Some Proprietary LED Current Balancing Techniques

by Sanjaya Maniktala

Introduction

This App Note is intended to provide a brief explanation of proprietary LED control modes, current balancing, and special synchronous operation, in particular those based on US Patent Application US 2012/0013259 (Assignee Microsemi Corporation; Inventor Xiaoping Jin). This explains how the chip LX27901 is designed and operated in such a way that it complements and exploits Microsemi's unique LED drive technologies. Refer to the datasheet of this part while consulting this App Note.

The LX27901 features three modes of operation: variable-frequency LLC (resonant mode) and two other non-resonant and fixed-frequency modes. The latter include conventional PWM modulated (square wave) converter and a unique "synchronous mode," which despite its name, has really nothing directly related to conventional synchronous topologies, but is in fact a unique control non-resonant method that simplifies LED circuit design considerably, requiring no dissipative sinks, and can also be synchronized to an external pulse train for reducing EMI if desired.

Method 1 *(see Figure 1)*

Two N-channel FETs are switched in a standard half-bridge topology. The Gate drive circuit is essentially self-oscillatory, and for that, we need to use an extra winding across the step-down transformer. But this can be the same winding used to derive power for the LX27901 and related control circuitry, so in fact, no additional winding is required.

When the top-FET (colored RED) conducts, AOUT will also go positive. This sends current indicated with the RED arrows. This flows from top to bottom in the LED string on the *left* side of the figure. Note that this string is in series with a low-side N-FET driven by the output AOUT of the chip. The timing diagrams are shown in the inset, and are compared to the input SYNC signal on the UVS/SYN pin. Keep in mind that the SYNC signal is derived from the transformer in this case, so it too follows the self-oscillation frequency, driving AOUT and BOUT alternately as shown. Observe that BOUT pin is used to drive a P-FET and is OFF during this particular time interval.

At some point, the Gate drives of the half-bridge FETs flip over as is typical of any self-oscillatory topology. But because there is a secondary-side coupling cap on the way to the LED strings, the voltage applied to the LED strings flips and acquires opposite polarity with respect to ground, as the capacitor attempts to equalize its charge balance ($\int(I)dt$). This voltage reversal therefore draws current out of the LEDs in a reverse direction --- through the GREEN arrows. Of course the P-FET now becomes a high-side FET in series with the

LEDs and we can control their brightness by its duty cycle, as dictated by the LX27901 regulation loop.

The LX27901 has a cycle-by-cycle current sense pin (ISENS) and a slower regulation loop based on the voltage sense pin (VSENS). In non-resonant operating modes, the chip responds to a high-voltage on the VSENS pin by lowering the duty cycle. This lowers the duty cycle of both the N-FET and P-FET in series with the two LED strings, thus reducing the LED current of both strings by equal amounts. Note that this simple circuit is self-protecting as with any self-oscillating topology. For example, if I_x (RED) and I_y (GREEN) are *more than slightly different* for any reason, transformer and coupling capacitor reset will not occur readily, and the LED current will staircase in one branch, eventually being arrested by the climbing ISENS pin, which will step in to prematurely terminate that branch (the one with excess current), thus restoring equality to a great extent. So this circuit is self-limiting and self-protecting to a great degree.

One disadvantage of this method is the cost and efficiency impact caused by a P-FET as compared to an N-FET.

Method 2 *(see Figure 2)*

In this technique too, as in above method, the chip is placed in proprietary synchronous mode by applying a voltage greater than 4V on the ENABLE pin. However note that AOUT and BOUT are now being used to pulse-width modulate the half-bridge itself, not as they were used in Method 1. This is an indication of the tremendous versatility of the LX27901. Now, by changing the duty cycle, we can in effect, change the output of the half-bridge itself, which provides the upper rail for driving the LED strings.

