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改善多路输出反激变换器的交叉调整率

IMPROVING CROSS REGULATION OF MULTIPLE OUTPUT FLYBACK CONVERTERS

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Abstract 摘要

Cross regulation has been a serious limitation in using Flyback converters with multiple outputs. This paper shows a simple technique which minimizes the problem by adding small external inductors. These inductors are used to control the rate at which the secondary current will change when the switch turns off. By controlling the rate of change, both line and load cross regulation will improve considerable.

在多路输出反激变换器的应用中，交叉调整率是一个重要的限制因素。本文提出了一种简单的方法，通过增加外部小电感使该问题最小化。用这些电感控制开关管关断时的次级电流变化率，通过控制变化率，电压和负载交叉调整率都可获得显著改善。

Introduction 引言

Theoretically cross-regulation in a flyback converter should be better then that of a forward converter, since an additional magnetic (inductor) is needed for the forward converter. In practice this is not the case. Due to the storing of energy during the on time, Ton, the input current will reach some maximum peak, Ip, at the end of Ton. This current will be transferred to the secondary when the power switch is turned "off'". The important point in understanding the cross-regulation is how this transferred current is shared between the secondaries. It will be shown that initially the majority of the current will be transferred to the output which has the smallest leakage inductance. If this output is not used by the feedback to control the PWM then peak detection will occur. If this output is used as the feedback then the duty cycle will be reduced, which in turn will reduce the other outputs.

理论上反激变换器的交叉调整率应该比正激变换器好，因为正激变换器必需多一个磁器件（电感）。实际上并非如此。由于导通期间即Ton的储能作用，在Ton结束时输入电流将达到某一最大峰值Ip。当功率管转为“关断”时，该电流将转变为次级电流。理解交叉调整率的关键点就是这个转变的电流在各次级间是如何分配的。下面将会看到最初该电流的大部分将传递到漏感最小的那路输出，如果该输出没有用于反馈控制PWM，那么将出现过冲现象。如果该输出用于反馈，那么占空比将会减小，从而将会降低其他输出。

Another important feature involving cross-regulation is selecting the number of turns for the non-fedback outputs. Typically, to keep the outputs within a certain tolerance it is necessary to add or delete a turn and /or adjust the feedback output. This will increase the select and test time it will take to bring in all to outputs within their specified tolerance. In many cases the cross-regulation problem leads to the use of additional linear and /or switching regulators for several outputs that are out of tolerance.

另一个对交叉调整率起重要作用的因素是非反馈输出绕组的匝数选取，为了保证输出在一定的偏差范围内，常常需要加或减一匝和/或调整反馈输出。为使各输出保持在各自的指标范围内，将会增加选择和测试的时间。很多情况下因为交叉调整率问题，几个超出偏差范围的输出需要增加线性和/或开关稳压器。

<u>Cross-regulation for a dual output</u>

双路输出的交叉调整率

In order to see how the transferred current is initially distributed, when the switch is turned off, we will reflect the second output,Vo2, to the output which is being fedback, Vo1, as shown in Figures 1 and 2.

