{MAIN} are given below:

Quality Factor	Q	0.3 – 0.4
Resonant Frequency	F_{RES}	25 – 40 kHz
Inductor Area Product	AP_{LRES}	8mm^4/W
Transformer Area Product	AP_{MAIN}	35 mm^4/W
Converter Voltage Ratio	V_{RATIO}	0.43

The resonant capacitor(s) should ideally be low-loss polypropylene types, adequately rated for the primary current and voltage.

The ferrites used in L_{RES} and T_{MAIN} cores should be low-loss types, such as PC47, PC95 or equivalents.

Base Drive Components

Base drive transformer is best procured fully assembled and tested from Acme Electronics.
(越丰电子（广州）有限公司).

The optimum value of the padding inductance L_{BASE} may be estimated using the following equation:

$$L_{BASE} = \frac{0.25}{(F_{RES} \times I_{OUT}/N_{TURNS} - 1/L_{RING})}$$

where L_{RING} is the inductance of the toroidal base drive transformer, measured across the control winding. If using the recommended base drive transformer from Acme, L_{RING} = 2.5mH. When chosen correctly, the storage time of the BJT's (Q1, Q2) should be roughly 200ns when running at full load, which gives the most efficient switching.

Base drive resistor values can be calculated from the equation below:

$$R_{BASE} = \frac{0.6 \times Nturns}{I_{OUT}}$$

Additionally, capacitors C_{BASE1}, C_{BASE2} may be fitted across the base-emitter of each BJT to prevent switching losses due to shoot-through. Typically 10-22nF, the maximum values of C_{BASE1}, C_{BASE2} is given by the equation below:

$$C_{BASE} < \frac{2 \times I_{TXSTART}^* \times t_{TXSTART}^*}{V_{BE(MAX)}} \times \frac{N_{CTRL}}{N_{BASE}}$$

where $\frac{N_{CTRL}}{N_{BASE}}$ is the turns ratio of the base drive transformer (normally $\frac{18}{6}$).

Auxiliary and VDD supplies

The Auxiliary winding on the main transformer provides the power for the Auxiliary and VDD supply rails. The Auxiliary voltage will depend on the output voltage and the Auxiliary/Secondary turns ratio (N_A/N_S) which can be chosen by the following equation:

$$\frac{N_A}{N_S} \approx 1.5 \times \frac{V_{DD}}{V_{OUT(MIN)}}$$

R_{AUX} is chosen to deliver enough power (but not too much) to the IC:

$$R_{AUX} > \frac{\left(V_{OUT(MAX)} \times \frac{N_A}{N_S} - V_{DD}\right)}{I^*_{DDSHUNT(MAX)}}$$

$$R_{AUX} < \left(V_{OUT(MIN)} \times \frac{N_A}{N_S} - V_{DD}\right) / I^*_{DDREG(MAX)}$$

The VDD decoupling capacitor needs to be large enough to sustain the VDD rail while the driver pulls up the output, which puts a minimum value on C_{DD}:

$$C_{DD} > I^*_{DDREG(MAX)} \times t_{STARTUP} / (V_{DDREG} - 2.4V)$$

where:

$$t_{STARTUP} = C_{OUT} \times V_{OUT(MIN)} / I_{OUT}$$

The Auxiliary rail decoupling capacitor C_{AUX} value must be large enough to provide power to the VDD rail but small enough to ensure that the primary voltage sensing function is responsive:

$$C_{AUX} > 300us / R_{AUX}$$
$$C_{AUX} < 10ms / R_{AUX}$$

Current Sense Resistor

The value of the current sense resistor R_{CS} determines the value of the constant current limit and the over-current protection threshold. Ignoring losses and other parasitic effects, the theoretical value is given by the equation below:

$$R_{CS} = \frac{V_{CSREG}{}^*}{I_{OUT}} \times \frac{N_P}{N_S}$$

Midpoint capacitor

A small mid-point capacitor helps to reduce switching losses in the BJTs and also helps to suppress RF emissions. If too big a value, the bridge is unable to commutate properly particularly during startup or when running at low line voltages, causing excessive heat dissipation in the BJTs. The maximum value is difficult to calculate and is best chosen by experiment, starting with the value given by the equation below:

$$C_{MID} = \left(\frac{430}{V_{HT}}\right)^2 \times \left(\frac{V_{OUT} \times I_{OUT}}{150}\right) \times \left(\frac{34k}{F_{RES}}\right) \times 2nF$$

