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L6561 - BASED SWITCHER REPLACES MAG AMPS IN SILVER BOXES

by Claudio Adragna

Mag amps (a contraction of "Magnetic Amplifier") are widely used in multi-output switching power supplies to get auxiliary regulated power rails. However, they are expensive, bulky, and require a high level of design expertise.

ST's L6561, an 8-pin Transition Mode PFC (Power Factor Corrector) controller, is surprisingly suitable for implementing a switch-mode architecture as an alternative to mag amps. Much better performance, a dramatic reduction of parts count, cost and design effort are the benefits of such an approach. Drawbacks? None. And once more the L6561 turns out to be a really versatile device.

Introduction

Desktop computer power supplies provide two or more low-voltage, high-current, isolated power rails, typically a 5V rail and a 12V rail. More an more often, it also provides a 3.3V auxiliary rail with high-current capability.

The power is generated by an off-line forward switching converter (inside the so-called "silver box") that regulates only one power rail through an isolated feedback loop. The other power rails are usually post-regulated to meet the specifications on the output voltage tolerance and regulation. A typical architecture is shown in fig. 1.

Figure 1. Typical architecture of an SMPS for desktop computer ("silver box").
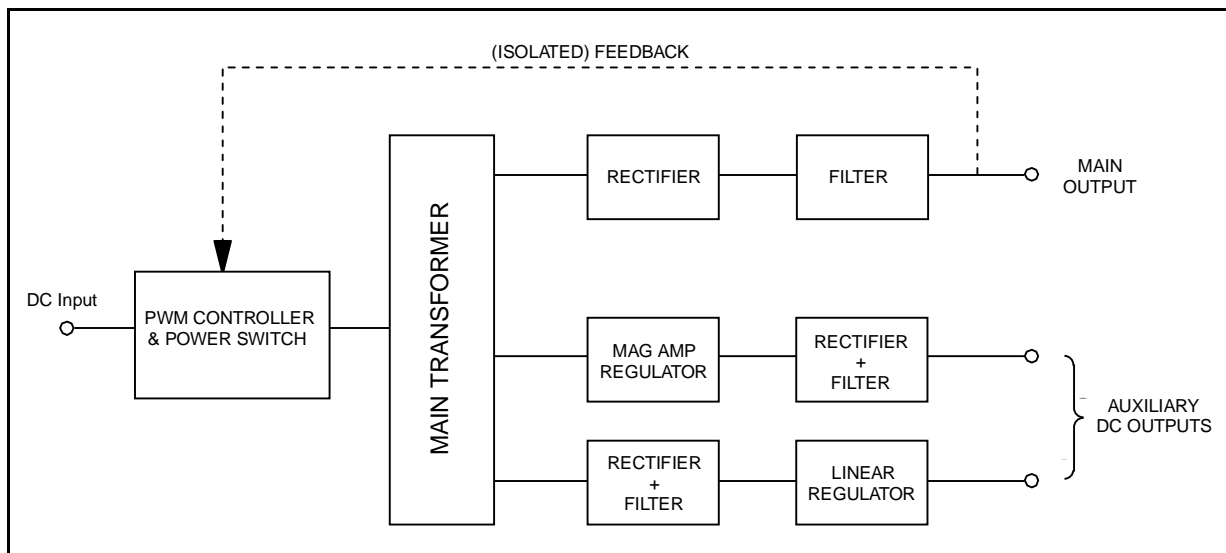
Many power supply manufacturers use magnetic amplifiers (in short, "mag amps") to achieve secondary post-regulation. Mag amps regulate the output voltage with a saturable core reactor that exhibits a square B-H loop: when not saturated, the core material has a very high permeability and the reactor a very high impedance, then it abruptly saturates thus the permeability drops to a very low value and so does the impedance of the reactor.

By varying the magnetic DC flux inside the core, mag amps control the time needed for the core to saturate under a given input voltage pulse. Therefore, the reactor acts basically as a delayed switch and perform PWM by modulating the leading-edge of the input voltage pulse applied to the output section.

Mag amps have a number of drawbacks: they are expensive, bulky, slow, inefficient and, last but not least, their design is not easy.

In this paper a switch-mode architecture is proposed as an alternative to mag amps. Basically, the saturable core reactor is replaced by a power MOSFET. The control circuitry is based on a well-known 8-pin controller IC, in this context used in a not conventional way: the PFC controller L6561.

The benefits of this architecture, which takes advantage of the current mode control offered by the L6561, will be detailed in this paper and can be summarized as follows: much better performance at a much lower cost.

