Bipolar Power Control Circuits
Data Book
1996

TEMIC
Semiconductors

Table of Contents

Alphanumeric Index

1 Explanation of Technical Data

1.1 Arrangement of Symbols According to DIN 41875 and IEC

For currents, voltages and power basic letter symbols are used. These basic symbols are having either upper-case (capital) or lower case (small) letters. Capital basic letters are used for the representation of peak, mean, dc or root-mean square values. Small basic letters are used for the representation of instantaneous values which vary with time.

In subscript (index), capital letters are used to represent continuous or total values, whereas small letters are used to represent the varying component alone. The following table illustrates the application of the rules given above.

Table 1.

Basic Letter	
Lower Case	Upper Case
Instantaneous values which vary with time	Maximum (peak), average (mean) continuous (dc) or root-mean square (RMS) values

Subscript(s)	
Lower Case	Upper Case
Varying component alone, i.e.: instantaneous, root-mean square, maximum or average values	Continuous (without signal) or total (instantaneous, average or maximum) values

Letter symbols for impedance, admittances, four-pole parameters etc.

In the case of impedances and admittances, four-pole parameters etc., upper-case basic letters are used for the representation of external circuits and of circuits in which the device forms only a part. Lower-case basic letters are used for the representation of electrical parameters inherent in the device.

These rules are not valid for inductances and capacitances. Both these quantities are denoted with capital basic letters.

In the index, upper-case letters are used for the designation of static (dc) values, whereas the lower-case letters are meant for the designation of small-signal values.

If more than one subscript is used (h_{FE}, h_{fe}), the letter symbols are either all upper-case or all lowercase.

If the index has numeric (single, double, etc.) as well as letter symbol(s), such as h_{21E} or h_{21e}, the differentiation between static or small-signal values is made only by a subscript letter symbol.

The following table illustrates the application of the rules given above.

Table 2.

Basic Letter	
Lower Case	Upper Case
Electrical parameters inherent in the semiconductor devices except inductance and capacitance	Electrical parameters of external circuits and of circuits in which the semiconductor device forms only a part; all inductance and capacitance

Subscript(s)	
Lower Case	Upper Case
Small-signal values	Static (dc) values

Examples:

R_G
Generator resistance

G_p
Power gain

h_{FE}
DC forward current transfer ratio in common emitter configuration

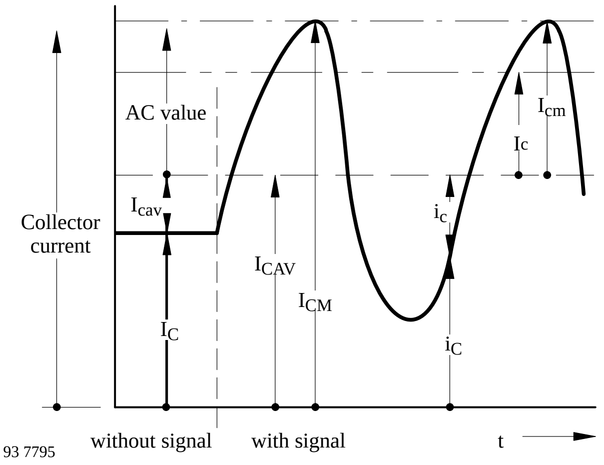
r_p
Parallel resistance, damping resistance

1.2 Examples of the Application of Symbols According to DIN 41785 and IEC 148

The figure below represents a transistor collector current consisting of a continuous (dc) current and a varying component.

Example of the application of the rules:

a) Transistor



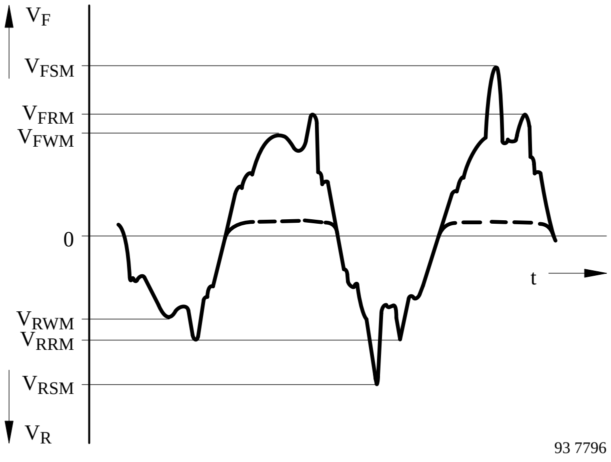
I_C	DC value, no signal
I_{CAV}	Average total value
I_{cav}	Average varying component value
I_{CM}	Maximum total value
I_c	RMS varying component
I_{cm}	Maximum varying component value
i_C	Instantaneous total value
i_c	Instantaneous varying component value

<u>It is valid:</u>

$I_{CM} = I_{CAV} + I_{cm}$

$i_C = I_{CAV} + i_c$

b) Diode



V_F	Forward voltage
V_R	Reverse voltage
V_{FSM}	Surge forward voltage (non-repetitive)
V_{RSM}	Surge reverse voltage (non-repetitive)
V_{FRM}	Repetitive peak forward voltage
V_{RRM}	Repetitive peak reverse voltage
V_{FWM}	Crest working forward voltage
V_{RWM}	Crest working reverse voltage

1.3 Letter Symbols

Letter symbols for currents, voltages, power etc. are used according to IEC publication 27. The standards given there are applicable, except where this chapter gives different standards. This is the case, e.g., in phase control circuits and zero voltage switches.

e.g:
V, v = Voltage (dc, ac)
I, i = Current
P = Power
T = Temperature
TC = Temperature coefficient
α = Phase angle

Subscripts:
AV, av = Average
F, f = Forward
I = Input
O = Open, output or zero
Ref, ref = Reference
tot = Total
S, s, k = Short circuit or, as a second subscript, surge
T = Threshold

e.g. with subscripts:
V_S = Supply voltage (dc)
I_S = Supply current
V_{Ref}, V_{ref} = Reference voltage
T_{amb} = Ambient temperature
V_T = Threshold voltage
V_{T7O} = Threshold voltage 70%
V_R = Reverse voltage
I_R = Reverse current
V_{os} = Off-set voltage

I_{IO} = Input zero current
V_{IO} = Input zero voltage
I_I = Input current
V_M = Mains voltage
V_{sat} = Saturation voltage
t_p = Pulse duration
t_r = Rise time
t_f = Fall time
G_V = Voltage gain
G_I = Current gain
V_{ICR} = Common-mode voltage range
CMR = Common-mode rejection
I_{HD}, I_L = Latching current, load current
I_H = Holding current

Use of Upper-Case Letters

Upper-case basic letters should be used for the representation of:

a) Maximum (peak) values

b) Average (mean) values

c) Continuous (dc) values

d) Root mean square values

Use of Lower-Case Letters

Lower-case basic letters should be used for the representation of instantaneous values which vary with time.

