RediSem's Patented Transistor Drive Circuit

Controlled Self-Oscillating technology (CSOC)

RediSem has a unique way of driving transistors based on a self-oscillating bridge that has been used in most of the world's ballasts and CFL's. We combine the simplicity of this self-oscillating system with a control IC to provide a half-bridge topology using low cost bipolar transistors that can provide a regulated output. The drive control on pins TX1 and TX2 of the IC's is well proven and has been used in RediSem's SMPC, CFL, Ballast and LED driver IC designs.

Existing Self-Oscillating half-bridge

A half-bridge stage from a typical Ballast / CFL circuit is shown in Figure 1. Windings W1, W2 and W3 are windings on the same core, typically a small ring core. The mutual coupling between the windings provides proportional base drive for the transistors that can keep the circuit oscillating.

When Q1 is turned on, V_{MID} goes high and this voltage step appears across the inductor L, so that the I_{MID} current starts to ramp positively. The resonant tank (formed by inductor L and capacitor C) gives the current waveform a sine wave shape during the on-time. The I_{MID} current in winding W1 causes a reflected current to appear in base drive winding W2, scaled by the turns ratio. The voltage developed across the base resistor and Q1 base-emitter junction and the self-inductance of the ring core causes the ring core magnetising current to ramp up. In this way, the current in W2 falls to zero after a number of microseconds, which starves Q1 and the transistor de-saturates. As Q1 collector-emitter junction opens up, all the Q1 collector current now flows out of Q1 base and it turns off rapidly. The current in inductor L continues to flow and this pulls down the mid-point node very quickly until it swings below the negative rail (HT-). At this point, transistor Q2 collector-base junction becomes forward-biassed and the I_{MID} current flows out of the Q2 base, turning Q2 on (but in reverse bias mode). The switching sequence is then repeated for Q2.
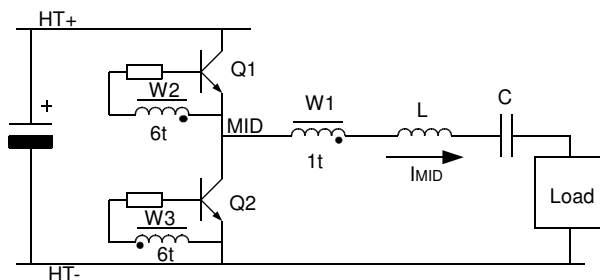

Figure 1: A Typical Ballast Half-bridge Driver Stage

This is resonant-mode switching: each transistor is turned on after the bridge has commutated, i.e. when the collector-emitter voltage is close to zero. Note that it is the current flowing through the inductor L that makes the bridge commutate. Therefore, it is difficult for the circuit to self-oscillate in capacitive mode. This self-oscillating circuit is therefore inherently robust.

In these traditional self-oscillating circuits, the operating frequency is determined by the inductance of the base winding, the voltage developed across it and the storage time of the transistors.   This means that the operating frequency is susceptible to component variations.   In addition, over temperature the ring core material and transistors change parameters which can result in poor performance over a wide temperature range.   This is a significant limitation to this technology.

