

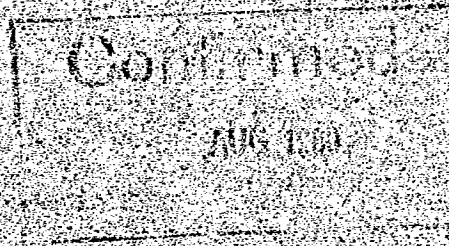


CP 1016 : Part 2 : 1973

UDC 621.382.004

Code of Practice for
**The use of
semiconductor devices**

Part 2. Particular considerations



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The following BSI references relate to the work on this Code of Practice
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CODE DRAFTING COMMITTEE ELCP/29

DIODES, TRANSISTORS AND RELATED SEMICONDUCTOR DEVICES

Mr. K. G. King *Chairman*

Dr. J. Shields

*British Electrical and Allied
Manufacturers' Association*

Mr. J. M. Woodgate

*British Radio Equipment
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Mr. H. K. Winwood

Electronic Engineering Association

Mr. P. A. Fleming

*Electronic Valve and Semiconductor
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*Institution of Electronic and Radio
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*Telecommunication Engineering Manufacturing
Association*



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Foreword

Part 1 'General considerations' of this Code of Practice was published in 1968 and deals with the general considerations applying to the use of all semiconductor devices.

Part 2 of this code deals with the particular considerations applying to the use of specific groups of or types of semiconductor devices. To avoid unnecessary repetition, reference is made, where appropriate, to the relevant clauses of Part 1 of the code.

British Standard Code of Practice for

The use of semiconductor devices

Part 2. Particular considerations

1. Scope

This Code of Practice is intended to give guidance to those concerned with the design, construction, use and maintenance of equipment using diodes, transistors, semiconductor integrated circuits or other similar devices so that optimum performance and optimum length of life may be secured. Particular considerations applicable to the use of specific groups of or types of semi-conductor devices are listed.

NOTE. The titles of the British Standards referred to in this code are listed on the inside back cover.

2. Special considerations applicable to signal diodes

This clause gives some of the special considerations that apply to the use of signal diodes and should be read in conjunction with Part 1 of this code.

Particular attention should be paid to the possibility of high-energy transients occurring in normally low-power applications, and diodes with the appropriate reverse voltage and forward current ratings should be chosen.

Where a signal diode is used in what is essentially a power rectifier application, some of the considerations of clause 3 may be applicable.

3. Special considerations applicable to rectifier diodes

3.1 General. This clause lists some of the special considerations that apply to the use of power rectifier diodes and should be read in conjunction with Part 1 of this code. Reference should also be made to BS 4417 and to BS 9300.

Although most of the recommendations in this section are expressed in terms of the use of diodes as power rectifier diodes operating from nominally-sinusoidal supplies, many of the considerations are relevant to other applications. Where the supply to a rectifier is non-sinusoidal, special care should be taken to ensure that the transient ratings of the device are not exceeded.

3.2 Basic rectifier configurations and circuit constants. The more commonly used circuits for the conversion of alternating current (a.c.) to direct current (d.c.) are given in BS 4417.

3.3 Voltage ratings and series operation

3.3.1 Voltage ratings. There are four distinct reverse voltage ratings of a diode, as follows:

- (1) crest (peak) working reverse voltage, V_{RWM} ;
- (2) repetitive peak reverse voltage (maximum recurrent reverse voltage), V_{RRM} ;
- (3) non-repetitive peak reverse voltage (peak transient reverse voltage), V_{RSM} ;
- (4) continuous (direct) reverse voltage, V_R

These ratings may depend on temperature, supply frequency and waveform. In addition, the non-repetitive peak reverse voltage V_{RSM} is associated with a time limitation.

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3.3.2 Transient voltages When using diodes in power rectifier equipment operating from a conventional a.c. supply, voltages in excess of the nominal value may occur across the diodes.

Causes of transient excess voltage include:

- (1) disturbances on the a.c. supply system;
- (2) opening of the a.c. supply circuit to the transformer when the primary current is not zero. (This is most likely to be troublesome when the output circuit is lightly loaded);
- (3) the interruption of fault current by fuses;
- (4) the effect of carrier storage in diodes;
- (5) opening of a d.c. circuit breaker on load;
- (6) disturbances on the d.c. system supplied by the rectifier.

Transient voltages can be reduced by resistor-capacitor (R.C.) circuits, non-linear resistors or selenium surge suppressors.

Controlled avalanche diodes are designed to be able to absorb a limited amount of energy when brought into the reverse-breakdown condition. This property gives some degree of protection against damage due to voltage transients.