Note: In data sheets

R_V = R_1 = Series resistance, dropper resistance

C_V = C_1 = Series capacitance

I_K = (Transformer) short-circuit current
= Constant current

2 Mounting Instructions

2.1 Soldering Instructions

The integrated circuits must be protected against overheating when soldering is carried out. If necessary, adequate measures must be taken for sufficient heat transfer. The following maximum soldering conditions should not be exceeded:

	Iron Soldering			Dip or Flow Soldering		
	Iron Temperature	Soldering Distance from the Case	Max. Allowable Soldering Time	Soldering Temperature	Soldering Distance from the Case	Max. Allowable Soldering Time
Metal case	≤ 245°C ≤ 245°C ≤ 245 to 350°C	1.5 to 5 mm > 5 mm > 5 mm	5 s 10 s 5 s	≤ 245°C ≤ 245 to 300°C	> 1.5 mm > 5 mm	5 s 3 s
Plastic case	≤ 245°C ≤ 245°C	2 to 5 mm > 5 mm	3 s 5 s	≤ 245°C ≤ 245 to 300°C	> 2 mm > 5 mm	3 s 3 s

2.2 Heat Removal

To keep the thermal equilibrium, the heat generated in the semiconductor junction(s) must be removed to the ambient.

In the case of low-power devices, the natural heat conductive path between case and surrounding air is usually adequate for this purpose.

However, in the case of medium-power devices, heat radiation must be improved by the heat dissipators, which increase the heat radiating surface.

Finally, in the case of high-power devices special heat sinks must be provided, the cooling effect of which can be increased further by the use of special coolants or air blowers.

The heat generated in the junction is conveyed to the case or header by conduction rather than convection; a measure of the effectiveness of heat conduction is the inner thermal resistance junction case, R_{thJC}, the value of which is governed by the construction of the device.

Any heat transfer from the case to the surrounding air involves radiation convection and conduction, the effectiveness of transfer being expressed in terms of an R_{thCA} value, i.e., the external or case-ambient thermal resistance. The total thermal resistance junction ambient is consequently:

$R_{thJA} = R_{thJC} + R_{thCA}$

The total maximum power dissipation, $P_{tot\ max}$, of a semiconductor device can be expressed as follows:

$$P_{tot\ max} = \frac{T_{jmax} - T_{amb}}{R_{thJA}} = \frac{T_{jmax} - T_{amb}}{R_{thJC} + R_{thCA}}$$

whereas

T_{jmax}
is the maximum temperature of a representative junction area on the silicon chip.

T_{amb}
is the highest ambient temperature likely to be reached under the most unfavorable conditions.

R_{thJC}
is the thermal resistance, junction case.

R_{thJA}
is the thermal resistance, junction ambient.

3 Quality Data

With an extensive system consisting of qualification, intermediate and final tests, TEMIC endeavours to supply the customers with components which fulfil the specifications of the OEM industry.

3.1 Delivery Quality

To secure the delivery quality, the following specifications are given:

- Maximum and minimum values of the characteristics
- AQL- (**A**cceptable **Q**uality **L**evel) values

Shipment lots whose defect percentage is equal to or less than the percentage given in AQL value shall be accepted with greater probability (L ≥ 90%) due to sampling tests (see the single sampling plan in chapter ‘Sampling Inspection Plans’).

3.2 Classification of Defects

The possible defects with which a semiconductor device can be subjected are classified according to the probable influence of existing circuits:

- Total (critical) defect

When one of these defects occurs, the functional use of the device is impossible.

Examples:
Open contacts, inter-electrode short circuits, breakdown in reverse characteristics, wrong type designation, broken leads, critical case defects

- Major defect

A defect which is responsible for the failure of a device.

If the specified limits given in the data sheets are exceeded, it is considered as a major defect. Typical values are given for orientation but are not tested.

- Minor defect

A defect which is responsible for the function of a device with no or only a slight reduction in effectiveness

There could be external defects such as wrong marking or light scratches.

3.3 AQL Values

According to the classification of defects mentioned in the chapter before, the following AQL values are valid for data sheets of semiconductor devices for professional equipments and applications unless otherwise specified. Inspection follows the single sampling plan for attribute testing, AEG 1415 (see chapter ‘Sampling Inspection Plans’), which corresponds mainly to DIN 40080 or MIL-STD-105 D inspection level II.

Quality Level	
Defect	IC
Total defect	0.1
Major defect	0.25
Minor defects	0.4
Sum of all defects	0.4

Different qualities required by the customer are possible, but require a special agreement.

