[4] Handling Guide for Semiconductor Devices

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1. Using Toshiba Semiconductors Safely

TOSHIBA is continually working to improve the quality and reliability of its products. Nevertheless, semiconductor devices in general can malfunction or fail due to their inherent electrical sensitivity and vulnerability to physical stress. It is the responsibility of the buyer, when utilizing TOSHIBA products, to comply with the standards of safety in making a safe design for the entire system, and to avoid situations in which a malfunction or failure of such TOSHIBA products could cause loss of human life, bodily injury or damage to property.

In developing your designs, please ensure that TOSHIBA products are used within specified operating ranges as set forth in the most recent TOSHIBA products specifications. Also, please keep in mind the precautions and conditions set forth in the "Handling Guide for Semiconductor Devices," or "TOSHIBA Semiconductor Reliability Handbook" etc..

The TOSHIBA products listed in this document are intended for usage in general electronics applications (computer, personal equipment, office equipment, measuring equipment, industrial robotics, domestic appliances, etc.). These TOSHIBA products are neither intended nor warranted for usage in equipment that requires extraordinarily high quality and/or reliability or a malfunction or failure of which may cause loss of human life or bodily injury ("Unintended Usage"). Unintended Usage include atomic energy control instruments, airplane or spaceship instruments, transportation instruments, traffic signal instruments, combustion control instruments, medical instruments, all types of safety devices, etc.. Unintended Usage of TOSHIBA products listed in this document shall be made at the customer's own risk.

2. Safety Precautions

This section lists important precautions which users of semiconductor devices (and anyone else) should observe in order to avoid injury and damage to property, and to ensure safe and correct use of devices.

Please be sure that you understand the meanings of the labels and the graphic symbol described below before you move on to the detailed descriptions of the precautions.

[Explanation of Labels]

⚠ DANGER	Indicates an imminently hazardous situation which will result in death or serious injury if you do not follow instructions.
⚠ WARNING	Indicates a potentially hazardous situation which could result in death or serious injury if you do not follow instructions.
⚠ CAUTION	Indicates a potentially hazardous situation which if not avoided, may result in minor injury or moderate injury.

[Explanation of Graphic Symbol]

Graphic Symbol	Meaning
	Indicates that caution is required (laser beam is dangerous to eyes).

2.1 General Precautions Regarding Semiconductor Devices

⚠CAUTION

Do not use devices under conditions exceeding their absolute maximum ratings (e.g. current, voltage, power dissipation or temperature).

This may cause the device to break down, degrade its performance, or cause it to catch fire or explode resulting in injury.

Do not insert devices in the wrong orientation.

Make sure that the positive and negative terminals of power supplies are connected correctly. Otherwise the rated maximum current or power dissipation may be exceeded and the device may break down or undergo performance degradation, causing it to catch fire or explode and resulting in injury.

When power to a device is on, do not touch the device's heat sink.

Heat sinks become hot, so you may burn your hand.

Do not touch the tips of device leads.

Because some types of device have leads with pointed tips, you may prick your finger.

When conducting any kind of evaluation, inspection or testing, be sure to connect the testing equipment's electrodes or probes to the pins of the device under test before powering it on.

Otherwise, you may receive an electric shock causing injury.

Before grounding an item of measuring equipment or a soldering iron, check that there is no electrical leakage from it.

Electrical leakage may cause the device which you are testing or soldering to break down, or could give you an electric shock.

Always wear protective glasses when cutting the leads of a device with clippers or a similar tool.

If you do not, small bits of metal flying off the cut ends may damage your eyes.

2.2 Power Devices

2.2.1 Power Devices

⚠ DANGER
Never touch a power device while it is powered on. Also, after turning off a power device, do not touch it until it has thoroughly discharged all remaining electrical charge. Touching a power device while it is powered on or still charged could cause a severe electric shock, resulting in death or serious injury. When conducting any kind of evaluation, inspection or testing, be sure to connect the testing equipment's electrodes or probes to the device under test before powering it on. When you have finished, discharge any electrical charge remaining in the device. Connecting the electrodes or probes of testing equipment to a device while it is powered on may result in electric shock, causing injury.

⚠WARNING

Do not use devices under conditions which exceed their absolute maximum ratings (current, voltage, power dissipation, temperature etc.).

This may cause the device to break down, causing a large short-circuit current to flow, which may in turn cause it to catch fire or explode, resulting in fire or injury.

Use a unit which can detect short-circuit current and ground fault current which will shut off the power supply if a short-circuit or a ground fault occurs.

If the power supply is not shut off, a large short-circuit current or a ground fault current will flow continuously, which may in turn cause the device to catch fire or explode, resulting in fire or injury.

When designing a case for enclosing your system, consider how best to protect the user from shrapnel in the event of the device catching fire or exploding.

Flying shrapnel can cause injury.

When conducting any kind of evaluation, inspection or testing, always use protective safety tools such as a cover for the device. Otherwise you may sustain injury caused by the device catching fire or exploding.

Make sure that all metal casings in your design are grounded to earth.

Even in modules where a device's electrodes and metal casing are insulated, capacitance in the module may cause the electrostatic potential in the casing to rise.

Dielectric breakdown may cause a high voltage to be applied to the casing, causing electric shock and injury to anyone touching it.

When designing the heat radiation and safety features of a system incorporating high-speed rectifiers, remember to take the device's forward and reverse losses into account.

The leakage current in these devices is greater than that in ordinary rectifiers; as a result, if a high-speed rectifier is used in an extreme environment (e.g. at high temperature or high voltage), its reverse loss may increase, causing thermal runaway to occur. This may in turn cause the device to explode and scatter shrapnel, resulting in injury to the user.

A design should ensure that, except when the main circuit of the device is active, reverse bias is applied to the device gate while electricity is conducted to control circuits, so that the main circuit will become inactive.

Malfunction of the device may cause serious accidents or injuries.

⚠CAUTION

When conducting any kind of evaluation, inspection or testing, either wear protective gloves or wait until the device has cooled properly before handling it.

Devices become hot when they are operated. Even after the power has been turned off, the device will retain residual heat which may cause a burn to anyone touching it.

3. General Safety Precautions and Usage Considerations

This section is designed to help you gain a better understanding of semiconductor devices, so as to ensure the safety, quality and reliability of the devices which you incorporate into your designs.

3.1 From Incoming to Shipping

3.1.1 Static Electricity

The maximum ratings designated for semiconductor products denote those values which should not be exceeded even for an instant, as described in the previous section.

However, it is probable that static electricity or surge voltages that exceed such values may be applied to transistors directly or indirectly while handling or operating them.

Especially, static electricity sometimes reaches several kV or tens of kV. Should this high voltage be discharged through the electrodes of transistors, high-frequency transistors or MOSFET transistors which are less resistive in structure to such high voltage, they may be deteriorated or break down. Since protective devices mounted on the transistors themselves are restricted to the purpose of assuring electrical characteristics, pay special attention to handling procedures and to setting up separate protective circuits.

Wires such as I/O signal wires and control wires connected to a printed circuit are often connected to other types of electronic components, and they are often very long. Should noise or surge voltage caused by induction be added to these I/O signal wires and control wires, devices may sometimes deteriorate or break down. Take advance protective measures such as inserting protective circuits.

3.1.1.1 Electrostatic Breakdown in Power MOSFET

If the oxide-film breakdown voltage exceeds the maximum specified for a MOS device, even for a moment, the result may be failure without possibility of recovery to normal condition. When static electricity is applied to a MOS device the electric charge stored in condenser “C” is applied directly to the dielectric film between gate and source, as shown in Figure 3.1. Therefore, effective voltage is greatly influenced by gate/source capacity; the larger the capacity, the lower the effective voltage.

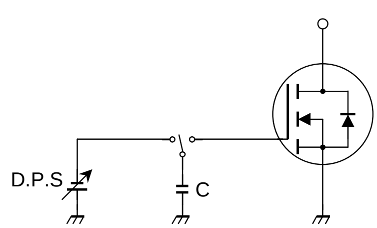


Figure 3.1 Electrostatic Test Circuit

3.1.1.2 Work Environment

One way to improve the electrostatic-breakdown resistance of a power MOSFET is to integrate a Zener diode between gate and source. This method lowers the input impedance and greatly affects the operating characteristics of a device.

The trend in power MOSFETs is toward remarkable compactness through structuring with ultra-fine manufacturing technology. When using these devices, it is therefore important to take the following measures as precautions against static electricity.

(1) When humidity in the working environment decreases, the human body and other insulators can easily become charged with static electricity due to friction. Maintain the recommended humidity of 40% to 60% in the work environment, while also taking into account the fact that moisture-proof-packed products may absorb moisture after unpacking.

If the relative humidity of a device's surroundings becomes less than 50%, the electric charge of the human body increases greatly. The workplace should therefore be maintained at a relative humidity above 50%.

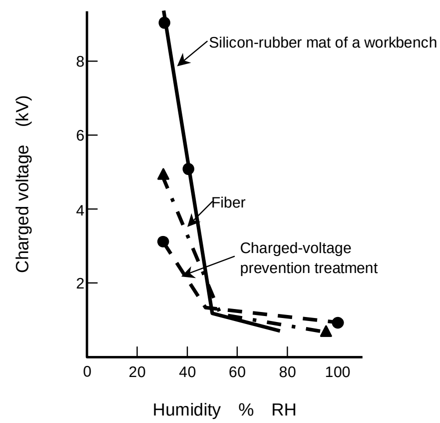


Figure 3.2 Relationship between the Human Body's Charged Voltage and Relative Humidity, under Different Working Conditions

(2) Be sure that all equipment, jigs and tools in the working area are grounded to earth.

(3) Place a conductive mat over the floor of the work area, or take other appropriate measures, so that the floor surface is protected against static electricity and is grounded to earth. The surface resistivity should be 10^4 to 10^8 Ω/sq and the resistance between surface and ground, 7.5×10^5 to 10^8 Ω.

(4) Cover the workbench surface also with a conductive mat (with a surface resistivity of 10^4 to 10^8 Ω/sq, for a resistance between surface and ground of 7.5×10^5 to 10^8 Ω).

The purpose of this is to disperse static electricity on the surface (through resistive components) and ground it to earth. Workbench surfaces must not be constructed of low-resistance metallic materials that allow rapid static discharge when a charged device touches them directly.

(5) Pay attention to the following points when using automatic equipment in your workplace:
   (a) When picking up devices with a vacuum unit, use a conductive rubber fitting at the end of the pick-up wand to protect against electrostatic charge.
   (b) Minimize friction on package surfaces. If some rubbing is unavoidable due to the device's mechanical structure, minimize the friction plane or use material with a small friction coefficient and low electrical resistance. Also consider the use of an ionizer.
   (c) In sections that come into contact with device lead terminals, use a material that dissipates static electricity.
   (d) Ensure that no statically charged bodies (such as work clothes or the human body) touch the devices.
   (e) Make sure that sections of the tape carrier which come into contact with installation devices or other electrical machinery are made of a low-resistance material.
   (f) Make sure that jigs and tools used in the assembly process do not touch devices.
   (g) In processes in which packages may retain an electrostatic charge, use an ionizer to neutralize the ions.

(6) Make sure that CRT displays in the working area are protected against static charge, for example by a VDT filter. As much as possible, avoid turning displays on and off. Doing so can cause electrostatic induction in devices.

(7) Keep track of charged potential in the working area by taking periodic measurements.

(8) Ensure that work chairs are protected by an anti-static textile cover and are grounded to the floor surface by a grounding chain. (suggested resistance between the seat surface and grounding chain is 7.5×10^5 to 10^{12} Ω/sq.)

(9) Install anti-static mats on storage shelf surfaces. (suggested surface resistivity is 10^4 to 10^8 Ω/sq; suggested resistance between surface and ground is 7.5×10^5 to 10^8 Ω/sq.)

