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Application Note

Phase-out/Discontinued

POWER MOS FET FEATURES AND APPLICATION TO SWITCHING POWER SUPPLY

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Date Published October 1997 N

Printed in Japan

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INDEX

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1. INTRODUCTION

Electronics equipment continues to grow lighter, thinner, shorter, and smaller, to require less energy, and to cost less.

In most electronics equipment, the power supply is the largest and heaviest unit. Improvement of the power supply unit, therefore, brings important benefits. When power supplies changed from series regulators to switching regulators, a need arose for a lighter, thinner, shorter, and smaller high-performance device suited to the switching regulator.

The power MOSFET deserves attention as the device best suited to future switching regulators. In fact, it is already in use for such applications. Power supply units for some new equipment use power MOSFETs instead of the conventional bipolar transistors. This trend is expected to grow rapidly.

This data sheet describes the features, structure, ratings, and characteristics of a power MOSFET; shows circuits using power MOSFETs in place of bipolar transistors; and provides notes for use of the power MOSFET.

2. FEATURES

a. High gain

- Because it is a voltage drive type, this device enables direct high-power control with ICs such as CMOS.

b. High-speed switching, low loss

- Device characteristics enable easy high-speed switching, low on-state resistance, and parallel operation.
- High switching speed, 10 to 100 times faster than that of a bipolar transistor, reduces switching loss.
- Low on-state resistance characteristic provides smaller losses in the low-current area than those of bipolar transistors.
- Positive temperature coefficient of on-state resistance enables easy parallel operation. The loss of each device is then $1/N^2$ for N equal to the number of devices operating in parallel.

c. Large SOA

- Unlike bipolar transistors, power MOSFETs suffer no secondary breakdown, so voltage and current values remain within the rated power (fixed).
- The sustained energy is about 1000 times larger than that of bipolar transistors reducing the failure rate during manufacture and use of the switching regulator.

In addition to the above application features, power MOSFETs offer:

- Established basic design
  Theoretical analyses are well established, so theory closely matches practice.
  This facilitates CAD and design simulation.

- Most advanced manufacturing process
  Power MOSFETs benefit from the most advanced semiconductor technology, that of MOS LSI techniques (such as CVD, ion implantation, and fine process techniques). Further improvements in performance can thus be expected in the future.
  Because it is easy to obtain stable process conditions with high repeatability, uniform quality and high reliability are ensured.

3. STRUCTURE

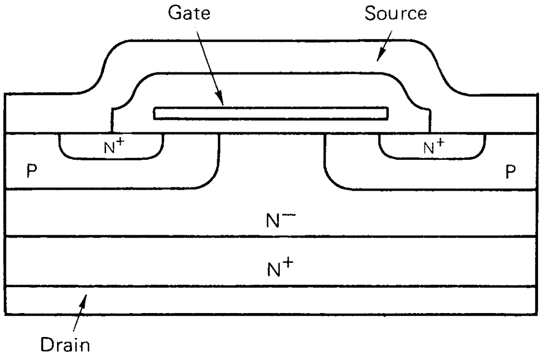

Figure 1. Power MOSFET structure

To control high current, a power MOSFET consists of thousands to ten thousands of FET cells arranged in parallel on one chip. NEC mainly employs the double-diffused MOSFET (DMOSFET) construction shown in figure 1 for:

a. Easy attainment of high-voltage protection

Figures 2 and 3 show MOSFET operations at power-ON and power-OFF respectively.

In a DMOSFET, the gate electrode covers the N^- layer of the drain, separated by a silicon oxide layer, so that a depletion layer connects the adjacent cells at low voltage to form a potential surface as a planar junction parallel to the chip surface. Resistance to high voltages is determined not by the individual cell but by the perimeter structure surrounding multiple cells. Structures employed for bipolar transistors such as guard ring shown in figure 4, can thus be easily applied for protection against high voltages.