3.3.3 Surge suppression. The manufacturer's recommendations should be followed both for the type of surge suppression to be used and the margin that it is advisable to allow between the crest working voltage to which the diodes will be subjected under normal conditions and the non-repetitive peak reverse voltage rating V_{RSM} of the diodes.

Causes of excess voltages that cannot normally be reduced by surge suppression equipment include:

- (1) supply voltage variation;
- (2) inherent regulation;
- (3) no-load voltage rise;
- (4) regeneration by motors on the d.c. system;
- (5) resonance between circuit inductance and capacitance.

The crest working voltage rating V_{RWM} of the diodes employed should be high enough to withstand these voltages (see also 2.1.3.5 of Part 1 of this code).

3.3.4 Series operation. For the precautions to be observed when using diodes connected in series see 2.1.3.6 and 2.3.4 of Part 1 of this code. The use of series connected diodes in individual rectifier limbs can sometimes be avoided with advantage by the choice of a suitable circuit.

3.4 Current ratings and parallel operation

3.4.1 Steady-state current ratings. There are three basic forward current ratings of a diode, as follows:

- (1) forward current (whole cycle average), $I_{F(AV)}$ for a 180° conduction angle;
- (2) repetitive peak forward current, I_{FRM} ;
- (3) forward current (continuous), I_F .

These ratings are applicable up to values of ambient or case temperature, shown in the manufacturer's data sheets. The ratings also depend on supply frequency, current waveform and conduction angle. For higher values of temperature, the manufacturer's derating curves should be consulted.

NOTE. To determine case temperature, it is necessary to determine the losses to be dissipated by the diode and the dissipation characteristic of the heat sink, allowance being made for the thermal resistance of the mounting.

Special derating may be necessary for high or low frequencies; at low frequencies because the junction temperature pulsates at the supply frequency and therefore reaches peaks of higher than the average value; and at higher frequencies because of the increasing effects of carrier storage.

3.4.2 Duty cycle current ratings. Current ratings for fluctuating loads are normally calculated from the dissipation characteristics given by the manufacturer and the transient thermal impedance data, the junction temperature being kept within the maximum rated value.

3.4.3 Fault current ratings. Manufacturer's data provide curves of permissible fault current versus time, showing the capability of the device to carry fault current while also carrying full load current.

Where the d.c. system on short-circuit produces a fault current greatly in excess of the rated load current, the magnitude of the resulting fault current and the time for fault protection equipment to interrupt this current is more likely to determine the current rating required of the diodes than the normal load current.

3.4.4 Parallel operation. For the general precautions to be observed when using diodes connected in parallel, see 2.1.3.6 and 2.3.4. of Part 1 of this code. Particular attention should be paid to the bus-bar layouts.

The number of diodes required may often be determined by the current under fault conditions rather than by the normal load current (see 3.4.3 and 3.7).

In some cases the number of parallel paths required per limb can be reduced by the use of rectifier circuits with a higher pulse number because

- (1) the total current is divided between the separate commutating groups, and
- (2) the prospective fault current is lower (see 4.7).

Grading according to forward voltage is usual for diodes used in parallel (see 2.1.3.7 of Part 1 of this code).

For controlled avalanche diodes it should be remembered that the spread of avalanche voltage is likely to be such that only one diode of a parallel group will absorb the reverse energy being dissipated. Thus the reverse dissipation capability of the group is no greater than that of any individual diode.

3.5 Losses. The losses in a diode are composed of three parts:

- (1) losses due to carrier storage;
- (2) losses due to forward voltage drop;
- (3) losses due to reverse leakage current.

Each of these may contribute significantly to the total diode dissipation.

The losses due to reverse leakage current and forward voltage drop can be calculated from the diode characteristics and the appropriate waveforms.

The loss due to carrier storage rises with frequency. It is normally negligible at frequencies less than 100 Hz, but for operation at higher frequencies the manufacturer should be consulted.

The total diode losses may be obtained from the manufacturer's power-loss curves.

3.6 Switching surges. Although in normal power rectification circuits the change from the forward conduction condition to the reverse blocking condition does not produce an excessive carrier current, special circumstances can arise where this occurs and the peak value of the initial reverse current may then be sufficient to cause failure of the diode. Obviously this may happen in a d.c. blocking application, but it can also occur in both single and three-phase rectification circuits where the load is highly inductive. Here the load current continues to flow after the a.c. supply is interrupted, 'freewheeling' through the rectifier circuit and decaying according to the time constant of the inductance of the load and the combined resistance of load and rectifier. If the a.c. supply to the rectifier is reconnected while the current is still of appreciable magnitude, one or two of the arms of the rectifier (according to the circuit used) may suddenly have applied to them a reverse voltage of high magnitude, depending on the instant in the cycle when the switch contacts reclose. Under this condition the peak magnitude of the carrier current is determined by the instantaneous value of this voltage and the transient impedance of the supply source only, and may be of such magnitude as to destroy the diode. One such application is a grab magnet fed by a rectifier that is directly connected to the mains supply.