(10) The device should be packaged in a conductive receptacle.

(11) During packing and transporting try to maintain the same electric potential.

(12) For transport and temporary storage of devices, use containers (boxes, jigs, bags) that are made of anti-static materials or of materials that dissipate electrostatic charge.

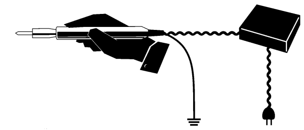
(13) Make sure that cart surfaces which come into contact with device packaging are made of materials that will conduct static electricity, and verify that they are grounded to the floor surface with a grounding chain. (the suggested resistance between the cart surface and grounding chain is 7.5×10^5 to 10^{10} Ω/sq.)

(14) In any location where the level of static electricity is to be closely controlled, the ground resistance level should be Class 3 or above. Use different ground wires for all items of equipment which may come into physical contact with devices.

3.1.1.3 Operating Environment

(1) Operators must wear anti-static clothing and conductive shoes (or a leg or heel strap).

(2) Operators must wear a wrist strap grounded to earth via a resistor of about 1 MΩ.



(3) Soldering irons must be grounded from iron tip to earth, and must be used only at low voltages (6 V to 24 V).

(4) If the tweezers you use are likely to touch the device terminals, use anti-static tweezers and in particular avoid metallic tweezers. If a charged device touches a low-resistance tool, rapid discharge can occur. When using vacuum tweezers, attach a conductive chucking pat to the tip, and connect it to a dedicated ground used especially for anti-static purposes (suggested resistance value: 10^4 to 10^8 Ω).

(5) Do not place devices or their containers near sources of strong electrical fields (such as above a CRT).

(6) When storing printed circuit boards which have devices mounted on them, use a board container or bag that is protected against static charge. To avoid the occurrence of static charge or discharge due to friction, keep the boards separate from one other and do not stack them directly on top of one another.

(7) Ensure, if possible, that any articles (such as clipboards) which are brought to any location where the level of static electricity must be closely controlled are constructed of anti-static materials.

(8) In cases where the human body comes into direct contact with a device, be sure to wear anti-static finger covers or gloves (suggested resistance value: 10^8 Ω or less).

(9) Equipment safety covers installed near devices should have resistance ratings of 10^9 Ω or less.

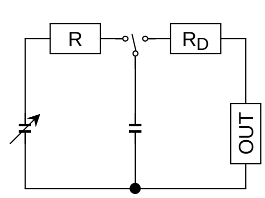
(10) If a wrist strap cannot be used for some reason, and there is a possibility of imparting friction to devices, use an ionizer.

3.1.1.4 Electrostatic Discharge Test

To determine suitable handing and control methods for a semiconductor device, it is very important to know its electrostatic breakdown level.

Table 3.1 shows an evaluation test for a device's electrostatic breakdown resistance, simulating the static electricity that can actually be observed in the device.

Table 3.1 Discharge Voltage Test of a Condenser

Test Object	Test Circuit	Test Conditions	Governing Standards
Condenser discharge voltage		C_D = 200 pF R_D: None Number of applied pulses: 1	JEITA IC-121-1981, C

3.1.1.5 Electrostatic Breakdown Resistance of Power MOSFETs

Examples of electrostatic breakdown test results obtained by the method outlined above are shown in Figure 3.3 for products with 10-V drive, 4-V drive (with protective Zener diode) and 4-V drive (without protective Zener diode).

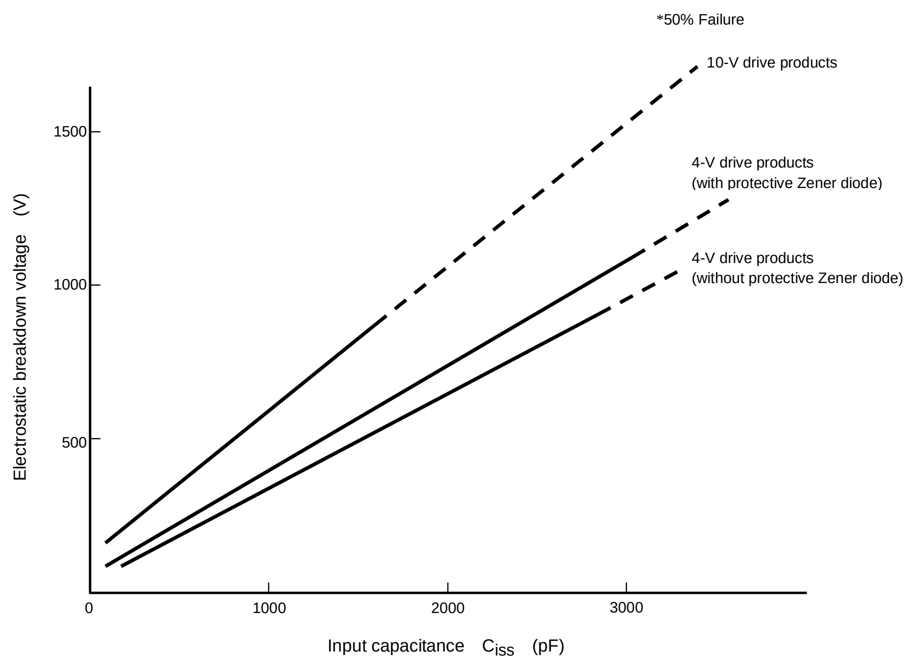


Figure 3.3 Electrostatic Breakdown Resistance Level of Power MOSFETs

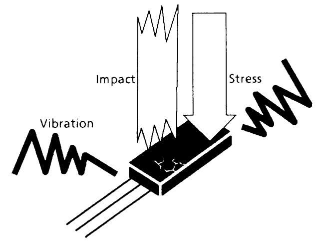
In terms of their electrical characteristics, devices with low current and voltage ratings tend to have low electrostatic breakdown resistance, as shown in the figure above. Such devices must be handled with great care.

The electrostatic breakdown resistance of a power MOSFET depends largely on its structure.

When using these devices, their actual resistance to electrostatic breakdown must be well understood, and appropriate measures and controls for handling them must be adopted.

3.1.2 Vibration, Impact and Stress

Handle devices and packaging materials with care. To avoid damage to devices, do not toss or drop packages. Ensure that devices are not subjected to mechanical vibration or shock during transportation. When any device or package type is installed in target equipment, it is to some extent susceptible to wiring disconnections and other damage from vibration, shock and stressed solder junctions.



Therefore when incorporating devices into the design of vibration-prone equipment, the structural design of the equipment must be thought out carefully.

If a device is subjected to especially strong vibration, mechanical shock or stress, the package or the chip itself may crack.

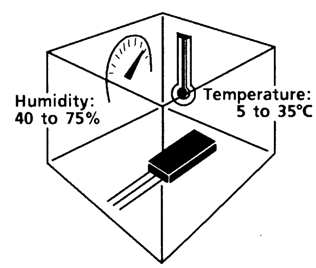
Furthermore, it is generally known that stress applied to a semiconductor device through the package changes the resistance characteristics of the chip because of piezoelectric effects.

Thus attention must be paid to the problem of package stress as well as to the dangers of vibration and shock as described above.

3.2 Storage

(1) Avoid storage locations where devices will be exposed to moisture or direct sunlight. (be especially careful during periods of rain or snow.)

(2) Do not place device cartons upside down. Stack cartons on top of one another in an upright position only; do not place cartons on their sides.



(3) The storage area temperature should be kept within a temperature range of 5°C to 35°C, and relative humidity should be maintained at between 45% and 75%.

(4) Do not store devices in the presence of harmful (especially corrosive) gases, or in dusty conditions.

(5) Use storage areas where there is minimal temperature fluctuation. Rapid temperature changes can cause moisture to form on stored devices, resulting in lead oxidation or corrosion. As a result, the solderability of the leads will be degraded.

(6) When repacking devices, use anti-static containers.

(7) Do not allow external forces or loads to be applied to devices while they are in storage.

(8) If devices have been stored for more than two years, their electrical characteristics should be tested and their leads should be tested for ease of soldering before they are used.

3.3 Design

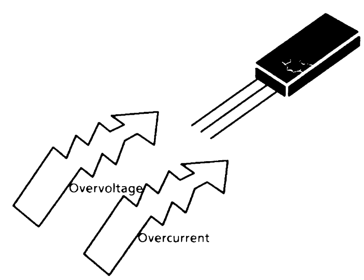
Care must be exercised in the design of electronic equipment to achieve the desired reliability. It is important not only to adhere to specifications concerning absolute maximum ratings and recommended operating conditions, it is also important to consider the overall environment in which equipment will be used, including factors such as the ambient temperature, transient noise, voltage and current surges, as well as mounting conditions that affect device reliability. This section describes some general precautions that you should observe when designing circuits and when mounting devices on printed circuit boards.

For more detailed information about each product family, refer to the individual technical datasheets, available from Toshiba.

3.3.1 Absolute Maximum Ratings

⚠CAUTION

Do not use devices under conditions in which their absolute maximum ratings (e.g. current, voltage or power dissipation) will be exceeded. A device may break down or its performance may be degraded, causing it to catch fire or explode resulting in injury to the user.



The absolute maximum ratings are rated values which must not be exceeded during operation, even for an instant. Although absolute maximum ratings differ from product to product, they essentially concern the voltage and current at each pin, the allowable power dissipation, and the junction and storage temperatures.

If the voltage or current on any pin exceeds the absolute maximum rating, the device's internal circuitry can become degraded. In the worst case, heat generated in internal circuitry can fuse wiring or cause the semiconductor chip to break down.

If storage or operating temperatures exceed rated values, the package seal can deteriorate or the wires can become disconnected due to the differences between the thermal expansion coefficients of the materials from which the device is constructed.

3.3.2 Recommended Operating Conditions

The recommended operating conditions for each device are those necessary to guarantee that the device will operate as specified in the datasheet.

If greater reliability is required, derate the device's absolute maximum ratings for voltage, current, power and temperature before using it.

3.3.3 Derating

When incorporating a device into your design, reduce its rated maximum voltage, current, power dissipation and operating temperature in order to ensure high reliability.

Since derating differs from application to application, refer to the technical datasheets available for the various devices used in your design.

3.3.4 Unused Pins

Because the input impedance of power MOSFETs is very high, when the gate is open, bias is applied between the gate and source by static electricity induction. The device is turned on and may be damaged. Do not use with gate open.

3.3.5 Thermal Design

The failure rate of semiconductor devices is greatly increased as operating temperatures increase. As shown in Section [3] 5. Heat Sink Design, the internal thermal stress on a device is the sum of the ambient temperature and the temperature rise due to power dissipation in the device.

Therefore, to achieve optimum reliability, observe the following precautions concerning thermal design:

(1) Avoid heat generation from the surrounding environment and keep the ambient temperature (Ta) as low as possible.

(2) If the device's dynamic power dissipation is relatively large, select the most appropriate circuit board material, and consider the use of heat sinks or of forced air cooling. Such measures will help lower the thermal resistance of the package.

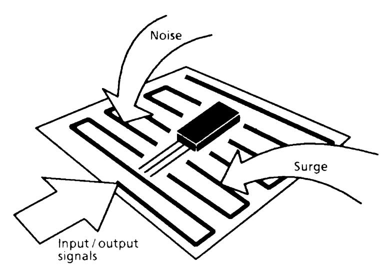
(3) Derate the device's absolute maximum ratings to minimize thermal stress from power dissipation.

3.3.6 Effect of Wiring Inductance

When power MOSFETs are used for high-speed switching, surge voltages caused by stray inductance are applied between drain and source. Thus, the voltage between drain and source (V_{DSS}) must be sufficiently larger than the surge voltage.