为了看清楚开关关断时电流开始如何分配，我们把第二路输出Vo2反射到反馈控制的输出Vo1，如图1和图2所示：

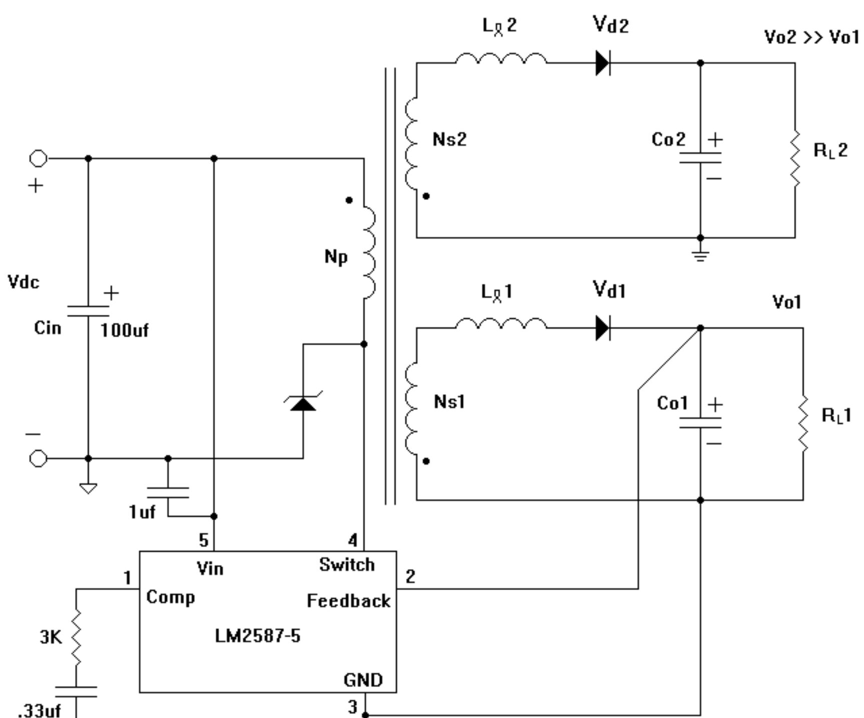

Fig. 1

图1

Assuming that $L_{\ell 2} = 2\,L_{\ell 1}$,

假设Ll2=2Ll1

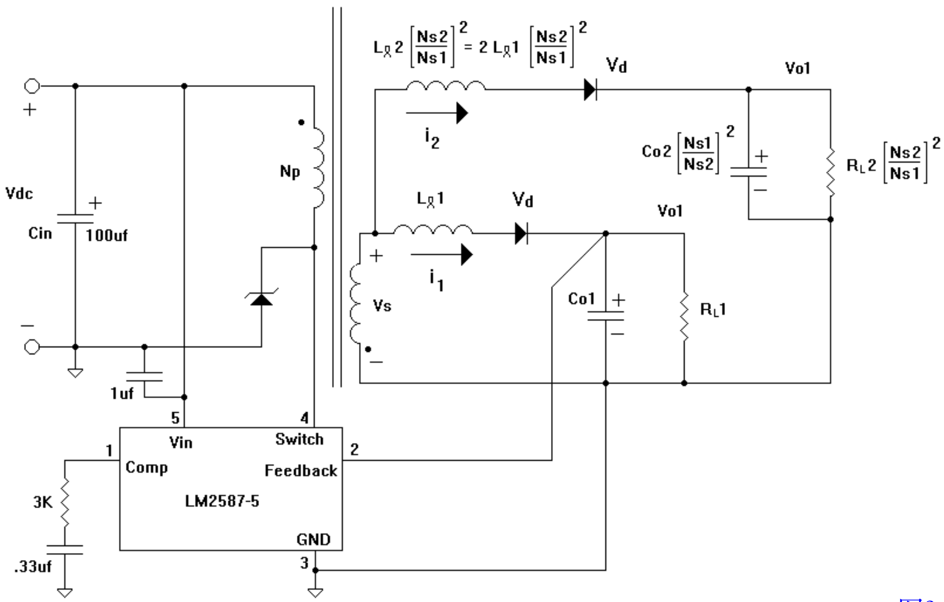

Fig. 2

图2

We notice that if Vd1=Vd2=Vd then the voltage across $L_{\ell 1}$ and $L_{\ell 2}$ will be the same. Call the voltage across the leakage inductors Vo=Vs-(Vo1+Vd). Then as soon as the switch turns off, the transferred current will be distributed in accordance with Faraday's Law.

我们注意到如果Vd1=Vd2=Vd，那么Ll2和Ll1两端的电压将会相等。可得漏感两端的电压为Vo=Vs-(Vo1+Vd)。于是一旦开关关断，转换电流将按照法拉第定律分配。

$$L_{\ell 2}\left[\frac{N_{S2}}{N_{S1}}\right]^2 \frac{di_2}{dt} = Vo$$

$$i_2 = \int di_2 = \int_0^t \frac{Vo}{2\,L_{\ell 1}\left[\frac{N_{S2}}{N_{S1}}\right]^2}\,dt = \frac{Vo}{2\,L_{\ell 1}\left[\frac{N_{S2}}{N_{S1}}\right]^2}\,t$$

The above equations are not exact since Vo is a function of time ,t, and we treated Vo as a constant, however for understanding how the leakage effects the cross-regulation it is effective.

