Textbook for Vocational Training – Components of Electrical Engineering/Electronics – Part 1

Table of Contents

Textbook for Vocational Training – Components of Electrical Engineering/Electronics – Part 1

CRYSTAL

Feedback: IBE e.V.
91–34–0214/2

Deutsche Gesellschaft für
Technische Zusammenarbeit (GTZ) GmbH

Institut für berufliche Entwicklung e. V.
Berlin

Lehr– und Lernmittel,
Informationen, Beratung

Educational Aids
Literature, Consulting

Moyens didactiques,
Informations, Service–conseil

Material didáctico,
Informaciones, Asesoría

Original tide:

Lehrbuch für die Berufsausbildung
"Bauelemente der Elektrotechnik/Elektronik Teil 1"

Author: Frank Ponemunski

Institut für berufliche Entwicklung e.V.
Parkstraße 23
13187 Berlin

Order No.: 91–34–0214/2

Preface

The present textbook was elaborated on the basis of the extensive experience in the field of vocational training in the FRG and is meant for the trainees in electrical engineering/electronics.

It comprises the knowledge of components of electrical engineering/electronics, the demands made on these, measuring processes on semi conductor components and shows the application of the components in some selected basic connections. Based on scientific general knowledge as well as on basic electrical and electronical knowledge, it includes, in a didactic form, the required knowledge in this field of electrical engineering/electronics.

By means of extensive illustrations and tables as well as by a vivid and comprehensible textual representation, it will be made easier for the trainees to comprehend the treated problems.

By a strict consideration of the relation between theory and practice, it can be used by the trainees as working basis both in the theoretical vocational training and in the practical vocational training.

At the end of the textbook, tasks and questions are put for recapitulation and control. They orientate on focal points of the necessary training contents and are at the same time useful for the trainees to check their knowledge.

1. Components

1.1. Definition of terms and requirements

Basic members of a functional unit (module) which can be determined by their functions and designs are designated as components.

In a discrete component, a functional and a constructional basic member form an integrated whole.

Integrated components (integrated circuits) unite several basic functional members in a basic constructional member into one integrated whole. Thus, they can be called "components" only up to a point. For designing, an integrated circuit is a component, for the circuit development it is a functional unit.

Electric components control an energy or signal transmission carried out by electric charge carriers or an energy or signal flow.

Electronic components influence the energy or signal transmission by controlling the charge carriers by means of electromagnetic fields.

From the point of view of the circuit designer, components are called "switching elements" as well. They are represented in circuit diagrams by means of circuit symbols.

Depending on the kind of energy conversion, electric and electronic components are subdivided into active components (transistors, thyristors) and passive components (resistor, capacitor, coil). The transmission behaviour (the input quantity in proportion to the output quantity or cause and effect) makes a classification of linear components (linear transmission behaviour) and non−linear components (non−linear transmission behaviour) possible. The classification of the components into "active" and "passive" components is made from the energetic point of view. If the (useful) output energy is bigger than the (useful) input energy, i.e. an amplification takes place, then one speaks of an active component. In all other casis the components are passive.

Passive components in a narrow (usual) sense are resistors, capacitors and coils.

Resistance to climate

Resistance to climate is the property of a component to fulfill its function also if it is exposed to special climatic conditions.

Reliability

Reliability is the probability that a component, an appliance or a unit keeps functioning during a preset time under certain employment conditions.

Tolerances

Technically it is not possible to exactly reach a preset value, the nominal value, in manufacture. The value which can be measured on the component, i.e. the true value, deviates more or less from the nominal value.

Use components with small tolerances only where it is absolutely necessary for the safe functioning of the appliance!

The manufacturer indicates the tolerance as the admitted ± variation of the true value from the nominal value when supplying the components. This variation is called "de livery tolerance".

1.2. Resistors

1.2.1. Definition of terms and requirements

The word "resistance" means a material property, namely to retard the electric current flow.

A resistor is an electric component which utilizes this material property.

A resistor is an electric component which hinders the electric energy flow to a certain amount.

Strictly speaking, the hindrance of the electric energy flow is a hindrance of the current, i.e. a part of the electric energy is converted into heat. A measure for the current retardation is the electric resistance R = U/I.

Often, a defined current intensity or voltage are required in electric or electronic circuits. These are achieved by resistors which act as current limiters or voltage dividers. Components can emit only a certain amount of heat to its surroundings. In case more energy is supplied to them, they warm up too heavily and the component will be destroyed. Therefore, the manufacturer indicates a maximum capacity, the nominal loss power P_n, which can be absorbed by the component and emitted as heat. This power depends on the mechanical dimensions (surface), the used materials and the structure. The limitation of the nominal loss power is correspondingly applicable to all components. In resistors, it is applicable only up to a fixed upper limit of the ambient temperature and has to be reduced when exceeding this limit. The degree of reduction is determined according to diagrams (Figure 1).

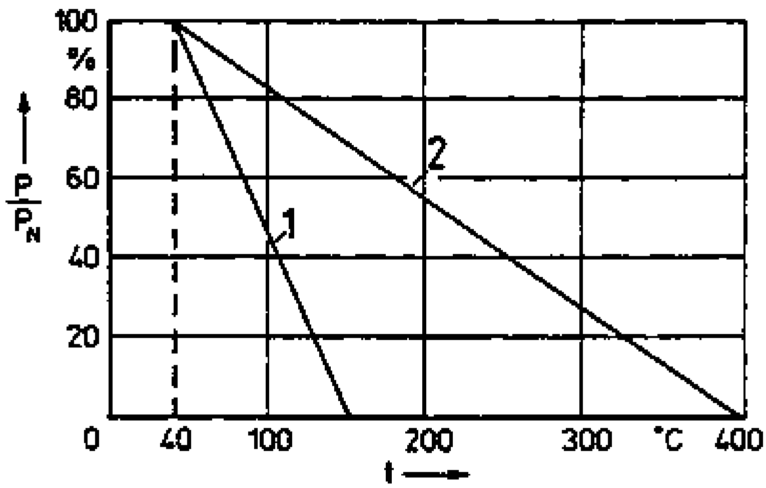


Figure 1. Reduction of the nominal loss power at higher ambient temperatures

1 Film resistors
2 Wire resistors

From physics and fundamentals of electrical engineering it is known that a resistor depends on the temperature. This dependence on the temperature is given in figures by the temperature coefficient ? of the material and is applicable to compact materials. Many resistors (film resistors), however, consist only of a thin film of the resistance material which was applied to a carrying body. For such films the value for ? is not more applicable. The manufacturer tries to keep the dependence on the temperature as small as possible by certain admixtures.

Therefore, a temperature coefficient of the resistor TK_R is indicated for the finished component which includes all influences of temperature on the resistance value.

The usual indication of TK_R relates the resistance change for each Kelvin to the resistance value at 20 °C (room temperature).

1.2.2. Linear resistors

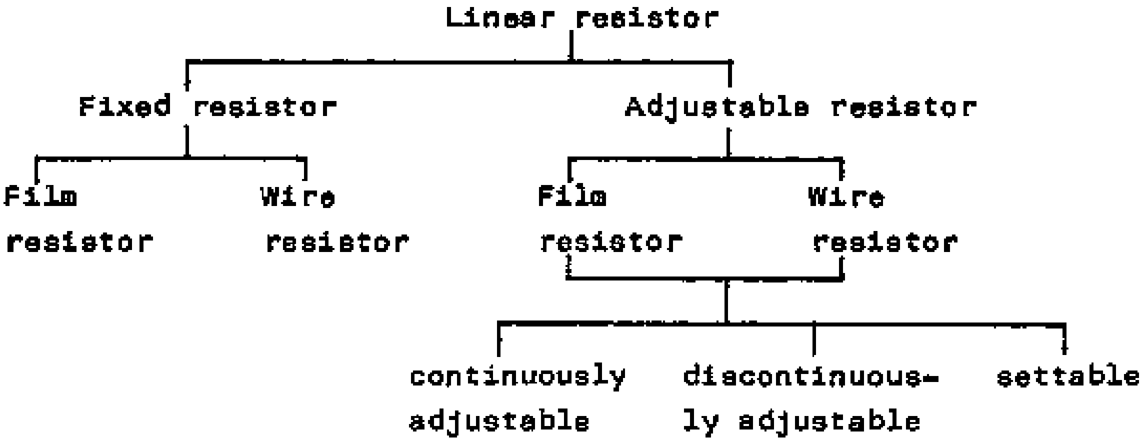


Table 1. Linear resistors

Linear resistors are characterized by a linear current intensity−voltage characteristic.

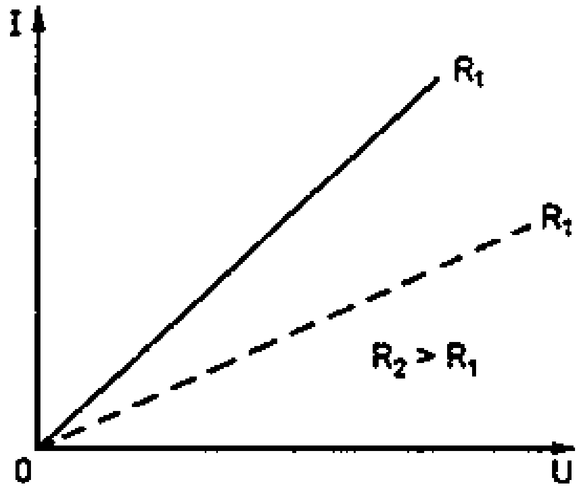


Figure 2. Current intensity−voltage characteristic of a linear resistor

When the resistance value cannot be changed by the user, one speaks of a fixed resistor. Mostly, it is designed as film or wire resistor. Film resistors are produced by depositing of a carbon or metal film on a ceramic body and their subsequent contacting. A varnish coat protects the resistance film against outside influences. Carbon film resistors are provided for general use. Metal film resistors meet better the requirements of measuring and texting engineering because they can be produced with smaller tolerances and a smaller TK_R. Furthermore, they are better resistant to aging.

Wire resistors are produced by winding a resistance wire onto a ceramic tube with one layer, contacting the ends by means of clamps and protecting them against outside influences by a silicone−cement coat. Some designs can be provided with sliding taps. Wire resistors are highly loadable and insensitive to overload and outside influences. For this reason, they are used for various applications in automation engineering. During operation, the wire resistors can take a high surface temperature (up to 400 °C). This must be kept in mind when installing them. Since the conditions of heat emission change in resistors with sliding taps, the wires covered by the clamps warm up heavier, the loss power has to be reduced. With one clamp it is still 65%, with two clamps 60% and with three clamps 55%. Film resistors as well as wire resistors are distinguished by nominal sizes.

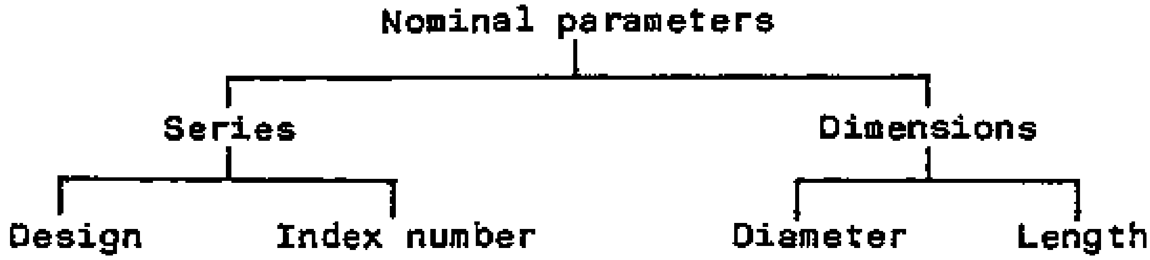


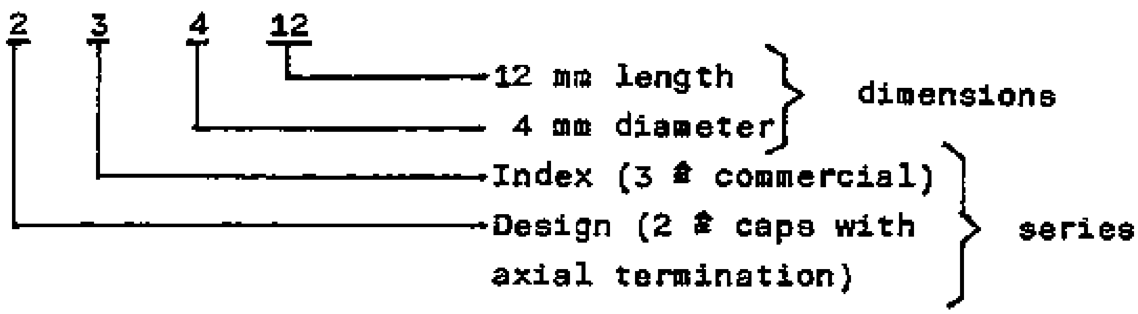
Table 2. Nominal parameters of film and wire resistors

All resistors of the same design and of similar properties are grouped in one series. The properties are given by means of a code/index. The following is applicable to modern series:

Index	Property/Application
1	precise
3	commercial
5	general

In the dimensions, the values of diameter and length rounded off to full millimetres are combined.

Example:



The relation between nominal size and loadability is given for some types in Table 3.

<u>Table 3. Nominal size and loadability of fixed resistors (selection)</u>

Nominal size	**Loadability W**		
	at a high a real load ambient temperature		**at a high time constancy**
	t_a = 40°C	**t_a = 70°C**	
Carbon film resistor series 23	0.33 to 3	0.3 to 2	0.2 to 1.4
Metal film resistor series 11	0.33 to 3	0.25 to 2.2	0.125 to 1
Wire resistor series 22	4 to 18		
Series 82/84			
• 1145	18/12 (1)		
• 1560	30/20 (2)		
• 1580	45/30 (2)		

• 22100	65/40 (2)		
• 22165	125/80 (2)		
• 23165	65/40 (2)		
• 23265	125/80 (2)		
• 29188	210/140(3)		
• 31250	300/200(3)		
• 33330	430/280(3)		

Note: The number given in brackets indicates the number of the sliding taps of series 84

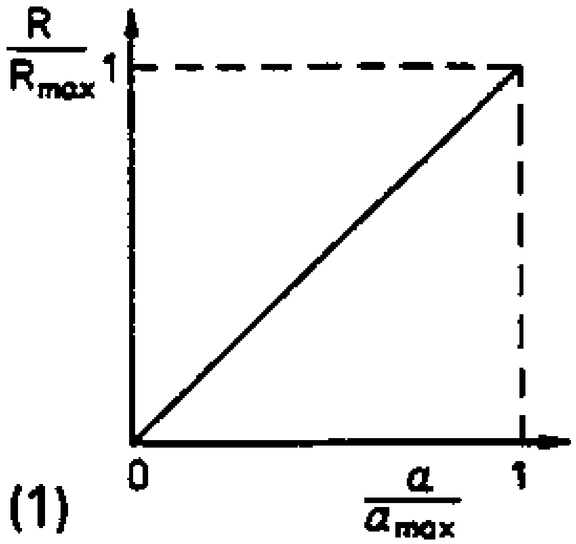
Variable resistors are mainly used in automation engineering as film or wire rheostats. In these resistors the resistance value can be set between a minimum and a maximum value.

Adjustable resistors can be adjusted as many times as you like during operation, settable resistors are to be actuated only for setting (balancing).

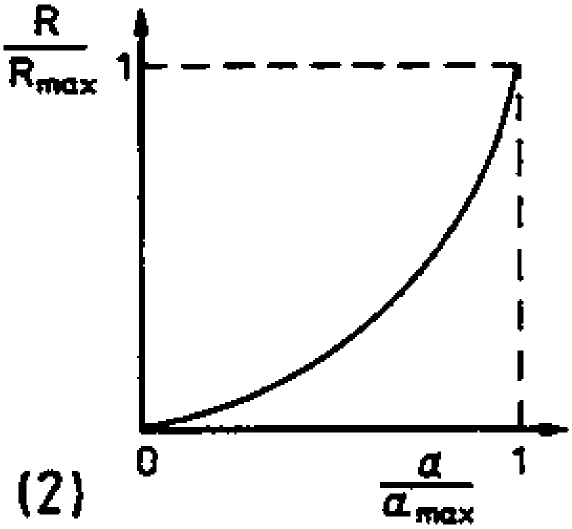
Film rheostats can be continuously adjustable or settable (setting regulator). Because of their low loss power (0.2 W) they can be used only in electronic circuits.

It is advantageous that they can be produced with different resistance changes depending on the rotational angle. Thus, it is easier to adjust them to the required setting characteristics of the circuit. The delivery tolerance is ± 20%, grading of the nominal values is done according to series E3.

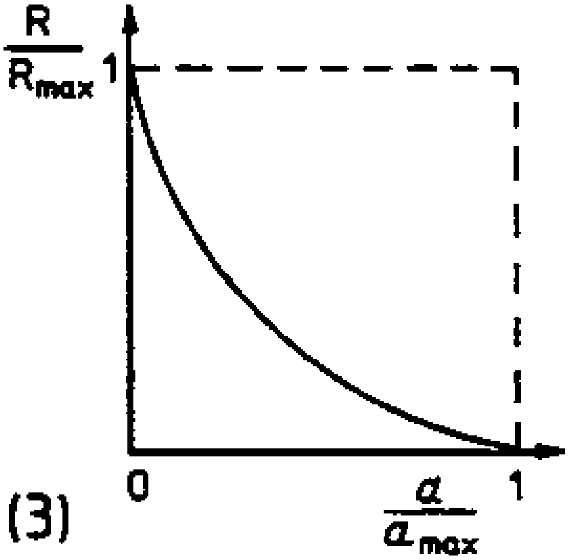
Figure 3. Resistance curve as a function of the rotational angle



(1) linear



(2) increasing exponential



(3) decreasing exponential

Wire resistors are produced as well in an adjustable or settable design, they have a considerably higher loss power than film rheostats and are classified as

standard wire rheostat	P ? 5 W
high−duty wire rheostat	P ? 250 W
pilot wire rheostat	P ? 8 W.