3.3.7 External Noise

Printed circuit boards with long I/O or signal pattern lines are vulnerable to induced noise or surges from outside sources. Consequently, malfunctions or breakdowns can result from overcurrent or overvoltage, depending on the types of device used. To protect against noise, lower the impedance of the pattern line or insert a noise-canceling circuit. Protective measures must also be taken against surges.



For details of the appropriate protective measures for a particular device, consult the relevant databook.

3.3.8 Electromagnetic Interference

Widespread use of electrical and electronic equipment in recent years has brought with it radio and TV reception problems due to electromagnetic interference. To use the radio spectrum effectively and to maintain radio communications quality, each country has formulated regulations limiting the amount of electromagnetic interference which can be generated by individual products.

Electromagnetic interference includes conduction noise propagated through power supply and telephone lines, and noise from direct electromagnetic waves radiated by equipment.

Different measurement methods and corrective measures are used to assess and counteract each specific type of noise.

Difficulties in controlling electromagnetic interference derive from the fact that there is no method available which allows designers to calculate, at the design stage, the strength of the electromagnetic waves which will emanate from each component in a piece of equipment.

For this reason, it is only after the prototype equipment has been completed that the designer can take measurements using a dedicated instrument to determine the strength of electromagnetic interference waves.

Yet it is possible during system design to incorporate some measures for the prevention of electromagnetic interference, which can facilitate taking corrective measures once the design has been completed. These include installing shields and noise filters, and increasing the thickness of the power supply wiring patterns on the printed circuit board.

One effective method, for example, is to devise several shielding options during design, and then select the most suitable shielding method based on the results of measurements taken after the prototype has been completed.

3.3.9 Peripheral Circuits

In most cases semiconductor devices are used with peripheral circuits and components. The input/output signal voltages and currents of these circuits must be chosen to match the semiconductor device's specifications.

3.3.10 Safety Standards

Each country has safety standards which must be observed. It is often required that an appropriate insulation distance be maintained between the device proper and the conductor pattern on the printed circuit board.

Such requirements must be fully taken into account to ensure that your design conforms to the applicable safety standards.

3.3.11 Other Precautions

(1) When designing a system, be sure to incorporate fail-safe and other appropriate measures according to the intended purpose of your system. Also, be sure to debug your system under actual board-mounted conditions.

(2) If a plastic-package device is placed in a strong electric field, surface leakage may occur due to the charge-up phenomenon, resulting in device malfunction. In such cases, take appropriate measures to prevent this problem, for example by protecting the package surface with a conductive shield.

(3) Ensure that no conductive material or object (such as a metal pin) can drop onto and short the leads of a device mounted on a printed circuit board.

3.4 Inspection, Testing and Evaluation

3.4.1 Grounding

⚠CAUTION

Ground all measuring instruments, jigs, tools and soldering irons to earth.
Electrical leakage may cause a device to break down or may result in electric shock.

3.4.2 Inspection Sequence

⚠CAUTION

1) Do not insert devices in the wrong orientation. Make sure that the positive and negative electrodes of the power supply are correctly connected. Otherwise, the rated maximum current or maximum power dissipation may be exceeded and the device may break down or undergo performance degradation, causing it to catch fire or explode, resulting in injury to the user.

2) When conducting any kind of evaluation, inspection or testing using AC power with a peak voltage of approximately 45 V or DC power exceeding 60 V, be sure to connect the electrodes or probes of the testing equipment to the device under test before powering it on. Connecting the electrodes or probes of testing equipment to a device while it is powered on may result in electric shock, causing injury.

(1) Before beginning device inspection, make a final check to ensure that all associated equipment is properly grounded to earth and that there is no electrical leakage as described above. Apply voltage to the test jig only after inserting the device securely into it. (do not power the test jig up or down abruptly; always apply or remove power gradually or in steps.)

(2) Make sure that the voltage applied to the device is off before removing the device from the test jig. Otherwise, the device may undergo performance degradation or be destroyed.

(3) Make sure that no surge voltages from the measuring equipment are applied to the device.

(4) During device inspection take care not to crack the chip or cause any flaws in it.
Electrical contact may also cause a chip to become faulty. Therefore make sure that nothing comes into electrical contact with the chip.

3.5 Mounting

There are essentially two main types of semiconductor device package: lead insertion and surface mount. During mounting on printed circuit boards, devices can become contaminated by flux or damaged by thermal stress from the soldering process. Particularly with surface mount devices, the most significant problem is thermal stress from solder reflow, when the entire package is subjected to heat. This section describes a recommended temperature profile for each mounting method, as well as general precautions which you should take when mounting devices on printed circuit boards.

Note, however, that even for devices with the same package type, the appropriate mounting method varies according to the size of the chip and the size and shape of the lead frame. Therefore, please consult the appropriate technical datasheet or [3] Power MOSFET in Detail.

3.5.1 Lead Forming

⚠CAUTION

1) Always wear protective glasses when cutting the leads of a device with clippers or a similar tool. If you do not, small bits of metal flying off the cut ends may damage your eyes.
2) Because some types of device have leads with pointed tips, you may prick your finger.

Semiconductor devices must undergo a process in which the leads are cut and formed before the devices can be mounted on a printed circuit board. If undue stress is applied to the interior of a device during this process, mechanical breakdown or performance degradation can result. This is attributable primarily to differences between the stress on the device's external leads and the stress on the internal leads. If the relative difference is great enough, the device's internal leads, adhesive properties or sealant can be damaged. Observe these precautions during the lead forming process (this does not apply to surface mount devices):

(a) Make the spacing of lead wire insertion holes on the printed circuit board the same as those of the lead wires on the device.

(b) Even if the spaces are not the same, do not pull the lead wires or push heavily against the device. For TO-220AB-type transistors, do not apply stress in the direction of the lead wire's thicker side.

(c) Do not bring the device into contact with the printed circuit board. Create a space between them by lead forming. At soldering, do not use a spacer to separate the device from the printed circuit board. After the solder hardens, heat may cause the spacer to expand, applying considerable stress to the device.

(d) When forming a lead prior to mounting onto a board:
- Bend the lead at a point 3 mm or more away from the body (lead root).
- Bend one lead wire after securing the other lead wire (near the main body).
- Keep a space between the device main body and a fixing jig.
- When bending the lead along the jig, be careful not to damage it with an edge of the jig.
- Follow other precautions described in respective standards.

(e) Do not bend or stretch the wires repeatedly.
When pulling in the axial direction, apply 5 to 10 N power, depending on the shapes of lead wires.

3.5.2 Socket Mounting

(1) When socket mounting devices on a printed circuit board, use sockets which match the inserted device's package.

(2) Use sockets whose contacts have the appropriate contact pressure. If the contact pressure is insufficient, the socket may not make a perfect contact when the device is repeatedly inserted and removed; if the pressure is excessively high, the device leads may be bent or damaged when they are inserted into or removed from the socket.

(3) When soldering sockets to the printed circuit board, use sockets whose construction prevents flux from penetrating into the contacts or which allows flux to be completely cleaned off.

(4) Make sure the coating agent applied to the printed circuit board for moisture-proofing purposes does not stick to the socket contacts.

(5) If the device leads are severely bent by a socket as it is inserted or removed and you wish to repair the leads so as to continue using the device, make sure that this lead correction is only performed once. Do not use devices whose leads have been corrected more than once.

(6) If the printed circuit board with the devices mounted on it will be subjected to vibration from external sources, use sockets which have a strong contact pressure so as to prevent the sockets and devices from vibrating relative to one another.

3.5.3 Soldering

When soldering a device to a printed circuit board, the soldering temperature is often so high that if long continued, it can adversely affect the device. Normally, tests are conducted at a soldering temperature of 260°C for 10 seconds or 350°C for 3 seconds. Be sure to complete soldering procedures within these conditions of temperature and time.

Be careful to select a type of flux that will neither corrode the lead wires nor affect the electrical characteristics of a device.

The basic precautions for soldering procedures are as follows:

- Complete soldering procedures in as short a time as possible.
- Do not apply stress to a device after soldering by correcting or modifying its location or direction.
- For a device employing a heat sink, mount it on the heat sink first; then solder this unit to a printed circuit board, confirming that it is fully secured.
- Do not directly solder the heat-radiating portion of a device to a printed circuit board.

3.5.3.1 Using a Soldering Iron

Complete soldering within ten seconds for lead temperatures of up to 260°C, or within three seconds for lead temperatures up to 350°C.

When using soldering irons, select those which have less leakage, and be sure to ground the soldering iron while in use.

3.5.3.2 Using Medium Infrared Ray Reflow

(1) Heating top and bottom with long or medium infrared rays is recommended (see Figure 3.4).

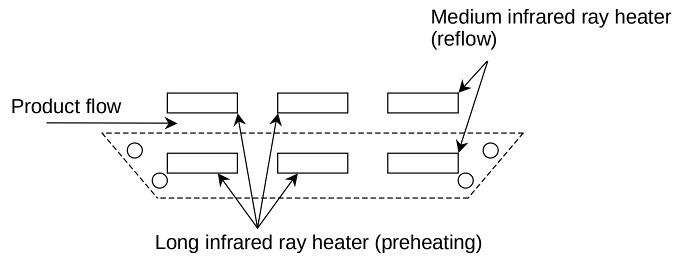


Figure 3.4 Heating Top and Bottom with Long or Medium Infrared Rays

(2) Complete the infrared ray reflow process within 30 seconds at a package surface temperature of between 210°C and 240°C.

(3) Refer to Figure 3.5 for an example of a good temperature profile for infrared or hot air reflow.

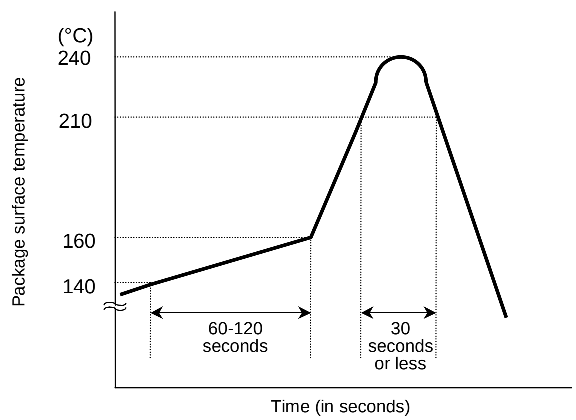


Figure 3.5 Sample Temperature Profile for Infrared or Hot Air Reflow

3.5.3.3 Using Hot Air Reflow

(1) Complete hot air reflow within 30 seconds at a package surface temperature of between 210°C and 240°C

(2) For an example of a recommended temperature profile, refer to Figure 3.5 above.

(3) In flow solder jobs, transistors are apt to float on the solder due to solder surface tension. When adjusting the locations of devices, be careful not to apply excessive stress to the roots of their lead wires.

3.5.3.4 Using Solder Flow

(1) Apply preheating for 60 to 120 seconds at a temperature of 150°C.

(2) For insertion-type packages, complete solder flow within 10 seconds with the temperature at the stopper, or at a location more than 1.5 mm from the body if there is no stopper, which does not exceed 260°C.

(3) Not recommended using solder flow for surface-mount packages.

(4) In flow solder jobs, transistors are apt to float on the solder due to solder surface tension. When adjusting the locations of devices, be careful not to apply excessive stress to the roots of their lead wires.

Table 3.2 Recommended Methods for Mounting for Each Discrete Semiconductor Packages

Classification	Package Name	Mounting Method: Solder Flow	Mounting Method: Far Infrared Reflow	Mounting Method: VPS&HOT Air Reflow	Mounting Method: Soldering Iron
Power devices	Pw-Mini	C	A	A	B
	SOP8	C	A	A	B
	TSSOP8	C	A	A	B
	SP	C	A	A	B
	DP	C	A	A	B
	Pw-Mold	C	A	A	B
	TO-220SM	C	A	A	B
	TFP	C	A	A	B
	VS6	C	A	A	B

A: Suitable B: Suitable only once C: Not suitable; other methods are recommended.

