

Utilizing Mag Amp Technique in Flyback Converter

Chern-Lin Chen, *Senior Member, IEEE* and Tso-Min Chen

Abstract—Mag amps have been widely used in forward converters to provide multiple regulated outputs. Owing to the inherent property of forward converter, bleed resistors are added in each output to ensure output voltage will not rise under light load condition. These added bleed resistors waste power and decrease circuit stability, it is worse when the number of outputs is increased. This paper presents a mag amp assisted flyback converter, which can provide multiple regulated outputs and only one output, which has no mag amp in front of its rectifier, has the minimum load requirement. Circuit operating principles and design considerations are introduced. Experimental results demonstrate that multiple regulated outputs can be obtained and only one bleed resistor is needed for the switching delay introduced by the mag amp.

Index Terms—flyback converter, mag amp, DC/DC converter, regulation.

I. INTRODUCTION

WITH a single pulse width modulation (PWM) control system, mag amps have been popular as post regulators in forward converters to provide multiple regulated outputs [1]-[5]. The main drawback of these circuits is that each output must have a bleed resistor to ensure output voltage will not rise under light load condition. Increasing the flux density swing of mag amps can reduce power loss on the bleed resistors, but the core loss of mag amps increases at the same time [5], the total loss of circuit does not reduce distinctly. Bleed resistors waste power and heat up the circuit, the condition becomes worse when the number of outputs increases.

The "time share" technique documented in [6] uses mag amps in flyback converter can provide tightly regulated outputs. But the single secondary winding arrangement of the power transformer causes that only the output with highest voltage level can be regulated by the PWM controller, thus leading to less flexible to some applications.

The proposed mag amp assisted flyback converter is shown in Fig. 1. Owing to the arrangement of mag amps, the conduction interval of the rectifier in the PWM-regulated output always lags behind that of other rectifiers in the non-PWM-regulated outputs, thus resulting in better dynamic response while the load is varying. The second advantage of

the proposed converter over its counterpart in [6] is that the output with either the lower or the higher voltage level can be regulated by the PWM controller under different design of the secondary windings of the power transformer. This will make it more flexible to different applications.

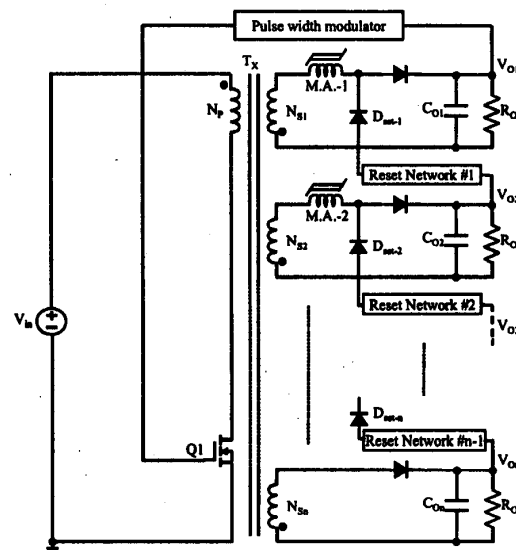


Fig. 1. Proposed mag amp assisted flyback converter.

II. PRINCIPLE OF THE PROPOSED CONVERTER

Fig. 2 shows the simplified circuit diagram of the proposed converter with only two outputs. Although in this section the new mag amp technique is described for the two outputs flyback converter, this technique can be applied to flyback converter with greater number of outputs. To describe the basic operational principles, several assumptions are made.

- The converter has reached a steady-state operation.
- The inductance of the mag amp is infinite when it is not saturated, and zero when it is saturated.
- All semiconductor components are ideal.
- The coupling of the power transformer is ideal, which means that the power transformer does not have the leakage inductance.

To facilitate the analysis of operation, Fig. 3 and Fig. 4 show the three topological stages of the converter during a switching cycle and its key waveforms, respectively.

Stage 1 [$t_0 \leq t < t_1$]:

Q1 is conducting and the current flowing through the

Chern-Lin Chen and Tso-Min Chen are with the Electrical Engineering Department, National Taiwan University, Taipei, Taiwan 106 ROC (e-mail: clchen@cc.ee.ntu.edu.tw).

primary magnetizing inductor of the power transformer T_X increasing linearly. The power, however, is not delivered to the output, but stored in the primary magnetizing inductor. In the output side, the deviated voltage of V_{O2} determines the reset current of mag amp.