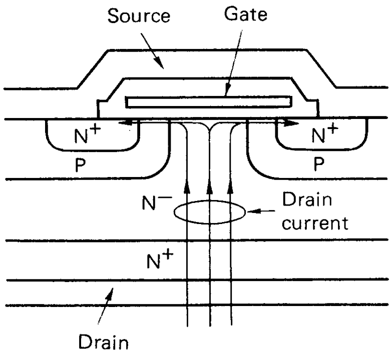

Figure 2.
Power-On Condition

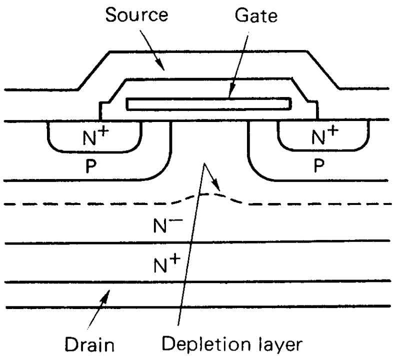

Figure 3.
Power-OFF Condition

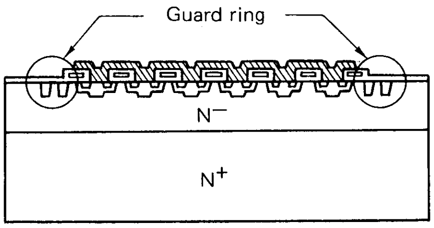

Figure 4.
Power MOSFET Guard Ring Structure

b. Low $R_{DS(on)}$

Not only does a DMOSFET device have inherently low ON resistance because of its vertical structure, but also IC/LSI technology can be applied to form the cells for even lower ON resistance by reducing the cell size.

c. Large sustaining energy

As previously described, when a DMOSFET switches off, multiple cells form planar junctions surrounded by a guard ring. The resistance characteristic between the drain and source therefore causes breakdown with no current concentration, so uniform power is generated through the entire chip to obtain high sustained energy resistance.

The DMOSFET thus offers the best structure among MOSFETs for meeting the needs of switching devices.

This structure has been proven best by its employment by most power MOSFET manufacturers around the world.

4. RATINGS AND CHARACTERISTICS

Power MOSFETs are superior to bipolar transistors in many ways. The data below compare power MOSFETs with bipolar transistors with regard to sustaining voltage, SOA rating, and switching characteristics.

4.1 $V_{DS(sus)}$

DMOSFET resistance to high voltages is determined by the cell perimeter without the need of a special high cell structure. The breakdown characteristic therefore shows avalanche breakdown current flowing mostly in the perimeter at low current and across the entire chip at high current. That is, it exhibits a steep VDS-IDS characteristic as shown in figure 5. The DMOSFET does not allow breakdown current flow for the entire chip to concentrate in a cell area as does an avalanche diode.

In a bipolar transistor, on the other hand, h_{FE} has a positive temperature coefficient. When breakdown current flows, therefore, it is amplified and concentrated on a specific area. This is called secondary breakdown. Figure 6 shows the sustaining voltage and current of a bipolar transistor. Power MOSFETs have an important advantage in that they are not subject to secondary breakdown.

Power MOSFETs have a sustaining energy resistance about 1000 times larger than that of bipolar transistors of the same chip size and with the same high-voltage resistance. (See figure 7.)

Table 1 shows test results for sustained resistances of the 2SK854 and 2SC2335.

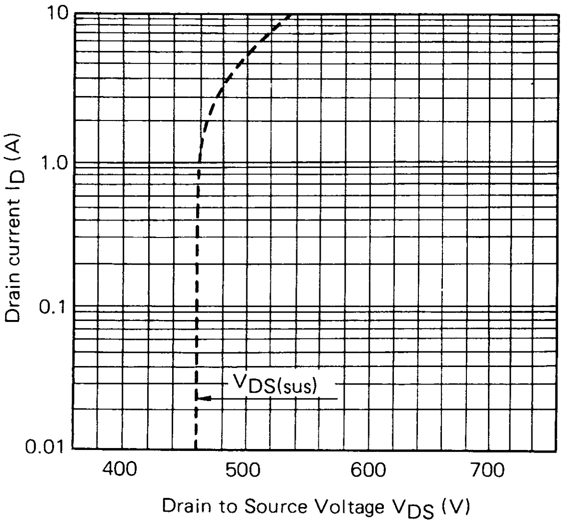

Figure 5. Sustaining Voltage of Power MOSFET (for 2SK854)

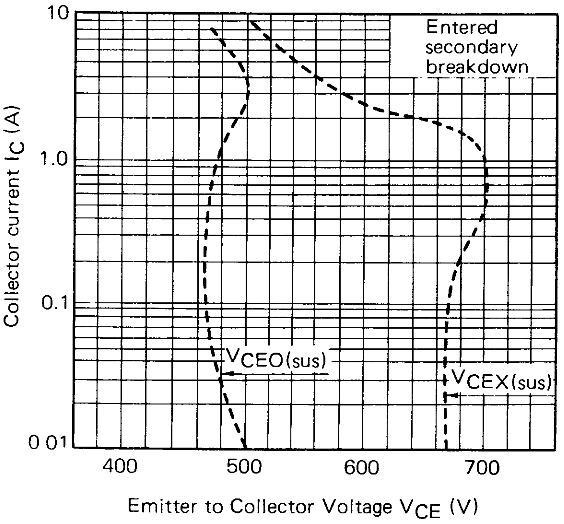

Figure 6. Sustaining Voltage of Bipolar Transistor (for 2SC2335)