All wire rheostats have a linear setting characteristic. The linearity error in the pilot wire rheostat types is ± 2.5% maximum.

The delivery tolerance can amount to ± 20% or ± 10%. The nominal values are graded according to series E12 or R10 (selection).

1.2.3. Non−linear resistors

For all resistors hitherto described it holds true that a definite current change, irrespective of the point of the characteristic where it takes place, always has the same definite voltage change as a consequence. In non−linear resistors the amount of this voltage change depends on the point of the characteristic where the current change takes place. The same current intensity change ?I provokes the voltage change ?U_1 at point 1 and the voltage change ?U_2 at point 2. From the example shown in Figure 4 it is visible that ?U_1 > ?U_2. The cause lies in the non−linear current−voltage characteristic.

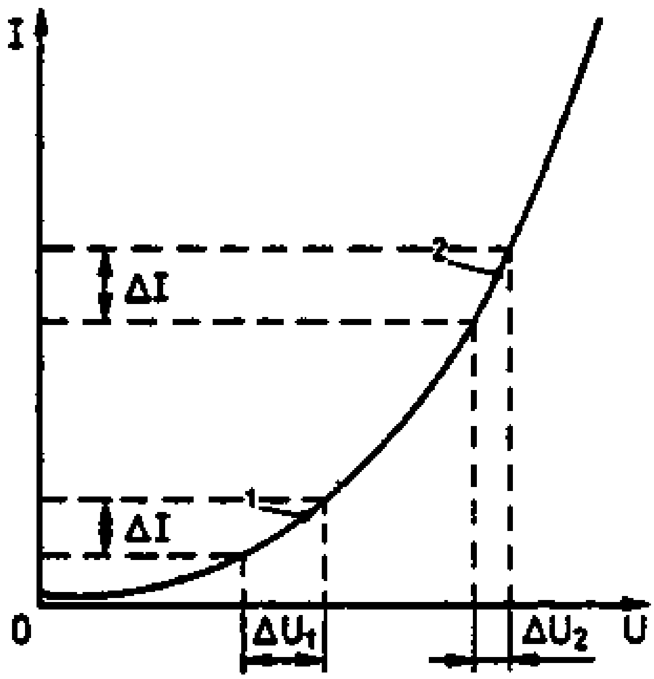


Figure 4. Current intensity−voltage characteristic of a non−linear resistor

Semiconductor resistors have gained special importance. In these resistors, the dependence on the temperature (thermistors) or the dependence on the voltage (varistors) of the resistor is utilized. Thermistors can have a negative temperature coefficient resistor NTC (NTC thermistor) or a positive temperature coefficient resistor PTC (PTC thermistor).

NTC resistors are manufactured as

NTC starting resistor	heating by the flowing−through current
NTC measuring resistor	heating by the measuring subject
NTC compensation resistor	heating by another component
NTC controlling resistor	heating by the flowing−through current.

The resistance of an NTC thermistor is in hot condition approximately 1000 times smaller than that at room temperature, that means the relation between initial and final resistance is approximately 10^3. The hot condition is in this case a heating to the admissible maximum temperature. It lies between 120 °C (NTC compensation resistor types) and 250 °C (NTC starting resistor types). The initial resistances are measured at room temperature (20 °C) and are graded according to series E12. The designation NTC comes from resistor depending on the temperature and negative temperature coefficient.

PTC resistors on semiconductor basis (TP types) have a large positive TK_R within a relatively small temperature interval (?T < 100 K) which causes the resistance in this interval to increase by about 3 powers of ten (10^3). Beyond the maximum temperature (Figure 5), the TK_R gets negative. In this range, PTC resistors must not be operated because, due to the negative TK_R, the resistance in this section decreases, the current intensity increases and the component is further heated.

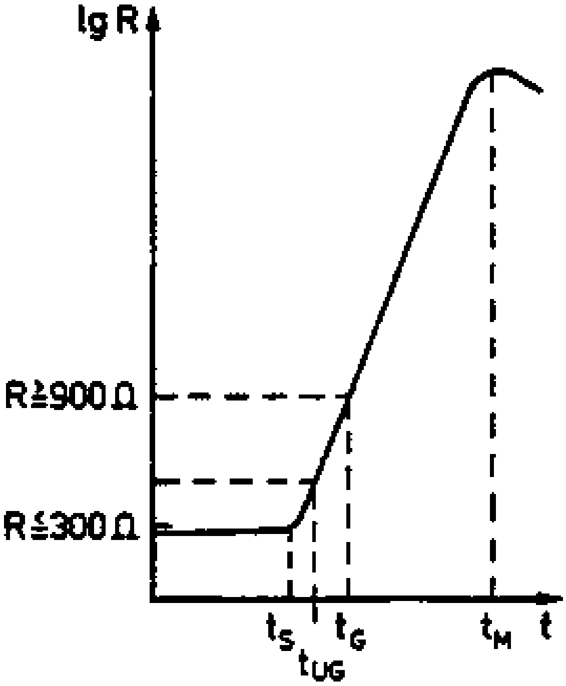


Figure 5. Dependence of the resistance on the temperature in a positive temperature coefficient resistor

By this heating the resistance continues decreasing, the current intensity still increases further, the PTC resistor is thermally destroyed. This statement, however, holds true for PTC resistors on semiconductor basis only. The designation TP comes from resistor depending on the temperature and positive temperature coefficient.

Only a few types are manufactured with transition temperatures between 50 and 120 °C. As transition temperature (t_S in Figure 5) that temperature is called at which the resistance of the PTC resistors has been increased to 1.5 to 5 times of its initial resistance.

Due to the large resistance change limited to a small temperature interval, PCT resistors can be advantageously used for temperature monitoring in machines and installations. Thus, a PTC resistor provided in the winding of an electric motor signalizes reliably when a limit temperature is reached by its increase in resistance and can release switching off of the motor (full motor protection).

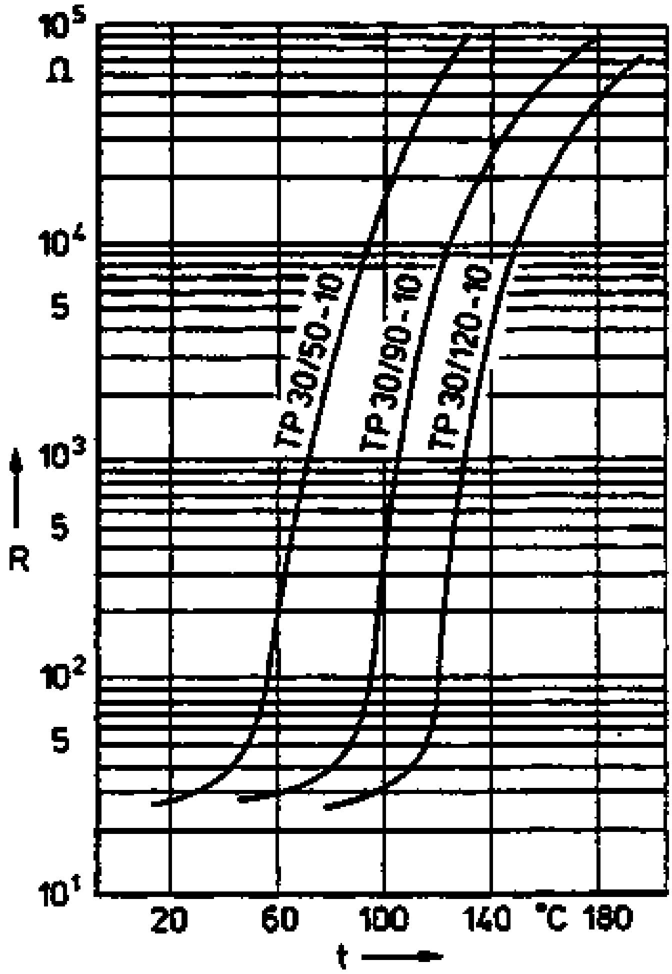


Figure 6. Dependence of the resistance on the temperature in some industrially manufactured positive temperature coefficient resistors

In another application, the PTC resistor is heated by a current flowing through it and its heat emitting conditions are changed by the surrounding medium (fluids or flowing gases).

Since all pure metals have a positive TK_R, they can be used as PTC resistors as well. An elegant solution is the use of an incandescent lamp the resistance of which changes between "cold" and "hot" by factor 10 to 100. Varistors are resistors depending on the voltage which have a small capacity and these are made of silicon carbide and pressed into disk form. They are volume semiconductors, i.e. many p–n junctions are distributed at random over the whole volume. By this, a current–voltage characteristic symmetrical to the origin of coordination is achieved.

The resistance decreases by an increasing voltage.

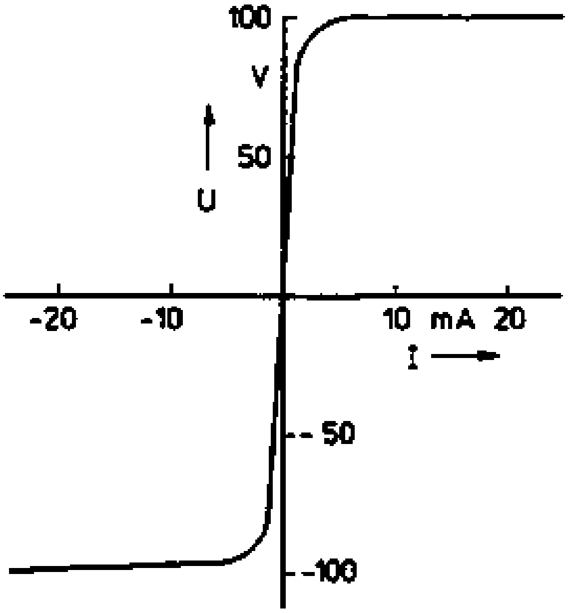


Figure 7. Current intensity−voltage characteristic of a varistor

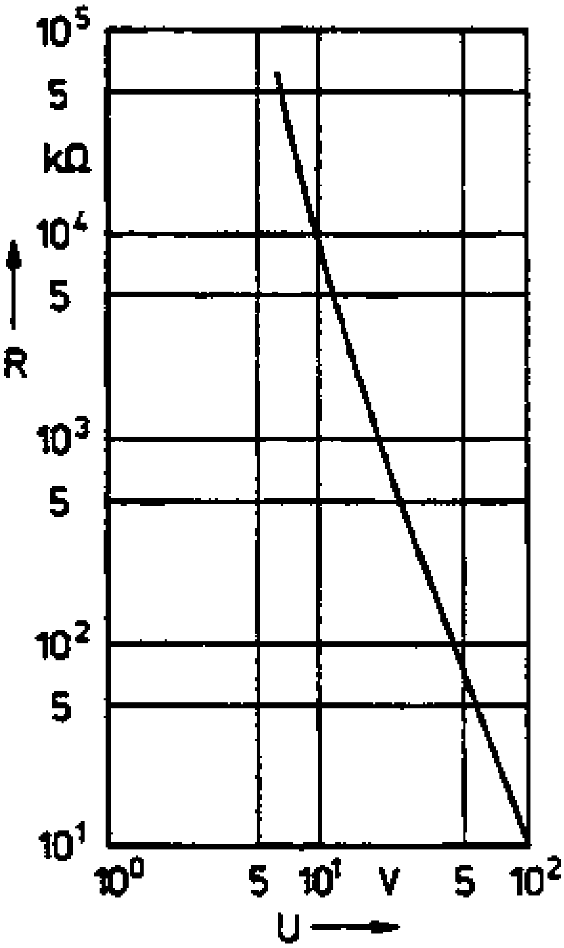
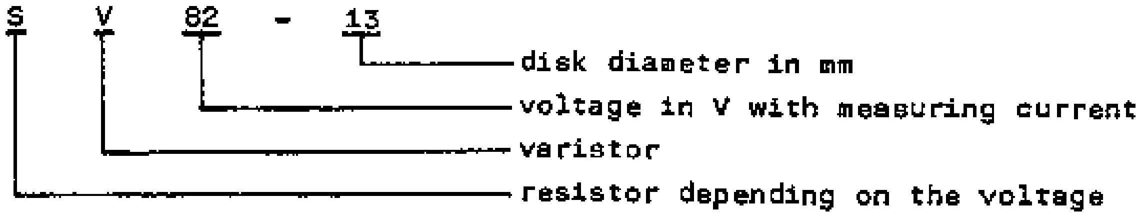


Figure 8. Resistance curve as a function of the voltage in a varistor

An applied alternating voltage with an amplitude which is big enough regulates a varistor in the positive and negative half−wave into the low−resistance range, both half−waves are restricted (symmetrical restriction). However, varistors have a relatively big capacity and can be only used at frequencies under 5 kHz. For limiting induced voltage peaks, as they occur when switching off electromagnetic circuits, varistors are very well suited. They are little sensitive to overload, the upper operating temperature is determined by contacting of the connecting wires.

The nominal values are graded according to series E12. The designation becomes clear from the following example:



1.3. Capacitors

1.3.1. Definition of terms and requirements

Two electric conductors, which are separated from each other by a non–conductor (dielectric), store an electric charge when applying a voltage. The stored charge is maintained also when the applied voltage source is removed and the conductors, which are called "coats", are connected but not electrically conducting. The accumulation of charge forms a potential difference, (voltage) between the coats. This voltage builds up an electric field that acts as energy store (the product of charge and voltage is an energy).

A capacitor is an electrical component which is capable to store a certain amount of electrical energy in an electrostatic field.

Energy storage is effected by a separation of charges. A measure for the storage capability is the capacitance ($C = Q/U$). Capacitors which are important for the automation engineering can be classified by the material of the dielectric as follows:

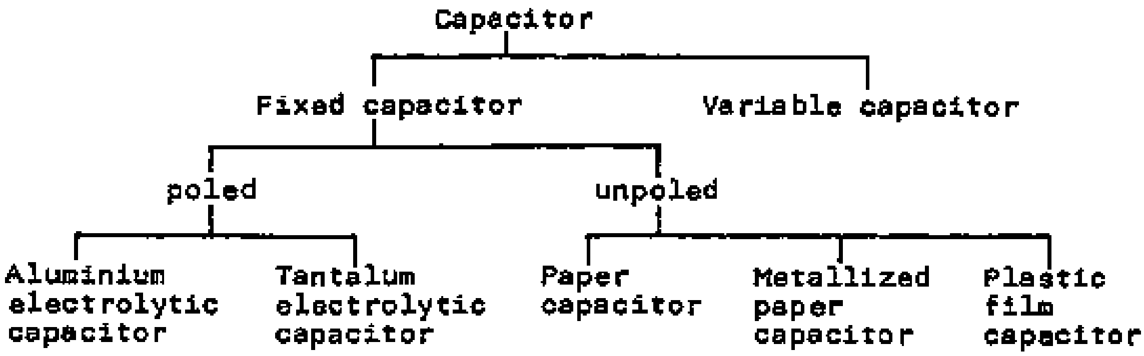


Table 4. Classification of capacitors according to the material of the dielectric

The mentioned capacitors with the exception of the tantalum electrolytic capacitor are manufactured according to the wire–wrapping technique. Two metal foils (coats) are wound up by laying in between insulating material (dielectric). The metal foils are contacted, the reel is filled in or is shielded against outside influences by means of a solded metal casing. Important factors for the application of capacitors in automation engineering are

- – dielectric strength
- – capacitance tolerance
- – resistance to climate.

1.3.2. Unpoled capacitors

The polarity of the service voltage can be allocated at will to the terminals of unpoled capacitors. They are also suited for the work with alternating voltage.

Paper capacitors have a special paper as dielectric. They are cheap and can be manufactured for high service voltages (up to 15 kV) as well. The capacitance values are graded according to series E3, the tolerance amounts to ± 20% or ± 10%. As for the design in solded metal casings, the climatic test class is 55/070/56.

Metallized paper capacitors (MP capacitors) are furnished with very thin (0.1 µm) metal coats evaporated on a paper strip. By this, their volume reduces in comparison with paper capacitors of the same capacitance and nominal voltage. When the dielectric breaks down, the metal coat evaporates in the surroundings of the breakdown point. Thereby a short circuit of the coats is prevented and the capacitor keeps functionable. This property is called "self−healing". With this it distinguishes compared with paper capacitors, whereas in the other properties it corresponds with these.

Paper and MP capacitors are predominantly used as power capacitors for compensating reactive powers or as motor service capacitors, e.g. for the operation of 3−phase current motors at single−phase mains.

Plastic film capacitors feature high time stability and small tolerances. For this reason, they are excellently suited for the use in timing elements. The supplyable capacitance values are limited towards above by C = 10 µF because of their small dielectric constants of the used dielectrics.

Regarding the structure, they are similar to the paper capacitors (standard design) or MP capacitors (varnished capacitors, metalized design). The used polymeres (polysterene, polycarbonate, polyester) have very good electric properties which make a wide range of application possible. Some designs can be applied between −40 and +100 °C. Paper, MP and plastic film capacitors are also manufactured as protective capacitors. The denomination "protective capacitor" was derived from their function. Many functional units or appliances produce undesired harmonic waves (e.g. universal motors or thyristor−controlled rectifiers), the radiation of which via the mains has to be avoided. Otherwise, the harmonic waves cause radio and television interferences. For this purpose, special protective capacitors, anti−interference capacitors, are used. They often connect live parts in the circuit with the housing. To avoid accidents which can occur when the dielectric breaks down, these capacitors have to meet special requirements.

