LETTER
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A simple circuit to remove X-cap bleeder resistor for reducing standby power consumption

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Abstract: A simple circuit is introduced in this paper for eliminating power dissipation of bleeder resistor when the power converter is plugged to the power outlet. The depletion-type NMOS device can be naturally turned-on to establish discharge path of X capacitor without driving voltage for safety consideration. And the depletion-type NMOS device is virtually turned off to disconnect bleeder resistor for improving the efficiency of power converter while AC power is on. As a result, the waste power can be removed in normal operation, light load, especially in standby load conditions for comply the newest energy star specification, EuP lot 6 and 5 star standards of mobile charger standby power regulations. Experimental results demonstrate that the proposed scheme can implement ultra low standby power of converter with a simple and low cost solution.

Keywords: x-cap, bleeder resistor, standby power, depletion-type NMOS
Classification: Electron devices, circuits, and systems

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1 Introduction

For solving conducted electromagnetic interference (EMI) problem, the EMI filters have been widely used in switching power supply. A typical flyback topology [1, 2, 3] switching power supply circuit is shown in Fig. 1. Using the X capacitor (C_X) for differential-mode (DM) noise and common-mode (CM) choke for CM noise to implement EMI suppression mechanism. The C_X is connected between the line (L) and neutral (N) of AC input connector. In order to meet the safety standard in electric equipment such as UL 1950 [4] and IEC61010-1 [5] regulations, the C_X discharge circuit should be installed to avoid the possibility of electrical shock. For common power design, the traditional methods parallel bleeder resistor (R_X) with the C_X to achieve the discharge purpose within a specification time after the AC power off. But the R_X continues to consume energy after the AC power on and it is one of the major elements of standby power loss. Every year, there are billions of new mobile phones appear in the world. The sum of all mobile charger's standby power are huge energy dissipation (many mobile chargers are plugged to the power outlet even not in use). To adopt with proposed scheme, the major element of standby power loss can be eliminated effectively.

◆UL1950: In 1 second for type-A equipment, the voltage across C_X must drop to 37% peak voltage of the AC input, in 10 seconds for type-B equipment.

◆IEC61010-1: After disconnection from supply source, the pins must not be hazardous within 5 seconds.

For comply with UL1950, the discharge time constant of bleeder resistor can be expressed as equation (1), and the power loss of R_X is shown as equation (2).

$$\tau_x = C_x \times R_x \leq 1\,\text{sec} \tag{1}$$

$$P_{loss\_R_x} = V^2_{AC\_rms}/R_x \tag{2}$$

A common value of C_X among 100 nF∼2.2 µF depends on the rated output power. The peak voltage of universal (90Vac–264Vac) AC input voltage is equal to 264 V ∗ 1.414 = 373 V, for meeting safety regulations, the voltage should be down to 373 V ∗ 37% = 138 V within 1 second after the converter is unplugged from the power outlet. The large output power requires more effective C_X to suppress DM noise, and the C_X needs smaller bleeder resistor to discharge energy rapidly. However, the smaller bleeder resistor results more power dissipation. For example, even 1 M ohm of bleeder resistor will bring about 264 V^2ac ÷ 1 M = 70 mW power loss in normal operation condition, considering other standby power consumptions from PWM IC, bridge rectifier, magnetic component, etc., it is not easy to meet the newest energy star [6], EuP lot 6 [7] and 5 star standards [8] of mobile charger's standby power [9, 10] regulation especially in low power solution. Therefore, we need some new scheme to disconnect the bleeder resistor after power on and to

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connect it after power off. The depletion-type NMOS would be adopted in proposed circuit due to it is normally "ON" at 0 V gate bias.

◆ENERGY STAR: For single voltage, external ac-dc power supplies under 50 W, the energy consumption criteria for no-load is below 0.3 W.

◆EuP lot 6: The standby power for adapter is below 0.25 W, European Union eco-design requirements for energy using products.

◆Five-star rating scheme regulating: The 5 star standards of mobile charger is the standby power consumption under 30 mW.