Note 1: For each mounting method, the table above shows whether or not it is suitable under Toshiba's recommended mounting conditions.

Note 2: When mounting is to be performed a number of times only those methods marked A can be used. In this case, mounting can be performed up to three times, with the interval between the first and third mountings being less than 24 hours.

For the latest information, contact a Toshiba sales office.

3.5.4 Flux Cleaning and Ultrasonic Cleaning

(1) When cleaning circuit boards to remove flux, make sure that no residual reactive ions such as Na or Cl remain. Note that organic solvents react with water to generate hydrogen chloride and other corrosive gases that can degrade device performance.

(2) Washing devices with water will not cause any problems. However, make sure that no reactive ions such as sodium and chlorine are left as residues. Also, be sure to dry devices sufficiently after washing.

(3) Do not rub device markings with a brush or with your hand during cleaning or while the devices are still wet from the cleaning agent. Doing so can rub off the markings.

(4) The dip cleaning, shower cleaning and steam cleaning processes all involve the chemical action of a solvent. Use only recommended solvents for these cleaning methods. When immersing devices in a solvent or steam bath, make sure that the temperature of the liquid is 50°C or below, and that the circuit board is removed from the bath within one minute.

(5) There are ultrasonic wave cleaning methods which offer highly effective cleaning within a short time. Since these methods involve a complicated combination of factors such as the cleaning bath size, ultrasonic wave vibrator output, and printed circuit board mounting method, there is fear that the service life of airtight seal-type devices may be severely shortened. Therefore, as far as possible avoid using the ultrasonic wave cleaning method on such devices. This concern is not applicable to plastic-mold type transistors, although the basic requirements mentioned below should be followed:

- Basic requirements for the ultrasonic wave cleaning method
  Frequency: 27 to 29 kHz
  Output: 300 W or less (about 0.25 W/cm^2 or less)
  Cleaning time: 30 seconds or less

Conduct ultrasonic wave cleaning with both the printed circuit board and the devices floating in the solvent, so that neither product comes in direct contact with the ultrasonic wave vibrator.
It is recommended to adopt steam cleaning or jet stream cleaning methods instead, because they exert less influence on devices than does ultrasonic wave cleaning; and it is assumed that various types of devices are mounted on a printed circuit board, some of which may be vulnerable.
Conventional cleaning solvents that contain freon are not recommended due to the danger that they pose to the earth's ozone layer. Alternative products listed below are available on the market. Some alternative cleaning agents that do not contain freon listed in Table 3.1. Contact Toshiba or a Toshiba distributor regarding cleaning conditions and other relevant information for each product type.

Table 3.3 Example of Alternative Cleaning Agents

Technocare	FRW-1, FRW-17, FRV-100	from Toshiba Corporation
Asahi Clean	AK-225AES	from Asahi Glass Co., Ltd.
Clean Through	750H	from Kao Co., Ltd.
Pine Alpha	ST-100S, ST-100SX	from Arakawa Chemical Co., Ltd.

3.5.5 No Cleaning

If analog devices or high-speed devices are used without being cleaned, flux residues may cause minute amounts of leakage between pins. Similarly, dew condensation, which occurs in environments containing residual chlorine when power to the device is on, may cause between-lead leakage or migration. Therefore, Toshiba recommends that these devices be cleaned.

However, if the flux used contains only a small amount of halogen (0.05% or less), the devices may be used without cleaning without any problems.

For details of individual devices' cleaning conditions, please contact Toshiba or a Toshiba distributor.

3.5.6 Mounting Chips

Devices delivered in chip form tend to degrade or break under external forces much more easily than plastic-packaged devices. Therefore, caution is required when handling this type of device.

(1) Mount devices in a well-prepared environment so that chip surfaces will not be exposed to polluted ambient air or other polluted substances.

(2) When handling chips, be careful not to expose them to static electricity.
In particular, measures must be taken to prevent static damage during the mounting of chips. With this in mind, Toshiba recommends mounting all peripheral parts first and then mounting chips last (after all other components have been mounted).

(3) Make sure that circuit boards (e.g. PCBs) on which chips are being mounted do not have any chemical residues on them (such as the chemicals which were used for etching the boards).

(4) When mounting chips on a board, use the method of assembly that is most suitable for maintaining the appropriate electrical, thermal and mechanical properties of semiconductor devices.

Note 3: For details of devices in chip form, refer to the relevant devices' individual datasheets.

3.5.7 Circuit Board Coating

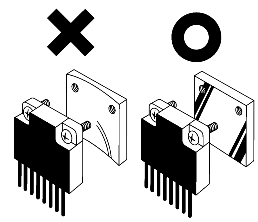
When devices are to be used in equipment requiring a high degree of reliability or in extreme environments (where moisture, corrosive gas or dust is present), circuit boards may be coated for protection. However, before doing so, you must carefully consider the possible stress and contamination effects that may result and choose the coating resin which applies the minimum level of stress to the device.

3.5.8 Attaching the Heat Sink

(1) When attaching a heat sink to a device, be careful not to apply excessive force to the device in the process.

(2) When attaching a device to a heat sink by fixing it at two or more locations, evenly tighten all the screws in stages (i.e. do not fully tighten one screw while the rest are still only loosely tightened). Finally, fully tighten all the screws up to the specified torque.

(3) The surface where the device is attached must be sufficiently smooth.



(4) A coating of silicone compound can be applied between the heat sink and the device to improve heat conductivity. Be sure to apply the coating thinly and evenly; do not use too much. Also, be sure to use a non-volatile compound, as volatile compounds can crack after a time, causing the heat radiation properties of the heat sink to deteriorate.

(5) If the device is housed in a plastic package, use caution when selecting the type of silicone compound to be applied between the heat sink and the device. With some types, the base oil separates and penetrates the plastic package, significantly reducing the useful life of the device. Two recommended silicone compounds in which base oil separation is not a problem are YG6260 from Toshiba Silicone.

(6) Heat-sink-equipped devices can become very hot during operation. Do not touch them, or you may sustain a burn.

3.5.9 Tightening Torque

(1) Make sure the screws are tightened with fastening torques not exceeding the torque values stipulated in individual datasheets and databooks for the devices used.

(2) Do not allow a power screwdriver (electrical or air-driven) to touch devices.

3.5.10 Repeated Device Mounting and Usage

Do not remount or re-use devices which fall into the categories listed below; these devices may cause significant problems relating to performance and reliability.

(1) Devices which have been removed from the board after soldering

(2) Devices which have been inserted in the wrong orientation or which have had reverse current applied

(3) Devices which have undergone lead forming more than once

3.6 Protecting Devices in the Field

3.6.1 Temperature

Semiconductor devices are generally more sensitive to temperature than are other electronic components. The various electrical characteristics of a semiconductor device are dependent on the ambient temperature at which the device is used. It is therefore necessary to understand the temperature characteristics of a device and to incorporate device derating into circuit design. Note also that if a device is used above its maximum temperature rating, device deterioration is more rapid and it will reach the end of its usable life sooner than expected.

3.6.2 Humidity

(1) Resin-molded devices are sometimes improperly sealed. When these devices are used for an extended period of time in a high-humidity environment, moisture can penetrate into the device and cause chip degradation or malfunction. Furthermore, when devices are mounted on a regular printed circuit board, the impedance between wiring components can decrease under high-humidity conditions. In systems that require a high signal-source impedance, circuit board leakage or leakage between device lead pins can cause malfunctions. The application of a moisture-proof treatment to the device surface should be considered in this case. On the other hand, operation under low-humidity conditions can damage a device due to the occurrence of electrostatic discharge. Unless damp-proofing measures have been specifically carried out, use devices only in environments with appropriate ambient moisture levels (i.e. within a relative humidity range of 40% to 60%).

(2) When semiconductor devices are to be used in equipment requiring a high degree of reliability or in extreme environments (where humidity is high, or where corrosive gas or dust is present), devices may be coated in order to moisture-proof them. In such cases, choose the coating resin which applies the minimum level of stress to the device.

3.6.3 Corrosive Gases

Corrosive gases can cause chemical reactions in devices, degrading device characteristics.

For example, sulphur-bearing corrosive gases emanating from rubber placed near a device (accompanied by condensation under high-humidity conditions) can corrode a device’s leads. The resulting chemical reaction between leads forms foreign particles which can cause electrical leakage.

3.6.4 Radioactive and Cosmic Rays

Most industrial and consumer semiconductor devices are not designed with protection against radioactive and cosmic rays. Devices used in aerospace equipment or in radioactive environments must therefore be shielded.

3.6.5 Strong Electrical and Magnetic Fields

Devices exposed to strong magnetic fields can undergo a polarization phenomenon in plastic material, or within the chip, which gives rise to abnormal symptoms such as impedance changes or increased leakage current. Failures have been reported in LSIs mounted near malfunctioning deflection yokes in TV sets. In such cases, the device's installation location must be changed or the device must be shielded against the electrical or magnetic field. Shielding against magnetism is especially necessary for devices used in an alternating magnetic field, because of the electromotive forces generated in this type of environment.

3.6.6 Dust and Oil

Just like corrosive gases, dust and oil can cause chemical reactions in devices, which will adversely affect a device's electrical characteristics. To avoid this problem, do not use devices in dusty or oily environments.

3.6.7 Fire

Semiconductor devices use combustion-resistant resin. They can emit smoke and catch fire if heated sufficiently. When this happens, some devices may generate poisonous gases. Devices should therefore never be used in close proximity to an open flame or a heat-generating body, or near flammable or combustible materials.

3.7 Disposal of Devices and Packing Materials

When discarding unused devices and packing materials, follow all procedures specified by local regulations in order to protect the environment against contamination.

4. Semiconductor Quality and Reliability

4.1 Semiconductor Quality and Reliability

4.1.1 Basic Concept

4.1.1.1 Commitment

The Toshiba group principle of management is embodied in the company motto "Committed to people, committed to the future." It is a principle based on respect for humankind. Its goal: "We, the Toshiba Group companies, based on a total commitment to people and to the future, are determined to help create a higher quality of life for all people, and to do our part in ensuring the continued progress of the world community." These ideals are reflected in our efforts to deliver high-quality and cost-competitive products that meet your needs and are backed up by the highest level of support and service.

Naturally, the Semiconductor Group is likewise continuing its efforts to ensure the quality of its semiconductor products, under the slogan of "Persistent improvement and inoventations to achieve the best quality and customer satisfaction in the world".

As well as seeking to obtain ISO 9000 certification as quickly as possible and enhancing quality-management systems, each of our manufacturing plants is participating in the Management Innovation 2001 Campaign and addressing quality improvement on a day-to-day basis.

4.1.1.2 Strategy

The following strategies are used by Toshiba in its quality and reliability (Q&R) assurance activities for semiconductor products:

(1) Integrate Q&R during the Design Stage (Designed-in Q&R)

The following steps are taken to achieve reliability goals at the design stage:

- Strictly enforce DR/AT (design review/approval test).
- Develop reliability evaluation and analysis methods in support of leading-edge technology.

(2) Integrate Q&R during the Manufacturing Stage (Built-in Q&R)

The following steps are taken to integrate Q&R at the processing source:

- Automate the manufacturing process.
- Enforce control of processed products.
- Establish a performance level index for each line.

(3) Improve Quality through Reliability Monitoring and Failure Analysis (Improvement)

The following steps are taken to assure the quality of shipped product:

- Monitor failure rates through reliability testing.
- Analyze failures and feed the results back to the manufacturing process.
- Set target failure rates and promote continuous quality improvement.