Note that the key feature here is a *lossless magnetic current balancer*. Here four windings are placed on the same magnetic core, but only two conduct at the same time. Note that when the upper FET of the half-bridge conducts (RED), it produces a current with RED arrows, that splits into two LED branches each carrying current I_x. However, carefully note that in the top core section, the current I_x flows down (within the winding) in a direction *away* from the polarity dot, whereas in the lower section, it flows *towards* the polarity dot. So if $I_x = I_y$ exactly, and there were no other asymmetries, there would be *total flux cancellation* inside the core.

When the lower FET of the half-bridge conducts, since there is a full-wave rectification stage on the secondary of the transformer, the current once again follows the same path through the LED strings (with GREEN arrows). However, now in the upper core section, the current is pointing *towards* the polarity dot, whereas in the lower core section, it is *away* from the dot. So once again, if $I_x = I_y$, total flux cancellation occurs.

What does it mean to say that in a transformer we have *total flux cancellation*? It means the transformer is not *presenting itself as an inductance*. Because inductance is related to stored energy, and we have no stored energy because the net flux in the core is zero. So if the current is completely balanced, the magnetic coupler does nothing at all. It is “out of the picture”.

The transformer “enters the picture” as soon as Ix ≠ Iy. It now appears as an *inductance* in series with the winding which is carrying more current, thus serving to limit that current. It is very similar to the use of ballasting resistors to equalize currents in two parallel chains, except that here inductance comes into the picture, and automatically so, as soon as imbalance occurs. Otherwise it is practically not present!

Since a magnetic component is “reactive”, it stores energy, but does not dissipate as a resistor does. It can also be shown that the energy related to the stored inductive energy inside the core (due to imbalance), does find its way to the output eventually. Therefore this method is considered “lossless”. It is also Microsemi proprietary.

Method 3 *(see Figure 3)*

This is an illustration of magnetic coupling used alongside high-efficiency LLC (resonant) half-bridge. In this case, by placing the ENABLE pin between 2V and 3V, we enter LLC mode. In this mode, AOUT and BOUT are complements of each other, and so we can create a 50% duty cycle bidirectional drive for the two FETs of the half-bridge. Also, if VSENS goes high, instead of varying the duty cycle as in conventional non-resonant topologies, here the LX27901 varies the switching frequency to try and regulate. This is well-known of course in LLC. The innovation here is the magnetic coupling circuit again.

In this case, there are two separate cores, each supporting two LED strings, which carry current alternately (RED and GREEN arrows). Note that each of the two strings in each branch have automatic sharing amongst themselves, because as in Method 1, if the current in each direction was different, the coupling capacitor would have charged up, or discharged, in an effort to equalize currents.

