Application Note

High Avalanche-Energy Capability MOSFET Series

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INTRODUCTION

Power MOSFETs are now used in a wide variety of electronic devices. Particularly for implementing switching power supplies, which are emerging as the main power supply circuit of electronic devices, power MOSFETs have become indispensable because their increasingly compact, high-efficiency circuit designs easily enable faster operation.

In general, when switching speed increases, flyback voltage may damage the device as a result of wiring inductance, for example. This must be taken into consideration when designing electronic circuits. It is possible to prevent devices from being damaged by flyback voltage by using products with guaranteed avalanche capability.

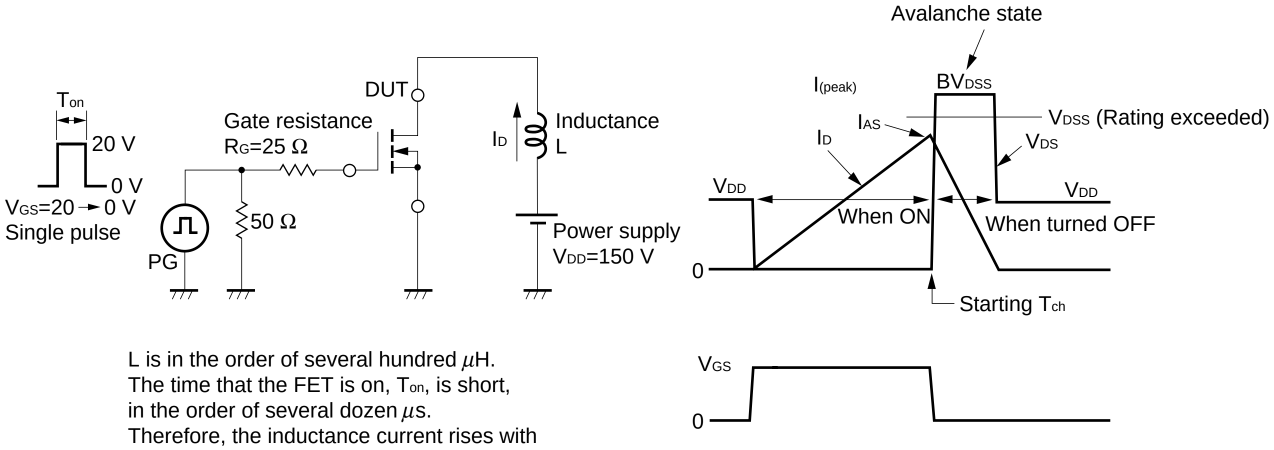
This document introduces the characteristics of a series of NEC-developed MOSFETs with a high avalanche-energy capability (high sustain capability) and a high breakdown voltage of 250 V or greater.

1. Avalanche-Energy Capability

Sustain damage is the most important consideration in switching power supplies, a typical MOSFET application. Damage from such causes as over-current and over-voltage during transient periods or unstable operation (i.e. when starting or load short-circuiting) are examples of actual faults that may occur. Sustain tolerance is the qualitative measure of this sustain damage. Of sustain tolerance, the avalanche-energy capability discussed here is subject to the most rigorous test conditions (non-clamp conditions).

Figure 1-1 shows an avalanche-energy capability test circuit. Initially, $1/2 \times LI_{(peak)}^2$ of energy is accumulated in the inductance from the drain current flowing when the FET is on. This energy generates a flyback voltage that exceeds the drain-source breakdown voltage when the power is turned off and causes avalanche breakdown in the FET. Stress, as shown below, is applied due to this avalanche breakdown, and the circuit may be damaged as a result.

Figure 1-1. Avalanche-Energy Capability Test Circuit



L is in the order of several hundred μH.
The time that the FET is on, T_{on}, is short,
in the order of several dozen μs.
Therefore, the inductance current rises with
a gradient of nearly V_{DD}/L.

Energy is accumulated when ON.