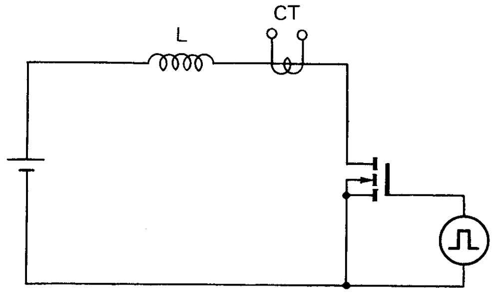

Figure 7. Sustaining Energy Test Circuit

Table 1. Sustaining Energy Comparison

Product name	Sample	Sustain energy (mJ)	L (See fig. 7)
2SK854	No. 1	45	100 µH
2SC2335	No. 1	$V_{CEO(sus)}$ 1.3 $V_{CEX(sus)}$ 0.14	100 µH
	No. 2	$V_{CEO(sus)}$ 3.2 $V_{CEX(sus)}$ 0.2	

4.2 SOA Rating

Bipolar transistors suffer current concentration because of local temperature increases in the chip that cause it to operate abnormally. This phenomenon is exhibited by a hot spot on the chip that causes secondary breakdown, lowering the allowable loss in the high-voltage region.

Power MOSFETs, on the other hand, do not suffer current concentration and abnormal operation; they maintain an SOA rating shown by parallel power lines, because the ON resistance has a positive temperature coefficient. The transmission characteristic shown in figure 8 indicates the negative temperature dependence in the high-current region. Figure 9 shows typical SOA values.

Figure 10 shows an SOA rating example for the 2SK854. As shown in this figure, the power MOSFET has almost no current concentration, so the current rating can be extended within the allowable power loss.