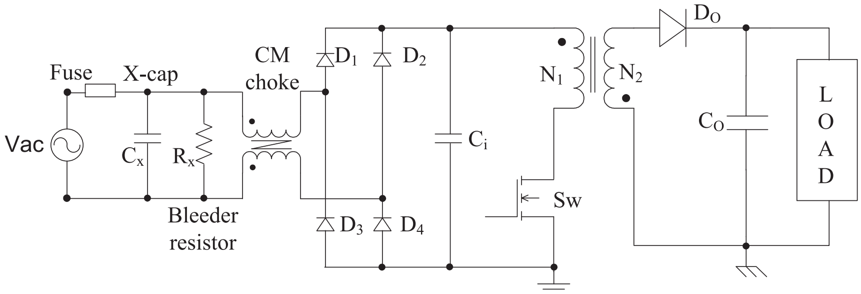

Fig. 1. A typical flyback switching power supply circuit.

2 Scheme description

Fig. 2 shows the proposed X capacitor discharge and R_X remove circuit, which consists of one X capacitor C_X, two bleeder resistors R_{X1} and R_{X2}, two depletion-type NMOS ($V_{DS\_max} = 600\,V$) Q_1 and Q_2 (total cost only USD$ 0.035) both are constructed by single SOT23-6 package, four rectifier diodes D_1~D_4, one Zener diode Z_1, one current limit resistor R_1, one DC blocking capacitor C_1, one diode D_5, one hold-up capacitor C_2, and one discharge resistor R_2.

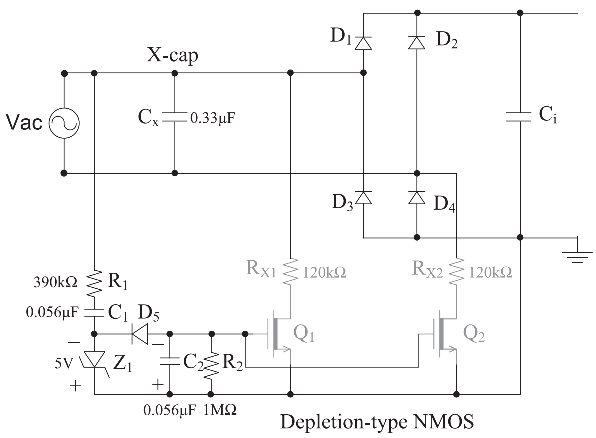

Fig. 2. Proposed R_X remove circuit in normal operation condition.

In normal operation condition as Fig. 2, the converter is plugged to the power outlet. In the negative half-cycle, the AC voltage through current limit resistor R_1 and blocking capacitor C_1 to offer reverse-bias voltage which cause zener diode Z_1 breakdown, therefore the result conducts diode D_5 and keeps negative voltage in

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hold-up capacitor C_2. The negative voltage of hold-up capacitor C_2 will turn off the depletion-type NMOS Q_1, Q_2 and disconnect two bleeder resistors R_{X1}, R_{X2} to eliminate their power dissipation.

When the converter is unplugged from the power outlet, the negative voltage of hold-up capacitor C_2 will be discharged by resistor R_2. Thus, the driving voltage of depletion-type NMOS becomes zero and the Q_1, Q_2 can be naturally turned on to discharge the energy of C_X for meeting the safety regulations. If line (L) is positive voltage as Fig. 3(a), the energy of C_X will through R_{X1}, Q_1, D_4 and be discharged.

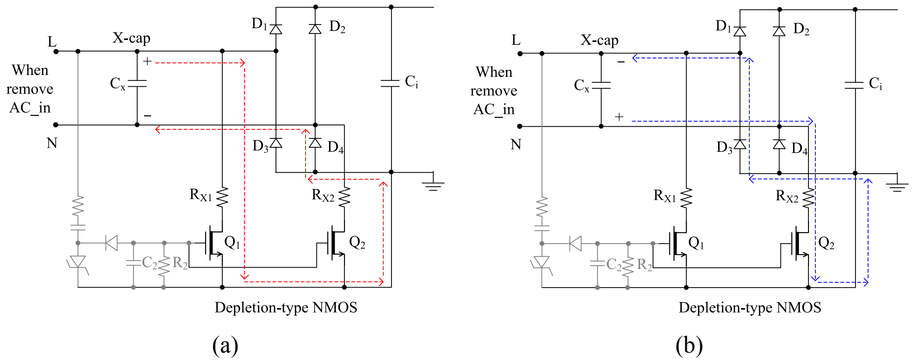

Fig. 3. Two discharge path when remove AC power.

If neutral (N) is positive as Fig. 3(b), the energy of C_X will through R_{X2}, Q_2, D_3 and be discharged. The proposed scheme is very simple and useful. Quite importantly, it can work without any auxiliary voltage, especially in the lack of AC power.