Mag amps as secondary post-regulators

Figure 2 shows a block diagram of a mag amp regulator. It looks simple but there are several aspects of the design that must be accounted for in order to ensure a proper operation.
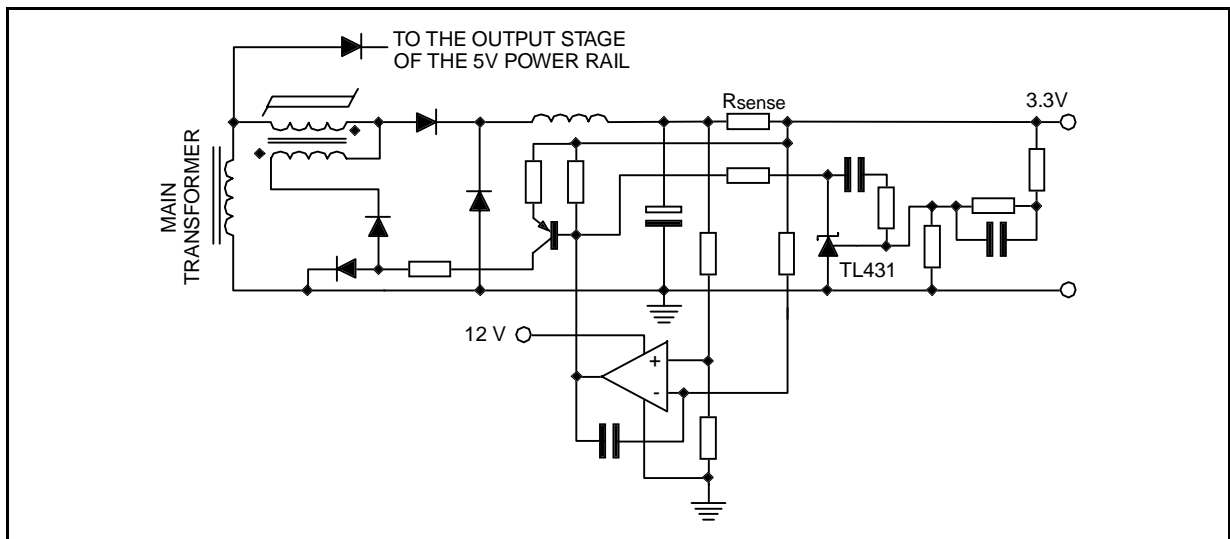
Figure 2. Mag amp regulator block diagram.
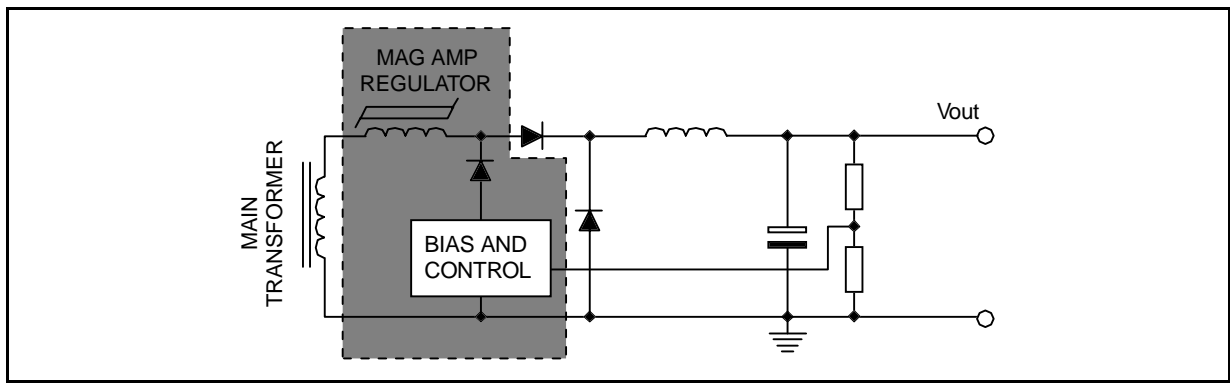
In figure 3, a real example of a mag amp regulator for a 3.3V power rail is shown.

The TL431 acts as a reference voltage/error amplifier. The PNP transistor, driven by the amplified and frequency-compensated error signal, acts as a controlled current generator that resets the mag amp core through the auxiliary winding wound on it. The sense resistor Rsense is part of the current limiting circuit, which includes also the overcurrent comparator with open collector output. The comparator, when triggered, saturates the reset PNP transistor, thus delaying as much as possible the positive pulses delivered downstream the reactor and limiting the overcurrent at the output.

Figure 3. Mag amp regulator electrical schematic.

Without going into details, the problems that arise in such regulators will be here summarized.