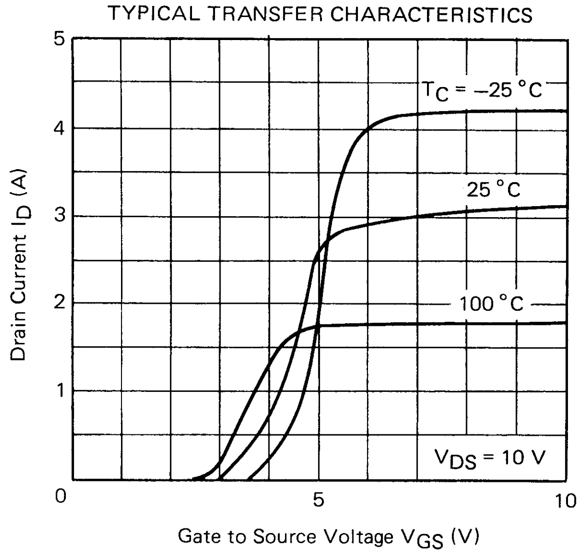

Figure 8. Transmission Characteristic

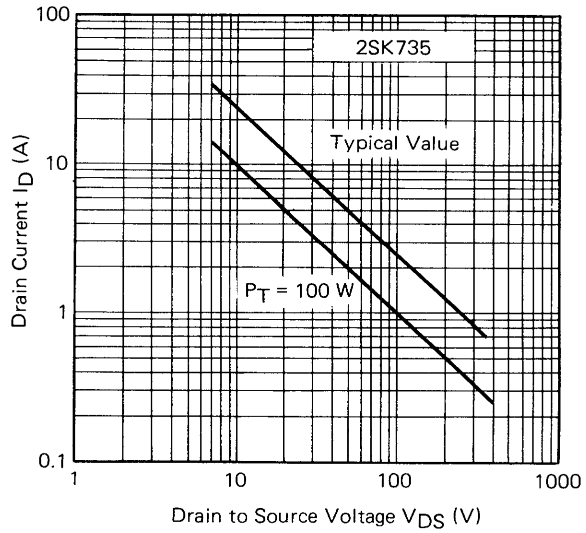

Figure 9. Typical SOA Values

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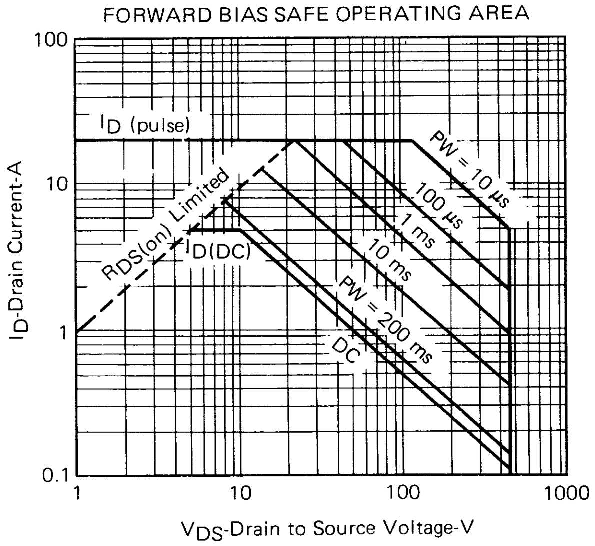


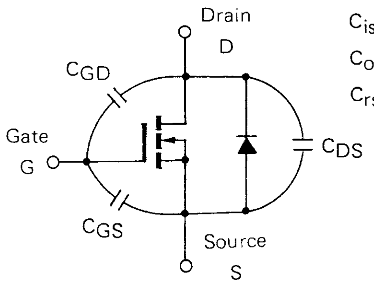
Figure 10. Pulse SOA Rating (for 2SK854)

4.3 Switching Characteristics

Power MOSFET devices have only one polarity for operation. Switching can thus occur at higher speeds than in bipolar transistors, which have two operation polarities. As shown in figure 11, power MOSFETs have input capacitance (C_{iss}), output capacitance (C_{oss}), and reverce transfer capacitance (C_{rss}) dictated by their structure. Switching time can thus be determined by the impedance to drive these capacitances.

Figures 12 and 13 and Table 2 show a switching-time test circuit, switching-time definition example, and the switching characteristics of the 2SK854 and 2SK735, respectively.

Figures 14 and 15 compare the current and temperature dependence of switching times of a bipolar transistor and power MOSFET. The switching time of the power MOSFET does not depend on temperature, thus allowing easy circuit design.



$$C_{iss} = C_{GS} + C_{GD}$$
$$C_{oss} = C_{DS} + C_{GD}$$
$$C_{rss} = C_{GD}$$

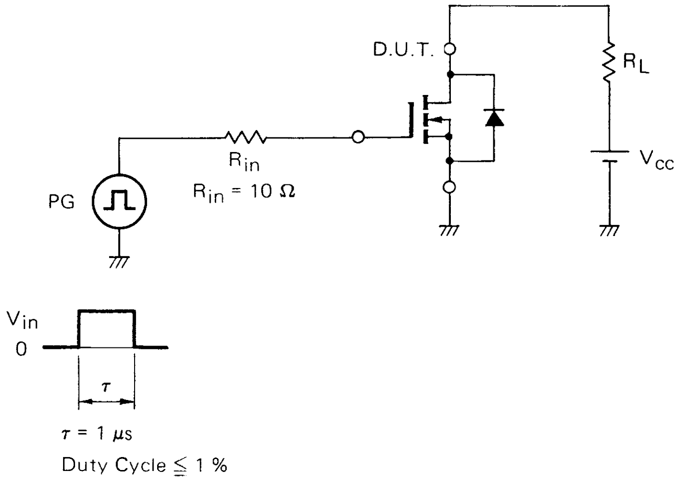


Figure 11.
Parasitic Capacitance of Power MOSFET

Figure 12.
Switching Time Test Circuit

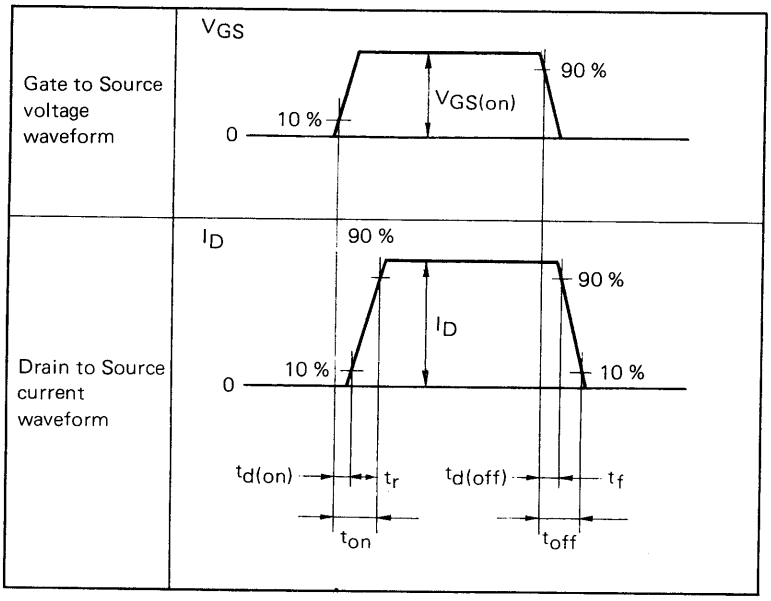


Figure 13. Switching Time Definition Example

Table 2. Switching characteristics of 2SK854 (5 A, 450 V, TO-220) and 2SK735 (10 A, 450 V, MP-88)