3.4 Sampling Inspection Plans

List of symbols:

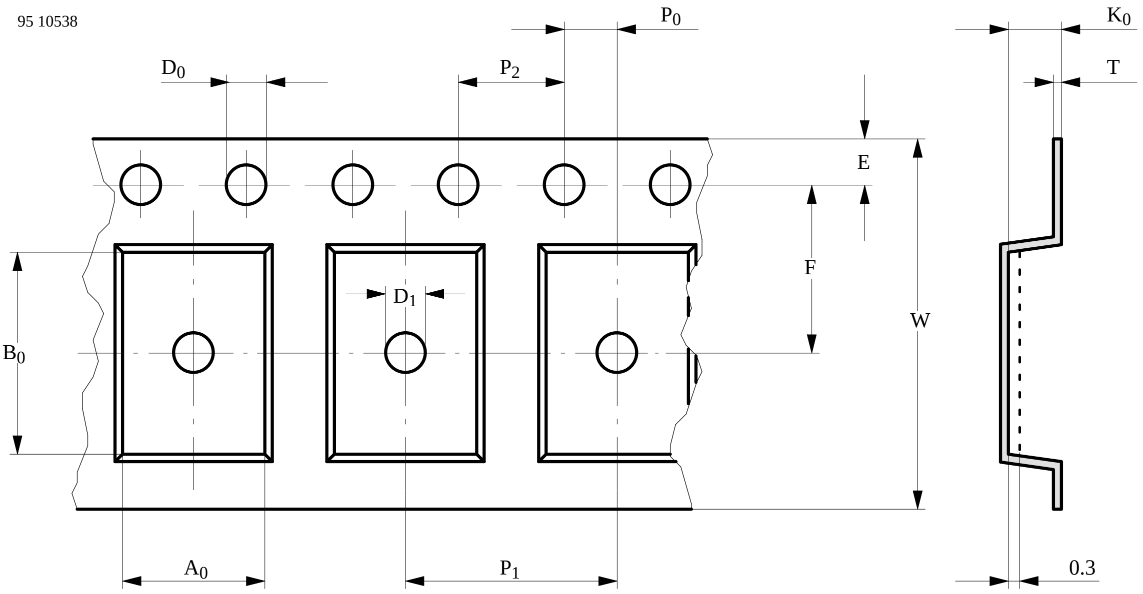
AQL	Acceptable Quality Level
N	Lot size
n	Sample size
c	Acceptance number
D_{max}	Average outgoing quality level

Single Sampling Plan for Attribute Testing According to DIN 40080 (MIL-STD 105 D)

Normal Inspection	AQL											Reduced Inspection
	0.06	0.10	0.15	0.25	0.40	0.65	1.0	1.5	2.5	4.0	6.5	
N	n–c (D$_{max}$ in %)											N
2–15	200–0 (0.18)	125–0 (0.29)	80–0 (0.45)	50–0 (0.71)	32–0 (1.1)	20–0 (1.7)	13–0 (2.6)	8–0 (3.9)	5–0 (6.7)	3–0 (9.6)	2–0 (15.6)	2–15
16–50										13–1 (4.8)	8–1 (9.2)	16–150
51–150								32–1 (2.3)	20–1 (3.6)	20–2 (6.0)	20–3 (8.4)	151–280
151–280							50–1 (1.5)		32–2 (3.8)	32–3 (5.4)	32–5 (8.8)	281–500
281–500						80–1 (1.0)		50–2 (2.4)	50–3 (3.5)	50–5 (5.7)	50–7 (8.1)	501–1200
501–1200					125–1 (0.64)		80–2 (1.6)	80–3 (2.2)	80–5 (3.7)	80–7 (5.2)	80–10 (7.7)	1201–3200
1201–3200				200–1 (0.41)		125–2 (1.1)	125–3 (1.5)	125–5 (2.4)	125–7 (3.5)	125–10 (5.0)	125–14 (7.2)	3201–10000
2101–10000			315–1 (0.27)		200–2 (0.68)	200–3 (0.68)	200–5 (1.6)	200–7 (2.2)	200–10 (3.2)	200–14 (4.6)	200–21 (7.3)	10001–35000
10001–35000		500–1 (0.17)		315–2 (0.44)	315–3 (0.61)	315–5 (0.99)	315–7 (1.4)	315–10 (2.1)	315–14 (3.0)	315–21 (4.7)		