However, the mechanism of the reset network for the mag amp used here is just the converse of that in the forward converter. The reset current applied to the mag amp is controlled by the reset network so that it is greater when the voltage level of V_{O2} is lower and becomes smaller when the voltage level of V_{O2} is higher.

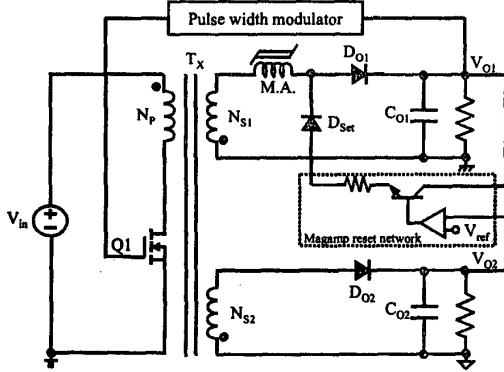


Fig. 2. Proposed mag amp assisted flyback converter with two-outputs.

Stage 2 [$t_1 \leq t < t_2$]:

During this stage, Q1 is off and the ampere-turns of the power transformer T_X can not instantaneously change. The voltage across all windings of the power transformer T_X reversed to force the current transfer to the secondary windings. Owing to the reset current applied to the mag amp during stage 1, the mag amp M.A. is under high impedance status and prevents current from flowing. Before the voltage difference across M.A. drives the core into saturation, only D_{O2} is conducted. The more reset current applied to the mag amp in the stage 1, which is determined by the deviated voltage of V_{O2} , the time required to bring the mag amp into saturation becomes longer.

The condition of the set operation applied on the mag amp is that the voltage across the mag amp must be greater than zero, which can be expressed as follows:

$$V_{MA} = \frac{N_{S1}}{N_{S2}} V_{O2} - V_{O1} > 0. \quad (1)$$

(1) can be further condensed into

$$\frac{N_{S1}}{N_{S2}} > \frac{V_{O1}}{V_{O2}}. \quad (2)$$

Stage 3 [$t_2 \leq t < t_0$]:

When the mag amp is saturated, its impedance drops to zero

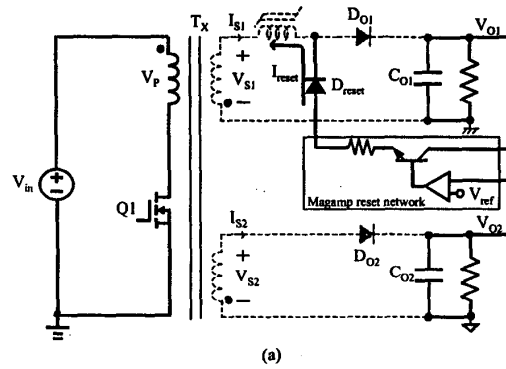
and V_{S1} is clamped to V_{O1} while D_{O1} starts to conduct. By properly design of the turns-ratio between secondary windings of the power transformer, the reflected voltage V_{S2} is lower than V_{O2} and D_{O2} is reversed bias. The condition of D_{O2} is blocked in the stage can be written as follows:

$$V_{S2} = \frac{N_{S2}}{N_{S1}} V_{O1} < V_{O2}. \quad (3)$$

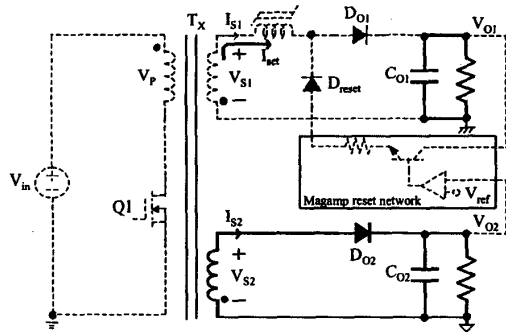
(3) can be further condensed into

$$\frac{N_{S2}}{N_{S1}} < \frac{V_{O2}}{V_{O1}}. \quad (4)$$

In the traditional multiple outputs flyback converter, all the output rectifiers start to conduct at the turn-off instant of the main switch. However, only one output rectifier is conducting in the proposed converter while the main switch Q1 is off, which is D_{O2} in stage 2 and D_{O1} in stage 1. This means that the "on-time" interval of the output rectifiers is "divided", which is the heart of the "time share" technique.