To ensure a safe operation also under short circuit conditions with maximum input voltage, the mag amp core must be overdesigned (typically by 100%). This increases its size, weight and cost.

Furthermore, the switching characteristics of the magnetic core are not so good, which limits the operational frequency and cause a poor dynamic response of the regulator. This has a negative impact also on the design of the main transformer of the supply and of the primary switch, which will require to be overdesigned as well.

Both the reactor and the reset PNP exhibit considerable losses, thus the efficiency is not so good.

Another drawback is that the system loses regulation at light output current, thus causing the output voltage to drift high. Moreover, if the regulator starts up with a light load current, the output voltage will experience an overshoot which can be risky for the load. A minimum current consumption (that may be in the hundred mA) must then be ensured in order to avoid these phenomena. This will require either an even bigger mag amp core (further size, weight and cost increase) or a dummy load (efficiency will be hurt) if the output current can go below the minimum value needed to ensure regulation.

Finally, it is not an easy task to tune a mag amp design so as to achieve a satisfactory behavior in the whole and, unless the designer has a high level of expertise, it also takes a long time.

On the other hand, mag amp approach has been either the most competitive or the only practicable solution for handling high load currents so far: it avoids the losses inherent in linear regulators and the complexity of conventional switchers.

L6561-based post regulators

Figure 4 shows an L6561-based post-regulator for generating a 3.3 V power rail, with the same rating as the one illustrated in fig. 3, running off the winding used for the 5V main output.

Compared to the schematic of fig. 3, the parts count is lower. Moreover, the bulkiest (as well as most expensive) components are replaced by smaller (and cheaper) ones. As a result, the Printed Circuit Board area that accommodates the L6561-based regulator is very likely to be half the one needed for a similarly rated mag amp-based regulator.

Figure 4. L6561-based switcher for secondary regulation.

The saturable core reactor is replaced by a power MOSFET (Q1). Its $R_{DS(on)}$ will be in the ten mΩ, according to the output current rating, in order to minimize conduction losses. Such a low $R_{DS(on)}$ does not involve big and expensive MOSFETs because the lowest V_{DSS} classes are required.

MOSFETs of such low voltage classes are available from ST in TO-220 package for through-hole assemblies and in DPAK / D2PAK packages for surface mount assemblies, as summarized in Table 1.

The table shows the devices suggested for typical output current ratings mentioned in Intel's Instantly Available PC (Power Supply '98) specification.

Table 1. Suggested MOSFETs for typical output current ratings (3.3V output).

I_{out} (A)	Part Number (TO-220)		Part Number (DPAK)		Part Number (D2PAK)	
6	BUZ10	55mohm	STD20NE06	40mohm	-	-
8	BUZ11	40mohm	STD20NE06	40mohm	-	-
10	STP40NE03L-20	20mohm	STD20NE03L	20mohm	STB40NE03L-20	20mohm
13	STP60NE03L-10	10mohm	-	-	STB60NE03L-10	10mohm

Q1 is driven with a gate-drive transformer (T2), with a coupling capacitor to eliminate the dependence of the gate-drive voltage on the duty cycle.

The control circuit is based on the L6561, a 8-pin Transition Mode PFC controller that turns out to be extremely useful for this application. Please refer to [1] for a detailed description of the device.

The supply voltage of the L6561 can be got in different ways, depending on the architecture of the entire power supply. A couple of examples are shown in fig. 5.

The operation of the circuit of fig. 4 will be now described, with the aid of the time diagrams shown in fig. 6.

Q1 is turned on on the negative edge of the secondary voltage, detected through the ZCD pin, that is when the primary switch is turned off. The rectifier D1 withstands the reverse secondary voltage.

The key point is: when Q1 is switched on, the current through D1 and Q1 is zero, thus Q1 does not experience any switching loss and the reverse recovery of D1 is here of no concern.

When the primary switch is turned on, the secondary voltage becomes positive and, being Q1 already on, D1 conducts. The secondary voltage (reduced by D1 forward drop) minus the output voltage is applied to the output inductor Lo, causing the inductor current to ramp up.

A current-sense transformer (T3) picks up the inductor current (flowing through Q1 as well) and develops a voltage on R_{sense} proportional to the current. This voltage, applied to CS pin, is internally compared to the output of the multiplier of the L6561 and when the two quantities are equal, Q1 is switched off. The system performs therefore a trailing edge modulation.