1) Lot size above 35000 must be divided

4 Packaging Information

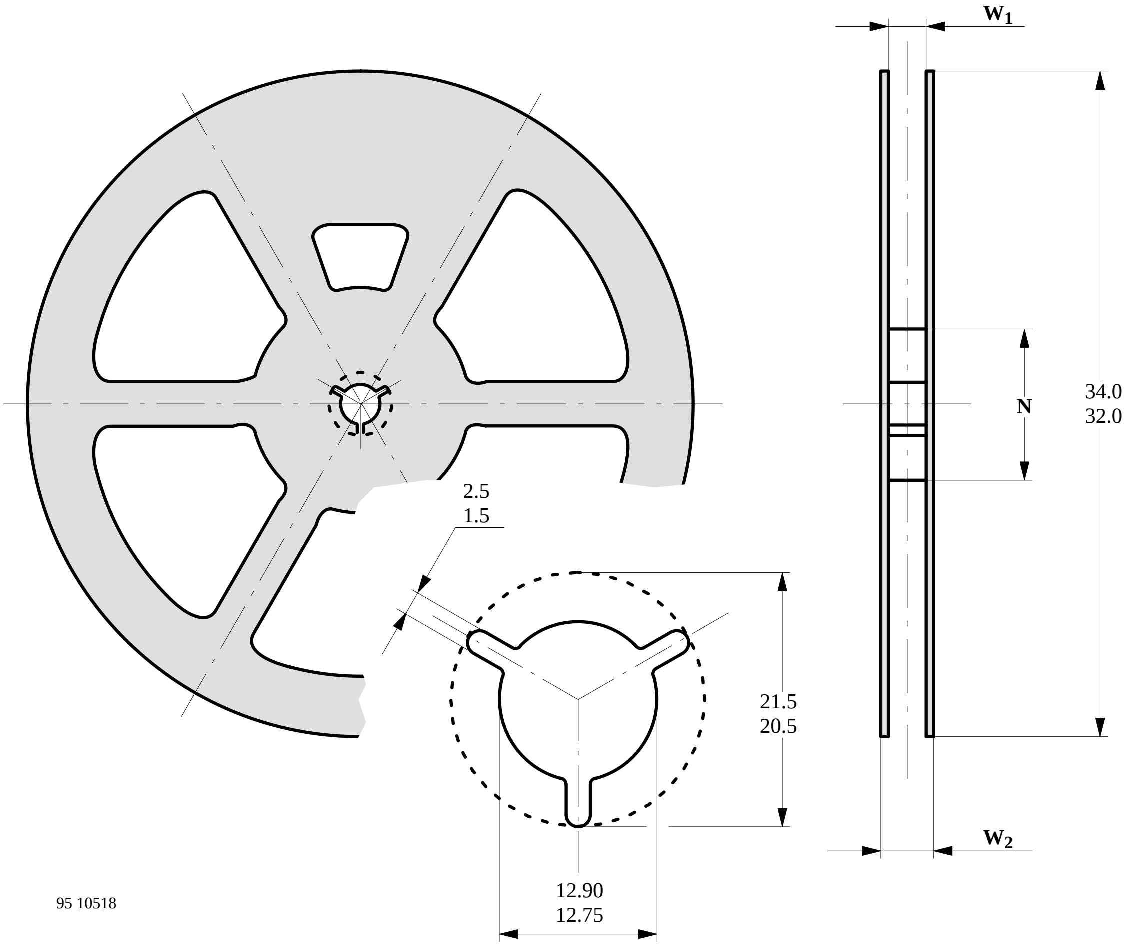


Package	Punched Cavity			Carrier Tape Sizes									Material
	A_0	B_0	K_0	W	T	P_0	P_2	P_1	D_0	D_1	E	F	
SO8	6.4 ± 0.1	5.2 ± 0.1	2.1 ± 0.1	12 ± 0.3	0.3 max.	4 ± 0.1	2 ± 0.1	8 ± 0.1	1.5 + 0.1	1.5 ± 0.1	1.75 + 0.1	5.5 ± 0.05	Conductive
SO16	6.4 ± 0.1	10.3 ± 0.1	2.1 ± 0.1	16 ± 0.3	0.3 max.	4 ± 0.1	2 ± 0.1	8 ± 0.1	1.5 + 0.1	1.5 + 0.1	1.75 + 0.1	7.5 ± 0.05	Conductive
SO16L	10.9 ± 0.1	10.7 ± 0.1	3 ± 0.1	16 ± 0.3	0.3 max.	4 ± 0.1	2 ± 0.1	12 ± 0.1	1.5 + 0.1	1.5 + 0.1	1.75 + 0.1	7.5 ± 0.05	Conductive
SO20L	10.9 ± 0.1	13.2 ± 0.1	3 ± 0.1	24 ± 0.3	0.3 max.	4 ± 0.1	2 ± 0.1	12 ± 0.1	1.5 + 0.1	1.5 + 0.1	1.75 + 0.1	11.5 ± 0.1	Conductive

All dimensions in mm

Packaging Information

SO8 – 16, SSO20 – 28 tape and reel



Version	Tape Width “W”	“N”	“W_1”	“W_2 max.”
A	12	60 +2.5 / – 0	12.4 +2 / –0	18.4
B	16	60 +2.5 / – 0	16.4 +2 / –0	22.4
C	24	100 ± 1.5	24.4 +2 / –0	30.4

All dimensions in mm

5 Explanation of General Terminology – Definitions

Phase Angle, Current Flow Angle, α_{max} Set:

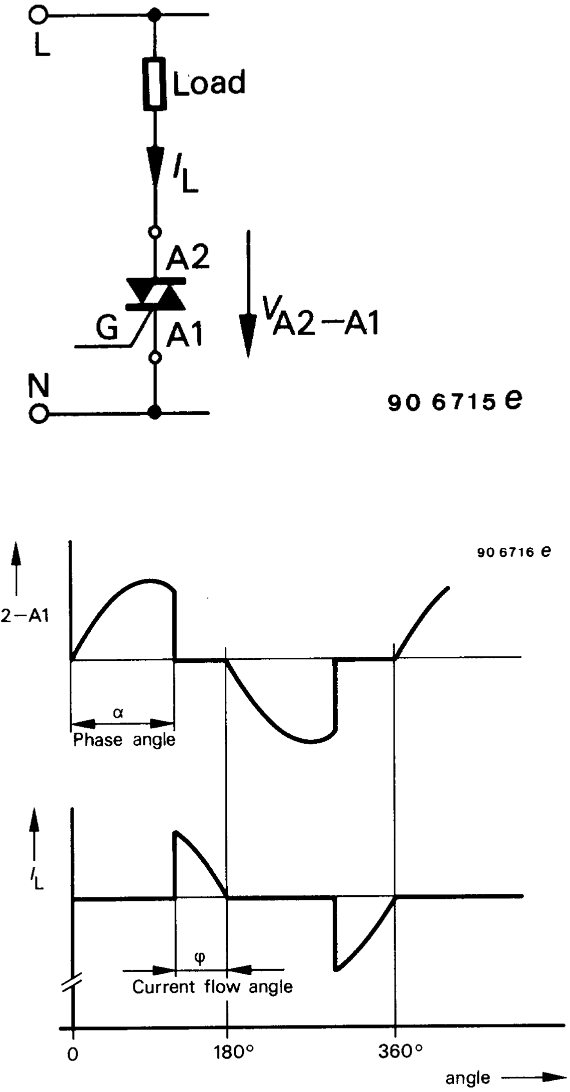


Figure 5.1.

Figure 5.1 shows the relationship between the phase angle (α) and the current flow angle (φ).

The time or angle where no current flows through the load (I_L = 0) is known as the phase angle.

The angle where the current is passed to the load for the remaining part of the sine half-wave, after the triggering of the triac or thyristor, is referred to as the current flow angle.

When the value of the phase angle is high, the energy (power) supplied to the load is low; but when the value of the current flow angle is high, the energy supplied is also high.

The term phase angle "α_{max}" means the angle which is determined with inactive control voltage by the voltage slope at the ramp capacitor C_φ owing to the charge current preset with R_φ. In applications where the phase angle extends beyond the control voltage of 180 to 0°, α_{max} must be set greater than 180° with R_φ.

For detailed informations regarding C_φ and R_φ, please refer to data sheet TEA1007.