(a)



(b)

(15) can be used to determine the maximum magnetizing inductance of the power transformer while the converter is operated under continuous current mode.

The turns-ratio between the secondary windings of the power transformer can be chosen according to (2) or (4) in section II, no matter the converter is operated under discontinuous current mode or continuous current mode.

(2).Mag amp:

The mag amp design of the proposed converter is almost the same as it used in the forward converter for post-regulation application except the reset network is just the converse of that in the forward converter. This means that the reset current becomes greater when the control signal voltage V_{O2} is larger and the reset network will cut down the reset current applied to the mag amp when the control signal voltage V_{O2} becomes smaller. Here lists some design considerations should be noted.

1. The blocking time of mag amp varies with load current of V_{O2} : While the mag amp is used in the forward converter, the blocking time remains the same under different auxiliary output current for the continuous current mode operation. But in the proposed converter, the blocking time of mag amp will increase while auxiliary load is increasing, and the maximum blocking time will occur at the maximum auxiliary load and minimum main load. While the main load is near off and its conducted time can be omitted, the maximum blocking time of mag amp is equal to the conducted time of D_{O2} .
2. The squareness characteristic results in the minimum load requirement in the auxiliary output: According to the circuit operational principle described in section II, there is no minimum load demand in any outputs for the "time share" mechanism of their output rectifiers. But in reality, owing to the inherent limitation of the mag amp, there exists a time delay before the mag amp becomes saturated from unsaturated status. This can be explained that even when no reset current is applied to the mag amp, the flux in the core will return to its residual value B_r . When the next power pulse is applied, there is a delay time before the mag amp is brought from the residual flux density B_r to the saturated level B_{sat} . This undesirable delay time limits switching frequency of mag amp and results in a minimum on time of D_{O2} . This means a minimum load requirement of auxiliary output is needed, and even when the number of outputs is increased, just only the output without a mag amp in front of its output rectifier has a minimum load requirement. This is because that all these mag amps will be set at the same time during this time delay.

IV. EXPERIMENTAL RESULTS

To verify the operation and performance of the proposed

converter, a prototype is implemented with the following specifications:

1. input voltage V_{in} : 300Vdc;
 2. main output: 5Vdc/0A~6A;
 3. auxiliary output: 12Vdc/0A~2A;
 4. switching frequency: 120kHz;
- The power stage consists of the following parameters:
1. power switch Q1: Toshiba 2SK962;
 2. diode D_{O1} : Toshiba 10GWJ2C48C;
 D_{O2} : Toshiba 5DL2C41A;
 3. power transformer:
 A_e of core: 1cm²;
primary: 24 turns of litz wire 20×0.1mm;
secondary: N_{S1} : 1 turn of litz wire 50×0.1mm;
 N_{S2} : 1 turn litz wire 20×0.1mm;
Magnetizing inductance: 235 μ H.
 4. mag amp: Toshiba MS15×10×4.5W with 6 turns.

Two load regulation curves of the mag amp regulated output voltage V_{O2} at different load conditions of the main output are shown in Fig. 5. Experimental result shows the proposed converter can achieve tight regulation of all outputs. Some typical waveforms measured on the prototype converter under extreme loading conditions are shown in Fig. 6. These waveforms resemble closely those shown in Fig. 4.

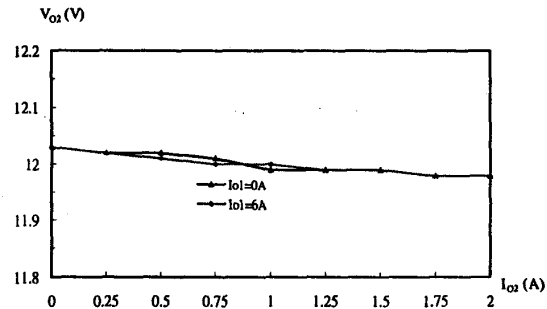
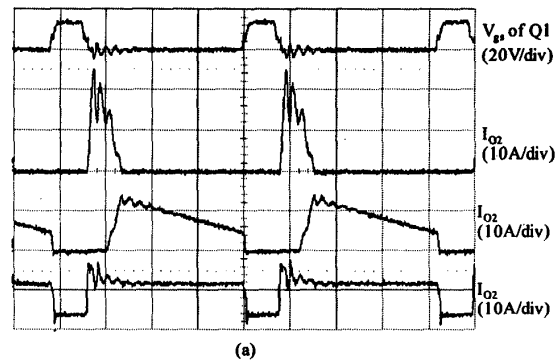


Fig. 5. Load regulation of auxiliary output V_{O2} at different main output load condition.



