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

References

www.fairchildsemi.com/application-notes/AN/AN-9752.pdf
[6] ENERGY STAR eligibility criteria (version 2.0) draft 1. Program requirements for single voltage external ac-dc power supplies.
[7] EuP preparatory study lot 6, standby and off-mode losses. Eco-design
requirements for energy using products, European Union.

1 Introduction

For solving conducted electromagnetic interference (EMI) problem, the EMI filters have been widely used in switching power supply. A typical flyback topology [1-3] 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).

\[
\tau_x = C_x \times R_x \leq 1 \text{sec}
\]

\[
P_{loss,R_x} = \frac{V_{AC_{rms}}^2}{R_x}
\]

A common value of C_X among 100nF~2.2μF depends on the rated output power. The peak voltage of universal (90Vac-264Vac) AC input voltage is equal to 264V*1.414=373V, for meeting safety regulations, the voltage should be down to 373V*37%=138V 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 1M ohm of bleeder resistor will bring about 264V^2/1M=70mW 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 connect it after power off. The depletion-type NMOS would be adopted in proposed circuit due to it is normally “ON” at 0V gate bias.

◆ ENERGY STAR: For single voltage, external ac-dc power supplies under 50W, the energy consumption criteria for no-load is below 0.3W.
◆ EuP lot 6: The standby power for adapter is below 0.25W, 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 30mW.

![Fig. 1. A typical flyback switching power supply circuit.](image)

### 2 Scheme description

Fig. 2 shows the proposed X capacitor discharge and RX remove circuit, which consists of one X capacitor CX, two bleeder resistors RX1 and RX2, two depletion-type NMOS (VDS_max=600V) Q1 and Q2 (total cost only USD$ 0.035) both are constructed by single SOT23-6 package, four rectifier diodes D1~D4, one Zener diode Z1, one current limit resistor R1, one DC blocking capacitor C1, one diode D5, one hold-up capacitor C2, and one discharge resistor R2.

![Fig. 2. Proposed RX remove circuit in normal operation condition.](image)

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 R1 and blocking capacitor C1 to offer reverse-bias voltage which cause zener diode Z1 breakdown, therefore the result conducts diode D4 and keeps negative voltage in hold-up capacitor C2. The negative voltage of hold-up capacitor C2 will turn off the depletion-type NMOS Q1, Q2 and disconnect two bleeder resistors RX1, RX2 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.

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, \((90-5)V/(R_1-jX_{C1})\) should be greater than 0.216mA (\(I_{ZT}\)), and to make sure the \((264-5)V/(R_1-jX_{C1})\) to be under maximum zener current (\(I_{ZM}\)). In general, we like to design \((90-5)V/(R_1-jX_{C1})\) close to 0.216mA, 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 -5V to about -3V, 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 (\(\approx V_{Z1}^2/R_2\)) in AC power on period. The limited \(V_{GS}\) of proposed depletion-type NMOS is -20V, so a smaller \(C_2\) with higher ripple is still acceptable. 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
   \[
   I_{R1} = I_{C1} = \frac{(90-5)V}{R_1 + \frac{1}{j(2\pi*f*C_1)}}
   \]
2. Base on the $I_{ZT}=0.216\text{mA}$, roughly calculate the complex impedance is:

\[ |Z| = |R_1 + \frac{1}{j(2\pi f C_1)}| = \frac{(90 - 5)V}{0.216\text{mA}} \approx 393.5\text{k}\Omega \]

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

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

5. The period of 60Hz is 16ms, and the negative half-cycle time is 8ms. Considering the ripple voltage on the hold-up capacitor $C_2$ is about 0.7V. From $Q=CV=IT$, the $C_2$ can be calculated as:

\[ C_2 = \frac{IT}{\Delta V} = \frac{50\text{nA} \times 100 \times 8\text{ms}}{0.7V} \approx 0.057\mu\text{F}, \quad \text{and choose 0.056µF for } C_2. \]

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 (230Vrms) and unplugged immediately. The waveform has three parts. Firstly, 0V (before plug to the AC source), secondly, when plug to the AC source, the waveform is around $2^{0.5} \times 230\text{Vrms} \approx 333\text{V} - 330\text{V}$ (positive and negative half-cycle of peak voltage), thirdly, $C_X$ is discharged from peak voltage to 0V (when unplugged from the AC source and captured in phase angle: $270^0 \rightarrow 360^0$). 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 0V) is around 550ms. And the dashed line denotes 37% of peak voltage. The same as 110Vrms condition, the peak voltage is between $2^{0.5} \times 110\text{Vrms} \approx 158\text{V}$ and -157V, the total discharge time is around 400ms as shown in Fig. 5. In normal operation condition, the power loss is only 4mW (in 230Vrms) and 1.3mW (in 110Vrms) 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>
<thead>
<tr>
<th>AC input</th>
<th>Discharge time (AC off)</th>
<th>Power Loss (AC on)</th>
<th>X capacitor</th>
</tr>
</thead>
<tbody>
<tr>
<td>230Vrms</td>
<td>550ms</td>
<td>4mW</td>
<td>0.33µF</td>
</tr>
<tr>
<td>110Vrms</td>
<td>400ms</td>
<td>1.3mW</td>
<td>0.33µF</td>
</tr>
</tbody>
</table>
Fig. 4. Cₓ discharge waveform with proposed scheme under 230Vrms.

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

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.