Operating frequency
The typical frequency for any output load range is given in figure 3 below, shown in normalized values, relative to the resonant frequency:

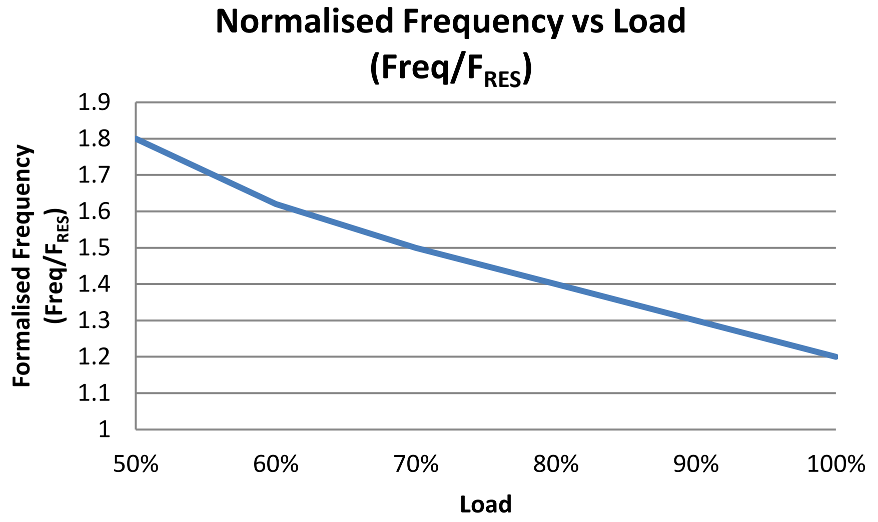

Figure 3: Normalised Frequency vs Load

Transformer Construction
The recommended transformer construction for T_{MAIN} is shown below.

W1:	primary winding
W2:	auxiliary winding
W3a, W3b:	secondary windings (wound together)

[Transformer construction and optimisation is discussed in greater detail in App Note AN2112]

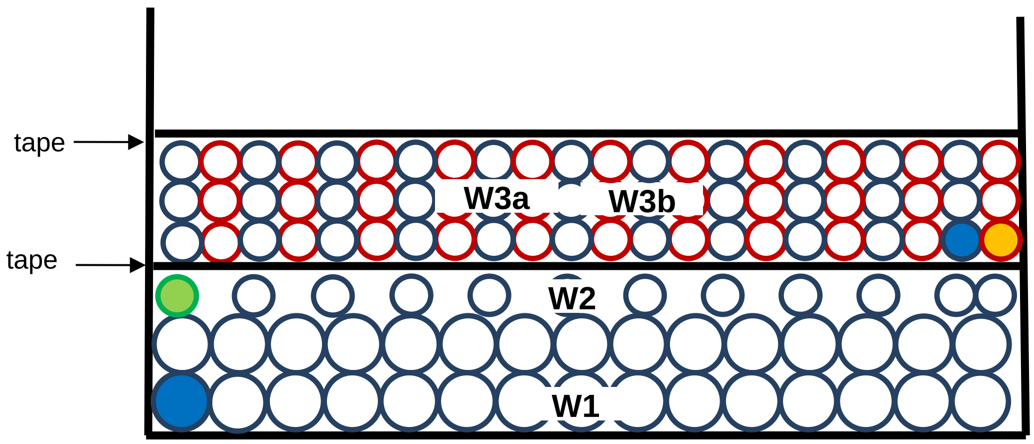

Table 1: Recommended construction for transformer T_{MAIN}

Startup sequence

For a smooth startup, the RediSem controller IC should be started up just as the HT rail has been boosted up to the target voltage. Most APFC controller IC's (e.g. the ST L6562A) have a very slow loop response, which means that the boosted HT rail will droop significantly in response to a large load step. The RediSem PFC LED driver ICs provide a special startup feature so that the load presented to the boosted HT rail is switched in small steps, to minimize the HT undershoot.