(4) Total Customer Service (Customer Satisfaction)

The following steps are taken to meet market quality requirements and attain customer satisfaction:

- Feed back customer quality requirements to the design and manufacturing processes.
- Provide sufficient quality information services.

4.1.1.3 ISO 9000 certification

In September 1992, Toshiba became the first company in Japan to receive ISO 9001 certification for its Oita Operations. Since then Toshiba has been granted the same certification for its manufacturing works at home and abroad as listed in Table 4.1. Today, efforts are concentrated on maintaining this certification, with continued improvements being made to the company QA system through periodic internal quality audits.

Table 4.1 Toshiba works and affiliate companies qualified for ISO 9000 Series

(Information current as of October 1999)

Div./Operations	Certification	Certification Body
Discrete Semiconductor Div.	ISO 9001	RCJ/ISO
Micro electronics Center	ISO 9002	
Kitakyushu Operations	ISO 9002	
Oita Operations	ISO 9002	RCJ/IEC (Note)
Himeji Operations – Semiconductor	ISO 9002	RCJ/ISO
Yokkaichi Operations	ISO 9002	
Iwate Toshiba Electronics Co., Ltd.	ISO 9002	
Toshiba Component Co., Ltd.	ISO 9002	
Kitsuki Toshiba Electronics Corporation	ISO 9002	RCJ/IEC (Note)
Taketa Toshiba Electronics Co., Ltd.	ISO 9002	
Oita Precision Coporation.	ISO 9002	
Kaga Toshiba Electronics Campany	ISO 9002	RCJ/ISO
Buzen Toshiba Electronics Coporation	ISO 9002	TUV
Toshiba Semiconductor GmbH	ISO 9002	DQS
Toshiba Electronics Malaysia Sdn. Bhd.	ISO 9002	SIRIM
Toshiba Semiconductor (Thailand) Co., Ltd.	ISO 9002	TISI
Toshiba Electronics Asia, Ltd.	ISO 9002	HKQAA
Toshiba America Electronic Components,	ISO 9001	DNV
Wuxi Huazhi Semiconductor Co., Ltd.	ISO 9002	CQEC
Dominion Semiconductor, L. L. C	ISO 9002	BVQI

Note: Qualified for the ISO 9000 Series under the IEC Quality Assessment System for Electronic Components of the Reliability Center for Electronic Components of Japan (RCJ).

4.1.2 Organization and Procedural Flow

Figure 4.1 shows an organization chart and Figure 1-2 shows a procedural flowchart for, respectively, the structure and activities of the Toshiba QA system employed in relation to Toshiba semiconductor products.

Figure 4.1 shows how each manufacturing department tries to incorporate the maintenance and improvement of product quality into its process flow, as propounded in the Toshiba slogan "Quality should be built into the process flow.". Furthermore, for all products manufactured at any given works, the works' own Quality Assurance Department is responsible for assuring the quality of in-coming components and raw materials, assuring the quality of the manufacturing processes used, ensuring product quality and reliability at the time of shipment, providing quality assurance services after shipment, and managing the measurement instruments that are used in the factory. In a continuous effort to improve product quality and reliability, the Quality Assurance Department also holds factory quality assurance meetings chaired by the plant manager.

Within each division, the Reliability Technology Department takes charge of the following: all planning relating to the quality and reliability of semiconductor products manufactured by the division; testing and evaluation (in co-operation with the relevant technical departments) of the reliability of the products developed; the methods used for ensuring the quality of newly distributed products; and the organization of quality and reliability data. The company's Quality Assurance Department coordinates inter-divisional quality issues by taking responsibility for the following areas: the preparation of specifications for customers, quality assurance agreements, the provision of quality assurance services, and training and discipline relevant to quality and reliability. In addition, each division tries to maintain and improve the quality and reliability of the semiconductor products that it manufactures by holding divisional quality assurance conferences chaired by the division's quality assurance manager; these are attended by the Quality Assurance Department managers and Engineering Department heads from each works.

Moreover, the each division also holds a Semiconductor Group quality assurance conference at which the quality assurance department managers from each division meet to discuss company-wide strategies for maintaining and improving quality and reliability.

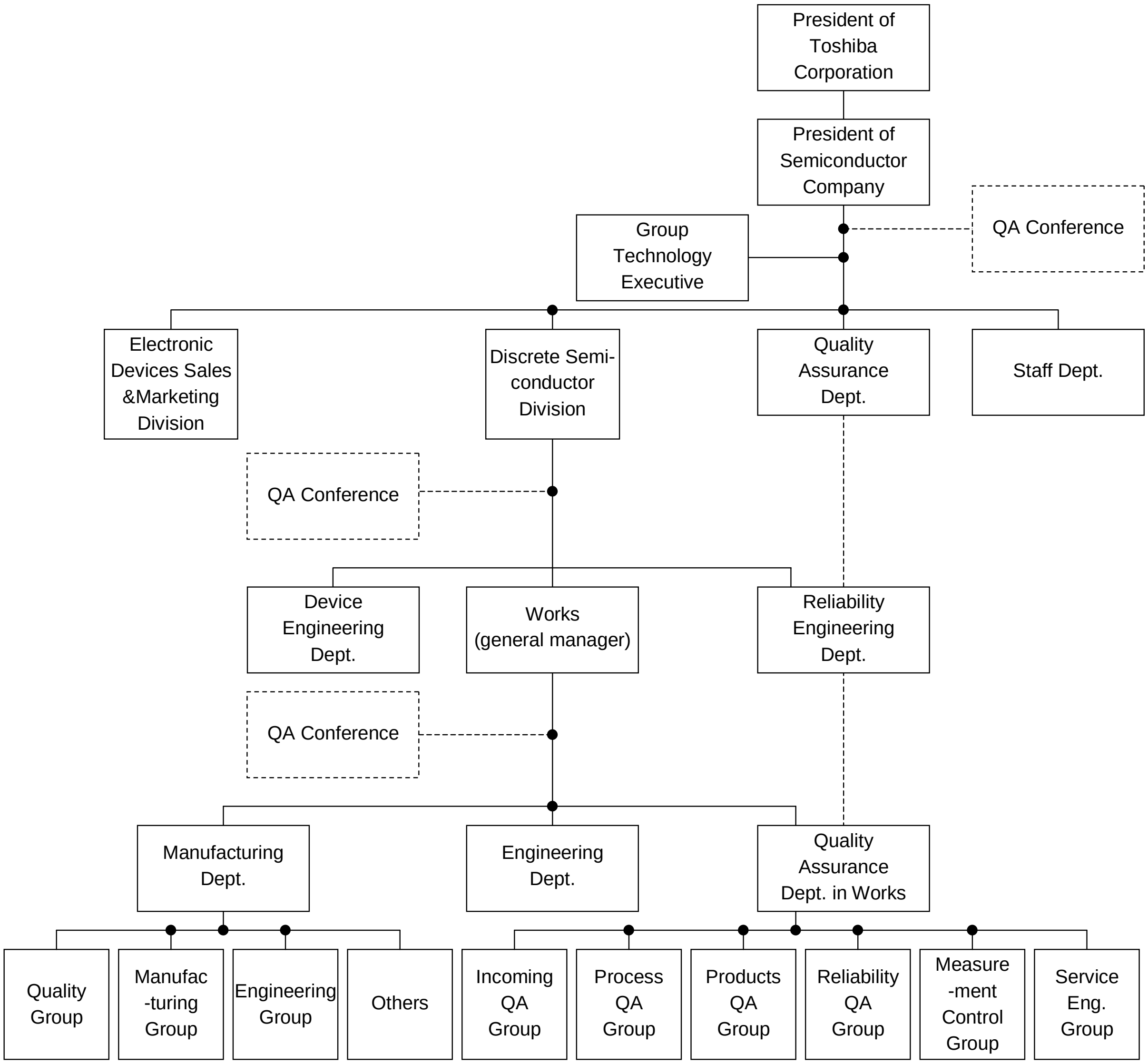


Figure 4.1 Quality assurance (QA) system organization

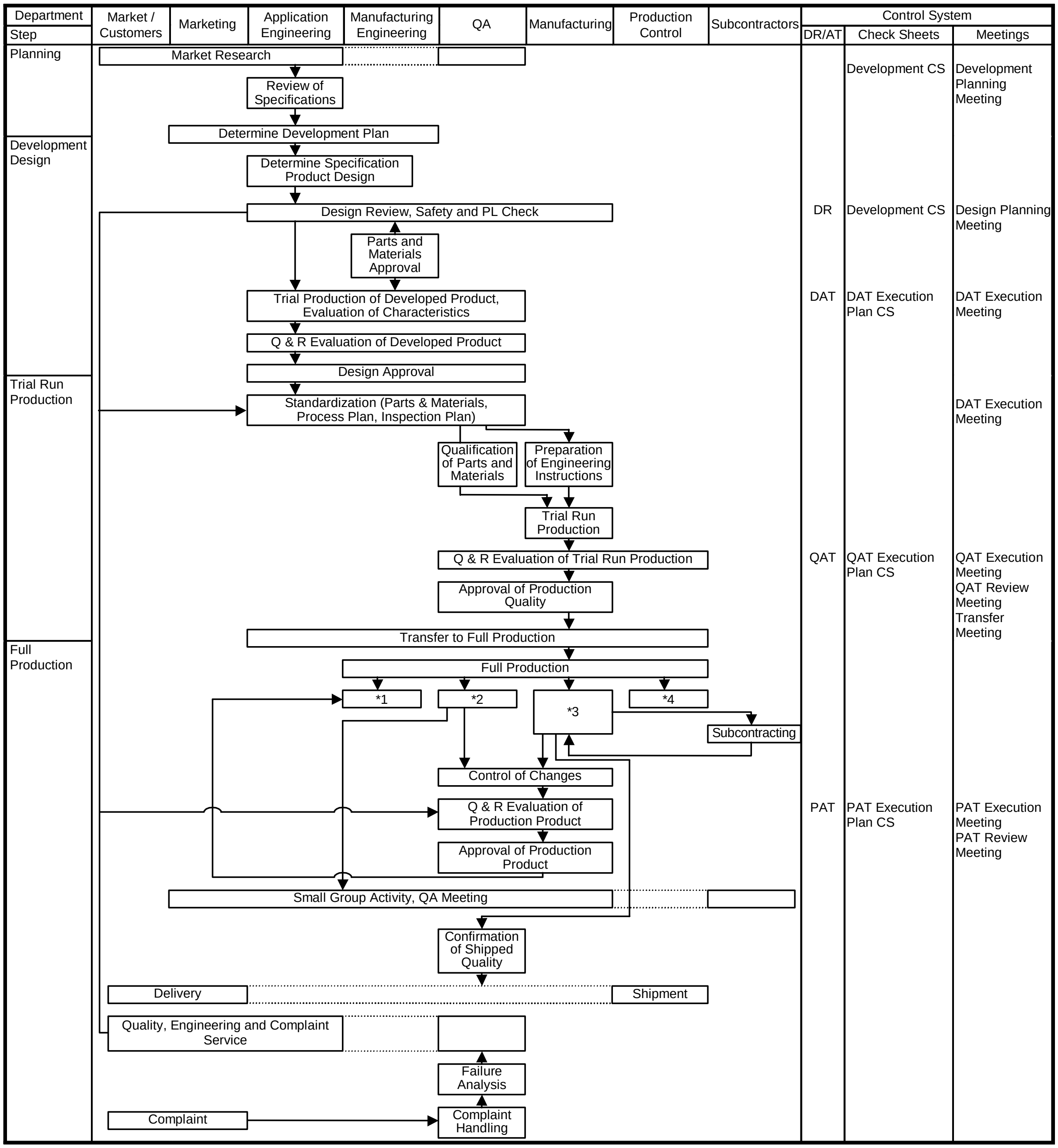
Toshiba are making a supreme effort to understand the customer's needs and to incorporate into product design the levels of quality and reliability dictated by the actual conditions under which products will be used in customer applications. During the design review process several departments are involved in confirming product safety and adherence to product liability safeguards.