上面的公式并不确切，因为Vo是时间t的函数但我们把它当作常数，不过对于理解漏感是如何影响交叉调整率这样做是有效的。

Similarly we calculate the current ,

类似地，我们计算出电流，

$$i_1 = \frac{Vo}{L_{\ell 1}} t$$

$$\text{Let} \quad m = \frac{Vo}{L_{\ell 1}} \qquad \text{Then} \quad i_1 = m\,t$$

comparing the two currents we have;

比较这两个电流，可得：

$$i_1 = \frac{Vo}{L_{\ell 1}} t = m\,t$$

$$i_2 = \frac{Vo}{2\,L_{\ell 1}\left[\frac{N_{S2}}{N_{S1}}\right]^2} t = \frac{m}{2\left[\frac{N_{S2}}{N_{S1}}\right]^2} t$$

since Vo2 >> Vo1, as an example lets say Vo2 = 50 V and Vo1 = 5 V then Ns2 = 10 Ns1

由于Vo2>>Vo1，比如Vo2=50V，Vo1=5V，那么Ns2=10Ns1

$$\text{Hence} \quad \left[\frac{N_{S2}}{N_{S1}}\right]^2 = \left[\frac{1}{10}\right]^2 = \frac{1}{100}$$

因此

$$\text{and} \qquad i_1 = m\,t$$

又

$$i_2 = \frac{m}{2\left[\frac{N_{S2}}{N_{S1}}\right]^2} t = \frac{m}{2\;\frac{1}{100}} t = 50\,m\,t = 50\,i_1$$

Hence the initial current flowing in Vo2 output is 50 times greater then the current in Vo1 output. This will lead to output Vo2 peaking well beyond 50 V.

因此初始流入Vo2输出的电流是流入Vo1输出的50倍之多。这将导致Vo2升高大大超过50V。

Lets us observe a graph to see what happens to the current in both outputs;

让我们通过图示来了解两路输出的电流发生了什么：

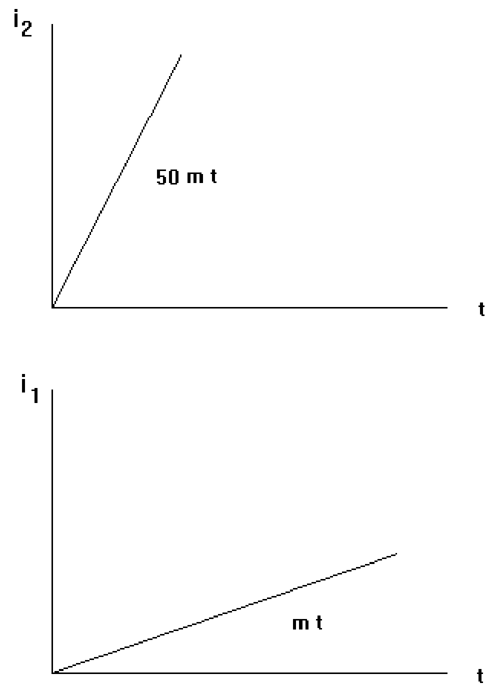

Fig. 3

图3

When the current , i_1, finally equals the output current, Io, and the charging current, Ic, (Ic is the current needed to charge the output capacitor Co1) a feedback signal is sent to terminate the duty cycle, but by this time the output Vo2 has overshot by a significant amount.

当电流i1最终达到输出电流Io加上充电电流Ic时（Ic是输出电容Co1需要的充电电流），将会送出一个反馈信号终止占空周期，但此时Vo2输出已经严重过冲了。

Solution to cross-regulation problem

交叉调整率问题的解决方法

If we add external inductors, as shown in Figure 4, such that the rate of change in both windings is the same, then there would be no (or very little) peaking.