Delay devices that prevent reclosing of the supply too soon after an interruption provide one method of preventing this trouble. Another method of reducing the effect is to insert a filter, consisting of a series inductance followed by a parallel capacitance, in each supply phase. Generally a double-wound transformer will provide the series inductance.

3.7 Overloads and output short-circuits. Power rectifiers are usually designed to be capable of delivering certain specified overloads, but they should be protected not only against overloads that are outside the specified limits as regards current or time, or both, but also against accidental output short-circuits.

The current under d.c. fault conditions is determined by the impedance of the circuit, which includes that of the supply system, transformer, busbars and connections.

Device manufacturers publish curves of overload characteristics that usually show the overload permitted when this is followed by a period at reduced load for a sufficient time to allow the temperature of the diode to fall to its normal full-load value. It is usually assumed that such overloads will occur infrequently in the life of the equipment. Where overloads occur frequently, a suitable derating allowance should be made and the manufacturer should be consulted as to the extent of this derating.

Where a power rectifier is to operate from a three-phase supply and is to provide an output having a specified voltage regulation, the magnitude of the transformer reactance is restricted by the necessity of meeting this voltage regulation. However, the relationship between transformer reactance and voltage regulation depends on the pulse number of the rectifier circuit and for the same voltage regulation, the transformer reactance can be doubled for twelve-pulse working as compared with six-pulse working. Provided that the secondary windings

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forming the different commutating groups of each phase are closely interwound (to reduce the leakage flux between them) this increase in the number of pulses can be used to reduce the level of the short-circuit current.

Usually it is the short-circuit current-time requirement that determines the current-carrying capability of the diodes rather than the rated load current, and hence, in large equipments, an increase in pulse number can reduce the number of parallel connected diodes required.

3.8 Overload and fault protection (fuses and circuit breakers). Reference to the overload characteristic curves published by device manufacturers shows that large overload currents or short-circuit currents have to be interrupted with very little delay if the diodes are not to be destroyed. This is a consequence of their small thermal mass relative to their loss dissipation and, in general, ordinary fuses are not fast enough to protect diodes against damage by fault currents. Protection against sustained overloads by means of fuses is, in general, not economically possible because the ratio of fusing current to sustained carrying current is too great.

For rectifier equipment of a few amperes capacity, overload and fault protection of the diodes may not be economical. Fuses will, however, be used to protect transformers, chokes and various other parts of the equipment.

For rectifier equipment of a few tens of amperes capacity the use of a special 'semiconductor' fuse is possible. These fuses are very fast in operation and for protection against fault conditions may interrupt the current before it reaches its prospective value. Such fuses may either be inserted in each limb of the rectifier or between the secondary winding of the transformer and the rectifier. These fuses can be selected to provide full protection, but sustained overload protection may only be possible if the diodes are operated with an appreciable current derating at full load.

For large equipment, overload protection is usually provided by a.c. circuit breakers controlled by inverse current-time relays. Special relays with time constants matching the average time constants of diodes and their heat sinks, so as to provide protection over a wide range of overloads without the nuisance of unnecessary tripping are available. Protection against load faults or short-circuits may be provided by d.c. circuit breakers, usually of the 'high-speed' type as in traction sub-station applications.

Consideration should be given to possible overloads caused by circuit-breaker operation. A.C. circuit breakers of the oil-immersed type usually interrupt the circuit at a zero current and do not produce appreciable overvoltages. Air-blast-type a.c. circuit breakers may, particularly on light loads, 'chop' or interrupt the circuit at an instant of time when the current is not zero. Interruption of the primary magnetizing current of the transformer in this way is a serious source of overvoltage (see 3.3.2).

D.C. circuit breakers interrupt the circuit by introducing an arcing voltage in excess of the circuit voltage, this excess 'counter-e.m.f.' opposing the inductive voltages in the circuit as the current decays. Care should be taken to see that the diodes have a sufficiently high value of non-repetitive peak reverse voltage rating (V_{RSM}) to withstand that portion of the arc voltage of the d.c. circuit breaker that is generated by the decay of the fault current in the a.c. portion of the fault circuits (mainly the transformer leakage reactance). Therefore, from the viewpoint of the diode voltage rating, it may be necessary to compromise in the choice of the circuit-breaker design between a fast fault clearance with a high value of arcing voltage and a slower fault clearance with a lower value of arcing voltage.