Toshiba carry out the Design Assurance Test (DAT) in order to evaluate the quality and reliability of products under development with reference to the Toshiba reliability testing standards. These Toshiba standards have been drawn up in accordance with various accepted standards, such as those of JIS, EIAJ, IEC, ANSI and JEDEC. The components and materials which are to be used in Toshiba products are standardized via a process of primary assurance by the relevant engineering department and secondary assurance by the Quality Assurance Department. If a product passes the Design Assurance Test, the Engineering Department carry out standardization of the components and materials, and of the production process and inspection. In addition, detailed factory standards regarding actual production and management are set in the factory where the products are to be made. Sample products are manufactured in order to evaluate product quality and reliability. If product quality and reliability are successfully assured in this manner, the factory will be put in charge of quality assurance for the actual production process.

During commercial production the Manufacturing Department carry out inspections of the process, work environment and equipment management, and the Reliability Engineering Department are responsible for acceptance inspection, change management, measurement management, regular reliability confirmation and production process auditing. The Engineering Group and the Engineering Department are also involved in problem solving and in improvement and automation of the production process.

In addition, new operators, supervisors and engineers constantly receive instruction and training.

Toshiba products undergo primary quality assurance testing and reliability monitoring by the Quality Assurance Department before shipping. Furthermore, in quality service areas such as the definition of specifications, the holding of meetings on quality and reliability, and the investigation and reporting of product defects, Toshiba are striving to achieve fast response times.



DR: Design Review
DAT: Design Approval Test
QAT: Quality Approval Test
CS: Check Sheet

*1 Improvement of Manufacturing Technology
Promotion of Automatization
*2 Inspection of Incoming Parts
Line Audit
Reliability Test
Measurement Control
Quality Training & Education
*3 Manufacturing Control
Environmental Control
Facility Control
Assurance of Quality, Cost & Delivery
*4 Control of Delivery and Quantity

Figure 4.2 Quality assurance (QA) system procedural flow

4.2 Inspection System

Semiconductor product quality and reliability are enhanced by building quality into the design and production phases. Thus, controls are established for each phase, monitoring is performed and, should any abnormal situation occur, appropriate measures are taken.

In addition, a final comprehensive inspection of products' electrical characteristics is conducted to eliminate potential product defects or defects in the wafer or assembly processes.

4.2.1 Inspection

Intermediate inspections, final inspections, quality monitoring and reliability monitoring are all performed according to standardized internal rules.

Figure 4.3 shows the inspection procedure.

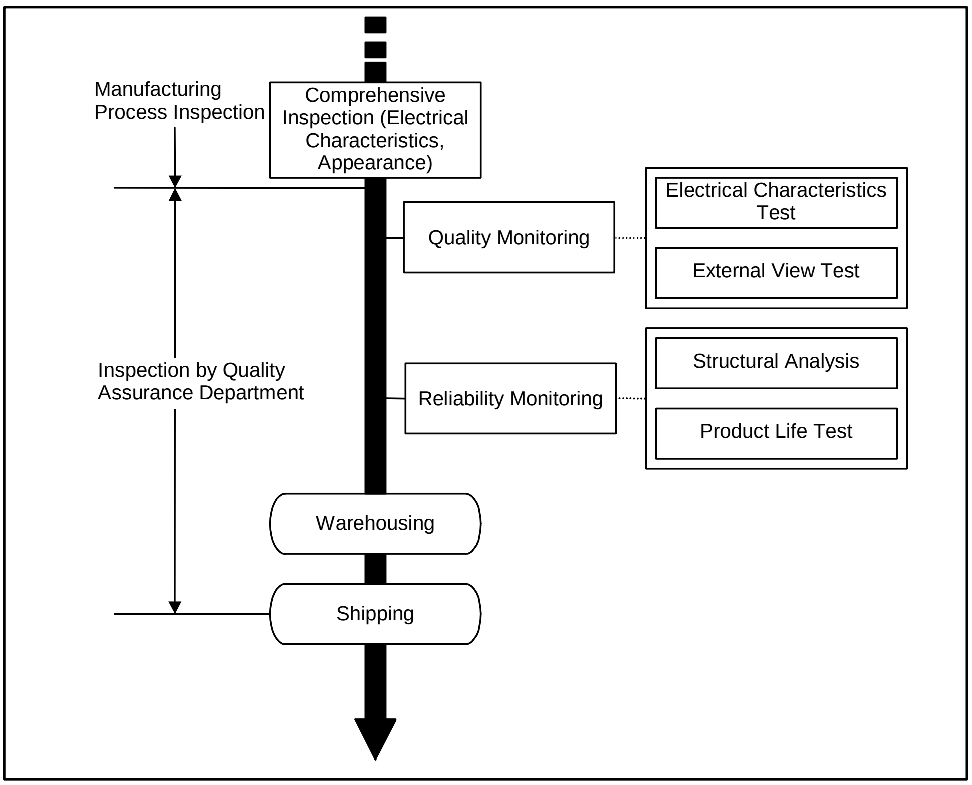


Figure 4.3 Inspection procedure

After a comprehensive inspection of the product's electrical characteristics, which is performed during the manufacturing processes, the Quality Assurance Department checks the quality level by carrying out quality monitoring.

Quality monitoring is used to verify the initial electrical characteristics and external specifications of selected sample products. This is an essential step in assuring the quality and reliability of the final product.

Reliability monitoring, on the other hand, is based on process type and package family type, and is used to assess the reliability of existing products from those perspectives.

4.2.2 Acceptable Quality Levels

Inspection sampling assures the acceptable quality levels (AQLs) shown in Table 4.2.

Table 4.2 Acceptable Quality Levels (AQLs) for Lots Based on ANSI Z1.4-1993 (normal inspection by single sampling)

Item \ Type		Discrete Device	Multiple Device
Electrical characteristics		0.04%	0.15%
Appearance	Serious defect	0.15%	
	Minor detect	0.25%	

Recently, customer requirements have reached levels that are difficult to meet using ordinary sampling inspection. To cope with increasing requirements for designed-in quality, in addition to normal inspections, a control method based on the parts-per-million (PPM) defect ratio has been implemented so as to further improve quality and reliability.

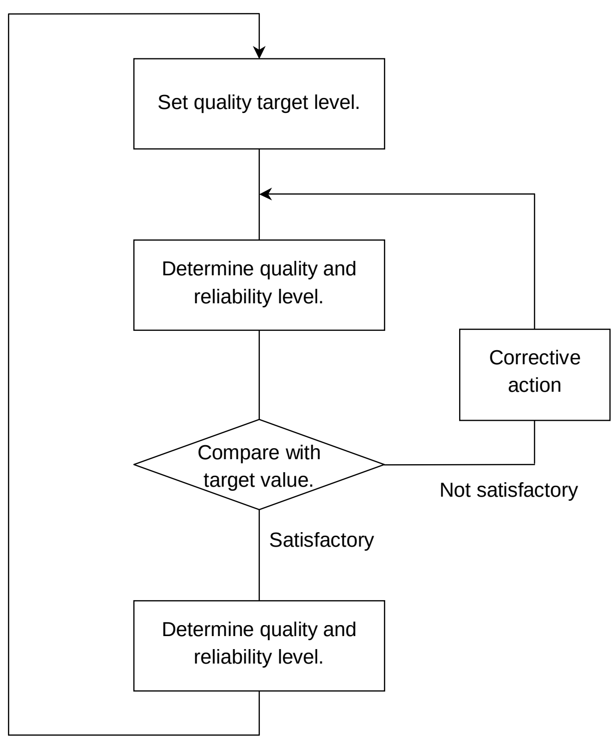


Figure 4.4 PPM Control Procedure

4.3 Complaint Services

Figure 4.5 shows the procedure used for complaint services. It enables quick analysis and quick response to customer complaints. In addition, information concerning complaints is fed back to the manufacturing process and related departments to prevent the recurrence of problems and to improve reliability. In this way, improvements can be monitored to determine whether they are effective in the long term.

New analysis methods and techniques (including the use of new analytical equipment) are continuously being introduced to further improve analysis efforts.

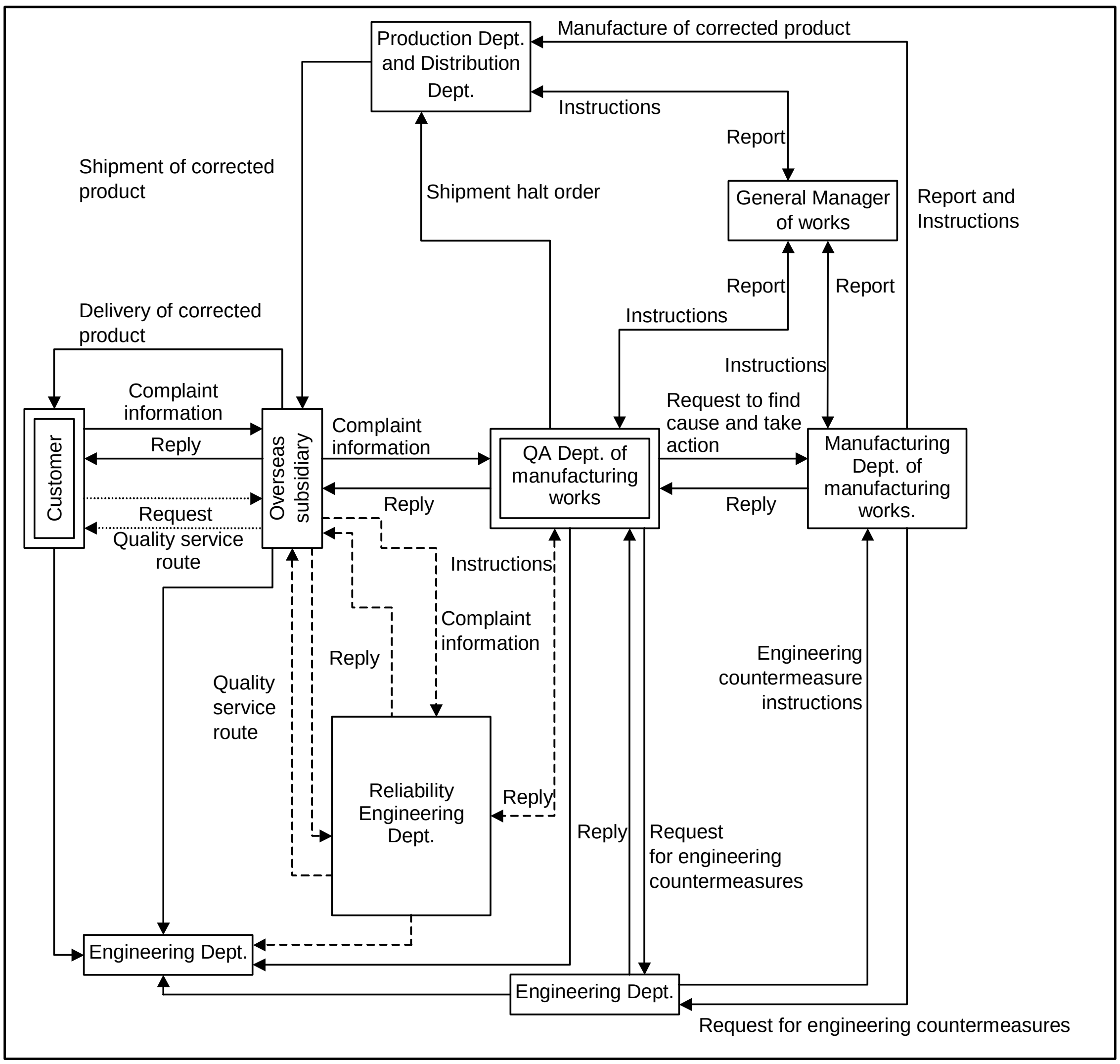


Figure 4.5 Quality service and complaint processing flow (for complaints from overseas)

4.4 Concept and Scale of Reliability

The quality that defines a device as being highly reliable is that, when used as a component of equipment, it "offers objective functions under stable conditions without failure for a specified duration of time".