The protective capacitors are distinguished by the admitted application in the appliance:

Class x	The capacitor must be installed only in such a way that in case of a contact closing (breakdown of the dielectric) no danger for the human being can occur. This, for instance, is applicable to the capacitor C1 in Figure 9, the breakdown of which only causes a short circuit.
Class y	The capacitor can also be used at those places where a danger of accident is caused in case of contact closing. This, for instance, is applicable to the capacitors C2 and C3 in Figure 9, which connect a conductor with the housing in case of a breakdown. This can cause a contact voltage which is dangerous to life.

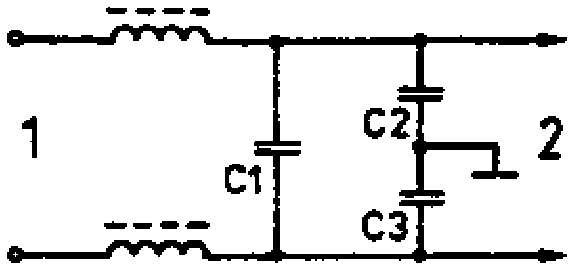


Figure 9. Example for the application of protective capacitors

> If in case of a possible contact closing the lives of human beings are endangered, only protective capacitors of class y must be used.

These capacitors are submitted to a high−voltage test. Marking of the protective capacitors is done by the additional indication of the protective class (x or y).

When assembling, see to a good electrical contact between capacitor and housing of the appliance because only then the radiation of the harmonic waves can be reduced.

1.3.3. Poled capacitors

Conditioned by their function principle, poled capacitors must be loaded with voltage only with the given polarity. They are known as electrolytic capacitors.

As for aluminium electrolytic capacitors, a pretreated aluminium foil is wound up together with a blotting paper strip and placed into an aluminium housing. Then the paper is impregnated with a special electrolyte. By the subsequent anodic oxidation, the Al_2O_3 layer on the surface of the aluminium foil is strengthened. It is highly resistant to voltage and functions as a dielectric, but it remains only when the foil is connected to the plus pole of the service voltage. To maintain the oxid layer, a permanent current flow (residual current) is necessary.

When connecting (poling) wrongly, the oxid layer is reduced. The capacitor has then still only a small insulation resistance. The current intensity flowing through is only restricted by the outer circuit. The capacitor warms up heavily, the electrolyte evaporates and escapes as in an explosion unless the instrument fuse responses earlier.

An analogous process takes place after a prolonged storage without voltage of electrolytic capacitors. The oxid layer is reduced and the insulating behaviour of the dielectric is cancelled also if the service voltage is correctly poled. By a slowly increasing service voltage, the oxid layer can be re−established and the capacitor can be made fully serviceable (post−formation). The post−formation is possible with means from the workshop as well. The capacitor is connected to a settable mains unit with d.c. voltage outlet with the prescribed polarity and the voltage of the unit is increased step by step until the nominal voltage is reached. When the nominal voltage is reached, the capacitor should be kept connected for about one hour. Electrolytic aluminium capacitors have big tolerances (up to +100%), are sensitive to voltage overload and heavily aging. Consequently, they can only be used where these properties do not disturb. The capacitance which can be achieved is very high. At present, the manufacturers indicate 65/070/56 is the highest climatic test class.

Tantalum electrolytic capacitors are furnished with similar properties, however, these are more reliable.

A porous sintered body of tantalum is oxidized. Its surface becomes covered with tantalum (V)oxide (Ta_2O_5) which has a relative dielectric constant ?$_r$? 27. Compared to electrolyte aluminium capacitors which have a relative dielectric constant of ?$_{rAl}$? 8, the capacitance−volume ratio is further improved. Because of the high price, electrolyte tantalum capacitors are to be used only where it is conditioned by the circuit or necessary from the point of use.

An unpoled design of electrolyte capacitors is produced when two electrolyte capacitors are connected in series opposite to each other.

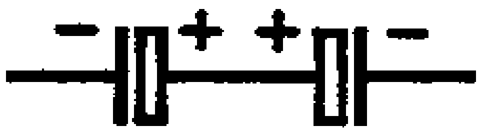
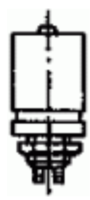


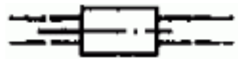
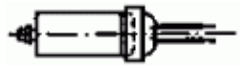
Figure 10. Interconnection of two electrolytic capacitors to an unpoled design

In this design, they are often used as motor starting capacitors. For this use, they are loaded with voltage only for a short time (starting of a motor).

The table 5 shows some typical sizes of capacitors.

Table 5. Selection of some capacitor types

Designation	**Test class**	**Nominal capacity µF**	**Operating voltage V**	**Form**
Varnished capacitor	40/070/56	0.47; 0.68; 1; 1.5; 2.2	$63_=$	
Electrolytic capacitor (Al)	40/085/56	10; 20; 50; 100	$450_=$	
(Ta)	65/085/56	1 to 100 series E3	$15_=$	

Anti−interference capacitor	25/085/21	0.1 (X) + 2x 2500 pF (Y)	250 ~ (nominal current 16 A)	
Compensating capacitor	25/085/21	4; 4.5; 7; 8; 9; 10; 12; 13.5; 16; 18; 20; 25	250 ~	
Motor service capacitor	25/070/56	2.5; 3; 4; 5; 6; 8; 10	380 ~	

1.4. Coils

1.4.1. Definition of terms and requirements

In the surroundings of a current−carrying wire, a magnetic field is generated. This field can be concentrated and therewith amplified when the wire is wound into a coil. A further amplification of the magnetic flux density is achieved by a coil core which is magnetically well conducting (e.g. iron).

In the magnetic field as well as in the electric field, energy is stored.

A coil is an electrical component which is capable to accumulate a certain amount of electrical energy in a magnetic field.

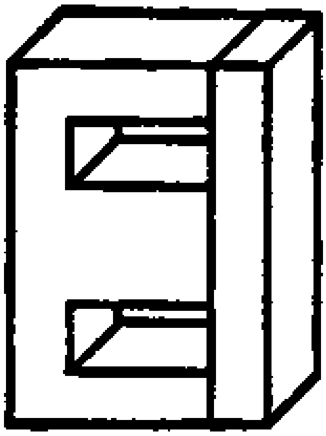
Energy accumulation is effected by a magnetic flux which is coupled with an electric current. A measure for the coupling is the inductance (L = ?/I).

Each time change of the magnetic flux or the magnetic flux density induces a source voltage (law of induction) in a conductor. It is of no consequence whatsoever this time change is produced by the current itself flowing in the conductor (self−induction) or caused by another circuit (mutual induction). But this means also that in an electrically conductive coil core as well a source voltage is induced which drives a current with an undefined direction through the core. Such a current is called "eddy current". By this, the core is heated. The power required for this is a loss power. It can be kept small when the electric resistance of the core material is high. This condition is fulfilled when the core consists of thin sheet layers insulated against each other, i.e. it is laminated, and transformer sheets (material denomination) are used. Coil cores for alternating voltage excitation are laminated from transformer sheets on principle.

In many cases, the core is at the same time supporting part of the mechanical structure.

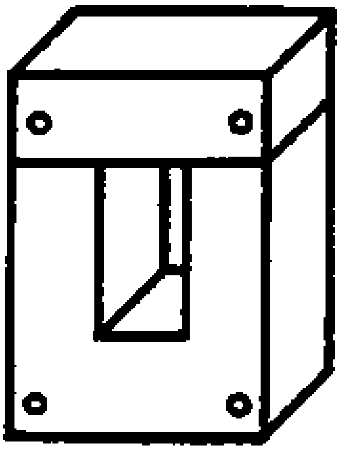
Some standardized core sheet sections are compiled in Figure 11.

Figure 11



(1)

1 Type EI



(2)

Type UI

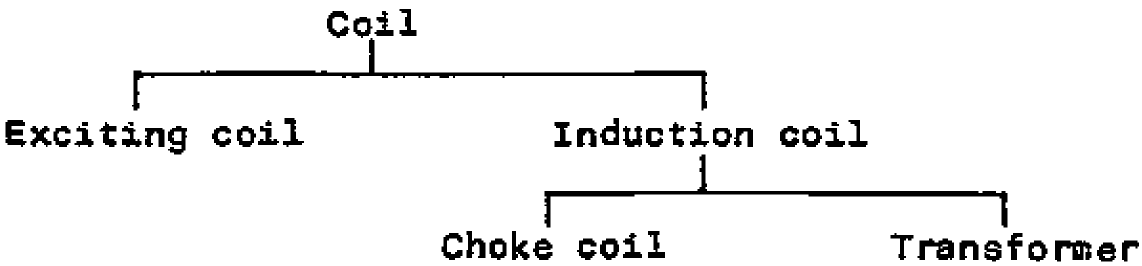


Table 6. Classification of coils according to their applications

1.4.2. Exciting coils

The magnetic field concentrated by an iron core and acting in an air gap is the characteristic feature of exciting coils. In the air gap,

- other magnetically conductive parts can be attracted (relays, magnetic drive, lifting magnet) by the effect of the magnetic influence or

- forces can be exercised on current−carrying conductors (electric motor, measuring system).

An important characteristic value is the magnetic flux density prevailing in the air gap. Among others, it depends on the current intensity and the number of windings existing in the coil. Because of the non−linear relation between field strength and flux density (magnetization curve) in iron, a calculation is only approximately possible. When the air gap is big enough, the influence of the path of the iron can be ignored. The force "F" is exercised on an iron part.

This force can be high (e.g. in lifting magnets for scrap handling). A special importance has the geometric structure of the air gap. The movable iron part of a magnetic circuit (mostly it is called "armature" shortens the air gap by the effect of the magnetic field. On one hand it has to be achieved that the initial force is big enough, on the other hand a small residual " air gap must remain which reduces the remanence. By this, "sticking" of the armature is avoided. Often the current intensity is reduced by the exciting winding after picking−up of the armature (making current − holding current). As for relays and contactors, a circuit can be used according to Figure 12. The series resistor reduces the power input and consequently the heating of the exciting coil.

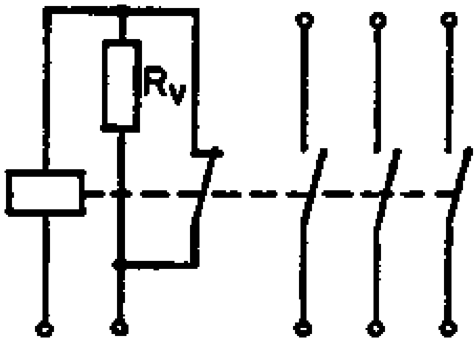


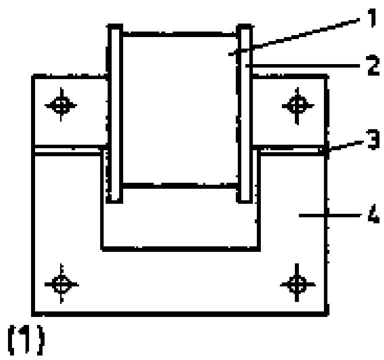
Figure 12. Connection to reduce the power input after pick−up of relays and motor contactors

1.4.3. Induction coils

<u>Choke coils</u>

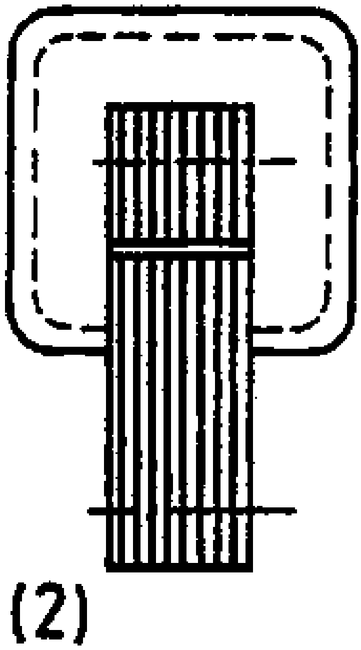
A choke coil consists of a coil which is carried by a coil body that protects the coil against mechanical damage. A laminated iron core is arranged around the coil body.

Figure 13. Principal structure of a choke coil



(1) view from the front

1 Winding
2 Coil body
3 Air gap
4 Core



(2) view from right−hand side

Choke coils have the function to

– smooth a pulsating d.c.
– restrict an alternating current (inductive series resistor)
– lock a current branch for high frequency, low frequency or technical alternating current.

When they are flown through by a d.c. and a superposed a.c. (d.c. magnetic biasing), the working point on the magnetization characteristic shifts and the effective inductance drops.

Whereas without magnetic biasing always the large hysteresis loop is passed, the magnetization of the core changes only in the small loop if a d.c. magnetic biasing has taken place.

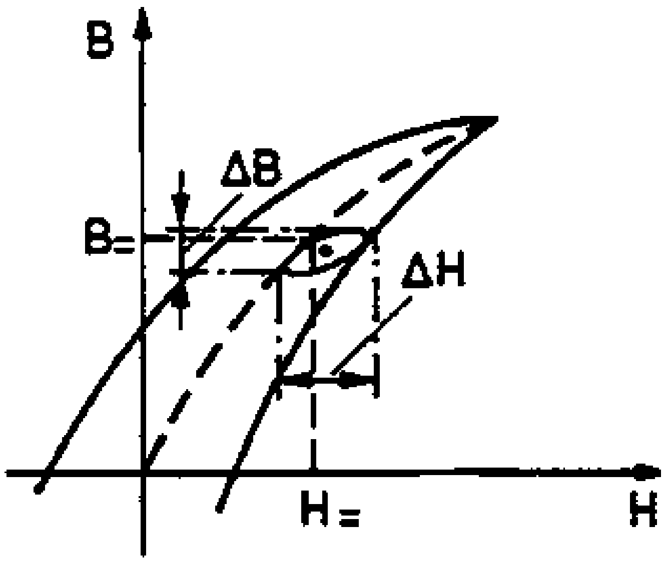


Figure 14. As to the effect of the d.c. magnetic biasing

In magnetically biased cores, the relative permeability μ_r converts into the reversible permeability μ_{rr}, it is always $\mu_{rr} < \mu_r$.

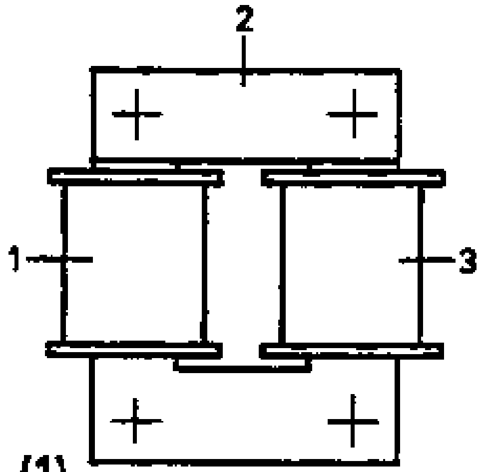
Often sheets with UI− and EI−sections are used as cores because between the U and the I part and/or the E and the I part easily an air gap can be produced by non−magnetic shims which reduces the effects of the magnetic biasing (see Figure 13). Moreover, the magnetic resistance of the circuit is increased by an air gap and the magnetization characteristic of the iron is linearized (sheared).

Transformers

A transformer consists of two coils arranged around a laminated iron core with or without an air gap. They can be jointly arranged on one coil body or each has a body of its own. However, in autotransformers both coils are connected with each other so that they are electrically conductive.

If a coil is flown through by an a.c., a magnetic field is established in the core which induces a source voltage in the other coil. This voltage can drive a current through a connected consumer (load). The energy−absorbing coil is designated as primary coil and the energy−releasing one as secondary coil. All values related with the primary coil are provided with the index 1, the values of the secondary coil with index 2, e.g. – L_1 means primary inductance, U_2 means secondary voltage.

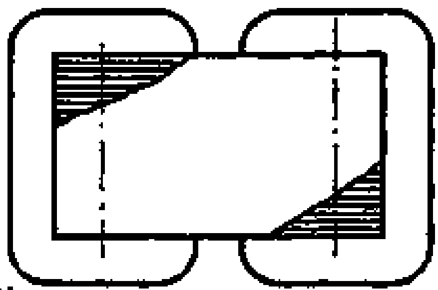
Figure 15. Principal structure of a transformer



(1)

(1) view from the front

1 Coil 1
2 Core
3 Coil 2



(2)

(2) view from the top

The arrangement "iron core with two coils" is called

– transformer if it is used for energy transmission at a certain frequency (mainly mains frequency)

– transmitter if it is used for energy transmission in a frequency band (e.g. LF−transmitter with f = 100 to 5000 Hz)

– converter if it is used for energy transmission at a certain frequency (almost always mains frequency) for utilizing a secondary value (current or voltage) for measuring purposes.

This break−up is very important for the manufacturer because e.g. in a converter where a high voltage is converted into a low measuring voltage, the insulation plays a decisive role or because the winding structure determines the transmissable frequency band of a transmitter. It is usual to speak quite generally of transformer and to subordinate the special design as transmitter or converter to this term. Therefore, in the following it is spoken of transformer only.