⇩

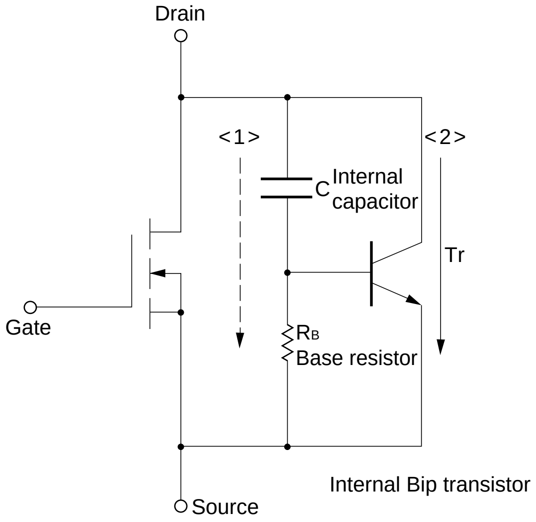
Absorbed by FET as avalanche energy when turned OFF.

1.1 Stress from Voltage Build-up Rate dV/dt When Power Is Turned Off

Incorrect operation of the internal Bip transistor in the FET may create a concentration of current that damages elements if the voltage build-up rate dV/dt is extremely high when flyback voltage is generated. Figure 1-2 shows an equivalent circuit in the MOSFET and the mechanism behind dV/dt damage.

Figure 1-2. Mechanism behind FET Damage from the dV/dt Effect

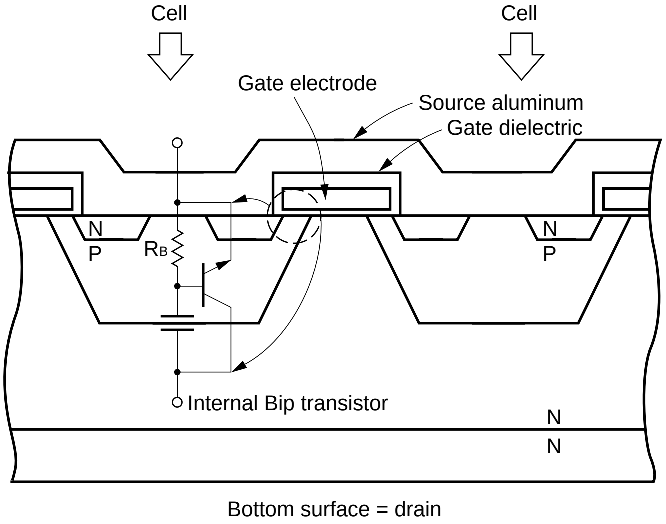
(1) Equivalent circuit in MOSFET



<1> Over-current flows to base resistor R_B via the internal capacitor C as a result of the sudden change to dV/dt when the power is turned off.

<2> The internal Bip transistor Tr is switched on by a fall in voltage of the base resistor R_B if over-current is extremely large. Current concentrates because the internal Bip transistor is switched on locally, and the circuit is damaged.

(2) Enlarged cross-sectional diagram of the MOSFET



Area corresponding to FET is circled in the dotted line.

1.2 Stress from Avalanche Energy

Avalanche energy E is the energy value absorbed by the FET in the avalanche region and, theoretically, can be derived by calculating the time integral of the product of the drain-source voltage V_{DS} and the drain current I_D, as shown in equation (1).

$$E = \int_{t=0}^{t=t_A} V_{DS}(t) \bullet I_D(t)dt \qquad (1)$$

$$E = \frac{1}{2} LI_{(peak)}^2 \frac{BV_{DSS}}{BV_{DSS} - V_{DD}} \qquad (2)$$

Inductance	L
Peak avalanche current	$I_{(peak)}$
Drain-source breakdown voltage	BV_{DSS}
Power supply voltage	V_{DD}

The circuit is damaged if the maximum capability of avalanche energy E is exceeded. High avalanche-energy capability is the ability to breakdown a high dV/dt of the flyback voltage and a large avalanche energy value.