3 Design considerations

The selection for R_1 and C_1 depends on the minimum zener current (I_{ZT}). The I_{ZT} exists when zener diode (Z_1) work in the reverse-bias voltage. In proposed case, $(90 - 5)\,V \div (R_1 - jX_{C1})$ should be greater than 0.216 mA (I_{ZT}), and to make sure the $(264 - 5)\,V \div (R_1 - jX_{C1})$ to be under maximum zener current (I_{ZM}). In general, we like to design $(90 - 5)\,V \div (R_1 - jX_{C1})$ close to 0.216 mA, because this zener diode is just for clamping an electric voltage to turn off depletion-type NMOS. Here, the function of zener diode is not for voltage regulator. The selection for C_2 and R_2 depends on the discharge time constant. Also, the current pass through the R_2 can dominate the operating of depletion-type NMOS. In proposed case, $\tau_2 = C_2 * R_2$ and $\tau_X = C_X * R_X$, the total discharge time must be less than 1 second for complying with UL1950. On the other hand, to ensure I_{R2} as the predominance, we design the I_{R2} current to be 100 times bigger than the gate-source leakage current (I_{GSS}) of depletion-type NMOS. In proposed case, when C_2 is discharged from $-5\,V$ to about $-3\,V$, the depletion-type NMOS will be turned on gradually, and C_X is also discharged gradually. A small C_2 is preferred, because the larger C_2 needs more time and smaller R_2 for discharge. The smaller R_2 will result more power dissipation ($\fallingdotseq V_{Z1}{}^2/R_2$) in AC power on period. The limited V_{GS} of proposed depletion-type NMOS is $-20\,V$, so a smaller C_2 with higher ripple is still acceptable.

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The step-by-step procedure of components design as below:

1. From minimum AC input voltage, the current pass through R_1, C_1, can be represented as $I_{R_1} = I_{C_1} = \dfrac{(90-5)\,\mathrm{V}}{R_1 + 1/j(2\pi * f * C_1)}$

2. Base on the $I_{ZT} = 0.216\,\mathrm{mA}$, roughly calculate the complex impedance is: $|Z_1| = |R_1 + 1/j(2\pi * f * C_1)| = \dfrac{(90-5)\,\mathrm{V}}{0.216\,\mathrm{mA}} \cong 393.5\,\mathrm{k\Omega}$

3. We can choose the approximation's standard resistor 390 kΩ for R_1 and reserve part proportion of complex impedance for C_1. From 60 Hz, the C_1 can be roughly calculated as 0.0507 µF and choose the standard capacitor 0.056 µF for C_1.

4. The typical I_{GSS} of depletion-type NMOS is 50 nA, hence, we design the current of I_{R2} as 100 times bigger than I_{GSS} in order to dominate the operating of depletion-type NMOS. So the R_2 can be calculated as $5\,\mathrm{V} \div (50\,\mathrm{nA} * 100) = 1\,\mathrm{M\Omega}$.

5. The period of 60 Hz is 16 ms, and the negative half-cycle time is 8 ms. Considering the ripple voltage on the hold-up capacitor C_2 is about 0.7 V. From Q = CV = IT, the C_2 can be calculated as: $C_2 = \dfrac{IT}{\Delta V} = \dfrac{50\,\mathrm{nA} * 100 * 8\,\mathrm{ms}}{0.7\,\mathrm{V}} \cong 0.057\,\mu\mathrm{F}$, and choose 0.056 µF for C_2.

6. Check the zener current whether over the maximum zener current (I_{ZM}) under 264Vac condition, and check the total discharge time whether less than 1 second.

4 Experimental results

Fig. 4 shows the converter is plugged into the AC source (230 Vrms) and unplugged immediately. The waveform has three parts. Firstly, 0 V (before plug to the AC source), secondly, when plug to the AC source, the waveform is around $2^{0.5} * 230\,\mathrm{Vrms} \fallingdotseq 333\,\mathrm{V} \sim -330\,\mathrm{V}$ (positive and negative half-cycle of peak voltage), thirdly, C_X is discharged from peak voltage to 0 V (when unplugged from the AC source and captured in phase angle: $270° \rightarrow 360°$). From the third part, before the Q_2 is turned on, the C_X is discharged by self resistor and other parasitic components, thus the slope of discharge is gently. Once the Q_2 is turned on, the C_X is discharged by R_{X2} rapidly. The total discharge time (from peak voltage to 0 V) is around 550 ms. And the dashed line denotes 37% of peak voltage. The same as 110 Vrms condition, the peak voltage is between $2^{0.5} * 110\,\mathrm{Vrms} \fallingdotseq 158\,\mathrm{V}$ and −157 V, the total discharge time is around 400 ms as shown in Fig. 5. In normal operation condition, the power loss is only 4 mW (in 230 Vrms) and 1.3 mW (in 110 Vrms) respectively. The basic concept for safety standard in electric equipment is to discharge energy of C_X within specification time. To meet a different safety standard, we just need to fine-tune the R_X for complying with different safety standard. Table I summarizes the key values of proposed scheme.