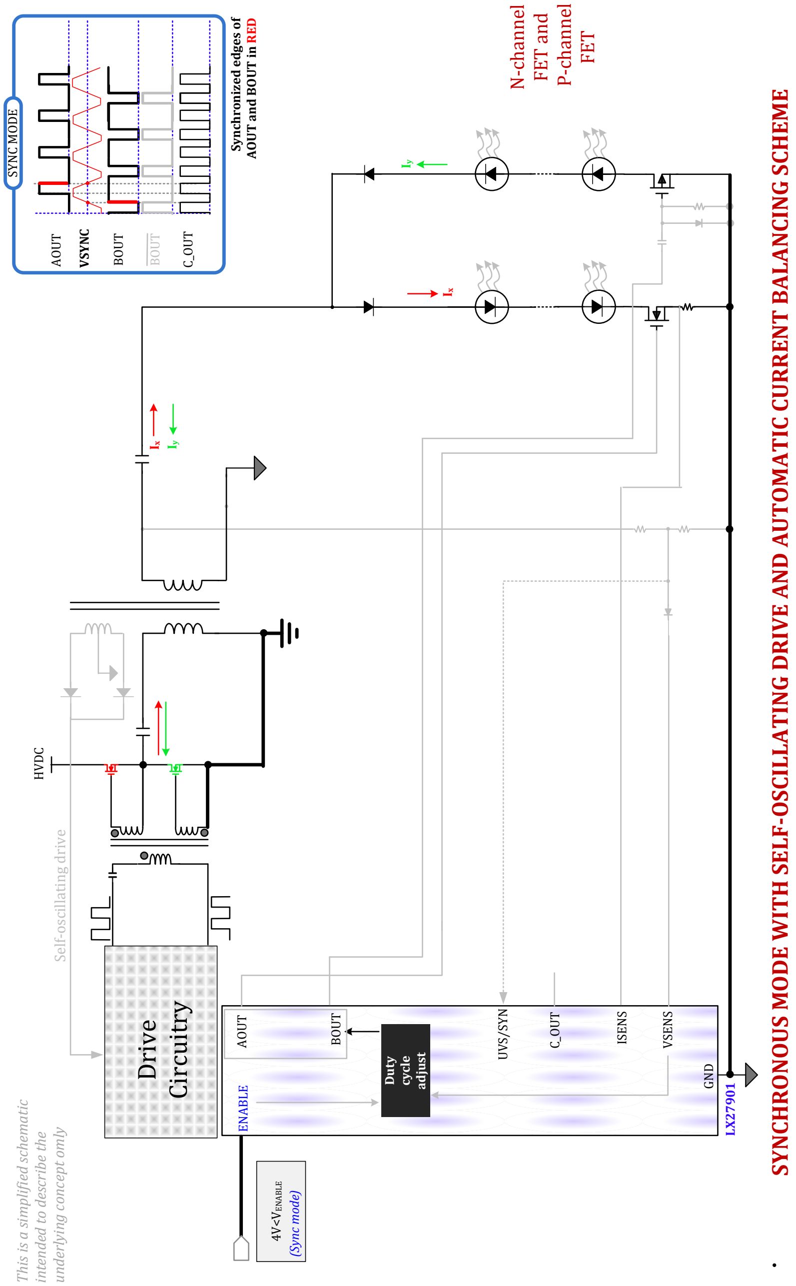
The reason the two *different branches* share the same current is due to the "*shared flux cancellation winding*", marked BLUE. This winding basically links the flux in the two cores once again, even though the cores are separate from each other.

Let us follow this through. Starting with the left side, when the RED arrows are flowing, the direction inside the core is *towards* the polarity dot. On the other side of the same core, by transformer action, we get exactly the same current (since the turns ratio is unity), but this RED arrow is away from the dot. So their flux cancels out in the left-hand core. But this current I_x now flows through into the core on the right side. This RED arrow is *away* from the polarity dot (inside the transformer). So by transformer action, it reflects exactly I_x on the other side of the core, and that RED arrow must be *towards* the polarity dot. Which as we can see is *downwards* into the LED branch on the right-hand side. But we know that we have I_y flowing here. So clearly, by symmetry, we satisfy $I_x = I_y$ once again.

Therefore, as in Method 2, *if the two currents are equal, there is no inductance present*. The mismatch starts as soon as $I_x \neq I_y$. Now we see an effective inductance in series with the winding which is carrying more current, thus serving to limit that current. It is, as in Method 2, very similar to the use of ballasting resistors to equalize currents in two parallel chains, except that here inductance comes into the picture, and automatically so, as soon as imbalance occurs.

CONCLUSION

The LX27901 is one of the most unique products in the market for high-voltage LED control. It was designed to complement extremely unique topologies as we can see even by the few examples above. Using this part makes automatically available, its underlying patents too.