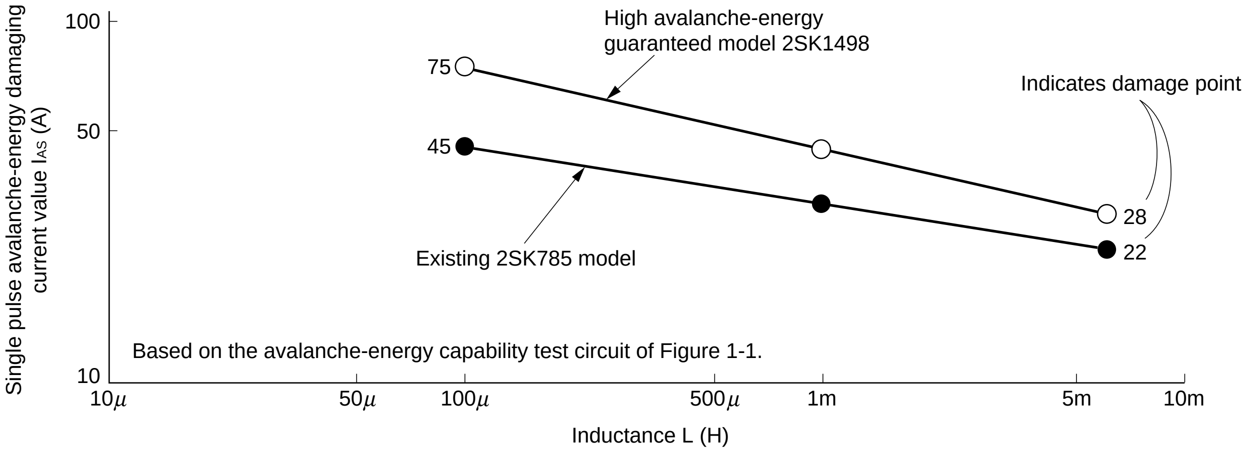
2. IMPROVING AVALANCHE-ENERGY CAPABILITY

To improve avalanche-energy capability, it is particularly important to design the circuit so that the internal Bip transistor does not operate incorrectly. As explained in the previous section on the mechanism behind dV/dt damage (see **Figure 1-2**), the internal Bip transistor turns on because the over-current flowing to the internal capacitor C biases the base resistor R_B. Therefore, avalanche-energy capability can be improved if consideration is given to ensuring that this base resistor is as small as possible during the design stage.

Figure 2-1 indicates that the single pulse avalanche-energy capability (damaging current value) of the previously released 500 V/20 A rated 2SK785 and the improved avalanche-energy guaranteed 2SK1498 with the same rating has been increased by approximately 1.5-times.

By designing improved avalanche-energy capability models under premise of guaranteed operation with high avalanche energy, NEC has developed a MOSFET with approximately 1.5-times the energy capability of existing models with high dV/dt ruggedness. All devices undergo avalanche testing because of variations in the manufacturing processes.

Figure 2-1. Avalanche-Energy Capability Comparisons for 500 V/20 A Rated Models



3. AVALANCHE-ENERGY CAPABILITY RATING

Ratings have been specified for the high avalanche-guaranteed series, as shown in Table 3-1. (The representative model is the 500 V/25 A rated 2SK1500)

Table 3-1. 2SK1500 Avalanche-Energy Capability Ratings

Item	Symbol	Conditions	Ratings	Unit
Peak avalanche current	I_{AS}, I_{AR}		37.5	A
Single pulse avalanche-energy	E_{AS}	Starting T_{ch} = 25°C R_G = 25 Ω, V_{GS} = 20 V to 0 See **Figure 1-1**.	907	mJ
Repetitive pulse avalanche-energy	E_{AR}	$T_{ch} \leq 150$°C $I_{AR} \leq 37.5$ A R_G = 25 Ω, V_{GS} = 20 V to 0	16	mJ

3.1 Peak Avalanche Current Value I_{AR}, I_{AS}

This rating indicates the maximum permissible current value in the avalanche state, and is designated in the range of 1/2 $I_{D(DC)}$ to 1.5 $I_{D(DC)}$, depending on the element.