In an energy transmission from the primary to the secondary side losses occur in the core as well as in the coils. In a careful configuration the loss power can be kept small in relation to the transmitted power and therefore can be often ignored. Under this precondition simple relations between primary and secondary values are resulted. For a lossless transformer the following is applicable:

$P_1 = U_1 I_1 = P_2 = U_2 I_2$.

The theoretic efficiency factor

$$\eta = \frac{P1}{P2}$$

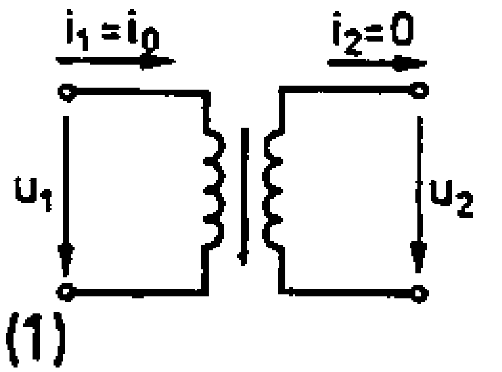
would then be 1 (in practice, depending on the core size, core material and core structure, approximately 0,75 to 0.99).

Unloaded transformer (no−load operation)

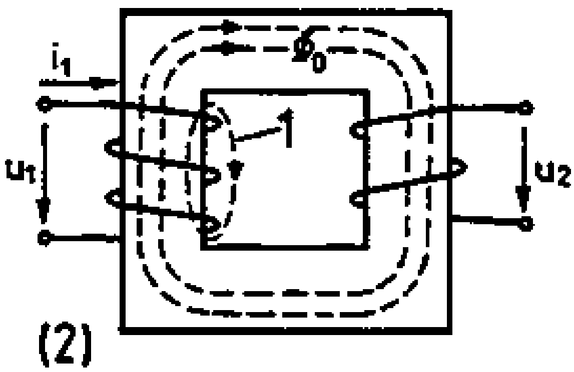
The primary voltage with the instantaneous value u_1 drives a no−load current i_0 through the primary winding which builds up the magnetic field (magnetization current) and covers the iron losses occurring in the core (iron loss current). The magnetization current is considerably higher than the iron loss current and lags the voltage by 90° (reactive current).

Consequently, the no−load current in the lossless transformer is a pure reactive current. For this reason, an idle running transformer acts at its primary terminals like a choke coil.

Figure 16. Unloaded transformer



(1) connection



(2) magnetic flow in the core

1 Leakage flux

The change speed of the magnetic flux (d $?_0$/dt is identical with that of the no−load current di $?_0$/dt.

According to the induction law

$$u_0 = -N\frac{d\varphi_0}{dt}$$

source voltages are generated in the primary as well as in the secondary winding.

$$u_{01} = -N_1\frac{d\varphi_0}{dt}$$

$$u_{02} = -N_2\frac{d\varphi_0}{dt}$$

As for a lossless transformer (leakage flux ignored), the following is applicable:

$u_{01} = -u_1$,

that means, the source voltage u_{01} induced in the primary winding counteracts the mains voltage u_1 and has the same amount. As for the idle running secondary side, the following is applicable:

$u_{02} = u_2$.

When u_{01} is divided by u_{02}, the result is:

$$\frac{u_{01}}{u_{02}} = \frac{N_1}{N_2} = \left|\frac{u_1}{u_2}\right|.$$

This proportion applicable to the instantaneous values is also applicable to the effective values

$$\left|\frac{U_1}{U_2}\right| = \frac{N_1}{N_2}.$$

The voltages in an unloaded transformer are proportional to the number of windings.

The aforesaid equation is the basis for the main function of the transformer to adjust the amount of voltage to the corresponding requirements.

The ratio

$$\frac{N_1}{N_2} = ü$$

is designated as transformation ratio, it can be $ü \gtrless 1$.

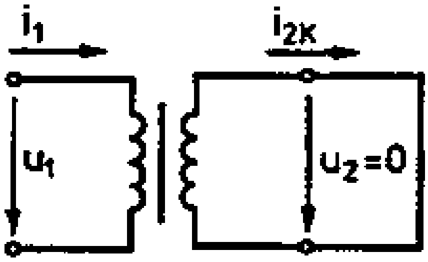
Short−circuited transformer

The secondary source voltage u_{02} drives a heavy current i_{2K} (short circuit) through the winding. This current causes a flux $?_2$ in the core. This flux wants to cancel its cause, the flux $?_0$ caused by i_0, that means it is opposite to this (law of Lenz). However, the flux $?_0$ is driven by the terminal voltage u_1 and is exclusively dependent on it (via i_0).

With the aim that $?_0$ can keep its value, a compensation of flux $?_2$ is necessary. For this purpose, the primary winding takes up an additional current i_{1Z} which generates a flux $_{1z} = _{-2}$. Then, the original flux conditions in the core are re−established because

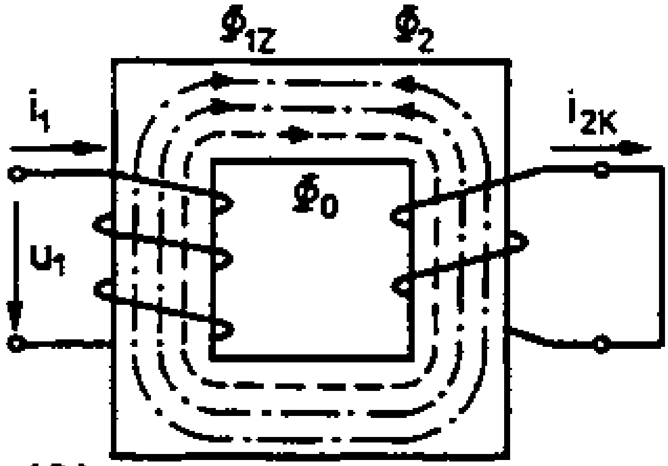
$_{1Z} + _2 = 0$.

Figure 17. Short−circuited transformer



(1)

(1) connection



(2)

(2) magnetic flow in the core

If one also here goes over to effective values and observes

? = N I,

the result is

I_{1Z} N_1 = I_{2K} N_2.

Practically, I_{1Z} >> I_0 and thus I_1 ? I_{1Z}, whereas I_{2K} = I_2.

Consequently

$$\frac{I_2}{I_1} = \frac{N_1}{N_2}.$$

In a short–circuited transformer the current intensities are reciprocal to the number of windings.

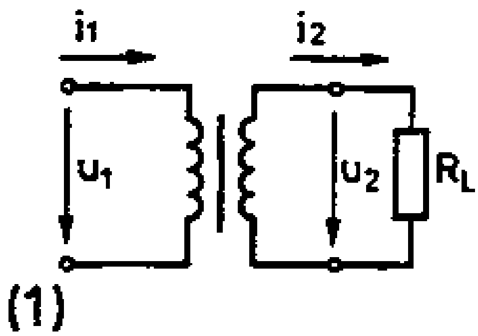
Since in usual transformer designs very high current intensities occur in the case of a short circuit, a short circuit is not admitted. Besides from the heating, great forces occur which can destroy the transformer. However, also transformers are produced which are short–circuit–proof (welding transformers, bell transformers). In these transformers the short–circuit current intensities are limited by magnetic shunts or by increased winding resistances.

Loaded transformer

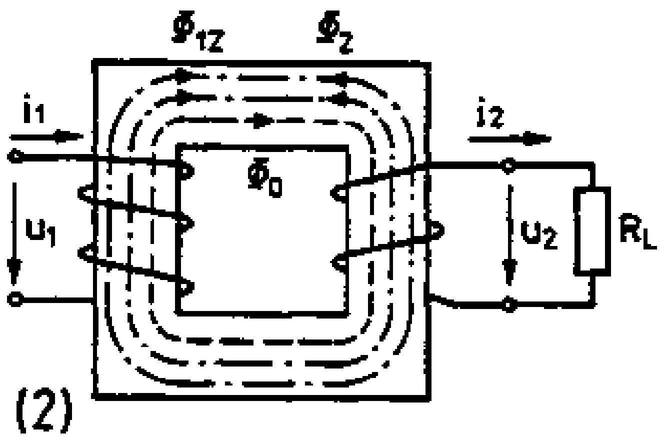
When a resistor (consumer) is connected to the secondary terminals, a current i_2 flows the intensity of which depends on the source voltage u_{02} and the load resistance R_L. Proportional to this current intensity, a flux $?_2$ is generated in the core which counteracts $?_0$. In order that the original flux $?_0$, which was released by u_1, can reappear, the primary current intensity must rise. A similar effect occurs as in a short circuit.

However, the current intensities are smaller. But they limit the loadability of the transformer because the losses in the winding resistors increase. Thus, the transformer warms up and the maximum admissible overtemperature sets a thermal limit.

Figure 18. Loaded transformer



(1) connection



(2) magnetic flow in the core

A vivid explanation can also be derived from the energy conservation law: the transformer has to absorb the energy converted in the load resistor on the primary side as well.

Regarding the transformation of current intensity and voltage, the statements given for the open circuit and short circuit are only approximately applicable.

An exact calculation of a transformer is only possible when the magnetic properties of the core material and the core itself are known; for this reason the calculation is reserved for the specialists.

Reasonably, the transformers are classified as to their application. Transformers are designated as mains transformers when they are connected with their primary winding to the mains voltage and are used for supplying appliances with electrical energy. For this purpose, they often have several secondary windings with different voltages and loadabilities.

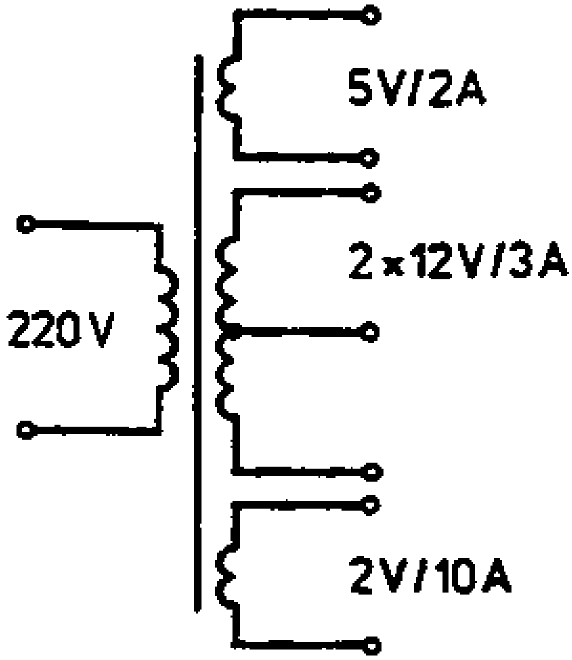


Figure 19. Example for a mains transformer with several secondary windings

The transmissable power is determined by the core cross−section. Up to a total secondary output power of 6.3 kVA they number among the small transformers. They are manufactured for single−phase feeding for secondary outputs up to 1 kVA. Transformers with secondary outputs beyond approximately 1 kVA are only manufactured as three−phase designs. The initial voltage (secondary voltage) can be infinitely chosen, for voltages u_2 > 500 V it is absolutely necessary to observe the relevant insulation prescriptions.

There is a danger of contact closing between the secondary and primary winding also in small secondary voltages which nullifies the desired galvanic separation from the mains and causes a high risk of accidents. For this reason, when manufacturing mains transformers, observe in any case the manufacturing regulations, the self−made construction without having available proper testing means has to be refrained from. In this case, especially the expert, who knows the risk, should set a good example! The further break−up of the transformers is determined by the special design or special application.

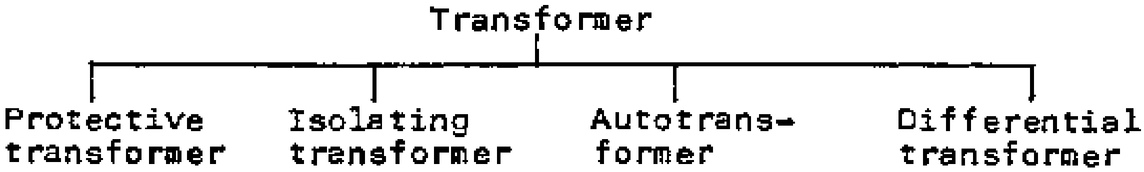


Table 7. Classification of transformers according to their applications

Protective transformers are to be manufactured so that a conducting connection between primary and secondary winding, primary winding and core or primary winding and housing also in case of a wire break is not possible. The amount of the secondary voltage is limited to 42 V (protective low voltage).

The protective low voltage is the most efficient protective measure against the appearance of too high a contact voltage and the risk of accidents related with this. Protective transformers are used for the supply of (special) electrical appliances with power for jobs to be done at places where there is a special risk of accident (mining industry, tank and container construction), for electrical toys; as bell transformers and at other places. Their applications in the a.m. fields are prescribed by law. Isolating transformers are used as well to reduce the risk of accident which is always given by the mains voltage. However, the requirements are not so strict as for protective transformers. Isolating transformers are designed to bring about a galvanic separation from the mains. Often they are designed with a voltage transmission ratio ü = 1 (220 V input voltage, 220 V output voltage). Then, also normal appliances designed for mains voltage can be connected.

But keep in mind the following:

Connect always only one appliance to an isolating transformer! The secondary side must not be earthed!

The protective measure "protective isolation" is only effective when considering these conditions.

Autotransformers have only one winding. The primary winding is a part of the secondary winding and vice versa. Therefore, such transformers have a galvanic connection between primary and secondary side.

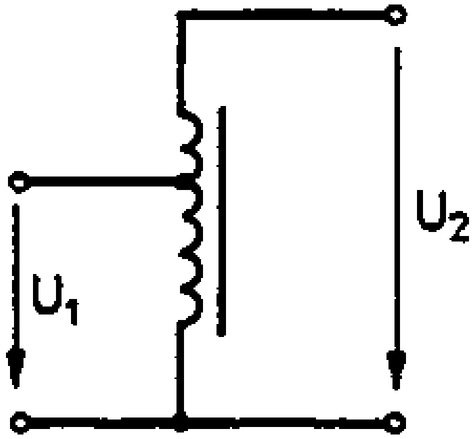


Figure 20. Autotransformer

Their advantage lies in the saving of copper (double utilization of one part of the winding) and iron (a smaller core cross−section can be chosen).

According to this principle, often adjustable transformers are manufactured.

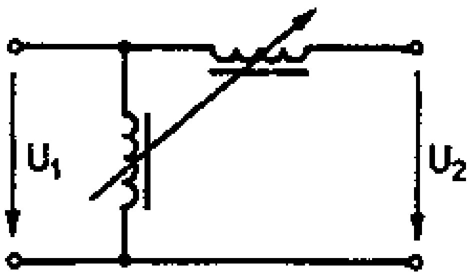
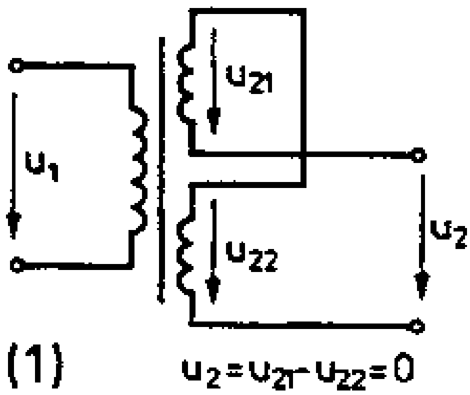


Figure 21. Adjustable transformer in economizing circuit

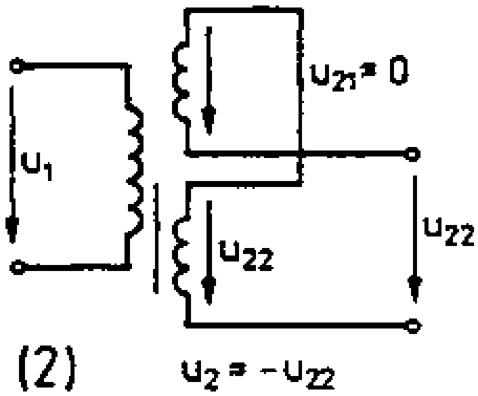
Autotransformers do not isolate galvanically from the mains. Risk of accident!

Differential transformers have a divided symmetrical secondary winding. Both secondary coils are connected opposite to each other, i.e. the voltages induced in them act against each other. The core or one part of the core is arranged movable. At its mid−position, voltages of the same amount but opposite phase positions are induced in both coils. The output voltage is then zero (Figure 22.1). If the symmetrical position of the core towards both secondary coils is changed, different voltages are induced in these and a voltage arises at the outlet (Figures 22.2., 22.3.). Its amount depends on the degree of core shifting. In this way, a differential transformer can be used for the conversion of a path into an electrical voltage.

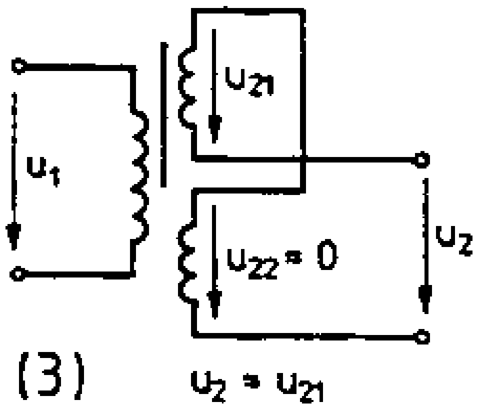
Figure 22. Operating principle of a differential transformer



(1) Core in centre position;



(2) Core in a final position,



(3) Core in the other final position

Regarding small changes around the mid−position of the core, the output voltage is proportional to the change of the path. When the core passes the mid−position (zero position), the phase position of the output voltage jumps by 180° because the dominating source voltage goes over from u_{21} to u_{22} or vice versa. However, both source voltages are opposite in phase that means they are staggered opposite to each other ?= 180°.