如果我们增加外部电感，如图4所示，这样两个绕组的变化率就会相等，因此也就不会（或很小）有过冲了。

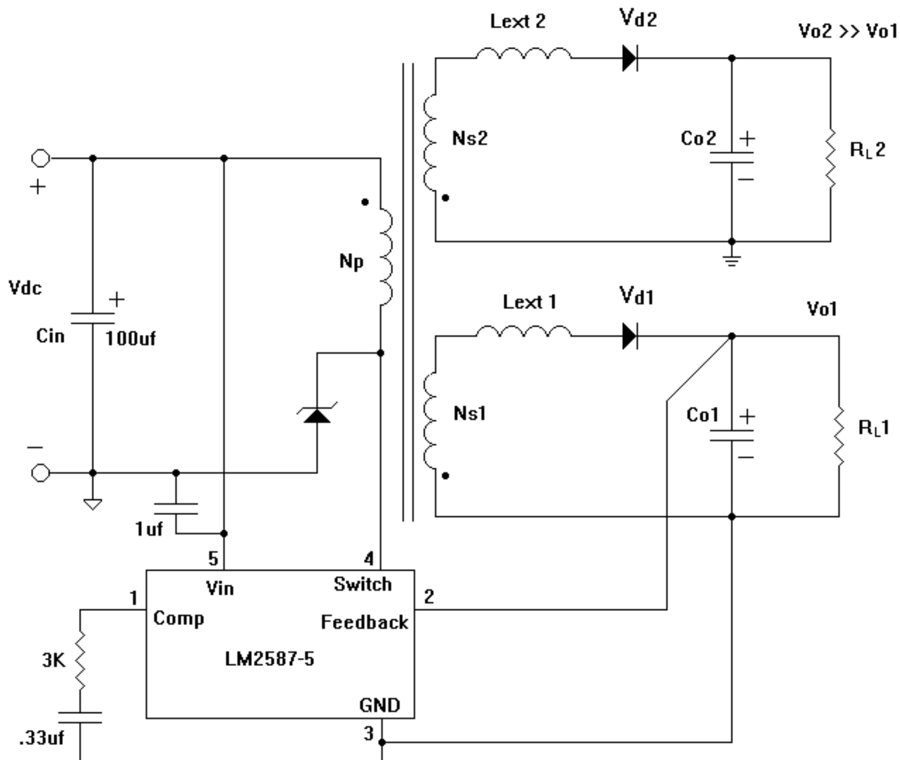

Fig. 4

图4

Note: Lext2 >> Leakage2
and Lext1 >> Leakage1

注意：Lext2 >> Leakage2
以及 Lext1 >> Leakage1

To minimize cost, Lext1 is a one turn MPP or powdered iron core and Lext2 is a similar core with the following value;

为了降低成本，Lext1是一个单匝的MPP或铁粉芯，Lext2也是类似磁芯，电感量如下：

$$Lext2 = \left| \frac{N_{S1}}{N_{S2}} \right|^2 Lext1$$

Now reflecting the output Vo2 to Vo1 as in Figure 5;

现在把输出Vo2反射到输出Vo1上，如图5：

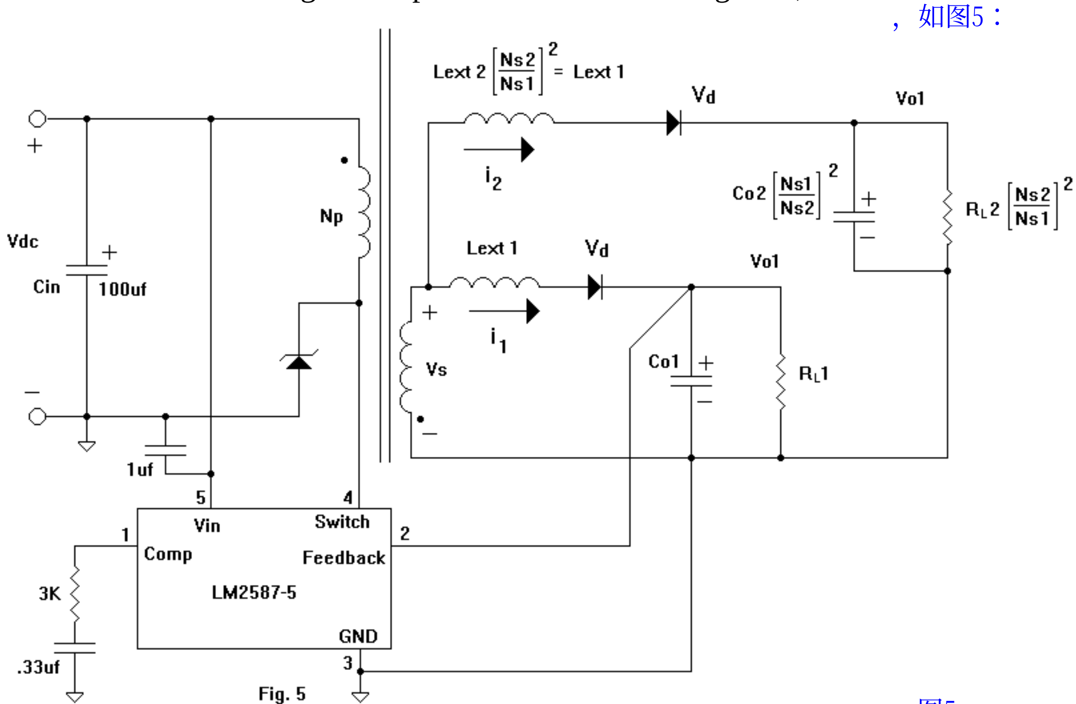

Fig. 5

图5

In accordance to Faradays Law we have the same rate of change of current in both outputs.