Item	Abbr.	Standard Characteristics		Unit	Conditions
		2SK854	2SK735		
Input Capacitance	C_{iss}	700	1270	pF	V_{DS} = 10 V V_{GS} = 0 f = 1 MHz
Output Capacitance	C_{oss}	175	320	pF	
Reverce Transfer Capacitance	C_{rss}	40	70	pF	
Turn-On Delay Time	$t_{d(on)}$	10	15	ns	$V_{CC} \doteqdot 150$ V $V_{GS(on)}$ = 10 V R_{in} = 10 Ω 2SK854: I_D = 2.5 A, R_L = 60 Ω 2SK735: I_D = 5 A, R_L = 30 Ω
Rise Time	t_r	15	20	ns	
Turn-Off Delay Time	$t_{d(off)}$	40	60	ns	
Fall Time	t_f	15	30	ns	

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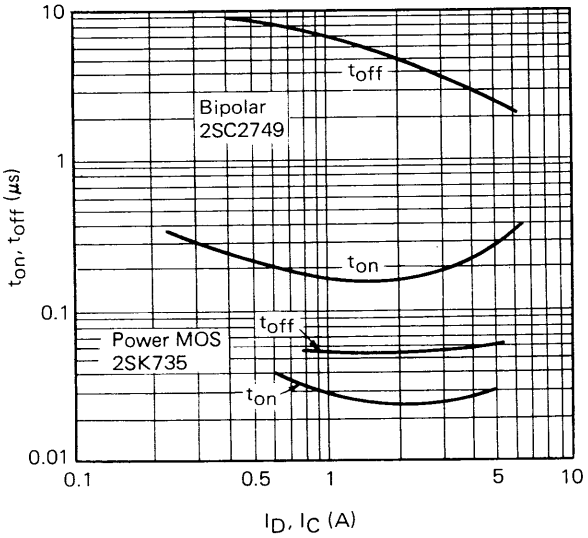