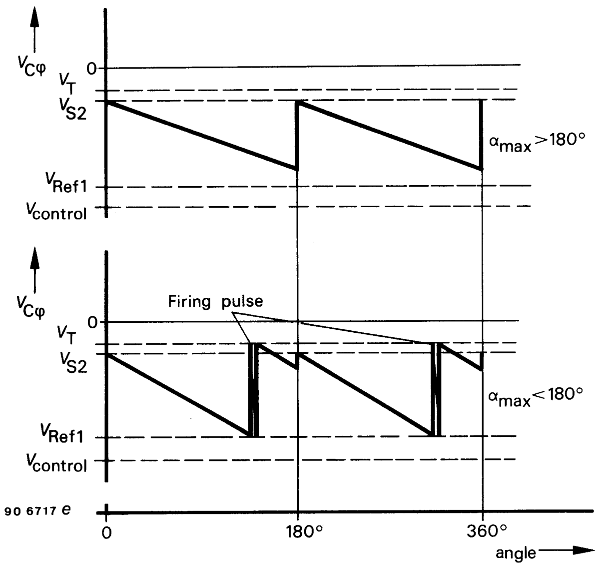


Figure 5.2.

Load Current Feedback (Compensation)

This is an alternative to speed control with feedback using a rotational speed sensor or control of the armature feedback voltage, as a load-independent speed characteristic.

For this purpose, the load current is detected (and controlled) via a shunt resistor. The direction of action and the weighting of the load-proportional signal is modulated on the selected set point so that as the load increases, the right amount of power is supplied to the drive to produce as low a rotational speed drop as possible.

Automatic Retriggering

The automatic retriggering circuit monitors the state of the triac after triggering. Dependent upon the type of circuit, this is carried out by the voltage detection of anode A2 or of gate G on the triac. This is shown in figures 5.3 and 5.4.

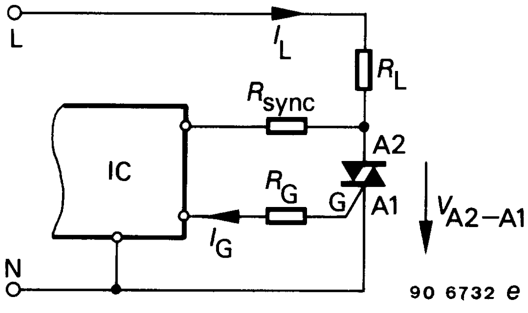


Figure 5.3. Triac state scanning via R_{sync} at A2

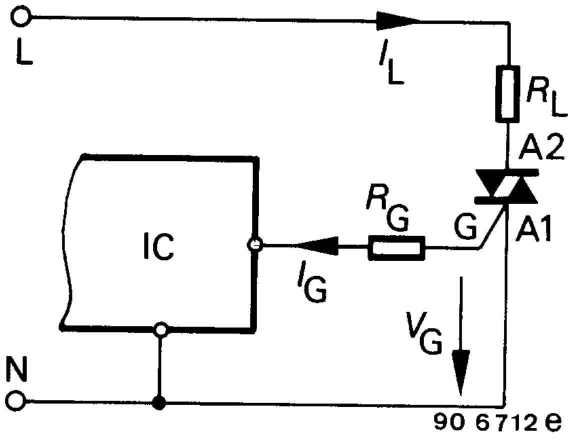


Figure 5.4. Triac state scanning via the control gate G

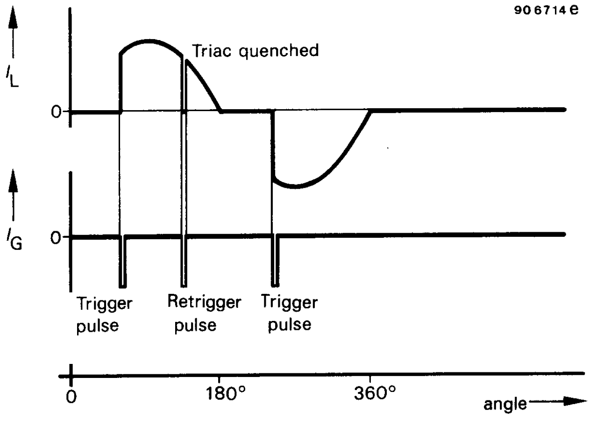


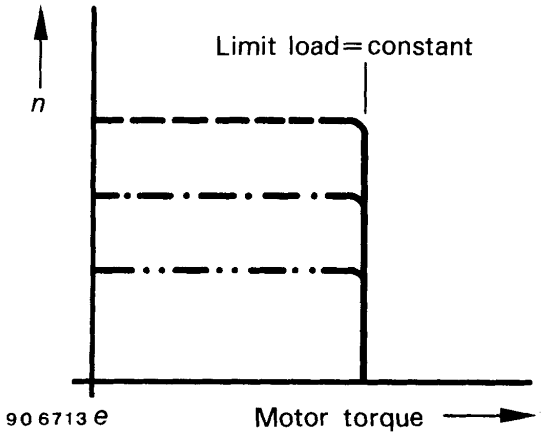
Figure 5.5.

If the triac is quenched within the relevant half wave after triggering (for example owing to low load currents before or after the zero crossing of current wave; or for commutator motors owing to brush lifters), the automatic retriggering circuit ensures immediate retriggering, if necessary with a high trigger rate, until the triac remains reliably triggered.

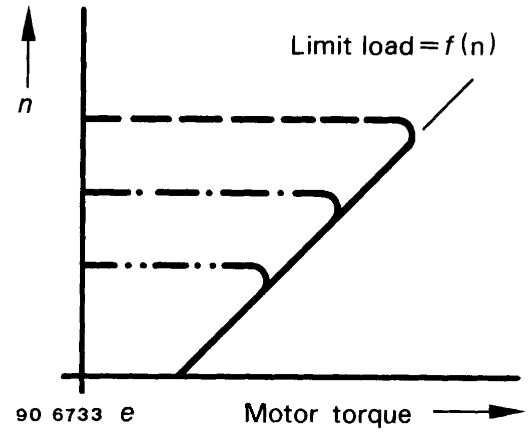
Foldback

Foldback is a technique used here for protecting electrically-driven motors from short circuits. After a certain output level is reached, any further load on the regulator results in less rather than more current.