RediSem's CSOC technology

RediSem adds a 4th winding is added to the ring core and attaches a control IC to this winding.   This enables RediSem IC's to fully control the frequency and remove all of the drawbacks associated with a self-oscillating converter.   To control the frequency, the IC selectively applies a short-circuit to the 4th winding at the instant that it requires the bridge to commutate.   The converter frequency is therefore no-longer influenced by transistor storage time or base drive transformer.   All the inherent robust advantages of the self-oscillating circuit described above still apply.   Figure 3 shows a sequence of pictures to depict the operation of RediSem's CSOC control method.
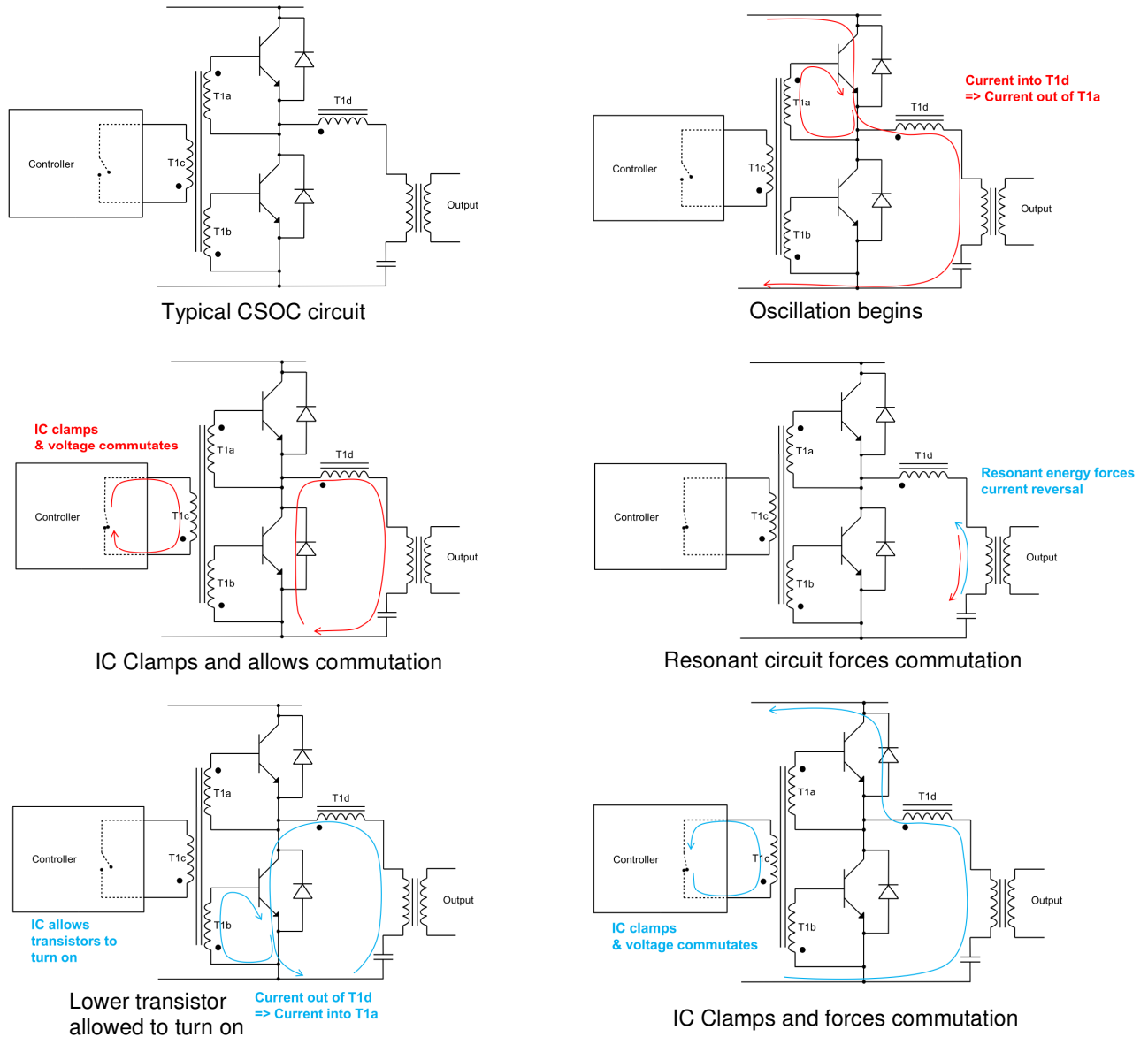
Typical CSOC circuit

Oscillation begins

IC Clamps and allows commutation

Resonant circuit forces commutation

Lower transistor allowed to turn on

IC Clamps and forces commutation

Figure 2: Current commutation and switching sequence

Important points about CSOC

CSOC is an excellent method of controlling bipolar resonant converter, but it can sometimes be difficult to understand.   There are two main points about the technology:

1. All the base drive current is supplied by the base drive transformer.   Base current is not supplied by the IC except to start the converter oscillating.
2. The IC is in control of the frequency by clamping the control winding.   This means that the converter frequency is not controlled by transistor storage time or the base drive parameters.
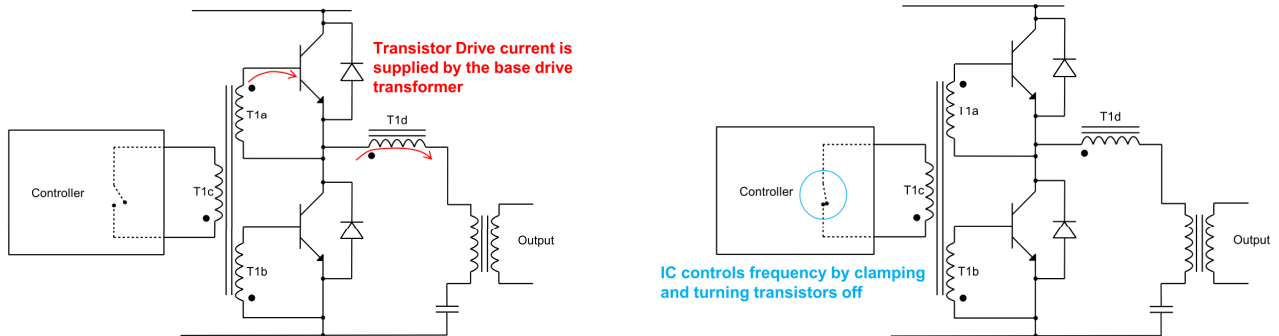
Figure 3: Important CSOC points