Figure 14.
Switching Speed Comparison

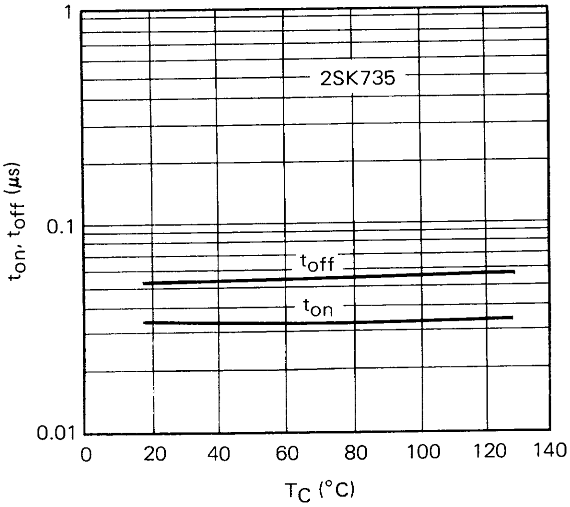
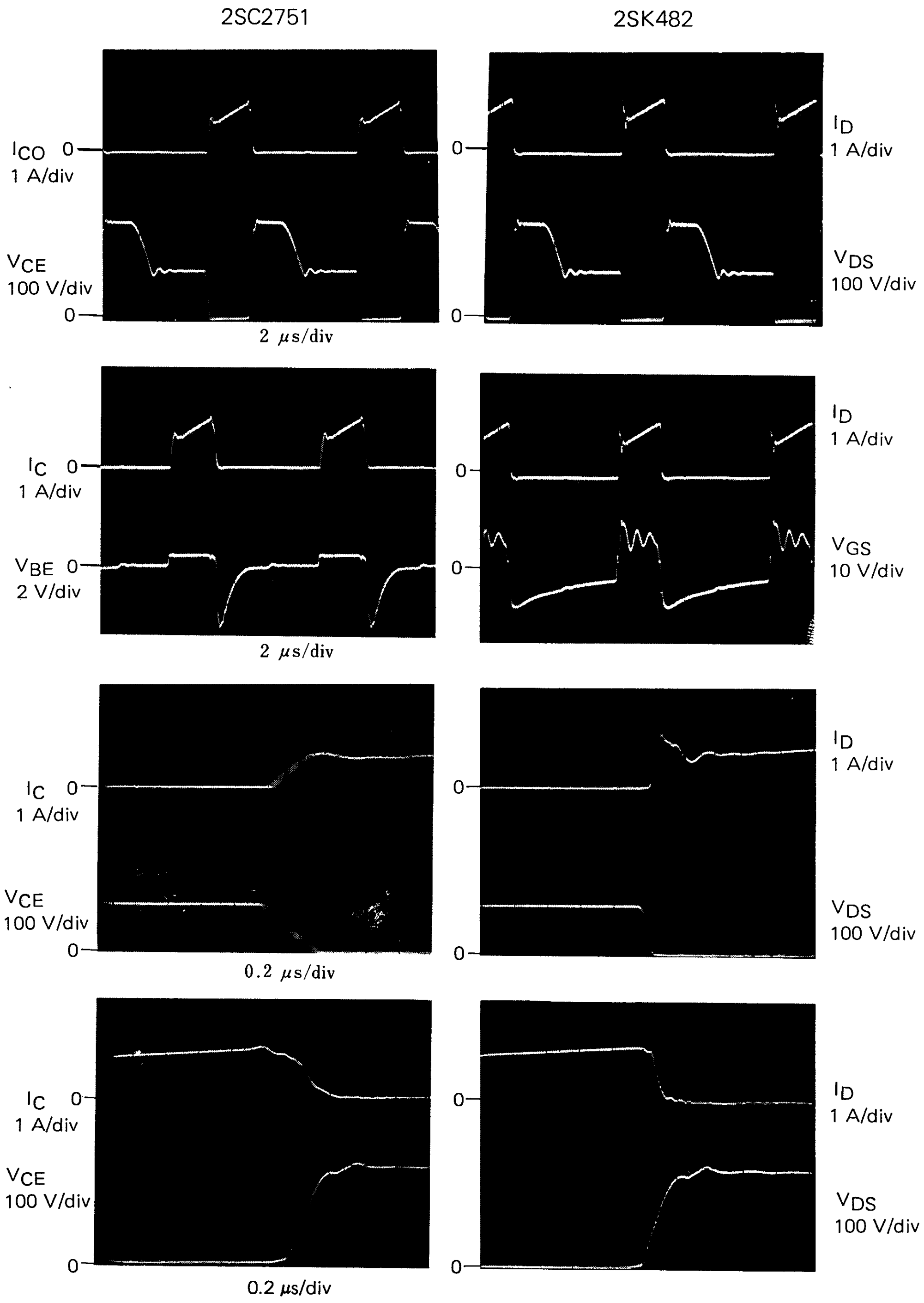


Figure 15.
Temperature Characteristics of Switching Speed



Photograph 1

5. APPLICATION TO SWITCHING POWER SUPPLY

This section introduces the performance of a power supply that conventionally consisted of bipolar transistors and was converted to power MOSFETs without changing the circuit configuration.

Figure 16 shows a line operation switching power supply using the µPC494C control IC with a bipolar transistor to drive the power MOSFETs. This is an 80-kHz circuit originally operated by bipolar transistor 2SC2751. Now, it is controlled by a power MOSFET. Note the following disadvantages:

- Bias voltage is insufficient because the turn ratio of drive transformer T2 is designed to drive bipolar transistors.
- The turnoff speed has increased so the spike voltage may be excessive.

The turn ratio of drive transformer T2 is 1:1. This ratio provides about 10 V as the gate bias voltage of power MOSFET 2SK482.

Photograph 1 compares waveforms for each location in the 2SC2751 and 2SK482; Table 3 shows the measured data and temperature rise comparison. As these show, a switching power supply using even power MOSFETs one rank lower than the prior bipolar transistors demonstrates improved efficiency.

Figure 17 shows a regulator circuit using switching regulator control µPC1094C, designed exclusively for power MOSFETs.

The µPC1094C has the following features:

- Usable at switching frequencies up to 500 kHz.
- Capable of direct drive of the power MOSFET at high speed because of the large-output-capacity (1.2 A peak) totem-pole output circuit.
- Low current consumption (standby current of 1.6 maximum).
- Remote control circuit and various protection circuits incorporated.

Table 4 summarizes specifications of the 2SK720A.