3.2 Single pulse Avalanche-Energy E_{AS}

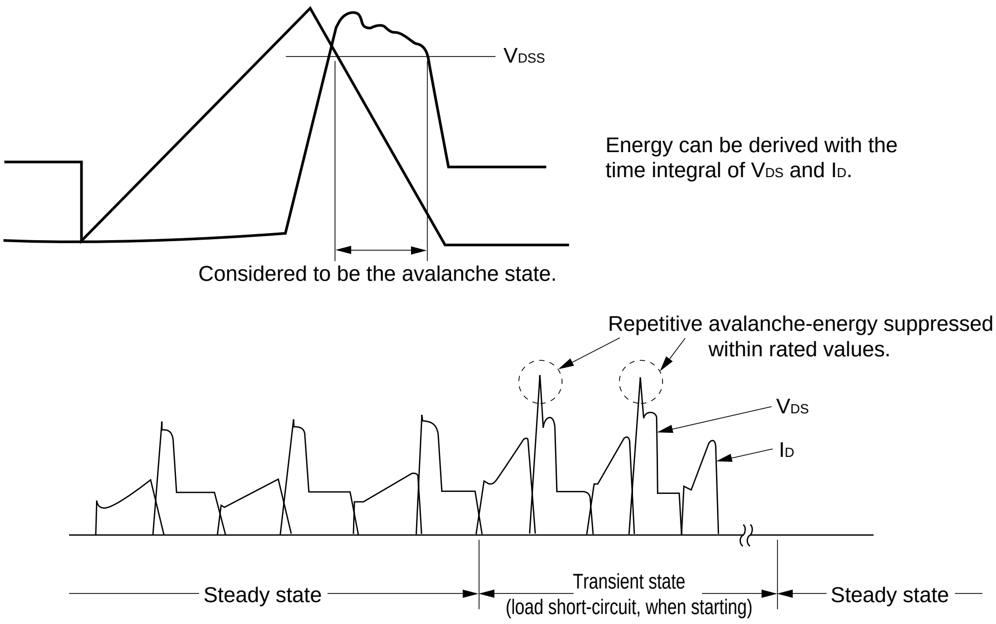
This rating indicates the maximum permissible energy value of a single pulse and is determined by de-rating from the breakdown fast distribution of the element.

3.3 Repetitive pulse Avalanche-Energy E_{AR}

As shown in Figure 3-1, this rating designates the maximum permissible transient avalanche-energy that may be applied to the element during a load short-circuit (the rating does not apply if the avalanche state is sustained). In consideration of the heat-dissipation of the element, the fixed energy value is set in the range from 1/10 to approximately 1/100 of the single pulse avalanche-energy.

In fact, it is necessary to confirm not only that the energy value has not exceeded the maximum permissible avalanche-energy E_{AR}, but also that the peak channel temperature during avalanche operation does not exceed 150°C.

Figure 3-1. Example of the Application of Avalanche-Energy Capability



Energy can be derived with the time integral of V_{DS} and I_D.

Repetitive avalanche-energy suppressed within rated values.

4. CHARACTERISTICS, FUNCTIONS, AND SPECIFICATIONS

In addition to high avalanche-energy capability, this product series has the following characteristics:

A) Guaranteed single pulse and repetitive avalanche-energy capability.
B) Input capacitance is 20% lower than current MOSFET models with the same on-resistance.
   Current models: 2SK819 (500 V/10 A)
   $R_{on}C_{iss}$ product = 1,270 Ω • pF
   Current models: 2SK1753 (500 V/10 A)
   $R_{on}C_{iss}$ product = 1,060 Ω • pF
C) Guaranteed gate breakdown voltage of ±30 V.
D) Gate protection diode is built in to prevent the destruction of MOSFET by static electricity when handling (±250 V or greater static electricity tolerance at C = 200 pF, R = 0).
E) Guaranteed gate cut-off voltage width is set at 1 V (2.5 V to 3.5 V) by controlling the voltage distribution.
F) New MP-25Z type surface-mount package added to TO-220 line-up of packages.

The breakdown voltages of products used in different applications are shown in Table 4-1.
Table 4-2 presents the series map for the new lineup of MOSFETs, while Table 4-3 shows their main specifications.

Table 4-1. High Breakdown Voltage Power MOSFET Applications

Main Applications	Appropriate Model Lineup	Corresponding Series
• DC 48 V input power supply for transmission applications • Inverter circuit of uninterruptible power supplies	250 V breakdown voltage series	2SK1491 2SK1492
• AC100 V input for a variety of electronic devices • Switching power supply	450/500 V breakdown voltage series	2SK1493 2SK1500 2SK1752 2SK1756
• AC adapter for notebook PCs, video cameras, etc.	600/700 V breakdown voltage series	2SK1664 2SK1758
• AC 200 V input switching power supply for a variety of electronic devices	900 V breakdown voltage series	2SK1501 2SK1760