Dead-Time Control

Unlike MOSFET half-bridges, dead-time is automatically controlled by the IC and the self-oscillation of the half-bridge, as described above. The base drive transformer will begin driving the following transistor once commutation has taken place. Because CSOC uses midpoint current to turn the bipolar transistors on, it is only able to drive the transistors on once the current has changed direction.

Component selection

Refer to partial schematic of CSOC converter in figure 4.
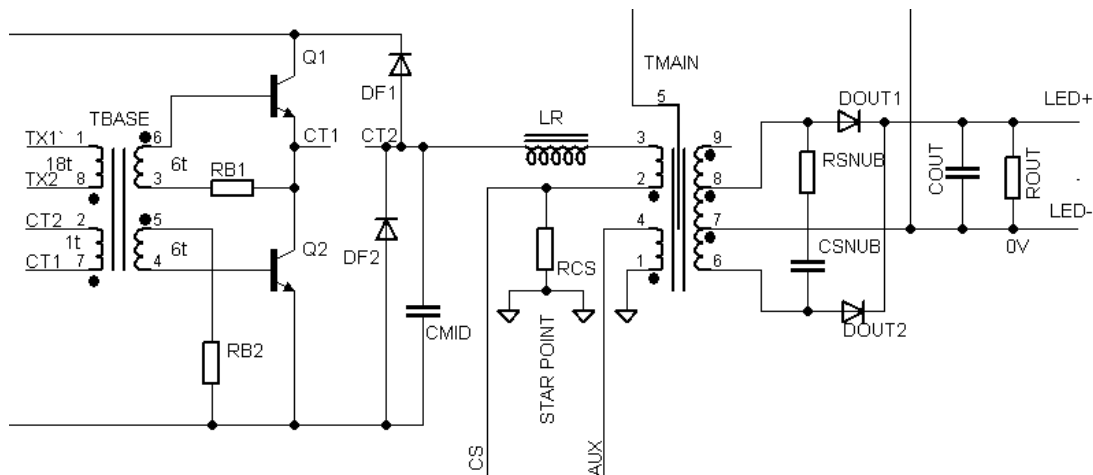
Figure 4: Partial CSOC converter schematic

Base drive Transformer

In CSOC converter designs, the IC is in control of the frequency which regulates the output. Very importantly, the base drive transformer does **not** control the frequency of the converter, the IC does. The

base drive transformer is only necessary to provide power to the transistors. Changing the number of turns or core material will not affect driver's operating power, but it will affect transistor temperature and operating performance, particularly at extreme temperatures and line/load combinations.

Core material

Choosing the transformer core material and permeability is important. It is better to have a temperature stable material, so that the driver can operate over a wide temperature range. Many ferrite materials have very low permeability at low temperatures and this can cause the driver to operate badly at these temperatures.

Transformer inductance

Choosing a base drive transformer core with a high A_L (Inductance) will increase losses in the transistors. Lower permeability typically reduces transistor switching losses.   In most of RediSem's designs a parallel inductance is used to tune the base drive transformer inductance.   A parallel inductor can be very accurate and will not have a temperature coefficient, so transistor losses can easily be optimized.   As a general rule, make sure that the transistors have a storage time of around 200ns at minimum mains voltage, full load. If the storage time is longer than this, then decrease the transformer inductance to reduce losses. If it is shorter than this, check that the driver can start up at low temperature, low mains maximum load.

Turns ratio

RediSem uses a turn ratio of 1:6:6:18 for most designs. 1 turn on the drive winding, 6 turns for each of the transistors and 18 turns for the IC. It is not recommended that the turns ratio is changed from what RediSem recommends until you understand the effect on the transistor switching behavior.