The optimum startup arrangement is described fully in AN2114. However, a brief summary of the startup and shutdown sequences is given here.

Start Up

1. The APFC controller is started up via a resistor chain off the rectified AC waveform;
2. Once the APFC converter starts, it provides its own power to run via the aux winding in the APFC boost inductor;
3. When the HT bus rises to almost full voltage, the APFC inductor aux winding also provides power to the RediSem controller to start it up;
4. The RediSem controller delivers output current starting from 50%;
5. The RediSem controller increases the output current to 100% over a period of about 100ms, to minimise the transient effect on the APFC controller;
6. When the output voltage rises, the main LLC converter power transformer powers the RediSem controller.

Shut Down

1. AC mains is lost, so the APFC stage turns off;
2. The LLC continues to deliver power to the load until the HT bus is run down;
3. The RediSem controller senses that there is a problem and latches off;
4. The RediSem controller can no longer restart because the APFC boost inductor aux winding cannot deliver enough power.

The startup sequence is shown below in figure 4:

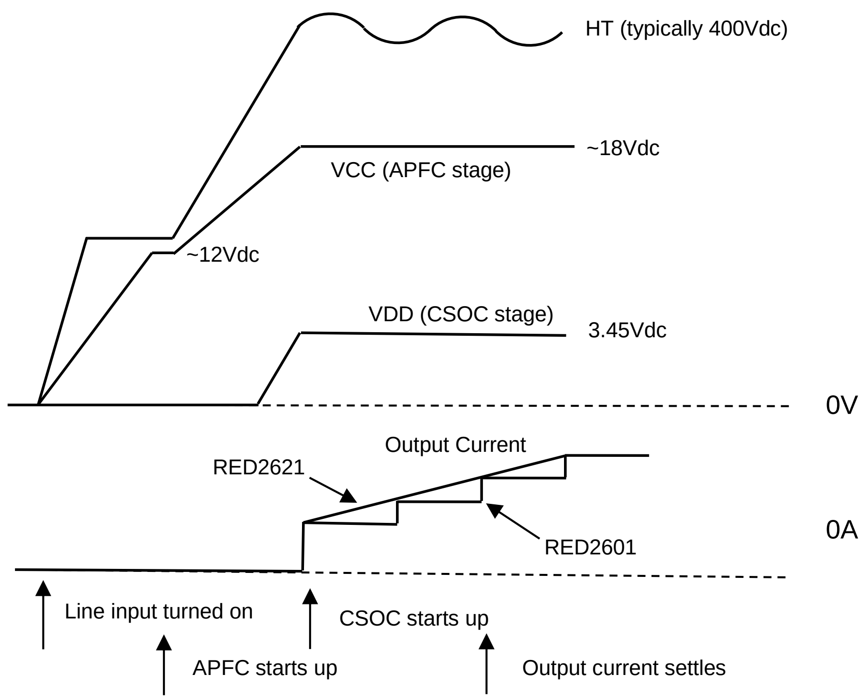

Figure 4: APFC and CSOC startup sequence

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:

- Do not have the CS resistor R_{CS} too far away from the IC
- Star the IC ground to the CS resistor ground. Do not have any other currents flowing in the IC ground track
- Position the RC components (C_{RC}, R_{RC}) near the RC pin of the IC. Keep the tracks as short and thin as possible
- Keep the track connected to the VFB, CS pins 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
- 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 D_{AUX} and C_{AUX} directly back to the transformer GND
- Keep the base drive tracks short
- Keep the "Noisy" tracks short. These are the switched node of the transistors both before and after the base drive winding and tracks to the main inductor L_{RES}
- Keep these "Noisy" tracks away from the IC and small signal tracks
- Make sure that the main inductor L_{RES} is polarized so that the noisy end (which is connected to Q1, Q2) is on the inside of the winding
- Keep the line input 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 line input CM inductor 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

An example of good layout is given in figure 5 below. Pay particular attention to the 0V tracking.