Such an element should be easily compatible in electrical properties when replaced if necessary.

Figure 4.6 illustrates failures observed in ordinary electronic parts and semiconductors with time as the independent variable.

It has been recognized that this curve shows a certain trend, divided into three periods:

- Initial failure period
- Random failure period
- Wearout failure period

Failure of semiconductor products is characterized by a gradual reduction in the failure ratio during the random failure period; it is important to minimize the failure ratio during this period in part because failure does occur at random.

To quantitatively represent reliability, the degree of reliability or the ratio of failure is used in a time-dependent distribution function. Generally, the failure ratio of semiconductor products is expressed by percentage per 1000 hours, assuming that time (t) = 1000 hours. Since the failure ratio is small judging from field data and the estimated failure ratio, $1/10^4$ times this value-namely 10^{-4} (%/1,000 hours) = 10^{-9} (failures/hour)-is commonly used, this unit being called one Failure In Time (1 fit). To represent the reliability of semiconductor products, an approximation is conducted using various types of distribution functions. Based on goodness of fit, either the exponential distribution or the Weibull distribution is often used for these products.

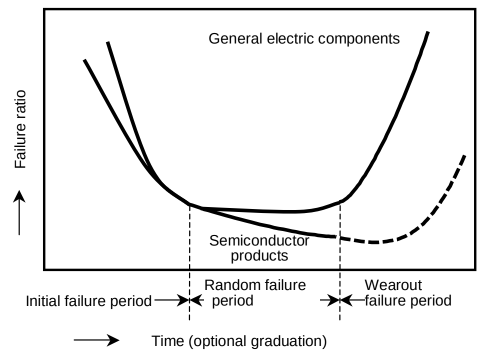


Figure 4.6 Time Variation of Failure Rate Regarding Elapsed

When assuming an exponential distribution, the most basic distribution pattern in the life time distribution of electronic components, the reliability function R (t) can be expressed by the equation-

$R(t) = \exp(-\lambda t)$

The instantaneous failure ratio λ (t) and average life μ are expressed as-

$\lambda(t) = \lambda$ (constant irrespective of time lapse)

$\mu = 1/\lambda$

$\mu = 1/\lambda$ = Mean Time To Failure (MTTF)

4.5 Reliability Factors

The reliability of semiconductor devices should be estimated not only for the transistors themselves, but also by taking operational stress and environmental stress into consideration. These factors are so closely inter-related that the following explanation may help users to utilize them with greater confidence.

(1) Operating conditions

Voltage and current supplied to transistors, and the operating conditions surrounding equipment, are important factors which affect device reliability. The operation points should be determined by selecting an appropriate device for a particular application and by designing an appropriate circuit.

It is known that the device failure ratio is substantially affected by temperature, and that as the temperature rises, the ratio is increased.

However, one exception is small-signal transistors which handle such low voltage and current that no special consideration need be given to temperature, except for some circuits designed for special-purpose operation. On the other hand, power transistors which handle comparatively large voltage and current have large dissipations as a result of a far larger volume of current compared with voltage.

This power dissipation causes a transistor to heat up, adversely affecting both its characteristics and its reliability. Such heat should be efficiently discharged.

In addition to considering the influence of temperature, attention should be paid to the application of surge voltage and to deviation in characteristics caused by external influences or induction. By lowering the limit values for allowable fluctuations in characteristics, to widen the difference between theoretical and actual operation limits when designing a circuit, it is possible to substantially increase the service life of a device, and hence, that of the equipment.

It is recommended that derating be applied to the voltage, current, and temperature specified by maximum ratings, so that devices may be employed with high reliability. Since derating is determined as a compromise between reliability and economic values, it is rather difficult to uniformly specify the degree of derating. The degrees mentioned below are those generally recommended:

Voltage: 70 to 80% or less of maximum rating
Current: 80% or less of maximum rating
Power: 50% or less of maximum rating

Regarding the degrees of derating, certain government agencies in Japan have established their own standards for operation and design, and have limited the application ranges. Such a movement represents a constructive basic activity for improving device reliability.

Figure 4.7 shows an example of relations between the temperature and the failure ratio, using a Toshiba silicon transistor. It is evident from that figure that the failure ratio is substantially affected by the operating temperature and that higher reliability can be expected by effecting derating.

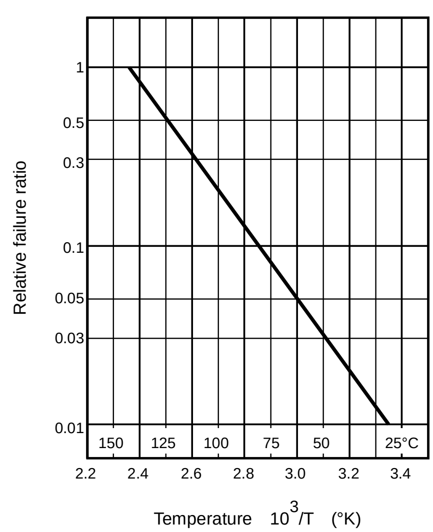


Figure 4.7 Derating Curre for Silicon Transistors

(2) Variations in transistor quality

The automatization of production processes and the improvement and progress of production technology have been outstanding, and the quality and reliability of transistors have continued to improve year after year thanks to this trend.

It would, however, be a great overstatement to say that there are no variations in quality thanks to the use modern controlling methods and the full automation of processes. Many semiconductor products are extremely small in size complex in structure and shape, and depend on microtechnology for replication of their high-precision properties technology. Therefore, even the slightest deviation in physical and chemical processing can exercise a large influence upon a device’s characteristics. It is rather difficult to maintain their various characteristics uniform, even by making full use of today's latest technology.

(3) Resistance against environmental factors

The housings of semiconductor products are classified into the plastic resin-sealed type and the airtight-sealed type using metal or ceramic housings. The plastic resin-sealed type, less expensive and easier to mass-produce, recently has been employed in the majority of cases covering a very broad range of semiconductor device types and applications.

This trend has been backed by the facts that resins with high mechanical strength and excellent electrical insulation as well as resistance against environmental factors have been developed and employed, and that reliability of this type has been greatly enhanced thanks to progress in molding techniques and surface treatment know-how.

The plastic resin-sealed package by now has reached the level of acceptance of the airtight-sealed type except for use in very special environments, even though devices are subjected to many environments in the markets. Since the plastic resin-sealed package type is not airtight, humidity infiltrates the device interior through the resin. It is recommended to employ the airtight-sealed type if the equipment or system is intended for use in a high-humidity environment, or when high reliability is required.

Be careful not to directly expose semiconductor products to dust, harmful gases, salty (sea) air, radioactive rays, or similar environments; otherwise, they will suffer from unstable characteristics or rust in the lead wires.

4.6 Failure Mode and Failure Mechanism

Types of failure are classified into three main categories: open circuits, short circuits, and deterioration.

(1) Open failure

Factors causing open failure are

(a) Structural flaws related to or caused by bonding

(b) Those caused by electrochemical reaction such as electromigration and local cell formation

(c) Application of stress exceeding that guaranteed by the standards

It is also possible that bonding wires and aluminum wires may be fused off as a result of a combination of the above three factors.

(2) Short failure

Principal factors causing short are

(a) Excessive stress caused by overvoltage and overcurrent

(b) Short failure caused by an extreme example of degradation

(c) Electrochemical reaction

(3) Degradation

Degradation from electrical characteristics can have such causes as the voltage falling below the standard value, abnormal surges in current, or drift of the characteristic values.

As the device is based on physical and chemical technologies, surface and internal thermodynamic changes in the device caused by voltage, current, temperature, or humidity can cause fluctuations, which gradually increase until they finally exceed the standards.

The following are causes of degradation:

(a) Manufacturing defects

(b) Design problems

(c) Usage problems

Table 4.3 shows the relationship between the failure modes and mechanisms caused by the above factors, and indicates countermeasures that can be taken.

Table 4.3 Relationships between Failure Modes and Failure Mechanisms

Failure Mode	Failure Mechanisms / Failure Factors	Structural Items				Seal		Interior					Surge		
		Structural Flaws	Connecting and Connecting Portions	Interaction between Components	Thermal Fatigue	Defective Housing	Sealing Imperfection	Junction Imperfection	Surface Channel Defect	Entrapped Foreign Gas Ions	Ionic Conduction	Corrosion	Overcurrent	Overvoltage	Static Electricity
Open circuit	Open lead (fused)												R		
	Open lead (mechanical)	R			R										
	Abnormal bonding	R	R	R	R							R			
Short circuit	Junction short circuit				R			R					R	R	R
	Arcing													R	R
	Pellet crack	R		R	R										
	Infiltrated foreign matter	R				R									
	Contact between leads	R	R	R		R									
Degradation	Atmosphere						R		R	R	R	R			
	Smears				R				R	R	R	R			
	Influence of surface oxidized film				R				R		R	R			
	Junction interior				R			R							R
	Arcing													R	R
	Pellet cracks	R		R	R										
Others	Defective external lead wires	R	R			R									
	Housing surface leak	R				R									
	Rust					R									

R: Relevant

4.7 Reliability Test

Reliability tests are conducted either for maintaining and confirming reliability assurance levels or for better understanding the design margins and limit levels which must be observed when renewing a design.

The reliability test methods and conditions differ according to particular test objectives. Normally, an accelerated life test and an environment test are conducted based on maximum ratings, simulating stresses to which transistors will be subjected in actual operation. Since some tests are destructive in nature, it is important to establish reproducible, generally applicable test methods and conditions.

Standard test methods applicable to semiconductor products include JIS, JEITA, MIL, and IEC standards. Among these, some standards in common usage for semiconductor products are described below; the contents of the corresponding reliability tests are listed in Table 4.4.