根据法拉第定律可知两路输出的电流变化率相等。

$$i_1 = i_2 = \frac{Vo}{Lext\ 1}\ t$$

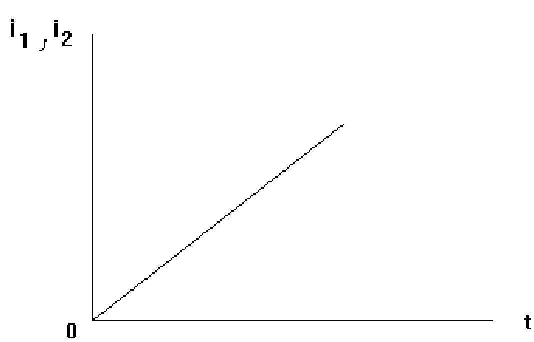

Fig. 6

图6

Since we have the same rate of change, peak detecting will be reduced significantly. This will improve the cross-regulation problem.

由于我们使变化率相同，极大减小了过冲现象。这会使交叉调整率问题得到改善。

Multiple outputs

多路输出

A similar situation and solution exists for multiple outputs as shown in Figure 7.

多路输出也存在类似的情形和解决方法，如图7所示。

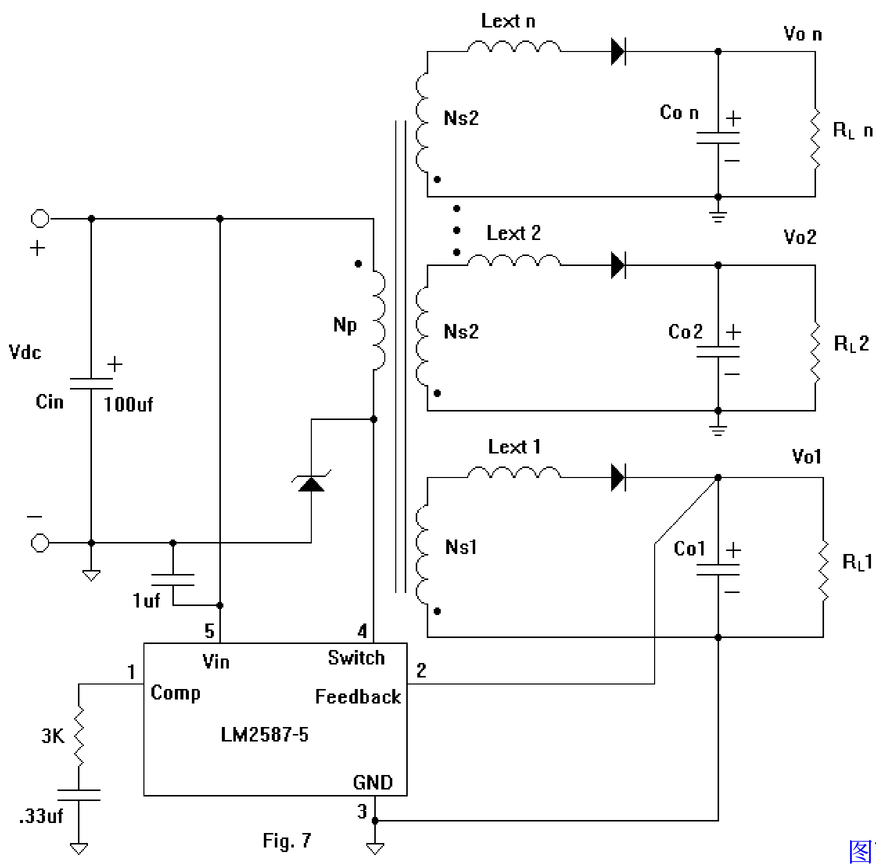

Fig. 7

图7

Reflecting all outputs to the feedback winding, Vo1, and selecting the external inductor follows;

把所有输出全都反射到反馈输出Vo1，并按照下式选择外部电感：

$$\text{Lext 1} = \left[\frac{N_{S1}}{N_{S2}}\right]^2 \text{Lext 2} = \left[\frac{N_{S1}}{N_{S3}}\right]^2 \text{Lext 3} = \cdots = \left[\frac{N_{S1}}{N_{Sn}}\right]^2 \text{Lext n}$$

This will assure that the rate of change of current in all the outputs will be the same. This will improve the cross-regulation in all outputs by minimizing peak overshooting or undershooting an any output.

这样可以保证所有输出的电流上升率都相等，通过减小每一路输出的过冲或欠冲改善所有输出的交叉调整率。

This technique also minimizes selecting the “right” feedback voltage, Vo1, such that all outputs are within tolerance.

该方法也使得选择“最佳”反馈电压Vo1以使所有输出都在偏差范围内的问题得以最小化。

Ref: 参考资料：

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[4] National Semiconductor Power IC’s databook 1995 edition, pages 3-116 to 3-139 (LM2587 datasheet).