Table 4-2. High Avalanche-Energy Capability MOSFET Series Map

Current Rating $I_{D(DC)}$	Package	Drain-Source Voltage V_{DSS} (V)				
		180/250	450	500	600/700*	900
2.0 A	△MP-3 ○MP-25 ◎MP-45F □MP-88				2SK1664(6.0) ◎* 2SK1758(4.2) ◎ 2SK1953(5.0) ◎ 2SK2040(5.0) △	2SK1994(7.5) ◎
2.5 A			2SK1988(2.8) ◎	2SK1989(3.0) ◎		2SK1793(7.5) ○
3.0 A			2SK1493(2.8) ○	2SK1494(3.0) ○		2SK1995(4.0) ◎
4.0 A		2SK1954(0.65) △				2SK1501(4.0) ○
4.5 A			2SK1990(1.4) ◎	2SK1991(1.5) ◎		
5.0 A			2SK1750(1.4) ○	2SK1751(1.5) ○		2SK1760(4.0) □
6.0 A			2SK1992(0.9) ◎	2SK1993(1.0) ◎		2SK1794(2.8) □
7.0 A			2SK1495(0.9) ○	2SK1496(1.0) ○		
8.0 A						2SK1795(1.6) □
10 A			2SK1752(0.9) □	2SK1753(1.0) □		2SK1796(1.2) □
12 A			2SK1784(0.6) □	2SK1785(0.7) □		
15 A			2SK1756(0.5) □	2SK1757(0.6) □		
20 A			2SK1497(0.35) □	2SK1498(0.4) □		
25 A		2SK1491(0.15) □	2SK1499(0.25) □	2SK1500(0.27) □		
35 A		2SK1492(0.10) □				

Table 4-3. Main Specifications of High Avalanche-Energy MOSFETs

Part Number	Package	Absolute Maximum Rating			Main Electrical Specifications				Remark
		V_{DSS} (V)	$I_{D(DC)}$ (A)	P_T (W)	$R_{DS(on)}$ @V_{GS} = 10 V		C_{iss} (pF)	C_{rss} (pF)	
					TYP. (Ω)	MAX. (Ω)			E_{AR} (mJ)
2SK1954	MP-3	180	4.0	20	0.52	0.65	300	53	2.0
2SK1491	MP-88	250	25	120	0.12	0.15	1950	410	12
2SK1492	MP-88		35	150	0.08	0.10	3000	620	15
2SK1988	MP-45F	450	2.5	30	2.2	2.8	350	45	3
2SK1493	MP-25		3.0	50	2.2	2.8	350	45	5
2SK1990	MP-45F		4.5	30	1.1	1.4	610	80	3
2SK1750	MP-25		5.0	50	1.1	1.4	610	80	5
2SK1992	MP-45F		6.0	35	0.7	0.9	1060	150	3.5
2SK1495	MP-25		7.0	70	0.7	0.9	1060	150	7
2SK1752	MP-88		10	100	0.7	0.9	1060	150	10
2SK1784	MP-88		12	100	0.5	0.6	1330	200	10
2SK1756	MP-88		15	120	0.4	0.5	1500	200	12
2SK1497	MP-88		20	120	0.28	0.40	2450	290	12
2SK1499	MP-88		25	150	0.20	0.25	3300	480	15
2SK1989	MP-45F	500	2.5	30	2.4	3.0	350	45	3
2SK1494	MP-25		3.0	50	2.4	3.0	350	45	5
2SK1991	MP-45F		4.5	30	1.2	1.5	610	80	3
2SK1751	MP-25		5.0	50	1.2	1.5	610	80	5
2SK1993	MP-45F		6.0	35	0.8	1.0	1060	150	3.5
2SK1496	MP-25		7.0	70	0.8	1.0	1060	150	7
2SK1753	MP-88		10	100	0.8	1.0	1060	150	10
2SK1785	MP-88		12	100	0.6	0.7	1330	200	10
2SK1757	MP-88		15	120	0.5	0.6	1500	200	12
2SK1498	MP-88		20	120	0.32	0.40	2450	290	12
2SK1500	MP-88		25	150	0.22	0.27	3300	480	15
2SK1664	MP-45F	700	2.0	30	5.0	6.0	490	65	3
2SK1758	MP-45F	600	2.0	30	2.8	4.2	360	50	3
2SK1953	MP-45F		2.0	25	4.2	5.0	275	23	2.5
2SK2040	MP-3		2.0	20	4.2	5.0	275	23	2
2SK1994	MP-45F	900	2.0	30	6.2	7.5	430	21	3
2SK1793	MP-25		3.0	75	6.2	7.5	430	21	7.5
2SK1995	MP-45F		3.0	35	2.8	4.0	790	55	3.5
2SK1501	MP-25		4.0	70	2.8	4.0	790	55	7
S2K1760	MP-88		5.0	100	2.8	4.0	790	60	10
2SK1794	MP-88		6.0	100	1.8	2.8	1000	60	10
2SK1502	MP-88		7.0	120	1.7	2.0	1550	75	12
2SK1795	MP-88		8.0	140	1.3	1.6	1740	110	14
2SK1796	MP-88		10	150	1.0	1.2	2500	120	15