Transformers are always special manufactures for a determined range of application or appliance. A series production for general requirement is not or only in exceptional cases possible because of the wide range of required parameters.

1.5. Contact devices

Although the trend in electrical engineering/electronics goes automatically more and more towards contactless components, still certain tasks today and in future cannot be solved without contact devices.

For example, in heavy−current electrical engineering, it must be possible to infinitely regulate or interrupt the energy flow (e.g. by means of power switches) in order to safely transmit electrical energy.

In the information and communication engineering, however, mainly selective and amplification functions are to be implemented; selective functions in the way that, depending on an input quantity, a previously fixed switching process or a selection of an information channel out of the quantity of the existing channels is accomplished in order to make a desired information connection. If for instance a big output power of the same kind of energy is controlled by means of a relay having a small input power, "one speaks of the amplifying function of a contact device. Normally, the indicated functions are to be solved by changing a switching state. The change of a switching state is designated as switching process.

Such a switching process can be implemented by a component which is able to open or close an electrical circuit. This component is the electrical contact which is consequently the most important part of each electromechanical switching device in heavy−current electrical engineering and electronics.

In general, two definitions for the electrical contact are usual:

First definition

An electrical contact is a state which results from the contact of two parts which serve to conduct a current.

Second definition

The electrical contact is a connection between two conductors which is suitable to conduct a current. These conductors are called contact pieces.

The contact pieces are subdivided into

– fixed, inseparable contact pieces (e.g. soldered joint)
– fixed, separable contact pieces (e.g. screwed joint) and
– movable contact pieces (e.g. contacts of a switch).

Contact pieces are exposed to many influences so that they must meet the following requirements:

– sufficient mechanical strength
– reliable electrical connection
– sufficient thermal strength in permanent operation
– Thermal and dynamical short−circuit strength
– resistance to climatic influences
– low material loss by arc burn−up.

Pre−conditions must be created for a low electric resistance of the contacts so as to keep the heating of the contacts as low as possible.

The electric resistance of a contact R_K depends on the contact material, on the form of the contacts and, above all, on the contact force F.

$$R_K \sim \frac{1}{\sqrt{F}}$$

The contact resistance consists of two portions:

$R_K = R_F + R_E$

R_F is designated as contamination layer resistance resulting from oxidation or contamination of the contact surfaces. The contact pieces must be constructed in such a way that this contamination layer will be destroyed (e.g. by rolling or sliding contacts). As for contacts in electronics, a voltage of about 100 V (fritting voltage) is also able to electrically destroy these contamination layers.

R_E is the construction resistance which results from the current lines concentrating at the contact transfer points.

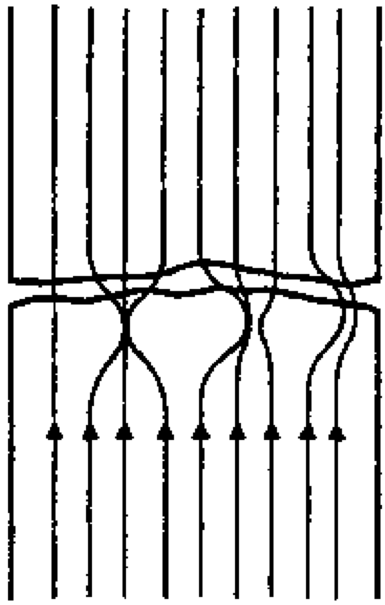


Figure 23. To explain the construction resistance

As for the contact surfaces, it must be distinguished between bearing surface and actual contact surface. A high stress of the contact pieces, above all in the heavy−current electrical engineering, where high electric powers have to be transmitted, is caused by the electric arc.

A material migration takes place by the electric arc which leads to a change of the contact surfaces and consequently influences the contact resistance. In an extreme case, a welding of the contacts can occur by a starting electric arc or too high a heating of the contact pieces due to too a big contact resistance. This welding, when switching in, can be avoided when switching in is effected chatter−free. For this purpose, determined relations between the weight of the contact pieces and the switching forces (spring forces) must be adhered to.

To meet all the requirements made on the contacts, a careful selection of the contact materials and an exact construction of the contact pieces are needed according to the prevailing conditions.

With low switching capacities and small switching forces (in electronics), noble metals, primarily silver, are used as contact material. Silvered contacts have a very good transition resistance and silver oxide is still a good conductor as well. The disadvantage is that silver is very soft and the melting temperature is relatively low. Therefore, silver can be only used in case of small switching forces (pressure contacts) and in such cases where no high electric arc load occurs.

Copper (mostly silver−plated) can be used for bigger switching forces. Its disadvantage is that copper oxide is a bad conductor and consequently the contamination layer has to be eliminated by special contact structures.

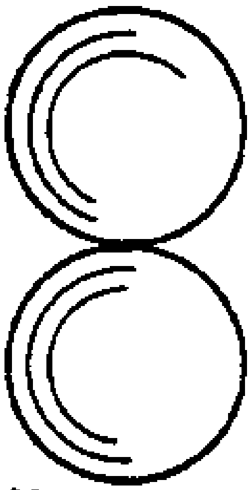
Apart from carbon (e.g. as current collector in rotating electrical machines), also a number of alloys is used as contact materials. The alloys are produced so that special contact properties are achieved. Thus, the alloy Cu−Ag (nickel silver), for instance, has a bigger hardness as silver at a low contact resistance. A specially high mechanical strength is achieved with the alloy Ni−Ag. Today, mainly sintered metals are used as contact materials for high−voltage switches.

Design and arrangement of the contact pieces are of decisive importance.

Proceeding from the punctate form, linear or area−shaped touching of the contact surfaces, different basic forms have developed:

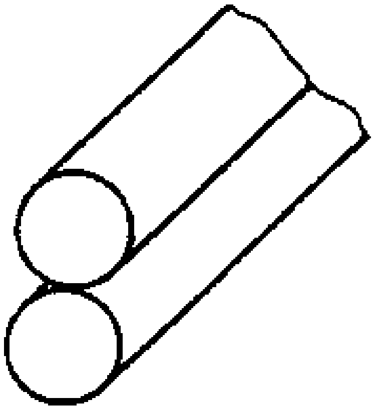
- pressure contact (no destruction of the contamination layer)
- rolling contact
- sliding contact
- contact by means of a liquid

Figure 24. Theoretical contact shapes



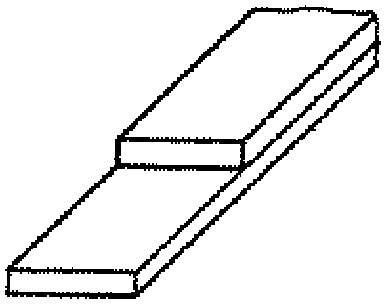
(1)

(1) point contact



(2)

(2) line contact

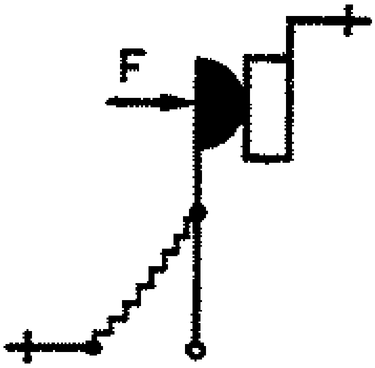


(3)

(3) area contact

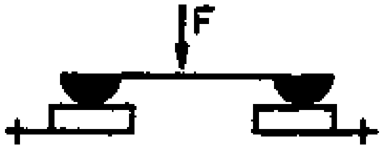
Regarding the arrangement of the contact pieces, the double break has found acceptance in contrast to the single break (Figure 27) in the heavy−current electrical engineering because the flexible joint between the movable contact piece and the fixed connection represents a weak point and reduces the mechanical life of the switches.

Figure 25. Comparison of contact breaks



(1)

(1) single break,



(2)

(2) double break

In Table 8, the individual elements of a contact component are grouped and their functions are named.

Table 8. Functions of the element of a contact component

Elements	Function
Contact pieces	Connection or disconnection of the current path
Clamps, soldering lugs	connection of the outer circuit
Contact wiper, contact lever, contact spring	moveable guide of the contact pieces
Metal tape, contact spring, slide spring, strand	conducting connection between the contact pieces and clamps
Fastening part	holding together of the individual parts and fastening of the contact; insulation
Leaf or helical springs	generation of the restoring force
Actuating part	transmission of the actuating force; insulation
Supports, stop screws, stop angles	limitation of paths of the moveable parts

1.6. Semiconductor components

1.6.1. Determination of terms and requirements

Semiconductor components utilize the mobility of free charge carriers in monocrystalline or polycrystalline solid bodies (mono = single; poly = multi (multiple).

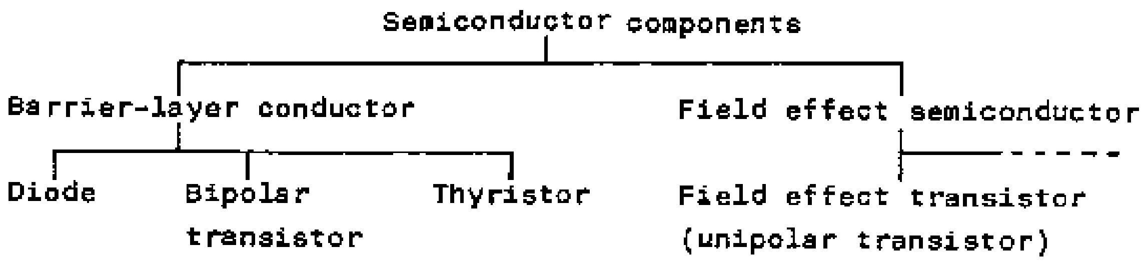


Table 9. Classification of semiconductor components

Characteristic features of barrier−layer semiconductors are p−n junctions, which are produced in a defined manner (position and form are known). There are positive and negative charge carriers. If they are also needed for the mode of operation, they are called bipolar components.

Of the field−effect semiconductors, transistors with insulated control electrode are only to be mentioned here. Since one kind of charge carrier suffices for the function, they are also called unipolar components.

<u>p−n junction</u>

A p−n junction appears when an n− and a p−doped region are adjoining in a crystal.

Trivalent (boron) or pentavalent (phosphourus) elements in a low quantity are added to the superpure silicon. This process is called doping.

Foreign atoms occupy regular lattice sites and create an excess weight of positive (p−silicon) or negative (n−silicon) charge carriers.

One type of charge carrier is present in excess by doping and determines the type of conductor.

n−conductor − electrons in excess

p−conductor − defect electrons in excess.

Due to the atoms' thermal excitation, bonds are broken up, and positive and negative charge carriers of the same number develop in addition. They give an additional conductivity to the semiconductor material, which is called intrinsic conduction (i−conduction).

Semiconduction of a material i, therefore, caused by

intrinsic conduction − it cannot be prevented

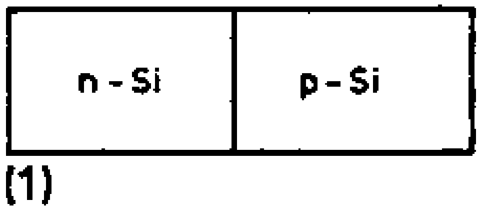
and

impurity conduction − impurities are deliberately produced by doping.

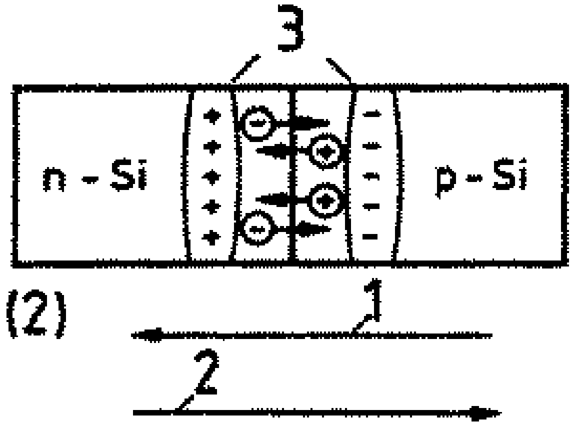
The charge carriers desired by doping are named major carriers, while the others are called minor carriers.

When two or more gases are led into a space, the gas molecules will have intermixed completely already after a short time. If sugar is dissolved in coffee, its molecules evenly distribute even without stirring. In both cases, the physical principle of greatest disorder is acting according to which separate substances intermix completely, if they are mixalbe at all. Differences in concentration, e.g. that of sugar in coffee, equalize. Such procedures are designated as diffusion. Therefore, charge carriers are exchanged by diffusion at a reflection point between a p− and an n−doped region. The positive charge carriers migrate to the n−region, with the negative ones migrating to the p−region. From the electrical point of view, this exchange of charge carriers is a current called diffusion current.

Figure 26. Currentless p−n junction



(1) schematic construction,



(2) diffusion effect

The principle of greatest disorder would not be fulfilled until a full equalization of different charge carrier concentrations was performed. However, this full equalization is prevented at the p−n junction. The free charge carriers (electrons or defect electrons) leave behind ions solidly built in the crystal lattice, carrying an opposite electrical charge. These ions are also called atomic torsos.

In the n−region, for example, the foreign atoms built in the lattice are positively charged by giving away one electron. As a whole, the crystal remains electrically neutral, because the charges neutralize. This equilibrium is not disturbed until the diffusion starts at the p−n junction. Due to the electrons diffusing to the p−region, a preponderance of positive charges occurs near the p−n junction, and vice versa a preponderance of negative charges in the p−region occurs due to the defect electrons (also called holes) diffusing to the n−region. These charges are caused by the foreign atoms built in the crystal lattice. They are designated as space charges and do not any more permit further diffusion of charge carriers, because they act like a barrier.

Strictly speaking, an exchange of charge carriers is initiated by the space charges in opposite direction, for the principle of greatest disorder also applies to them. It would be fulfilled when the space charges disappeared.

This exchange of charge carriers is called field current, because it is released by the electrical field acting between the space charges. The field current is counteracting the diffusion current. Practically speaking, a dynamical equilibrium appears, the diffusion current tries to equalize the charge carrier concentration difference, the field current tries to equalize the space charges building up. Both currents are equally strong in the case of equilibrium and nullify, because they have different (counteracting) directions.

A voltage externally applied disturbs this state of equilibrium. In this case, the p−n junction shows a typical behaviour dependent on the polarity of the external voltage.

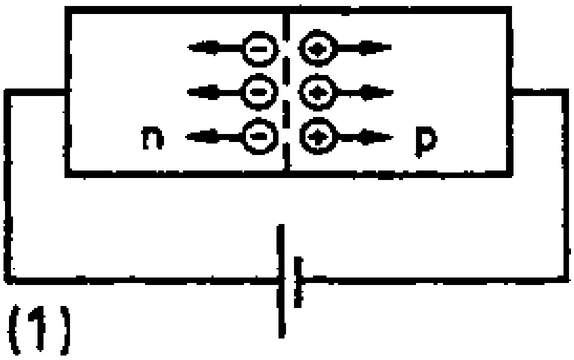
Operation in flow direction

When the positive pole of a voltage source is connected to the p−region and the negative one to the n−region, a high diffusion current flows. The external voltage produces a flow field in the semiconductor, counteracting the flow field produced by the space charge at the p−n junction, with the latter being low−resistive and inundated with charge carriers. The flowing current is designated as on−state current or forward current.

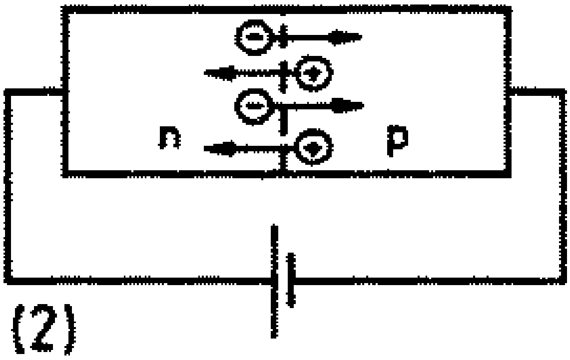
Operation towards barrier direction

When the polarity of the external voltage source is reversed, the space charge field is supported. The number of charge carriers is reduced at the p−n junction, with the latter becoming high−resistive. This statement only applies to the major carriers, while the minor carriers can pass the p−n junction, because they operate in flow direction. A small reverse current is flowing. Since the number of minor carriers strongly depends on the temperature, the reverse−current is also strongly dependent on the temperature. Even small voltages (about 1 V) have a saturation characteristic. Then all minor carriers take part in the current flow. Thus, a p−n junction shows a so−called valve action. The characteristic is represented in Figure 28.