- Japanese industrial standards (JIS)
  - JIS C5003 General test procedure of failure ratio for electronic components
  - JIS C5700 General rules for reliability assured electronic components
  - JIS C7021 Environmental testing methods and endurance testing methods for discrete semiconductor devices
  - JIS C7030 Testing methods for transistors
  - JIS C7032 General rules for transistors
  - JIS C7210 General rules for reliability assured discrete semiconductor devices
- Electronic industries association of japan (JEITA) standards
  - JEITA SD-121 Environmental and mechanical test methods for discrete semiconductor devices
  - JEITA SD-71 Transistor test methods
  - JEITA SD-31 Field-effect transistor test methods
- U.S. military standards (MIL)
  - MIL-STD-202 Test methods for electronic and electrical components parts
  - MIL-STD-750 Test methods for semiconductor devices
  - MIL-S-19500 Semiconductor devices, general specifications for

Table 4.4 Types and Contents of Reliability Tests

Classification	Tests	Description	Applicable Standards
Initial performance tests	Initial characteristics test:	Items of electrical characteristics specified as ratings by respective standards are tested to confirm that they fall within requirements of the standards.	
	Appearance, dimensions, and structure tests:	Tests are conducted to confirm that materials, polarity, structure, external shapes, dimensions, marking, and external appearance of a device are in normal condition or within the allowable limits specified.	
Operation life tests	Steady state operation life test:	Durability of a device is judged by applying electrical stress (voltage and current) and thermal stress (including temperature rise caused by load) to the device over a long period. This test is normally conducted by continuously applying voltage, current, or power at 25 ± 5°C.	JEITA SD-121 B-4 JIS C7021 B-4 MIL-STD-750B: 1026
	Intermittent operation life test:	Electrical and mechanical durability of a device is judged by intermittently feeding power to the device and by raising/lowering temperature in accordance with ON/OFF conditions. This test is normally conducted at 25 ± 5°C under separately specified electrical and time conditions (such as power feeding cycle and interrupting cycle.)	JEITA SD-121 B-6 JIS C7021 B-6 MIL-STD-750 B: 1036
Storage life tests	High-temperature storage life test:	Durability of a device is judged by storing the device at high temperature. Normally, the test temperature is the maximum rated storage temperature (T_{stg} max).	JEITA SD-121 B-9 JIS C7021 B-10 MIL-STD-750B: 1031
	Low-temperature storage life test:	Durability of a device is judged by storing the device at low temperature. Normally, the test temperature is the minimum rated storage temperature (T_{stg} min).	JEITA SD-121 B-11 JIS C7021 B-12
	High-temperature/high-humidity storage life test:	Durability of a device is judged under operation and storage at high relative humidity over a long period. Normally, the test conditions are 60°C and 90%RH.	JEITA SD-121 B-10 JIS C7021 B-11 MIL-STD-202E: 103B
Environment tests	Soldering heat test:	Heat resistance of a device is determined against heat to which it is subjected while soldering. Normally, the test is conducted at 260 ± 5°C for 10 seconds.	JEITA SD-121 A-1 JIS C7021 A-1 MIL-STD-750B: 2031
	Temperature cycling test:	Thermal resistance of a device is determined by exposing it to high and low temperatures. Normally, the test is conducted for 5 cycles of minimum and maximum storage temperatures.	JEITA SD-121 A-4 JIS C7021 A-4 MIL-STD-750B: 1051
	Thermal shock test:	Thermal resistance of a device is determined by exposing it to sudden temperature change. Normally, the test is conducted for 5 cycles, between the cyclical limits of 100°C and 0°C.	JEITA SD-121 A-3 JIS C7021 A-3 MIL-STD-750B: 1071
	Moisture resistance test (temperature/humidity cycling test):	Durability of a device is determined by exposing it to high humidity during low and high temperature cycles. Normally, the test conditions are Ta = 25°C to 65°C to −10°C and RH = 90 to 98%. The test is conducted for ten cycles, with one cycle continued for 24 hours.	JEITA SD-121 A-5 JIS C7021 A-5 MIL-STD-750B: 1021
	Seal test:	Airtightness of the seal is determined. Tiny gas leakages are detected by using tracer gas, large leakages by air bubbles.	JEITA SD-121 A-6 JIS C7021 A-6 MIL-STD-750B: 1071

Classification	Tests	Description	Applicable Standards
Mechanical tests	Solderability test:	Ease in soldering lead wires is determined. Normally, the test is conducted at 230 ± 5°C for 5 seconds.	JEITA SD-121 A-2 JIS C7021 A-2 MIL-STD-750B: 2026
	Vibration test:	Durability against vibration during transportation or operation is determined. Normally, changes in vibration frequency (100 to 2000 Hz) are applied.	JEITA SD-121 A-10 JIS C7021 A-10 MIL-STD-750B: 2046 2056
	Shock test:	Structural and mechanical durability is judged. The test is conducted by applying 14700 G three times each in four directions.	JEITA SD-121 A-7 JIS C7021 A-7 MIL-STD-750B: 2016
	Mechanical test:	Constant acceleration test. Durability of a device at constant acceleration is judged. Normally, the test is conducted at 196000 G for 6 orientations (1 minute for each direction).	JEITA SD-121 A-9 JIS C7021 A-9 MIL-STD-750B: 2006
	Drop test:	Structural and mechanical durability is judged. Normally, a test device is dropped three times from a height of 75 cm onto a maple board.	JEITA SD-121 A-8 JIS C7021 A-8
	Lead strength test:	Lead strength is determined as to whether or not leads are strong to enough to endure force to be applied while mounting, wiring, or operating. Normally, lead wires are bent three times through an angle of 90° by applying a 250 g weight.	JEITA SD-121 A-11 JIS C7021 A-11 MIL-STD-750B: 2036
	Salt atmosphere test:	Corrosion resistance of a transistor is determined. Normally, the test is conducted at 35°C room temperature, by spraying with 5% salt solution for 24 hours.	JEITA SD-121 A-12 JIS C7021 A-12 MIL-STD-750B: 1046
Acceleration tests	Accelerated life test:	Generally, life tests consume a long time; at present, especially, when the reliability of devices over time has been enhanced substantially, life tests require an extremely long time and many samples. Therefore, a forced deterioration test is conducted by increasing stresses to levels exceeding the rated values. The types of forced deterioration factors which should be used in a test such as this differ substantially depending on the mechanism observed to cause failures. It is important, therefore, to select forced deterioration factors suitable for the mechanism to be inspected. Additionally, it is necessary to fully comprehend the relations between accelerated and normal life tests.	

4.8 Reliability Characteristics

(1) Reliability test results

As an example, Table 4.5 lists the results of reliability tests conducted for a plastic-encapsulated power MOSFET.

Table 4.5 Reliability Test Results for 2SK2233 Power MOSFET

Table of Test Conditions

Thermal Environment Tests

Test	Applicable Standard	Test Conditions	Remarks
Soldering heat	JEITA ED-4701 A-133A	T_{sol} = 260°C, 10 s, once	Immersed 1.5 mm from base of device
Temperature cycling	JEITA ED-4701 B-131	−55°C (30 min) to 25°C (5 min) to 150°C (30 min) to 25°C (5 min)	100 cycles
Thermal shock	JEITA ED-4701 B-141	0°C (5 min) to 100°C (5 min)	50 cycles
Moisture resistance	JEITA ED-4701 B-132	25°C to 65°C to −10°C, 90% to 98% RH 24 h/cycle	10 cycles

Mechanical Environment Test

Vibration	JEITA ED-4701 A-121	100 to 2000 to 100 Hz 196 m/s^2 4 times each in 3 direction	
Mechanical shock	JEITA ED-4701 A-122	14700 m/s^2, 0.5 ms 3 times each in 4 direction	
Constant acceleration	JEITA ED-4701 A-123	196000m/s^2, 1 min once in each in 6 direction	
Solderability	JEITA ED-4701 A-131A	230°C, 5 s, once	95% or more (using flux)
Lead intensity	JEITA ED-4701 A-111	Load 10.0 N, 0° to 90° to 0°, bent 3 times	No separation or breakage allowed

Lifetime Tests

Steady-state operation	JEITA ED-4701 D-321	PD = 9.3 W, Ta = 25°C (using heat sink)	1000 h
High temperature reverse bias	JEITA ED-4701 B-323	Ta = 150°C, V_{GS} = 20 V	1000 h
High-temperature storage	JEITA ED-4701 B-111	Ta = 150°C	1000 h
High-temperature and high-humidity storage	JEITA ED-4701 B-121	Ta = 60°C, RH = 90%	1000 h

Others

Autoclave test (PCT)	JEITA ED-4701 B-123	Ta = 121°C, 203 kPa (RH = 100%)	24 h

Failure criteria (Ta = 25°C)

Parameter	Symbol	Measuring Conditions	Minimum Criteria	Maximum Criteria
Gate leakage current	I_{GSS}	$V_{GS} = \pm 16$ V, $V_{DS} = 0$	—	USL × 2
Gate cut-off current	I_{DSS}	$V_{DS} = 60$ V, $V_{GS} = 0$	—	USL × 2
Drain-to-source breakdown voltage	V_{DSS}	$I_D = 10$ mA, $V_{GS} = 0$	LSL × 1.0	—
Drain-to source ON-resistance	$R_{DS\ (ON)}$	$V_{GS} = 10$ V, $I_D = 25$ A	—	USL × 1.2

LSL: Lower specification limit, USL: Upper specification limit

Test Results

Thermal Environment Tests and Mechanical Environment Tests・Others

Test	No. of Samples	No. of Failures
Soldering heat	32	0/32
Temperature cycling	50	0/50
Thermal shock	32	0/32
Moisture resistance	32	0/32

Test	No. of Samples	No. of Failures
Vibration	11	0/11
Mechanical shock	11	0/11
Constant acceleration	11	0/11
Solderability	11	0/11
Lead intensity	11	0/11

Lifetime Tests

Test	No. of Samples	168 h	500 h	1000 h	Remarks
Steady-state operation	30	0/30	0/30	0/30	
High temperature reverse bias	30	0/30	0/30	0/30	
High-temperature storage	30	0/30	0/30	0/30	
High-temperature and high-humidity storage	30	0/30	0/30	0/30	

Others

Test	No. of Samples	24 h
Autoclave test (PCT)	20	0/20

(2) Reliability characteristics (oxide film breakdown over time)

The gate electrodes of power MOSFETs are insulated with thin oxide film. Although the intrinsic breakdown voltage of the oxide film can reach as much as 10 MV/cm, that of ordinary oxide film is usually closer to 6 MV/cm to 8 MV/cm. This means that for a gate oxide film thickness of about 1000 Å, the breakdown voltage is around 60 V to 80 V.

However, even when the applied voltage is below the dielectric breakdown level, over time the oxide film insulation degrades, leading to an eventual breakdown when it is subjected to a strong electrical field. This phenomenon is referred to as time-dependent dielectric breakdown (TDDB).

Figure 4.8 is an example showing the lifetime of an actual power MOSFET relative to the TDDB phenomenon. The diagram shows how, at low temperature, when the applied voltage between the gate and the source is reduced, the lifetime of the power MOSFET is extended proportionately. In this example the lifetime of the power MOSFET can be is lengthened by as much as 20 times by lowering V_{GS} by around 5 V. This suggests that for applications where reliability is critical, care must be taken not to set the gate-to-source voltage unnecessarily high.

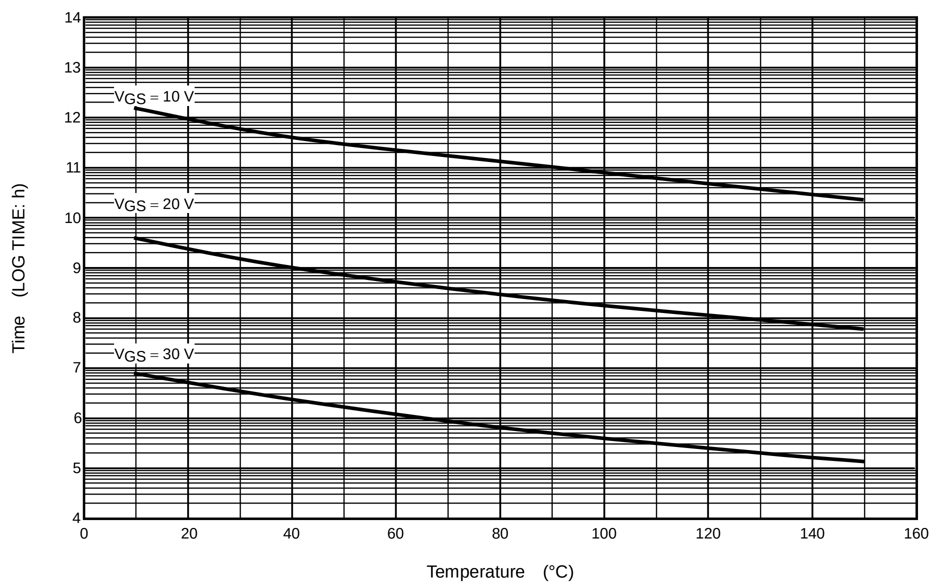


Figure 4.8 Life of Gate Oxide Film for the 2SK1544 Power MOSFET (cumulatire failare rate 1%)