5. APPLICATION CIRCUITS

Figure 5-1 shows an example of the implementation of a single-ended forward switching power supply. The merits of the new series for this circuit are described below.

A) Snubber circuit design and MOSFET selection is simplified through application of repetitive avalanche-energy capability technology.
The specific reasons for this simplification can be described as follows. Figure 5-2 is an example of the main switching circuit of the switching power supply. A reset circuit and snubber circuit between the drain and source may be added to suppress surge voltage. Even if peak voltage is safely suppressed during stable operation, peak voltage rises more than 20% when starting and or during load short-circuits compared to the level during stable operation. The snubber circuit is used to absorb surge voltage during these periods of high peak voltage.
The high avalanche-energy guaranteed series is intended to be used for the circuit here. If peak voltage rises to 460 V during load short-circuit without a snubber circuit when peak voltage is 360 V during stable operation, then the peak voltage must be suppressed below 450 V with a snubber circuit in order to use a 450 V rated model. A 500 V rated model is needed if the snubber circuit is disconnected. However, a 450 V rated model can be employed even when the snubber circuit is disconnected if the avalanche-energy capability guarantee can be applied in this circuit and it is used within the repetitive avalanche-energy capability.
Thus, it is possible to significantly reduce the breakdown voltage margin whether the snubber circuit is disconnected or not because the surge voltage generated in a transient state can be absorbed by the operation of the avalanche-energy capability MOSFET. The method of application in this case is the same as explained in the section on repetitive avalanche-energy. Since the surge voltage is great, a model with equivalent on-resistances and a guaranteed avalanche-energy capability of 900 V can be used if the circuit is similar to a circuit using a MOSFET with a breakdown voltage of 1000 V.

B) The circuit can be designed with ample margin for overshoot of gate driving voltage and other potential causes of damage because gate breakdown voltage is ±30 V. (In the past, it was necessary to suppress over-shoot by such measures as inserting a constant-voltage diode or other component between the gate and source.)

C) Reducing gate drive loss by lowering input capacitance is an effective means of boosting set efficiency.

D) For power supplies of approximately 100 W or less, set miniaturization is easier because the through MOSFET can be surface-mounting using the MP-25Z type package.