Figure 27. Major and minor carriers at a p−n junction poled in barrier direction



(1) influence on major carriers (junction blocked),



(2) influence on minor carriers (junction opened)

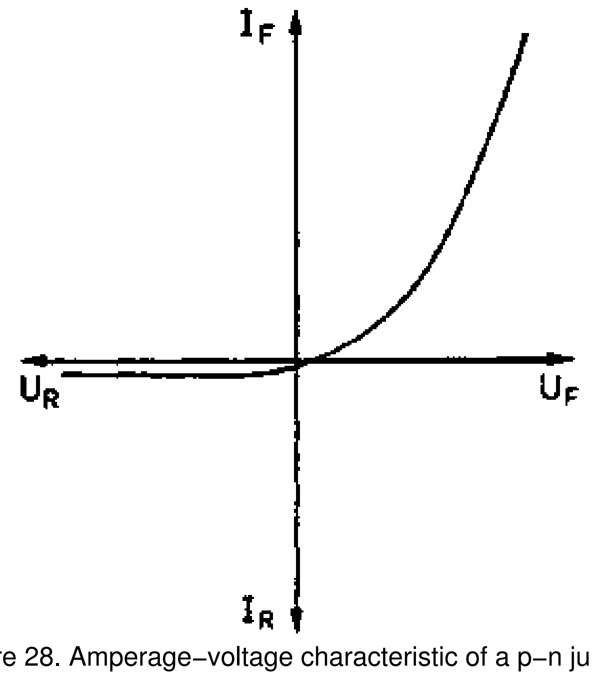


Figure 28. Amperage−voltage characteristic of a p−n junction

F flow direction (forward)
R reverse direction

Breakdown action

Effects appear in the non−conducting zone, which are marked by a high rise in current intensity. The barrier layer is disrupted and may be distroyed. This process is called breakdown. There are reversible and irreversible breakdowns.

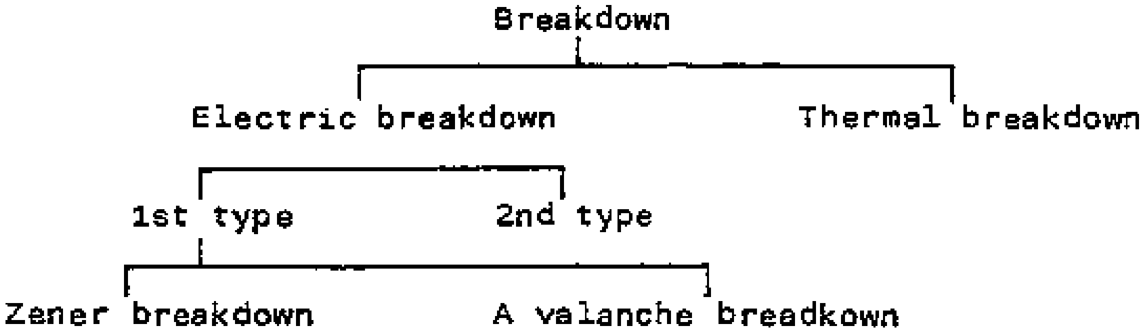


Table 10. Types of breakdowns

1st type breakdown

Fast increase in the reverse current intensity with simultaneous voltage existence over the p–n junction is the characteristic feature of the 1st type breakdown. This applies to the Zener and avalanche breakdowns.

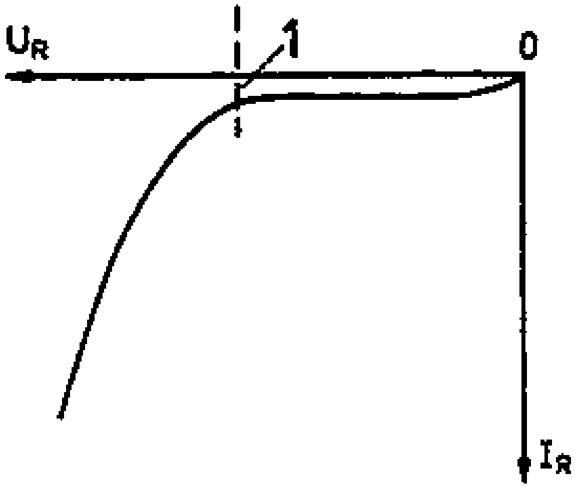


Figure 29. Characteristic with breakdown of 1st type

1 1st type breakdown

Zener breakdown

It only appears with small reverse voltages (U_R < 6 V) and is always intentional. Due to the field intensity effective in the p–n junction, charge carriers are torn out of their bonds (Zener effect). This is practically used in Z–diodes. The breakdown is reversible, if the p–n junction is not thermically overloaded.

Avalanche breakdown

As for higher reverse voltages, the charge carriers are multiplied by collision ionization. The free charge carriers have a high kinetic energy and can, therefore, knock out other charge carriers from their bonds (avalanche effect). This effect is practically utilized in rectifier and Z–diodes, but also in special transistors. Also this breakdown is reversible, if there is no thermical overload.

As for the 2nd type of breakdown described below, the fast rise in reverse current intensity is linked with a collapse of voltage over the p–n junction.

2nd type breakdown

A 2nd type breakdown occurs in power elements having several p–n junction (transistors, thyristors). Due to local current concentrations, the crystal is heated up to the melting point at these locations. *In* this case, the p–n junction is shorted and the element is destroyed. The manufacturer indicates the limits, within which a 2nd type breakdown can safely be avoided.

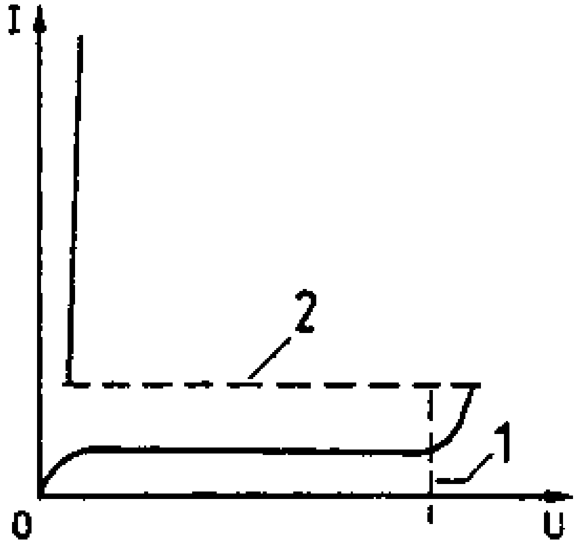


Figure 30. Characteristic with 2nd type of breakdown

1 Breakdown 1st type,
2 Breakdown 2nd type

Thermical breakdown

This breakdown always results in destroying the element, caused by thermical overload and may occur both in the non−conducting zone as well as in the flowing region.

Field effects

Distribution and transport of electrical charge carriers are influenced by electrical or magnetic fields. In field effect transistors, the conductivity of a semiconductor section − designated as channel − is changed by an electrical field. In this connection, only one charge carrier type (p or n) is effective.

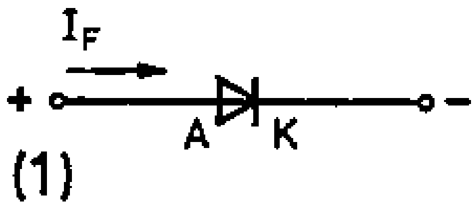
1.6.2. Diodes

A diode is a two−pole arrangement with valve behaviour.

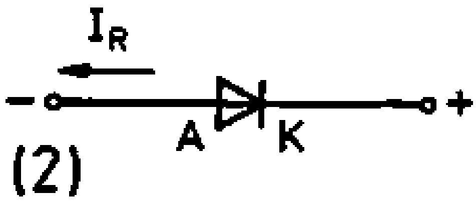
Today, thermionic diodes have been replaced by diodes constructed on semiconductor basis.

A semiconductor diode is a component with a defined p−n junction. The amperage−voltage characteristic is, therefore, identical with that of a p−n junction. Depending on the task, valve behaviour (rectifier and efficiency diodes) or 1st type breakdown (Z−diodes) are used. Figure 31.3 is a simple equivalent circuit for a diodes. r_F indicates the resistance of the diode in flow−direction (on−state resistance), r_R is the diode resistance in barrier direction (reverse resistance) und U_S means gate voltage (for Si ? 0.7 V; for Ge ? 0.3 V). Gate voltage is the voltage applied between anode and cathode, so that a noticeable current flow through the diode starts. Gate voltage is dependent on the semiconductor material.

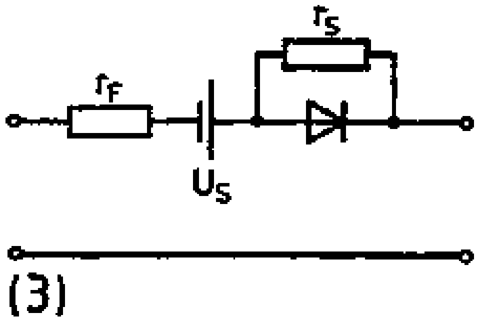
Figure 31 Semiconductor diode



(1) poled in forward direction,



(2) poled in reverse direction,



(3) simple substitute circuit

Serviceability of diodes can be quickly checked with a multipurpose instrument in the resistance measuring range. For that purpose, the diode is connected with the R_X terminals and the resistance value so shown is read. A rough reading is sufficient. The diode connections are changed on the R_X terminals and the resistance value indicated is read again.

When the diode is serviceable, a value so read is at about some ten to some hundred ohms (forward range), and the other value goes toward infinity. For more exact values, the characteristic curve has to be measured point for point. Figure 32 shows a simple circuit for measuring a characteristic curve. Polarity of the instruments have to be reversed for transition from non–conducting zone to forward zone and vice versa.

Table 11. Marking of semiconductor diodes

Letter	at 1st place	at 2nd place	at 3rd place
A	germanium	diode (general)	–
B	silicon	–	–
E	–	tunnel diode	–
G	germanium	–	–
K	silicon	–	–
P	–	photodiode	–
R	–	four–layer diode	–
S	silicon	–	–
X	–	–	for commercial use
Y	–	rectifier diode	
Z	–	Z–diode	

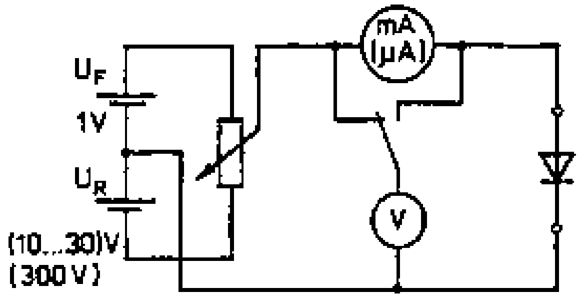


Figure 32. Circuit to take up a diode characteristic

Rectifier diodes

These diodes are designed for high reverse voltages and forward currents. They have the function to transform a.c. energy into d.c. energy. For that purpose, the valve action of the p−n junction is used.

Important rated values are:

– rated reverse voltage	U_{RWM}
– periodical reverse voltage	U_{RRM}
– non−periodical reverse voltage	U_{RSM}
– average rectified current (arithmetical average value of on−state current with defined casing temperature)	$I_{F(AV)}$
– periodical on−state current (index M indicates the maximum value)	I_{FRM}

Booster diodes

Due to the voltage−to−current intensity ratio both in the forward zone and also in the non−conducting zone, resistances are defined, which are called on−state resistance and reverse resistance. On−state resistance, also called forward resistance, is dependent on the manufacturing technology, while the reverse resistance is additionally depending on the semiconductor material. As for booster diodes, the on−state resistance is of about 1... 10 ohms, the reverse resistance of about > 100 M ?. By switching over from forward zone into non−conducting zone and vice versa, which is attained by changing the polarity of a d.c. voltage, a switch effect can be obtained. The forward zone corresponds to the switch position "ON" and the reverse zone is the switch position "OFF". The values obtained by mechanical switches (ON−resistance of some milliohms, OFF−resistance towards infinity) are, however, not obtained. The values attained by diodes are sufficient for a lot of cases of application. When changing from the on−state zone (forward zone) over to the non−conducting zone, a certain tine passes before the diode has achieved its reverse action. This period is an essential quality criterion for a booster diode.

An energy flow cannot be switched on or off inertialessly. That is what the switching sequences show, which have considerable switching times, especially as far as concentrated inductances and capacitances are concerned.

A p−n junction operated in the on−state zone is inundated by charge carriers. When it is switched over to barrier direction, a time is required until it is freed from these charge carriers. The manufacturer defines a reverse recovery time t_{rr} which passes before the reverse current intensity has reached a certain value (I_{R1} in Figure 33). This period is between some nano−seconds and some hundred micro−seconds.

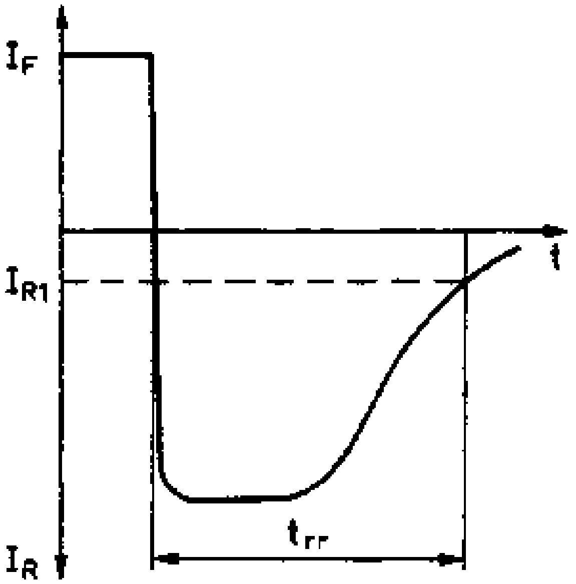


Figure 33. To define reverse recovery time

As for automation technique, booster diodes are of great importance, because modern micro−electronical circuits work very fast, and new circuit concepts (e.g. switching power supplies) can only operate economically, when diodes with high forward currents and small reverse recovery times are used.

Z−diodes

Avalanche or Zener effect is used in these diodes. That means they are operated in barrier direction and the voltage is raised so far that the breakdown is effected. Dependent on manufacture, the breakdown voltage varies about an average value. The manufacturer sorts the diodes according to these average voltage values. Z−diodes are mainly used in voltage stabilizing circuits. As for higher demands on accuracy, temperature dependence of breakdown voltage has to be considered.

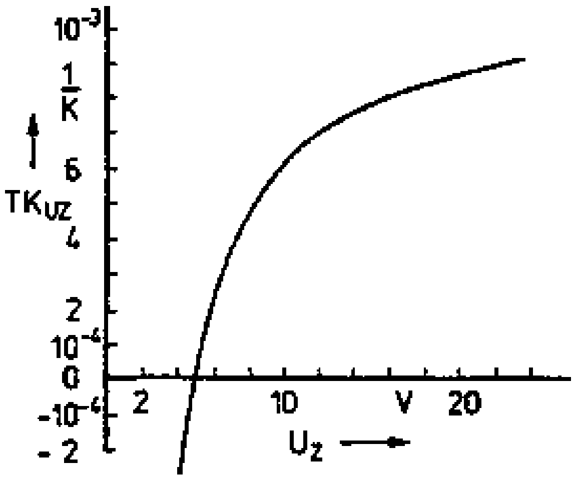


Figure 34. Temperature dependence of breakdown voltage in Z−diode

If high demands are made on the breakdown voltage constancy, reference elements (reference diodes) have to be applied. They consist of a Z−diode having a low positive temperature coefficient of the breakdown voltage TK_{UZ} and of Si−diodes connected in series and operated in forward direction. Latter ones have a negative TK_U. When properly selected, the resulting TK can be kept very small. The essential rated values of a Z−diode are stated in Figure 35. All values of breakdown region get the index Z.

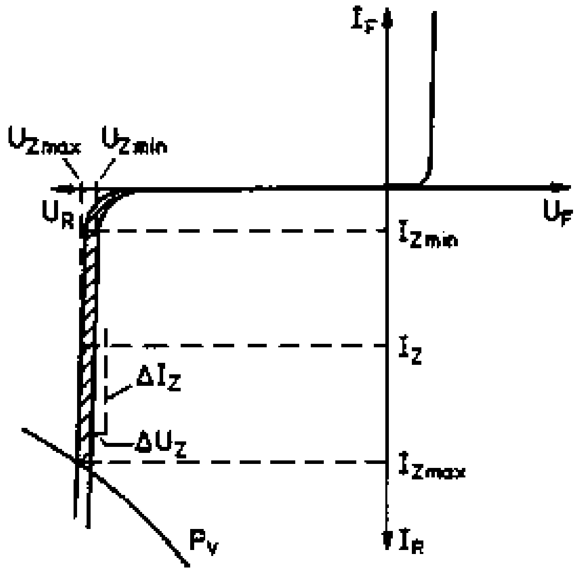


Figure 35. Characteristic of a Z−diode (dashed scattering range of the breakdown voltage)

The dynamic internal resistance

$$r_Z = \frac{\Delta U_Z}{\Delta I_Z}$$

is an a.c. resistance. It has an essential influence on the obtainable degree of stabilization. The maximum breakdown current intensity $I_{Z\,max}$ is determined by the admissible loss power P_V. It is indicated by the manufacturer.

The equation reads

$$I_{Z\,max} = \frac{P_V}{U_{Z\,max}}.$$

Minimum breakdown current intensity I_{Zmin} is to amount to about 5... 10% of I_{Zmax}. Like all Si−components, also Z−diodes may have temperatures of 100 C and more during operation. This has to be taken into consideration while assembling.

1.6.3. Transistors

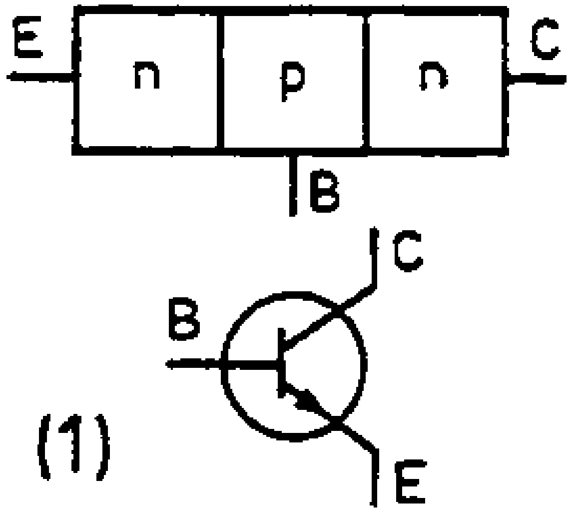
One distinguishes between bipolar and unipolar transistors. In discrete technique, bipolar transistors exist in essentially more types than unipolar ones. It is common to designate bipolar ones as transistors and unipolar ones as field effect transistors, with the latter ones having at present only secondary importance. Their manufacturing technique is, however, of great significance for integrated circuits of high integration level. That is why the construction in principle of field effect transistors is here explained, too.