SYNCHRONOUS MODE WITH SELF-OSCILLATING DRIVE AND AUTOMATIC CURRENT BALANCING SCHEME

This is a simplified schematic intended to describe the underlying concept omly

Figure 1: Using Self-Oscillatory Drive for Balancing Current in Two LED Branches

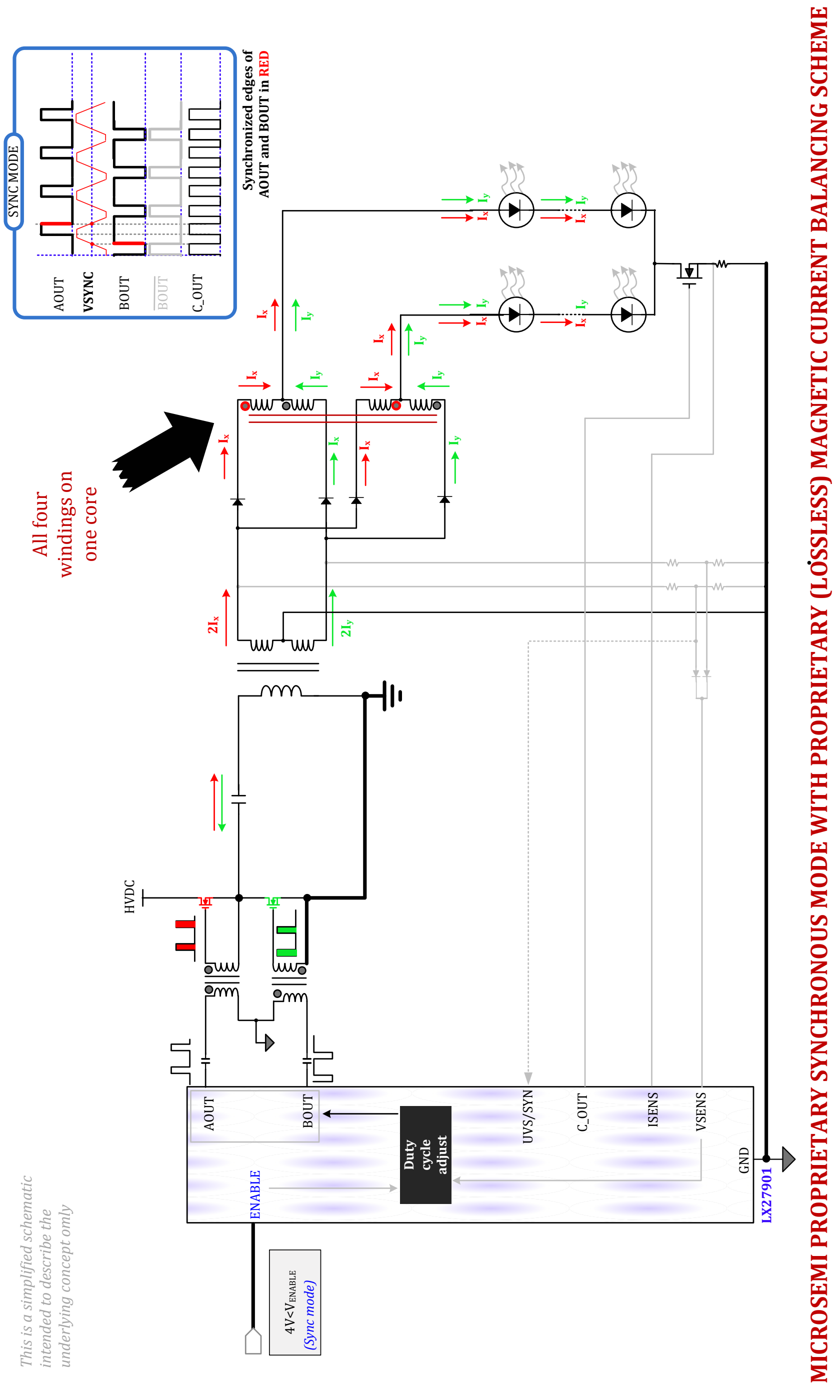


Figure 2: Using Synchronous Mode and Lossless Magnetic Coupling (one embodiment)