Table I. The discharge time and power loss under AC ON/OFF with proposed scheme

AC input	Discharge time (AC off)	Power Loss (AC on)	X capacitor
230 Vrms	550 ms	4 mW	0.33 µF
110 Vrms	400 ms	1.3 mW	0.33 µF

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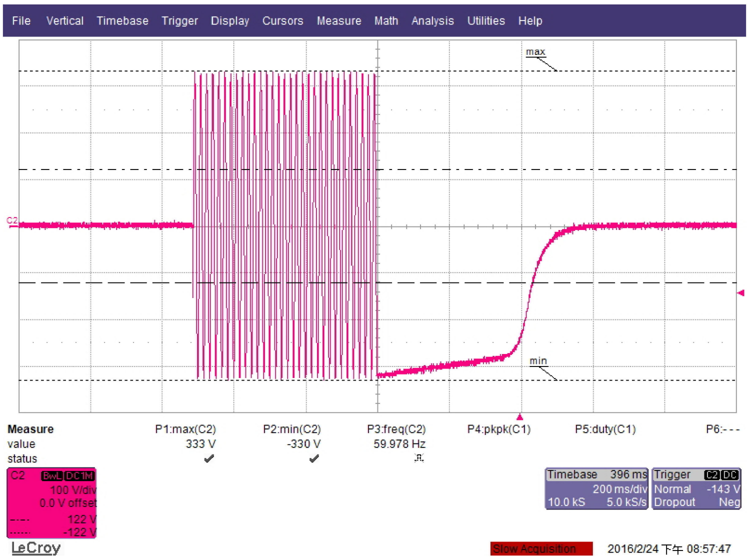

Fig. 4. C_X discharge waveform with proposed scheme under 230 Vrms.

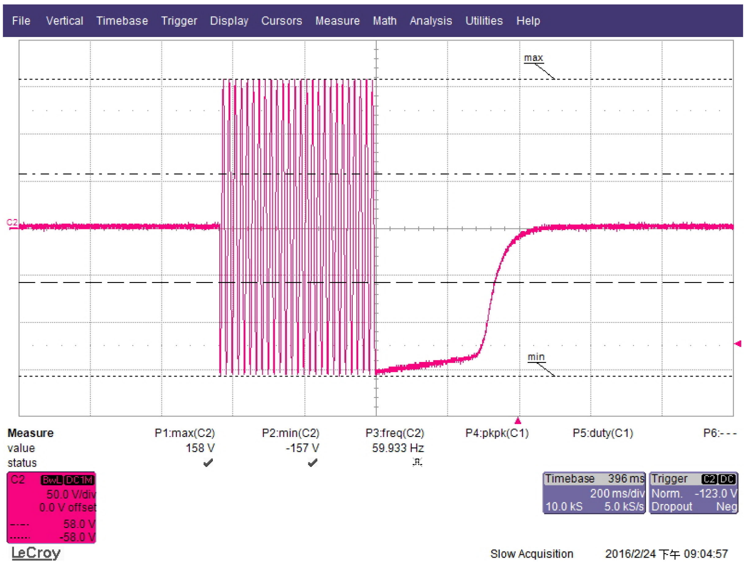

Fig. 5. C_X discharge waveform with proposed scheme under 110 Vrms.

5 Conclusion

A simple circuit for removing X capacitor bleeder resistor is presented. The use of proposed depletion-type NMOS can be naturally turned on without any driving voltage to discharge the energy of X capacitor for complying with the safety regulations. On the other hand, the depletion-type NMOS can be turned off to remove the bleeder resistor in normal operation condition. Experimental results show when AC power is off, the fast discharge time appears. Once AC power is on, there is low power loss. The efficiency of the power converter is improved and the power dissipation of bleeder resistor is removed. Furthermore, the newest standby power regulations can be conformed.

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