Table 4. 2SK720A Specifications

Item	Symbol	Condition	Standard	Unit
Drain to Source Voltage	V_{DSS}	$V_{GS} = 0$	250	V
Drain Current	$I_{D(DC)}$		±20	A
Drain to Source On-State Resistance	$R_{DS(on)}$	$V_{GS} = 10$ V, $I_D = 10$ A	0.23 max.	Ω
Input Capacitance	C_{iss}	$V_{DS} = 10$ V, $V_{GS} = 0$ f = 1 MHz	1650 typ.	pF
Reverse Transfer Capacitance	C_{oss}		550 typ.	pF

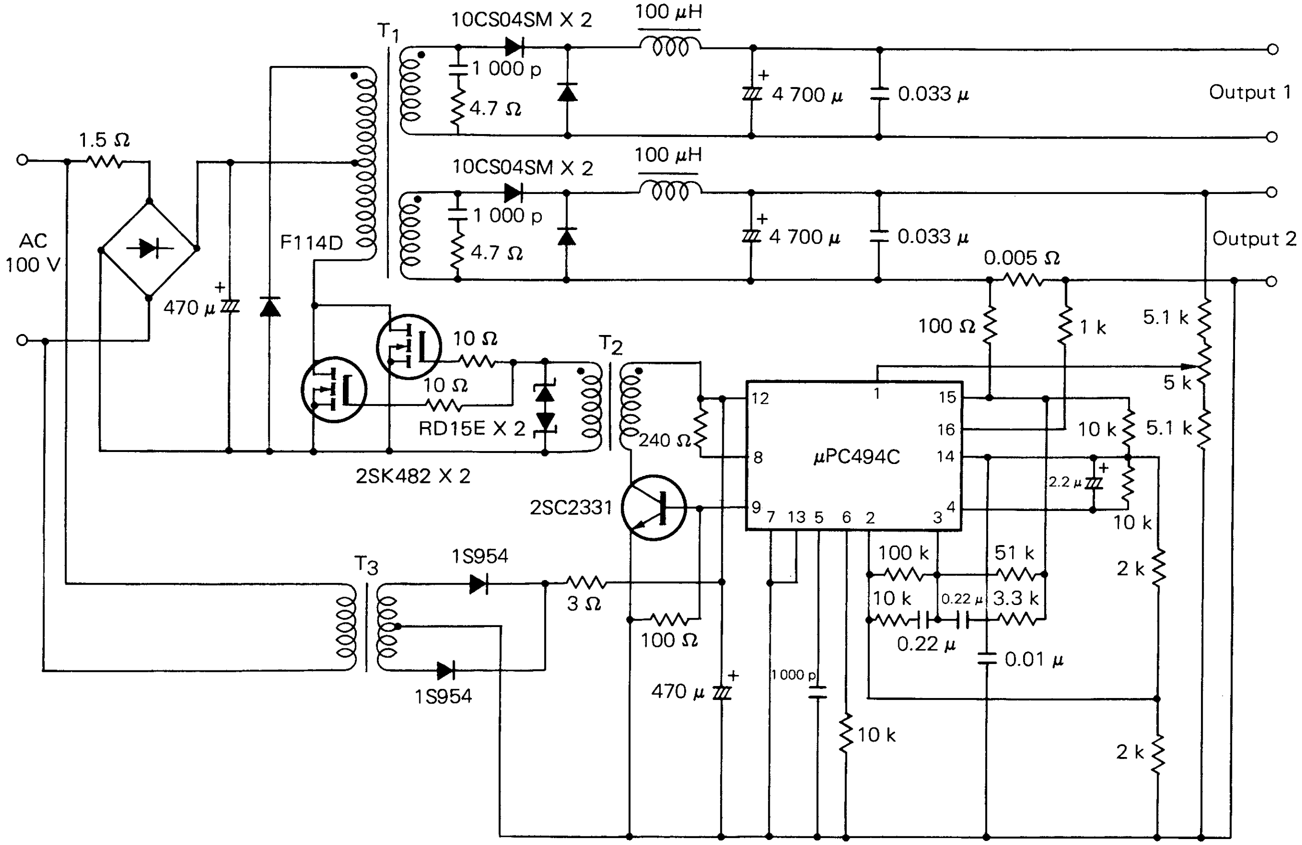


Figure 16. Switching Regulator Controlled by μPC494C

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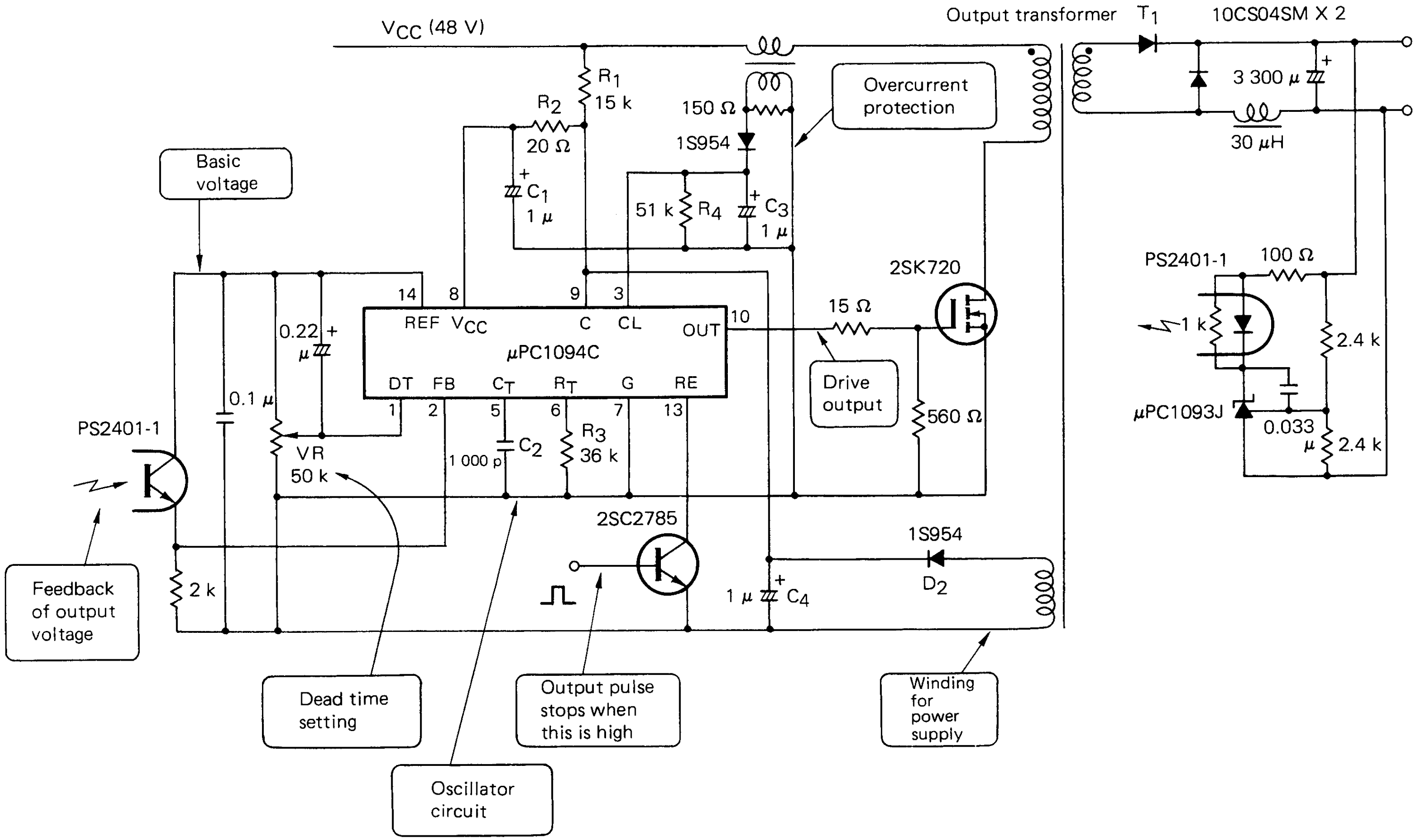

Figure 17. Switching Regulator Using µPC1094C

Table 3. Comparison Between Switching Time and Case Temperature of 80-kHz Switching Regulators

Item \ Product Name		2SC2751	2SK482
Package		MP-80	TO-220
Switching Time	t_r	0.26 μs	0.05 μs
	t_f	0.30 μs	0.08 μs
Case Temperature Rise	ΔT_C	56 °C	21 °C

6. NOTES FOR USE

The higher the voltage resistance becomes, the larger (by the square of the voltage resistance) the ON resistance of power MOSFET. For this reason, the voltage resistance is distributed to minimize the ON resistance. The voltage resistance margin for a power MOSFET is therefore smaller than that of a bipolar transistor, as shown in Figures 5 and 6. The bipolar transistor has a V_{CEX} about 1.5 times larger than the rated value, preventing the voltage from reaching V_{CEX}. This feature may prevent failure of a bipolar transistor. A power MOSFET, on the other hand, may fail because the power loss at breakdown easily exceeds the rated value, even if it has no concentration of breakdown current and has large sustained energy resistance. Please bear this in mind for circuit design.

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