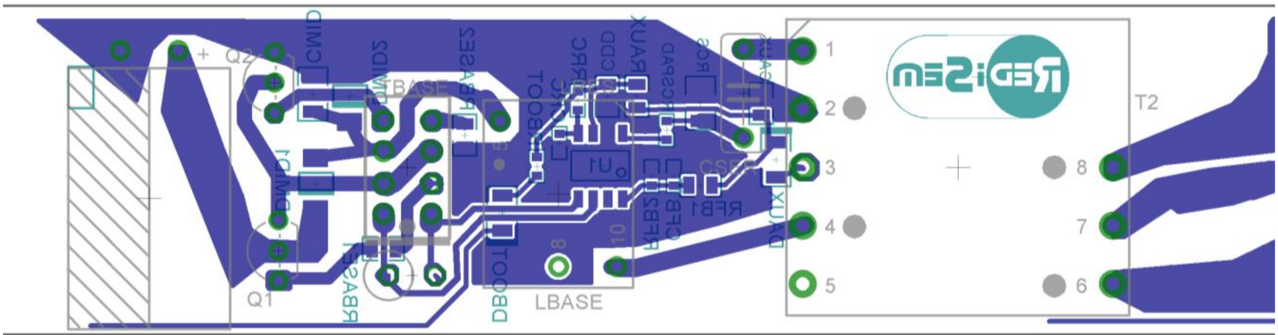

Figure 5: PCB layout example

Troubleshooting

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 core is not gapped – measure the primary winding inductance

- Check all Ecap polarities

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 (C_{HT}) 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 (3.3V to 3.6V) – Check startup capacitor/resistor and RC capacitor connection
- Check the BJT's are in the correct way round – base, 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 3.7V 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 the following cases:

- Check V_{HT} voltage level.
- Bad E-load. Check by using an LED load. Some E-loads are slow to respond so the IC senses an OVP and protects against it by shutting down. See AN2116 for more data on using slow E-loads.
- Incorrect C_{DD} value – make it larger 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: 50kHz-100kHz.
- Aux winding or aux diode D_{AUX} is broken (No Aux power).
- Aux resistor R_{AUX} 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 R_{FB1} & R_{FB2} ratio is wrong. If V_{FB} pin is too high (>1.2V) then the IC will protect and shut down.
- CS pin is sensitive to noise in bad PCB layouts, an additional capacitor 330pF CS to GND helps to reduce the noise.

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:

- Ripple at full load, minimum line voltage (high frequency can be filtered by a small output choke).
- Thermal test at minimum and maximum line inputs, maximum and minimum loads.
- Low temperature startup at minimum line, full load.
- Check when the unit will restart with higher output voltage (one extra LED).
- Reduce output voltage until the unit shuts down (min load voltage protection), related to R_{AUX} value.
- Apply maximum line and full load, then disconnect the load; check the maximum output voltage is SELV and will not damage the output diodes D_{OUT1}, D_{OUT2}.
- Does the LED 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 (R_{CS}) to set an accurate output current. Note that resistors generally 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.
- R_{AUX} sets the turn-off output voltage. A higher value of R_{AUX} will cause the driver to shut off at a higher voltage. Select R_{AUX} to cope with high temperature and IC spread.
- R_{FB1} / R_{FB2} ratio sets the maximum output voltage. Allow 10% headroom for CC LED drivers.
- Efficiency of the unit might reduce if a low quality components are used for mid-point capacitor (C_{MID}) resonant capacitors or switching diodes.
- To reduce the switching frequency output ripple current it is best to add a small inductor in series with Vout+.

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 minimum load

- 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 (D_{MID1}, D_{MID2}) – 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 (C_{MID}) is positioned correctly and is of good quality – replace with a polypropylene capacitor to confirm. A higher value reduces switching losses in Q1, Q2.
- 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.
- Reducing 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 C_{MID} might be too small – increase and check again

Transistors too hot at full load

- Hot transistors is most likely caused by conduction losses or capacitive mode problems
- Check for capacitive mode switching. The bridge output 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 C_{MID} 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.

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

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