Besides limit-load cut-off with or without automatic restart, another method is that of limit-load control (figure 5.6.a). In this case, the output torque remains constant.



a) Limit-load control with constant torque



b) Limit-load control with “foldback” characteristic

Figure 5.6.

A limit-load control circuit with foldback characteristic is characterized by the fact that the (cut-off) point of limit-load control is dependent on the relevant speed (figure 5.6.b). This mode of operation is possible due to the fact that a motor permits higher power consumption at high speed than at low speed due to the improved cooling action.

Periodic Pulse-Train Control (Symmetrical Burst Control)

In contrast to phase control which is based upon power control per half-wave, the periodic pulse-train control system cyclically supplies a certain number of pulses (one period = positive and negative half-wave) to the load (see figure 5.7). The number of periodic pulse trains can be controlled within a given cycle time (ramp time), thus determining the supplied power.

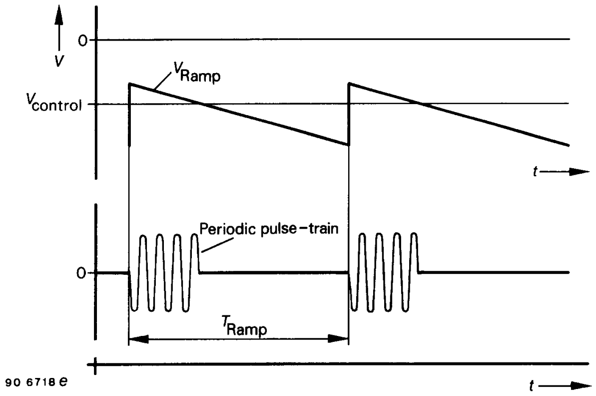


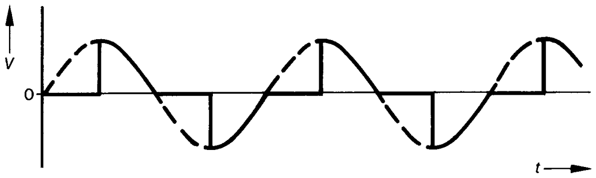
Figure 5.7.

A periodic pulse-train control system is used wherever the load-specific time constant increases by about 300 ms, e.g., heating systems with a power delay or inertia. This system is not appropriate for motor or lighting control systems.

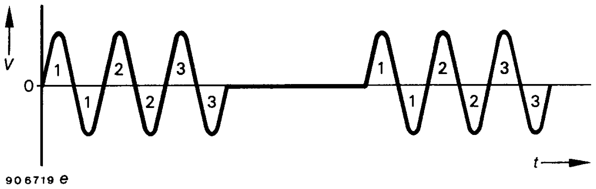
The periodic pulse-train control system is generally switched at the zero crossing point so that, unlike the phase control system, it does not produce interference. This means that no interference-suppression measures are required.

Full-Wave Control

The term “full-wave control” generally means symmetrical control of the positive and negative half-wave of mains-powered loads. Full-wave control is always required if it is necessary to eliminate the possibility of the mains or load being influenced by dc. This means that the arithmetic mean of the voltage-time integral of both polarities must be zero. This requirement applies both to the phase control (see figure 5.8.a) and to the periodic pulse-train control (see figure 5.8.b). Full-wave control is particularly important in relation to operation of inductive loads such as transformers or magnetron tubes.



a) Full-wave phase control



b) Full-wave periodic pulse train control

Figure 5.8.

Pulse-Position Optimization

A pulse-position-optimized zero-voltage switch allows for the triac characteristics in relation to the ratio of “holding current to latching current” of approximately 1:2. This is why the trigger pulse on such circuits is not generated symmetrically with the zero crossing, but with the time ratio of the trigger pulse before the zero crossing to that after the zero crossing is selected according to the situation, also at 1:2.

The required triggering power can be reduced in this way by approximately 25%, as compared with symmetrical triggering.

The first pulse (see figure 5.9.a) is to ignite the triac, whereas the following pulses (see figure 5.9.b) are dimensioned in such a way that the triac cannot be switched off (holding current) during the mains zero crossing. The interference signal is therefore not generated.

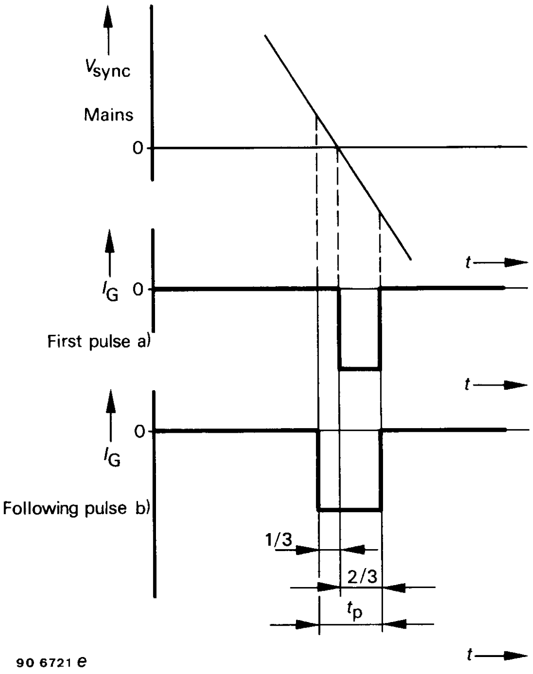


Figure 5.9.

Flicker Standard

The European Standard EN60555, Part 3, defines the operation of domestic appliances and similar electrical devices and their effect upon the mains power-supply system.

Switching a load connected to the mains generates a voltage fade which corresponds to the mains impedance. This voltage fade may result in a light “flickering” if the lamps are operated at the same time. The Standard defines the maximum possible switching frequency (minimum possible cycle time) at a given load, see figure 5.10.