Bipolar transistors have got two p−n junctions closely adjacent. Here, the zone sequences p−n−p are possible. When applying transistors, the zone sequence has to be taken into consideration, since polarity determins the supply voltage. Each zone is contacted. The connections have the following designations:

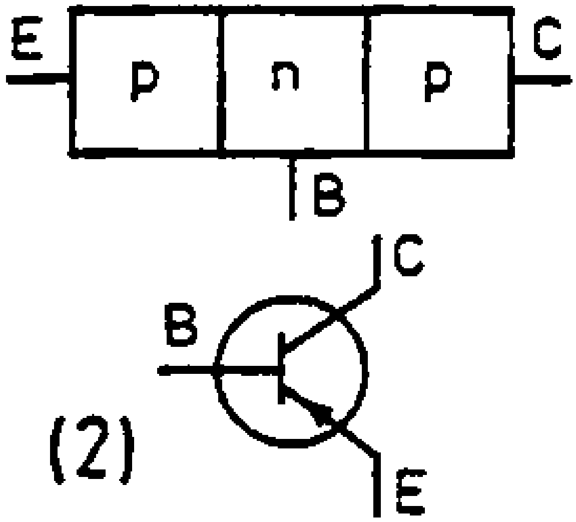
Emitter (E)	zone emitting charge carriers
Collector (C)	zone collecting charge carriers
Base (B)	zone between collector and emitter.

The schematic construction of a transistor is represented in Figure 36. The space between emitter and collector zones − the base width − is very small. It amounts to W ? 1... 10 µm only. The doping level varies very much. The emitter zone is doped strongly, the collector zone more weakly and the base zone very weakly.

Figure 36. Schematic construction and denomination of bipolar transistor connections



(1) n–p–n type,



(2) p–n–p type

As for common application of transistors as amplifier component, the p–n junction between collector and base must be poled in barrier direction. This results in the polarity of the supply voltage.

Current flow in the interior of a transistor is schematically shown in Figure 37.

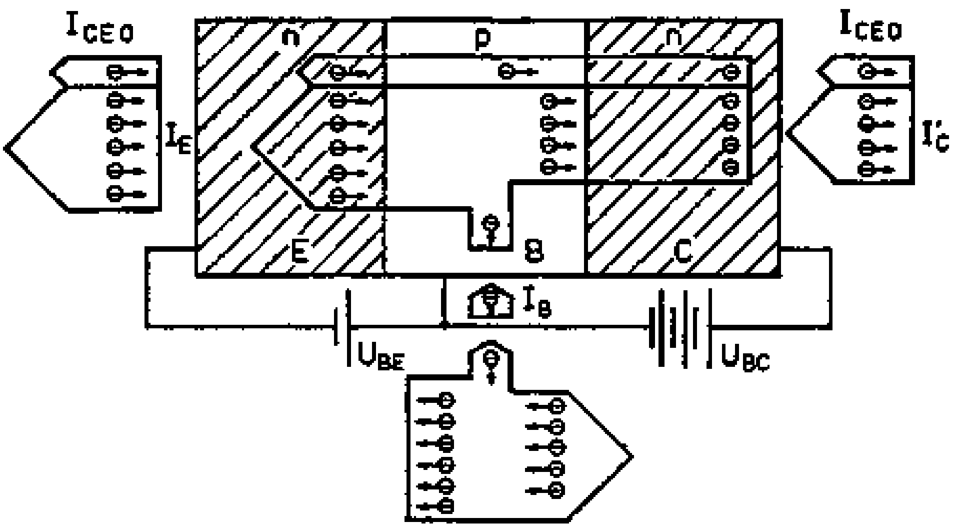


Figure 37. Flow of charge carriers in an n–p–n transistor

The emitter emits (injects) his charge carriers (electrons) into the base zone. These electrons are minor carriers in the small base zone, for it is p−doped and its major carriers are holes. A very small portion of the electrons injected (about 1%) re−combines in the base zone. In order to obtain a low rate of recombination, the base zone was weakly doped and its spatial extension (base width) was kept very small. All the other electrons diffuse into the collector zone. This is possible, because the p−n junction of base−collector zone is only barred for the major carriers, i.e. holes in base zone. This diffusion is supported by the collector voltage applied. Thus, the overwhelming portion (approx. 99%*)* of the charge carriers injected by the emitter becomes effective as collector current.

The residual collector current I_{CEO} is caused (generated) by the charge carriers evoked by intrinsic conduction in the collector−base zones. As for Si−transistors, it can be neglected, its intensity is about some nanoamperes. The emitter current intensity can be drastically modified by weakly altering the base−emitter voltage. This alteration is almost completely transmitted to the collector current. Therefore, in a collector resistor connected between collector and power source, a voltage alteration occurs that is proportional to that of the base−emitter voltage.

The proportion

$$v_u = \frac{\Delta U_{CE}}{\Delta U_{BE}}$$

is called voltage amplification.

Field effect transistors are produced especially frequently as MOSFET (Metal − (Silicon) Oxid−Semiconductor − Field − Effect −Transistor). In a host crystal (substrate, bulk) the conductivity of a channel is changed. A channel is a crystal layer enriched with charge carriers. n−Channel or p−channel types can be produced.

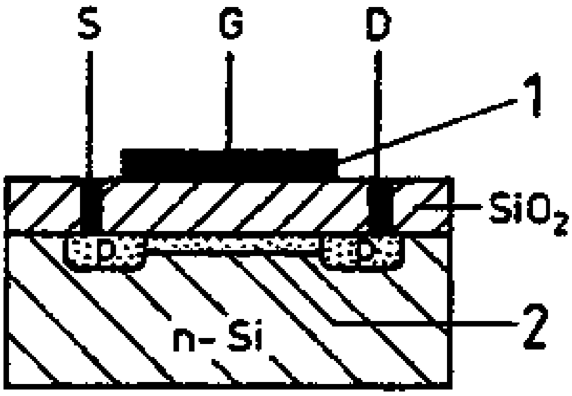


Figure 38. Schematic construction of MOSFET

1 metal, 2 p−channel

The connections are designated as

$$\left.\begin{array}{lll} \text{Source (S)} & \leqslant & \text{emitter} \\ \text{Drain (D)} & \leqslant & \text{collector}\} \\ \text{Gate (G)} & \leqslant & \text{base} \end{array}\right\} \text{in bipolar transistors}$$

The charge carrier flow for a p−channel MOSFET is schematically represented in Figure 39.

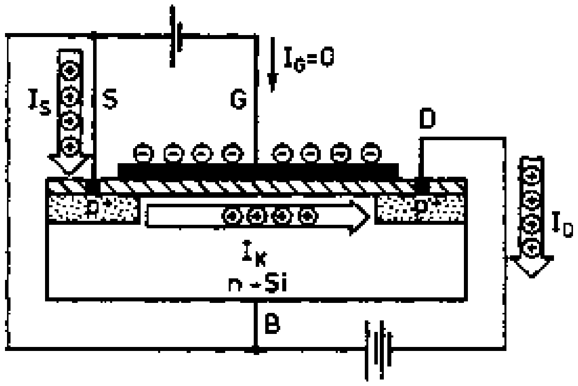


Figure 39. Flow of charge carriers in MOSFET (enrichment type)

As the gate is isolated, the gate current intensity I_G is equal to 0. In connection with the n−Si−bulk, it forms a capacitor with the SiO_2 layer as dielectric. A negative voltage applied to the gate enriches the n−silicon with positive charge carriers by influence under the gate. They form a channel between source and drain. Thus, a current flow I_K between these two electrodes is feasible. Conductivity of the channel is dependent on the enrichment level of the charge carriers flowing in it, and thus on the voltage height U_{GS} (gate voltage). As there is not a gate current, the drain current can be controlled wattlessly. The equation for it is $I_S = I_K = I_D$.

If the gate voltage becomes positive, a channel cannot form, the positive charge carriers are displaced from the source and drain region. The path between the electrons becomes high−resistive.

Field effect transistors, in which a channel does not form until a gate voltage is applied, are designated as enrichment types or as self−locking.

The gate voltage, for which a drain current $I_D = 0$ is needed, is called threshold voltage U_{T0}.

Threshold voltage is a characteristic quantity; it has its cause in the so−called traps. They are positive charges solidly bound in the Si−SiO_2 barrier layer and inducing electrostatically independent reverse charge from the gate voltage in the channel. Thus, channel conductivity is not only dependent on the gate voltage.

Threshold voltage U_{T0} is that gate voltage, with which the drain current ID equals to 0 (practically speaking I_D ? 10 µA).

Already during the manufacturing process, a channel can be produced besides the possibility of producing a channel by influence through the gate voltage.

In this case, the gate voltage obtains such a polarity that the charge carriers are displaced from the channel.

Field effect transistors, in which a channel was already generated during production, are designated as depletion types or as self−conducting.

Independent of the kind of channel generation, an increase in drain−source voltage results in a channel pinch−off at its drain−side end. Between drain and bulk, a (blocked) p−n− junction is formed, which expands more and more in the channel region with increasing drain voltage and finally pinches the channel off. This process is called pinch−off effect.

The pinch−off voltage U_{DSP} is that drain−source voltage, with which the channel (at drain−side end) is pinched off.

The equation is as follows:

$U_{DSP} = U_{GS} - U_{T0}$.

Pinch−off at the source−side end of the channel is not possible, because the source−bulk voltage difference is essentially smaller than the drain−bulk difference. Mostly is $U_{SB} = 0$ (conducting link between source and bulk).

Even in MOSFETs the voltage load capacity is limited for the drain−source line by breakdown effects of the drain−bulk p−n junction (like in bipolar transistors).

The maximum gate voltage is a particularly important quantity. The gate−bulk space is determined by the SiO_2 layer, whose thickness is less than 1 µm. Thus, the breakdown voltage is relatively small. Due to the very small capacitance between gate and bulk, already small charge amounts are quite enough to reach and exceed the breakdown voltage. That is why special measures have to be considered while working with MOSFET.

Bipolar transistors

Already a few years after the transistor effect had been discovered by Shockley, Bardeen and Brittain (in 1948), the technical production of transistors started. A serious competitor of the electronic tube was born, and after a short period (approx. 10 years) it dominated that field. The transistor's smallness, its low service voltages and its higher reliability made it superior to electronic valve (tube). In the same measure as the manufacturing techniques for transistors were mastered, the price could be lowered. Therefore, the tube has been displaced to a few special fields today. However, the transistor production, too, has exceeded its climax. Integrated circuits are replacing more and more the discrete circuits and thus, the individual components. This is the outcome of the scientific and technical revolution.

It will also displace the transistor to special fields in a few years. Knowledge about its mode of operation in principle is, however, necessary for understanding the complex circuits.

The correlations between the input and output quantities of all transistors can only be graphically represented in the form of families of characteristics, because they are not linear. The characteristics course in principle and the measuring circuit for their ascertainment are shown in Figures 40 and 41.

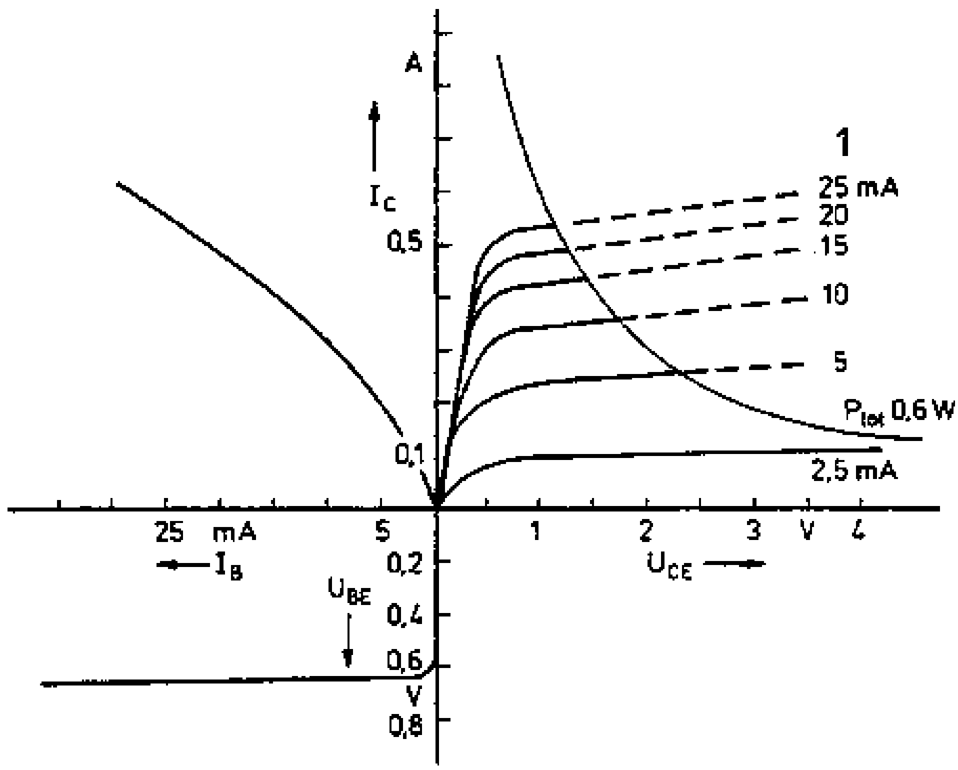


Figure 40 Characteristic fields of an n−p−n transistor

1 I−parameter

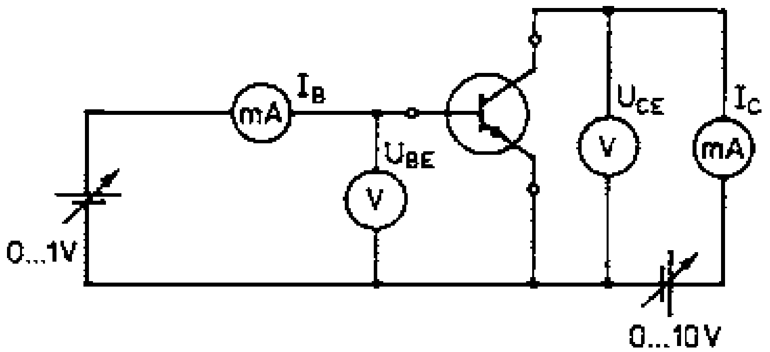


Figure 41 Circuit to take up n−p−n transistor characteristic fields

The modulation is performed around an operating point adjusted by uniform quantities. With the prerequisite of a small−signal modulation (here, the bend of characteristic has not yet an obtrusive effect) the transistor can be regarded as an active linear quadripole. In electrical engineering, circuits having four terminals are called quadripoles. A (formal) statement concerning a quadripole can also be made from the terminal action of currents and voltages, if its internal circuit is not known. This is what the four−pole theory utilizes. It defines quadripole parameters describing the correlations between (terminal)−voltages in general.

As for application of transistors in automation technology, the hybrid parameters (h−parameters) are well suited. They result from the formulation

$$u_1 = h_{11}i_1 + h_{12}u_2$$
$$i_2 = h_{21}i_1 + h_{22}u_2.$$

The four−pole theory marks the inlet quantities with the index 1 and the output quantities with the index 2.

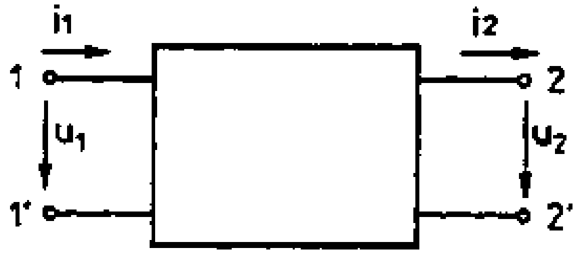
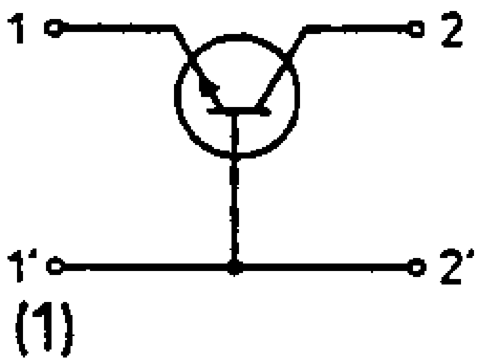


Figure 42. General representation of a quadripole

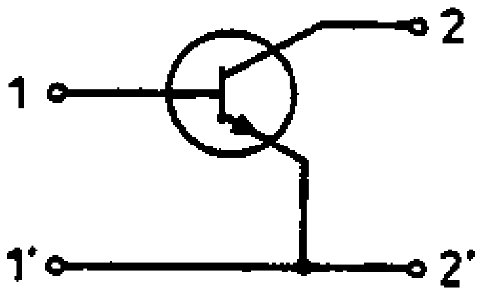
It is usual in transistor technique to reverse the direction of current i_2. This procedure is applied in later representations. Also the use of small letters for voltage and current symbols showing alternating quantities here was adapted to the common manner of writing.

As to circuitry, every electrode of the transistor can be used as input or output. The basic circuit is designated according to the electrode that is common for input and output. Figure 42 and the respective equations apply to each of these three basic circuits.