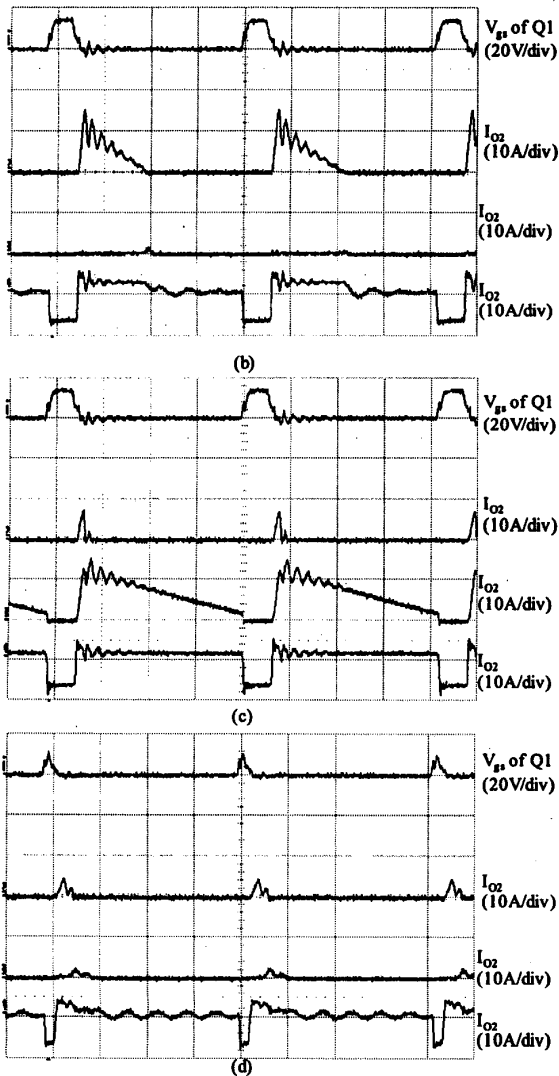


Fig. 6. Typical operating waveforms measured on the prototype converter at
 (a) $I_{o1}=6A$, $I_{o2}=2A$;
 (b) $I_{o1}=0A$, $I_{o2}=2A$;
 (c) $I_{o1}=6A$, $I_{o2}=0A$;
 (d) $I_{o1}=0A$, $I_{o2}=0A$.

V. CONCLUSION

This paper presents the analysis, design, and experimental results for a 54W multiple-regulated-outputs flyback converter employing mag amp circuitry. The incorporation of the mag amp circuit into the traditional multiple-outputs flyback converter provides a mechanism for achieving tight regulation for all the multiple outputs. Experimental results show circuit characteristic resembles closely the analysis.

REFERENCES

- [1] A. I. Pressman, "Switching Power Supply Design," McGraw-Hill, 1991, pp. 381-412.
- [2] K. H. Billings, "Switchmode Power Supply Handbook," McGraw-Hill, 1999, pp. 2.174-2.190.
- [3] R. Mammano, "Magnetic Amplifier Control for Simple, Low-Cost Secondary Regulation," Unitrode Seminar Manual SEM500, 1986, pp. 7.1-7.9.
- [4] R. M. Tedder, "Limitations of the Magamp Regulator and an Improved Magamp Choke Design Procedure," Applied Power Electronics Conference, 1988, pp. 109-117.
- [5] I. J. Lee, D. Y. Chen and C. Jamerson, "Magamp Postregulators, Practical Considerations to Allow operation under extreme loading conditions," IEEE Trans. Power Electron., vol. 5, no. 1, pp. 69-76.
- [6] O. N. Nelson, "Time Share Mag Amp," High Frequency Power Conversion Conference, 1998, pp. 49-54.