The number of turns on the base windings provides a good tradeoff between saturation voltage (on-state loses) and turn-off losses. The number of turns on the control winding should be chosen to ensure that the peak voltages appearing on the Tx pins and the current through them does not exceed the limits given in the RediSem IC datasheet; 18 turns is a good choice, giving peak Tx pin voltages of about 3.5V at worst case. In lower power designs, such as 25W, 18turns can be reduced to 12 turns. This has no effect on the rest of the design except to make increase the current in the IC's TX pins while reducing the voltage on the pins.

Winding construction

Winding construction is important as it has a big impact on transistor losses and therefore transistor operating temperature. The best winding technique is to keep a good coupling between the 6:6:18 windings. The single turn does not have to be tightly coupled. It is therefore highly recommended that the three important windings are wound on top of each other. The two 6t base windings should not be closely coupled, so they should not be wound at the same time.

Start by following the base drive transformer designs from RediSem. These have been optimized to give a good compromise between transistor losses, whilst operating across wide temperature and mains voltage ranges. Figure 5 shows the overlaid winding structure.
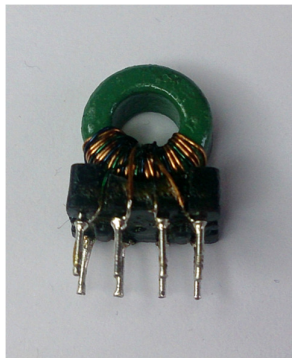

Figure 5: Typical Base Drive Transformer

Procurement

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

Transistor choice (Q1, Q2)

Transistor choice is important in RediSem's LED driver solutions. Transistors in RediSem's LED driver design have been optimized to operate at low temperatures in normal running conditions, but are also capable of surviving at 50°C at 198VAC and 264VAC. Choosing alternative transistors might compromise the design.

Some design considerations:

- Most transistors will work in our applications, but they might run cooler or warmer depending on switching characteristics.
- Try to choose the correct transistor for the application. Do not oversize it. If a transistor is running hot, do not simply increase the transistor size to make it cooler. Often a larger transistor runs hotter. Choose a transistor so that the ratio of transistor current rating $I_{C(MAX)}$ to peak primary current $I_{PRI(PEAK)}$ is as per the following equation:

$$4 > \frac{I_{C(MAX)}}{I_{PRI(PEAK)}} > 2$$

- Short storage time is preferable, as this helps the bridge to commutate when the driver is operating in capacitive mode. The best switching types have hollow or cellular emitter structures.
- Short turn-off Collector current fall-time (t_F) is important. This means low losses and cool transistors. This data is often not detailed on datasheets.
- Please follow our recommendations where possible. We have selected high performing low cost transistors suitable for our applications.

Base Resistors

The base resistor values affect the transistor storage and fall times. Choose large base resistor values to achieve fast turn-off times. However, make sure that the reflected drive voltage appearing on the Tx pins of the controller IC does not exceed the datasheet limits (4V).
As a starting point, choose the value for the base resistors from the following equation:

$$R_{B1} = R_{B2} = \frac{40W}{P_{OUT}} \times \frac{V_{IN}}{230V} \ \Omega$$

Flywheel Diodes

D_{F1} and D_{F2} provide a route for the primary magnetizing current to return to the HT+ and HT- supply rails. The types chosen should be fast turn on and fast recovery to ensure snap-free commutation. (Note that most datasheets do not specify turn-on time). If these diodes have too slow turn-on, it can cause switching transistors Q1, Q2 to run hot, due to shoot-through current spikes. Good diode types are HS1J available from Taiwan Semi (台湾半导体有限公司).

Mid-point capacitor (C_MID)

There is a mid-point capacitor on the half-bridge output which helps to reduce switching losses in the transistors and suppress RF emissions. Make sure that this capacitor is good quality (COG or NPO) and is has a high voltage rating. The use of a low cost capacitor can result in capacitor failure, high EMI emissions, imbalanced transistor temperatures and an elevated transistor temperature.

Base capacitors

It is possible to have a small amount of shoot-through if the base drive transformer is made badly or the tracks connecting to the base drive transformer are long. Monitor the collector current of Q1 (or Q2) using a current transformer. There should be no current when the transistors are in the off state. If there is, a small capacitor can be added to remove this shoot-through. 10nF capacitor between base and emitter of both transistors should be enough for most designs, but for higher power a larger capacitor can be used

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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