The multiplier output voltage is proportional to the product of the error amplifier output voltage (at pin COMP) times the multiplier input voltage (at pin MULT). COMP voltage is in turn a function of the amplified difference between a portion of the output voltage (set by R1 and R2) and the internal 2.5V

Figure 5. Circuits for the generation of the L6561 supply voltage
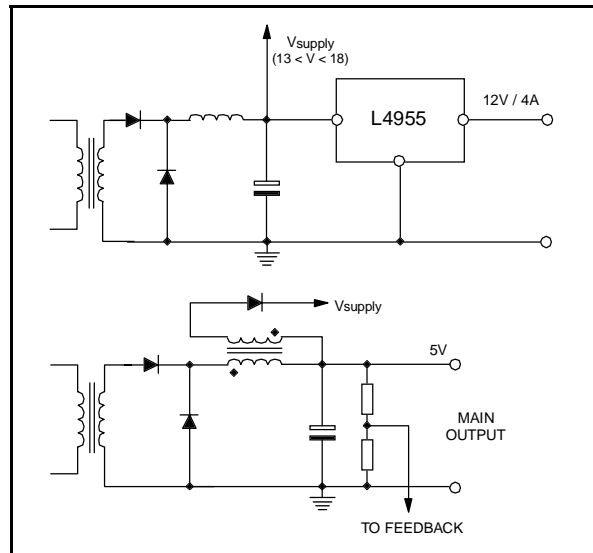
Figure 6. L6561-based switcher time diagrams.
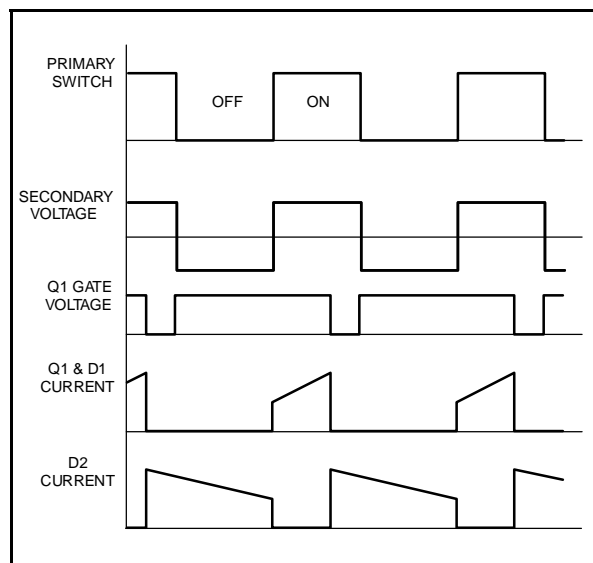
($\pm$1% @ T_j = 25°C) voltage reference.

VMUL voltage is connected to the output voltage, in this way providing foldback current limiting. This function provides a short circuit current lower then the normal load current, thus greatly reducing the stress on the power components in case of failure.

The diode D3 avoids latchoff, that is prevents the output current from dropping to zero during short circuits and staying at zero even when the short circuit is removed. Furthermore, at start-up, there is a soft-start action because of the limitation of the current inflow.

The regulator will exhibit a better efficiency over its mag amp counterpart: the dissipation on the MOS-FET is quite limited (about 1W with the parts suggested in Tab.1), while the mag amp dissipates on the copper and the core of the reactor, as well as some hundreds mW on the reset PNP transistor.

The "peak" current mode control performed by the circuit offers many more benefits: excellent load regulation from very low output current up to the maximum load, fast response to step-load changes, good line regulation due to the inherent input voltage feedforward and one-pole transfer function of the output stage, which simplifies frequency compensation.

Additionally, since the L6561 can be disabled by grounding the ZCD pin, the entire regulator can be either enabled or shut down with a logic signal. Besides, being the L6561 on the secondary side, the interface needed to feed the enable/disable signal will be extremely simple, like the one shown in the schematic of fig. 4.

This disable feature achieves a real zero-power shutdown. In fact, when the regulator is disabled, Q1 is kept off and the secondary winding is an open circuit . The only power consumption is a couple of mA from the supply pin of the L6561.

This functionality turns out to be extremely useful in those systems were power management is required, as stated in Intel's Power Supply '98 specifications, for example.

Conclusions

The replacement of a mag amp-based post regulator with an L6561-based one for the generation of a given auxiliary power rail allows to save numerous external parts among which the bulky and expensive mag amp core. Such a regulator will benefit a dramatic cost reduction from the lower number and cost of the parts used, from the shrinkage of the PCB area needed to accommodate the circuit and from a cut of the design time.

In spite of that, the result is a much more performant system which takes advantage of all the benefits inherent in switching regulation with current mode control as well as of the functionalities available from the versatile L6561.

REFERENCE

[1] "L6561, Enhanced Transition Mode Power Factor Corrector" (AN966)