Figure 5-1. Single-Ended Forward Switching Power Supply

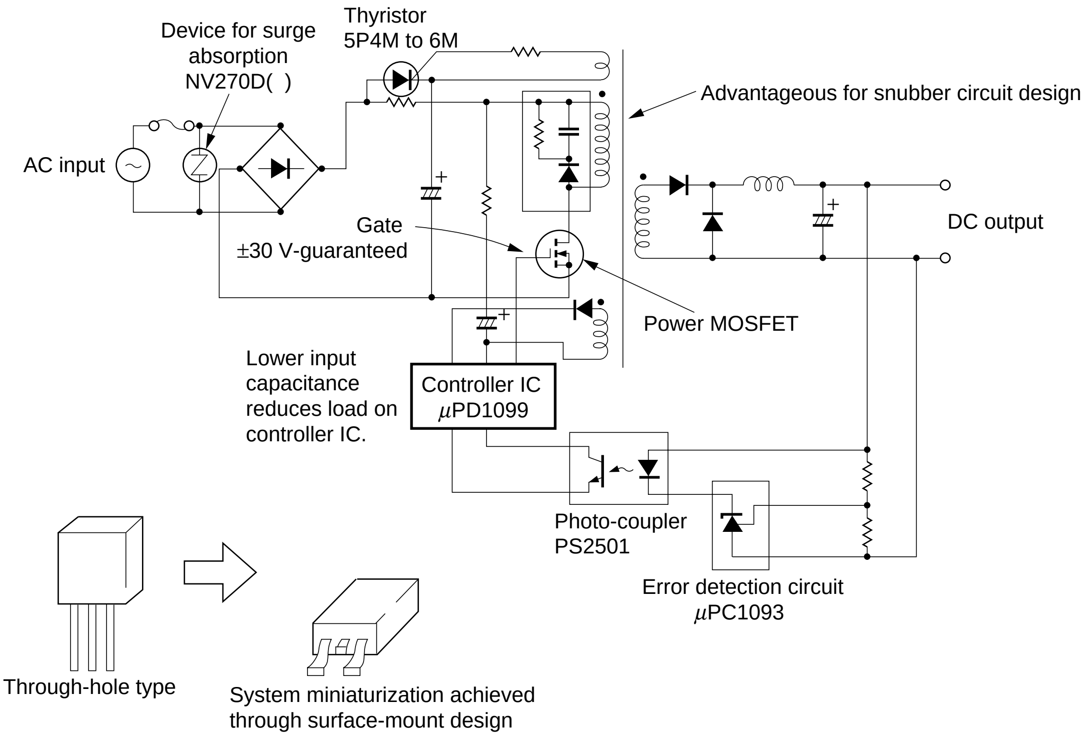
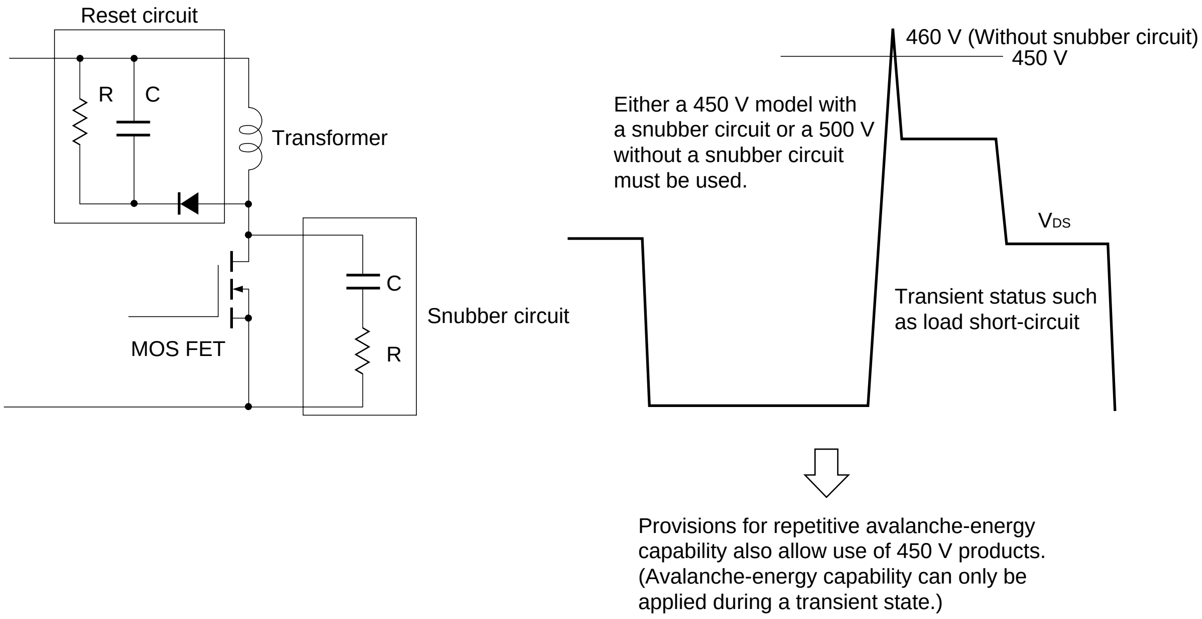


Figure 5-2. Example of Application of Avalanche Operation



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