3.9 Protection against diode reverse failure. Where four or more diodes are used in parallel in each limb of a rectifier it is usual to provide one path more than is necessary to accommodate the rated current, then if one diode in a parallel group suffers reverse failure it can be isolated from the system by a suitable fuse and the equipment can continue to operate.

When a diode fails in this way it is a total loss and cannot be saved by any form of protection. Since, however, it places a short-circuit on the transformer through the other diodes it has to be isolated as quickly as possible to prevent it from causing further damage. Where four or more diodes are in parallel it is not difficult to achieve discrimination so that only the fuse in series with the failed diode is blown and not the fuses in the other limbs through which the fault current also flows.

Discrimination is also possible so that diode fuses are not blown by through-faults (load short-circuits) while the main protection is operating. To achieve such discrimination, a careful choice of size of fuse is made and a special class of 'semiconductor' fuse is used. These special fuses are very fast in operation and prevent the current reaching its prospective value. This latter feature removes the possibility of the diodes' failure operating the main protective system, which is essential if the equipment is to remain in operation. Such fuses are designed to operate with a limited arcing voltage in order not to cause an excessive voltage across diodes that are in parallel with the one that has failed. The arcing voltage is given as part of the fuse data and allowance has to be made for this when considering the voltage rating of the diodes.

'Striker pin' fuses are commonly connected in parallel with diode fuses to give a visual indication of a blown fuse and are also often employed to operate microswitches and give remote indication that a diode has failed in the equipment.

When fewer than four diodes are connected in parallel in each limb it is not usually possible to provide economically for operation with one failed diode and arrangements have to be made for a diode failure to cause complete shut-down of the equipment. This can be provided by instantaneous overcurrent relays tripping the main circuit breaker or by diode fuses with associated 'striker pin' fuses arranged so that the operation of a 'striker pin' trips the main circuit breaker, ensuring that the equipment cannot be left on load with one diode failed, thus overloading other diodes.

Diodes are sometimes provided as units complete with heat sinks, with shunt resistors and capacitors and also with diode fuses. If a number of such units are connected in series to produce a higher voltage, it may be necessary to replace these individual fuses by a single fuse with a voltage rating suitable for the higher voltage. If this is not done there is a risk that one of the fuses connected in series may commence to fuse first and thus insert its arc voltage into the circuit, thereby commencing to reduce the fault current and perhaps prevent the others from fusing. The low arc voltage of the one that is fusing will then take a relatively long time to reduce the current to the extinguishing value and before this occurs the arc inside the fuse may have burned through an end cap of the fuse and produced a dangerous condition with the evolution of ionized gas.

4. Special considerations applicable to microwave diodes

This clause lists some of the special considerations that apply to the use of microwave diodes and should be read in conjunction with Part 1 of this code.

4.1 Causes of damage. Microwave diodes are easily damaged because they have a small contact or junction area (to minimize their capacitance) and because they have a low turnover voltage and high forward conductance. Such damage is called burn-out and can be caused by:

- (1) transmit/receive (T.R.) cell leakage in excess of the burn-out rating of mixer diodes;
- (2) pulse power absorption in excess of the rating of detector diodes;
- (3) stray oscillatory voltages across the diode;
- (4) excessive d.c. voltages;
- (5) discharge of static electricity through the diode;
- (6) stray radio-frequency (r.f.) radiation, e.g. exposing unshielded microwave diodes to intense r.f. fields.

4.2 Precautions. Precautions should be taken to reduce the likelihood of burn-out, for example,

- (1) the diode socket can be checked for voltages with the diode out of circuit but the equipment otherwise working;
- (2) for testing diodes, properly designed test sets in which the applied voltage does not exceed 0.5 V in either direction can be used;
- (3) metal shields should not be removed until the last possible moment.

4.3 Mechanical compatibility. Microwave diodes are associated with transmission lines or with wave-guides and the diodes are therefore designed to be mechanically compatible with these. The diode mount should be designed to accommodate satisfactorily any diode complying with the relevant outline drawing.

5. Special considerations applicable to photo-sensitive devices

This clause lists some of the special considerations that apply to the use of photo-sensitive devices and should be read in conjunction with Part 1 of this code.

5.1 Types of device. There are three main types of photo-sensitive semiconductor devices: photo-diodes, photo-transistors and photo-conductive cells. These involve a wide range of basic semiconductor materials and are available in many configurations with widely varying limitations that necessitate very careful attention to the manufacturer's data sheet.