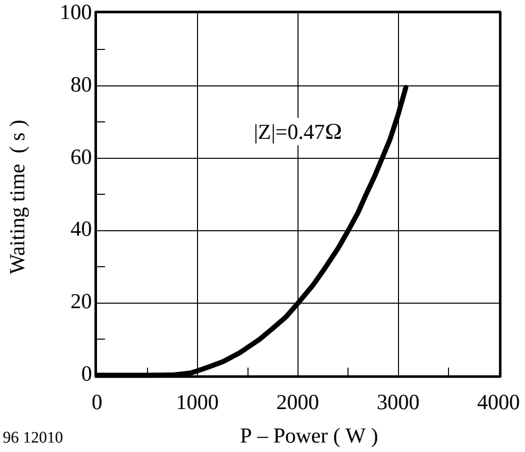


Figure 5.10.

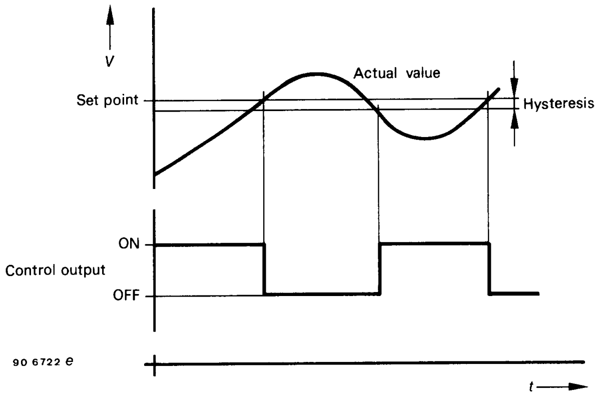
Two-Point Control/ Proportional Control

A two-point controller is characterized by the fact that the control output remains active until the actual value has reached the set point. If the actual value drops below the set point threshold less an hysteresis, the control output is switched back to 100% active. In the case of controlled systems with long dead time or long delay, such as space heaters, a two-point control system frequently tends to produce undesirable overshoot of the set point (see figure 5.11.a).

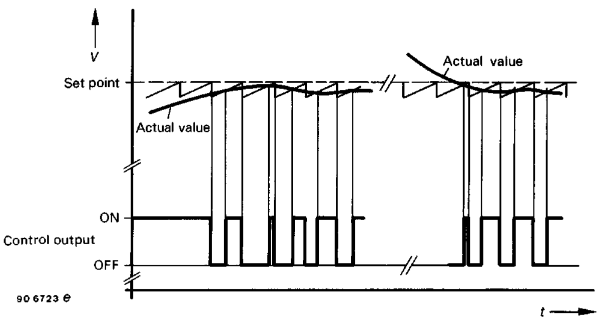
In such cases, proportional controllers are generally used in order to avoid an oscillating control behavior. Proportional controllers contain a ramp generator whose ramp voltage has a modulating influence (proportional band) on the set point or actual value (see figure 5.11.b).

If the set point or actual value is within the proportional band, the on/off ratio is reduced within the ramp cycle time with decreased spacing between the set point and the actual value.

This means that the control output reduces the power supplied, dependent upon the proportional bandwidth, before the set point is reached.



a) Two-point control



b) Proportional control

Figure 5.11.

General Information on Ratings when Designing the Circuit Power Supply

Many circuits described in this book aim to support power control with a triac connected to the mains (220 V∼ or 110 V∼). For this purpose, the circuits are generally powered directly by the mains and, if necessary, synchronized.

The following section shows the possible methods of powering the circuit and intends to provide the user with appropriate selection criteria and aids to rating. The corresponding data sheets specify versions and methods which differ from this.

Basically, the power supply series resistance may be either ohmic or capacitive. However, provided the power dissipation permits, an ohmic series resistance should always be given preference, see figure 5.12, since an additional circuit is required for protection against mains spikes in the case of capacitive supply, see figure 5.13.

If a capacitive series impedance is used, see figure 5.13, a current-limiting series resistor R'_1 should be used to protect against sharp mains spikes. R'_1 should be $\approx$ (1/10) X_C.

A Z-diode is needed not only to reverse the charge of C_0 in the positive half-wave, but it also adds supplementary voltage limiting.

Rating of the series impedance R_1, Z_1:

$$R_{1\,max} = Z_{1\,max} = 0.85\,\frac{V_{M\,min} - V_{S\,max}}{2 \times I_{tot}}$$

I_{tot} = $I_S + I_P + I_X$

where:

I_{tot} = Total current consumption

I_S = Current requirement of the IC

I_P = Average current requirement of the triggering pulses

I_X = Current requirement of other peripheral components

$$R_{1\,min} = Z_{1\,min} = \frac{V_{M\,max} - V_{S\,min}}{2 \times I_{Smax}}$$

$$Z_1 = \sqrt{X_c^{\,2} + (R_1)^2}$$

if $R_1 \approx$ (1/10) X_c then

$$Z_1 \approx X_c = \frac{1}{\omega \times C_0} \quad \Rightarrow \quad C_0 = \frac{1}{\omega \times X_c}$$

I_{smax} is the limiting value of the circuit current consumption. Power dissipation of series impedance:

$$P_{(R1)} = \frac{(V_M - V_S)^2}{2 \times R_1}$$

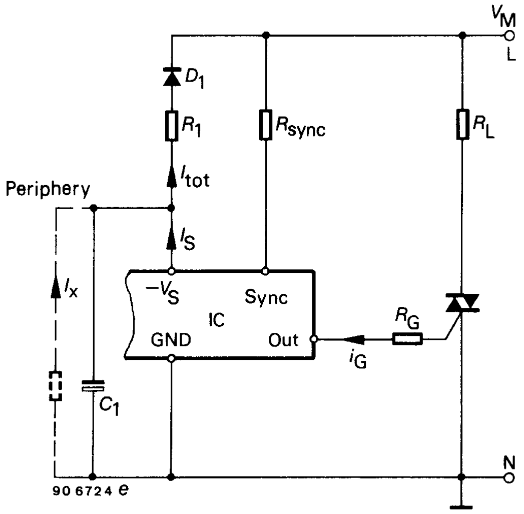


Figure 5.12. Power supply via series resistance

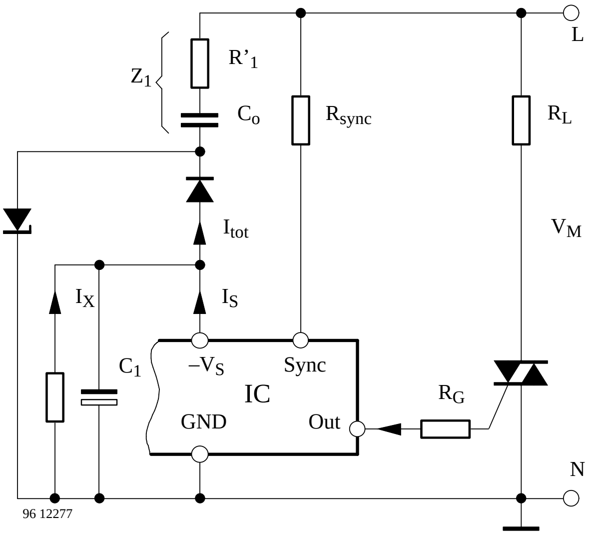


Figure 5.13. Power supply via capacitive series impedance

Low-Voltage Power Supply

A low-voltage power supply with a transformer is always recommended either if a higher supply current is required for other peripheral components, see figures 5.14 and 5.15, or if the circuit must be operated with electrical isolation (see figures 5.16 and 5.17).

In both cases, synchronization can be derived from the low voltage. The half-wave information must be retained for synchronizing zero-voltage switch circuits (bridge rectification is not possible), whilst zero synchronization is adequate in the case of phase-controlled circuits.

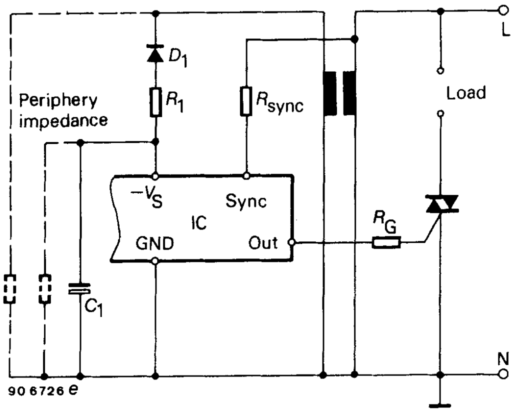


Figure 5.14.

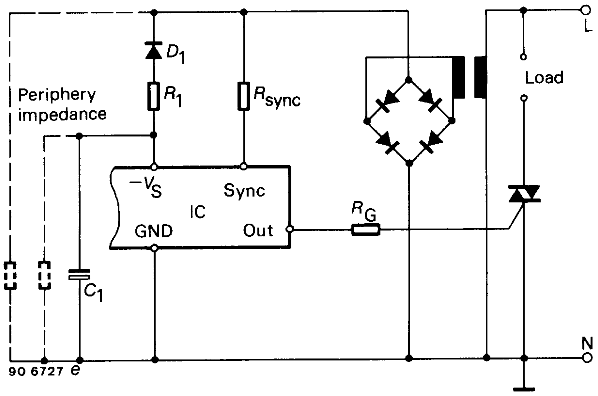


Figure 5.15. Low-voltage power supply with zero synchronization for phase control applications

The application with zero voltage should be tested individually, so that the phase shift between the mains and the secondary voltage at the transformer with regards to sync. can be accepted. A sync. pulse is recommended direct from the mains for systems which are not galvanically isolated.

Apart from transformer power supply, an electrically isolated triac control circuit is required for implementing electrically-isolated control systems. Figures 5.16 and 5.17 show possible methods of doing this.

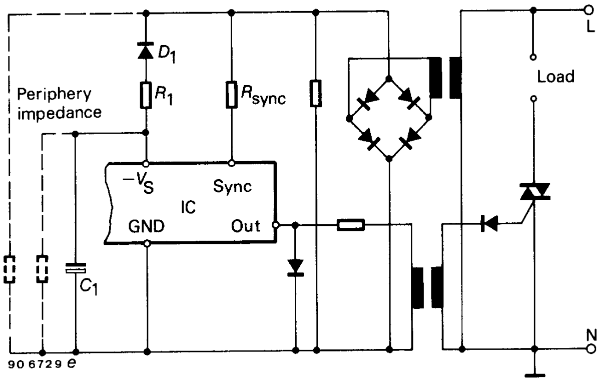


Figure 5.16. Triac control with firing transformer

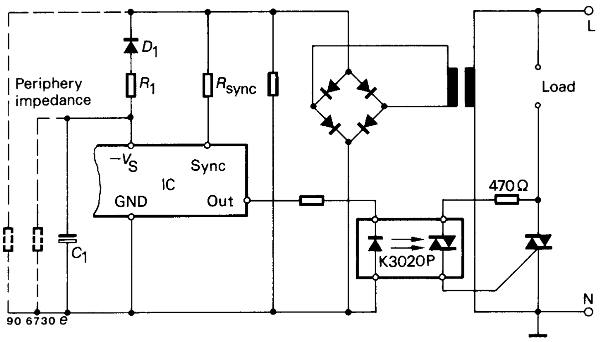


Figure 5.17. Triac control with optotriac

Selection of the Transformer Voltage

With regard to synchronization, a high primary voltage must be selected in order to generate the best possible zero voltage crossing point which is sharp.

However, the primary voltage determines the power dissipation on the limiting resistor R_1 at a corresponding total current consumption. In practice, it has proven useful to select a primary nominal voltage which is approximately twice the value of the relevant circuit operating voltage.

The following approximate formula can be applied calculating the rating for R_1:

$$R_{1\,max} \approx 0.85\,\frac{V_{O\,min} - V_{S\,max}}{2 \times I_{tot}} - \frac{V_O}{I_K} \quad \text{for half-wave rectification}$$

$$R_{1\,max} \approx 0.85\,\frac{V_{O\,min} - V_{S\,max}}{I_{tot}} - \frac{V_O}{I_K} \quad \text{for bridge rectification}$$

$$R_{1\,max} \approx 0.85\,\frac{V_{O\,max} - V_{S\,min}}{\hat{I}_{S\,max}}$$

V_O = Transformer no-load voltage

V_S = Circuit supply voltage

I_{tot} = Total current requirement

I_K = Transformer short-circuit current