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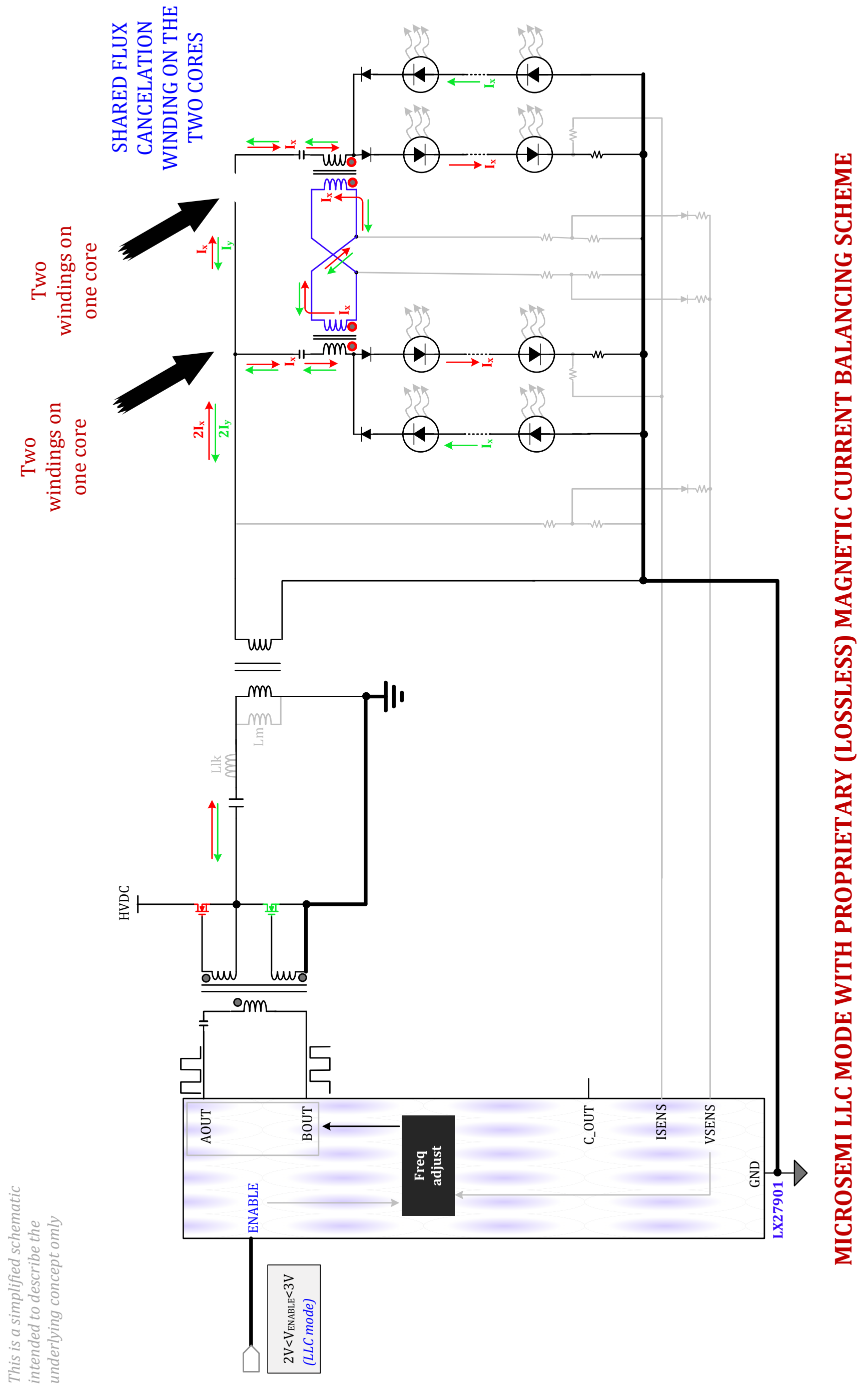

Figure 3: Using Synchronous Mode and Lossless Magnetic Coupling with LLC (second embodiment)