Figure 43. Fundamental circuit of a bipolar transistor

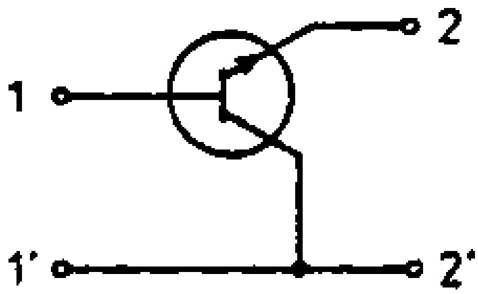


(1) base circuit,



(2)

(2) emitter circuit,



(3)

(3) collector circuit

The emitter circuit has gained a special importance. It realizes a gain in current and voltage of more than 1 and thus, the highest power gain.

Table 12 contains the service quantities for all three basic circuits.

<u>Table 12. Approx. values of service quantities of a transistor in the three fundamental circuits</u>

Service quantity	**Base circuit**	**Emitter circuit**	**Collector circuit**
Voltage amplification	100	100	1
Current amplification	1	100	100
Power amplification	100	10000	100
Input resistance	100 ?	1 K?	100 K?
Output resistance	100 K?	10 K?	100 ?

The figures mentioned are approximate values only and are to make possible a rough comparison.

One may assume an alternating uniform quantity as alternating quantity ($U_{\sim} = ?U_{=}$).

As for the emitter circuit, the input voltage appears between base and emitter. For that purpose, one can write

$U_1 = ?U_{BE}$

When this is continued consequently, a representation of the h–parameters can be deduced for each basic circuit due to alternating uniform quantities (? – quantities):

$h_{11e} = \frac{\Delta U_{BE}}{\Delta I_B}$ U_{CE} = const. short–circuit input resistance

$h_{12e} = \frac{\Delta U_{BE}}{\Delta U_{CE}}$ I_B = const. open–circuit voltage reaction

$$h_{21e} = \frac{\Delta I_C}{\Delta I_B}$$ U_{CE} = const. short−circuit current gain

$$h_{22e} = \frac{\Delta I_C}{\Delta U_{CE}}$$ I_B = const. open−circuit output admittance

e = emitter circuit

h−Parameters are different physical quantities (resistance, admittance, gain, reaction). That is why their designation is hybrid (bastard). They depend on operating point, temperature and frequency.

As for application in automation technology, the frequence dependence can be neglected nearly always. The dependence in principle on the operating point and on the temperature is stated in Figures 44 to 46.

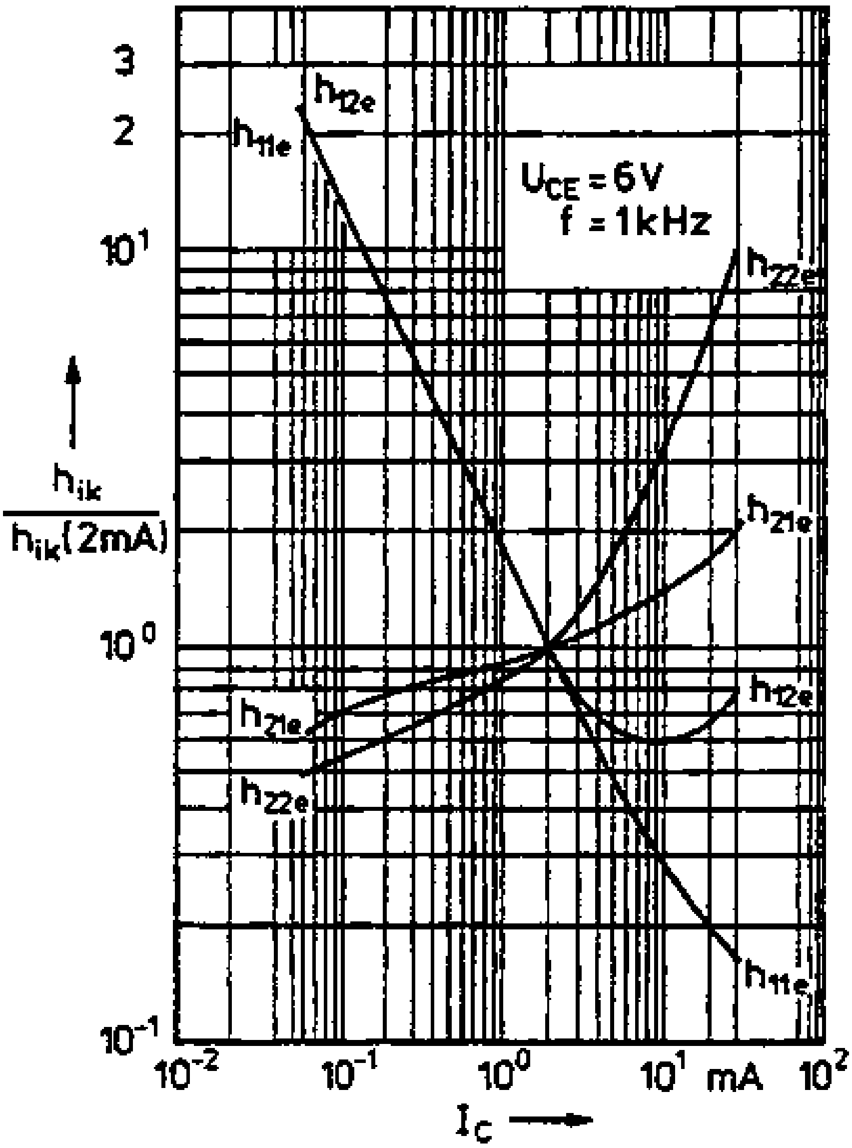


Figure 44. h−parameter dependence on collector current intensity

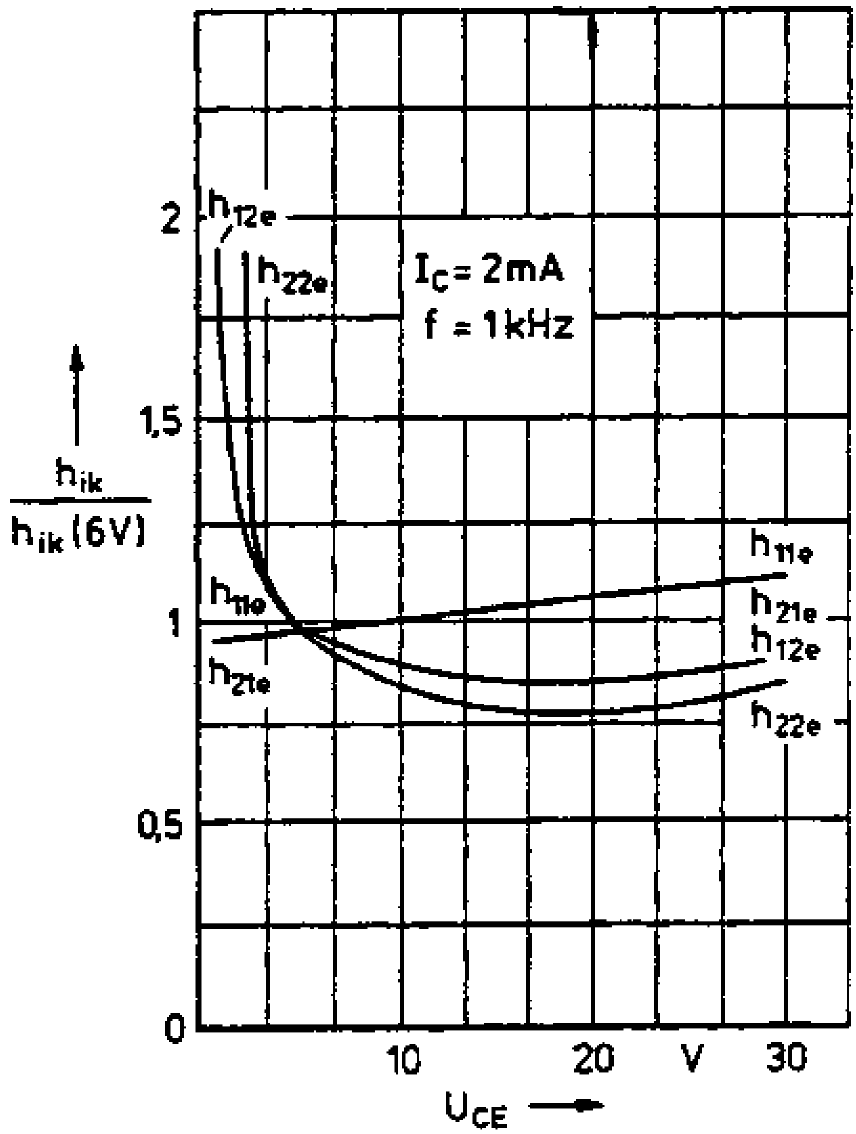


Figure. 45 h−parameter dependence on collector−emitter voltage

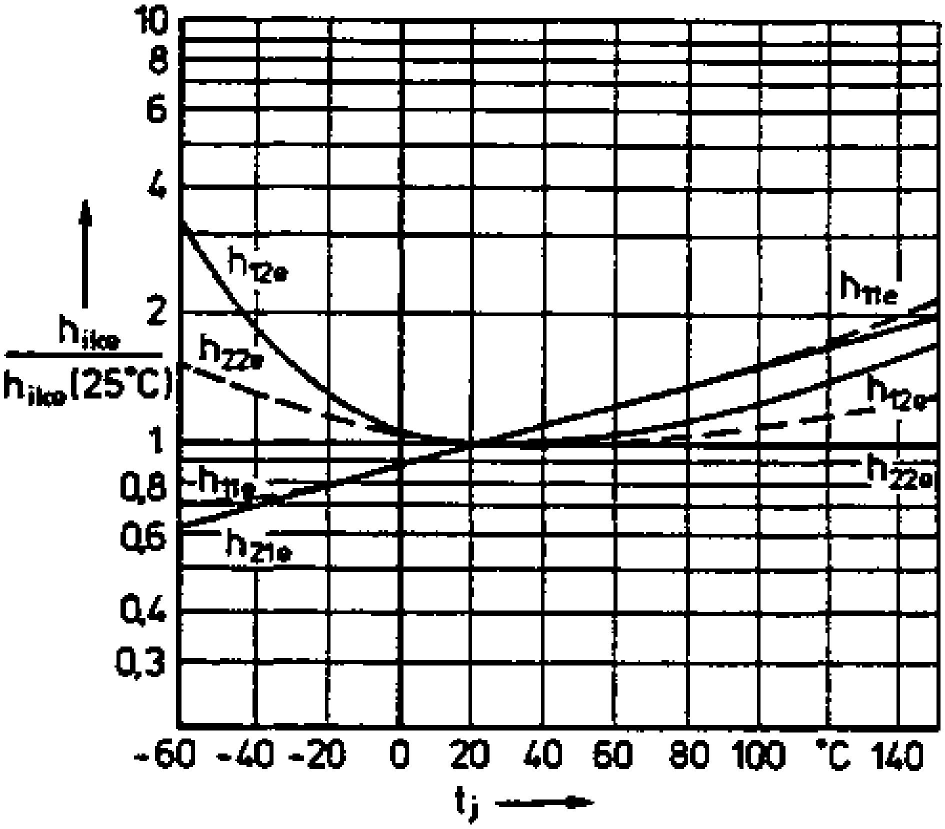


Figure 46. h−parameter dependence on barrier layer temperature

With the h−parameters, a formal equivalent network diagram can also be indicated for a transistor. It is frequently used, and in the given form applies to all three basic circuits. But it has the disadvantage that the physical properties of the transistor have not been recorded and therefore are not taken into consideration. Calculation with the four h−parameters is complicated, and it applies to the operating point only. Often approximate solutions suffice, which also consider the fact that manufacturers' data are made for an "average" transistor, and the scattering, depending on the element, of these values may amount to ± 50%. Therefore, an exaggereated accuracy in the calculation is less suggestive and, as indicated, not necessary in many fields of transistor application, either.

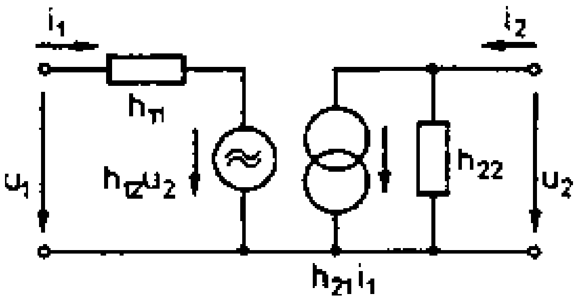


Figure 47. Formal four−pole substitute circuit scheme for a bipolar transistor

Considering these reflections, a simple equivalent network diagram for a bipolar transistor can be given for very low frequences ($f \lesssim 0.1\ f_T$). The transition frequency f_T is a characteristic given by the manufacturer.

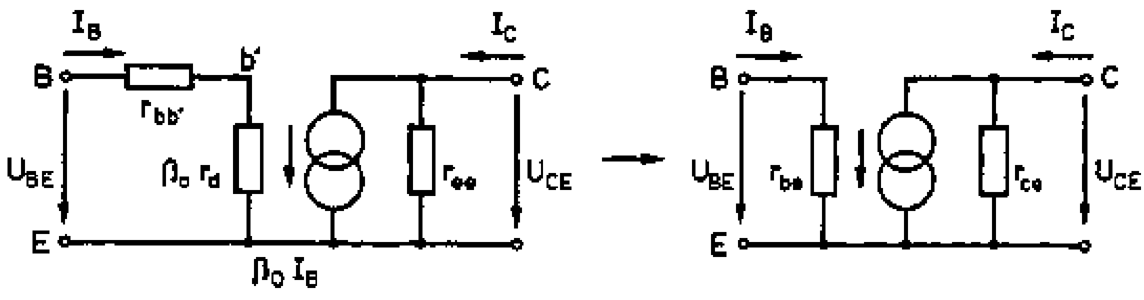


Figure 48. Modified substitute circuit scheme for a bipolar transistor in emitter circuit

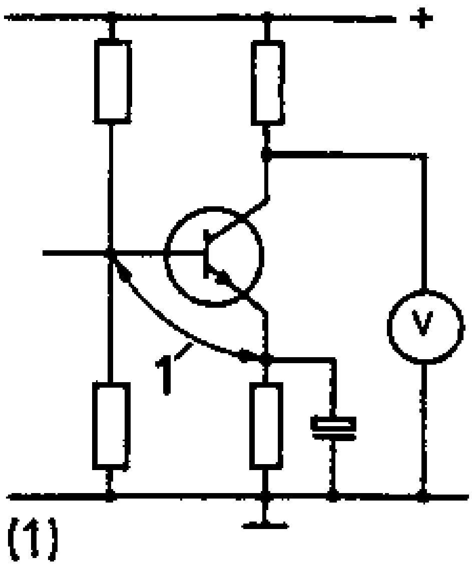
b' inner base connection (not admissible)

Symbols of the equivalent network diagram as to Figure 48 have the following meaning:

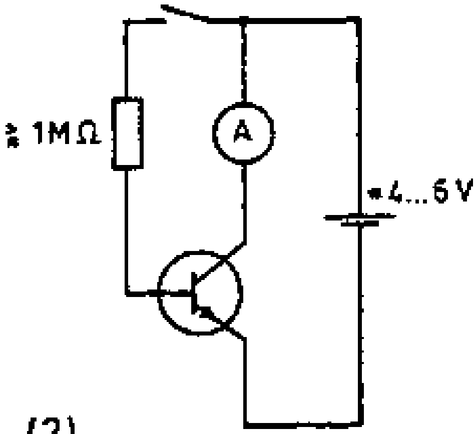
$r_{bb'}$? 10... 500 ohms	base–bulk resistance
$r_d = \frac{U_T}{I_E} \approx \frac{U_T}{I_C}$	emitter diffusion resistance
$U_T = \frac{KT}{e} \approx 26 mV$ at t = 25°C	temperature voltage
$K = 1.38 \cdot 10^{-23}\ W \cdot s \cdot K^{-1}$	(Boltzmann constant)
T	(absolute temperature)
$e = 1.6 \cdot 10^{-19}\ A \cdot s$	(elementary charge of an electron)
$r_{be} = r_{bb'} + rd\ B_0 = h_{11e}$	
r_{ce} ? h_{22e}^{-1}	current gain in operating point (at low frequencies)
$B_0 = h_{21eA}$	

Also here, the use of small letters again points to alternating quantities. Especially in case of repairs, the question often arises the for serviceability of a transistor. A simple check method is shown in Figure 49.

Figure 49. Circuits to check serviceability of transistors



(1) for a transistor soldered in a circuit,



(2)

(2) for a transistor removed from circuit

Figure 49.(1) represents the test possibility of a transistor soldered in a circuit. Due to the short−circuit of the base−emitter line, the transistor blocks. In this connection, its collector voltage rises approximately to the value of the service voltage. This rise is a sure mark for the transistor's serviceability.

If the transistor is removed, its serviceability can be checked in a circuit according to Figure 49.(2). Instead of the base resistance, bridging the collector−base can be performed with a damp finger. The multipurpose meter switched to the most sensitive range is recommended as ammeter. As to an open base, a residual collector current is only allowed to flow, which with silicon components hardly causes the pointer to deflect. When the base is connected, a base current is flowing, which is indicated more strongly by the ammeter as collector current. The marked increase in the collector current intensity, when the base is connected, is a sign for the serviceability of the transistor checked.

Of several possible forms to sort out transistors, the following one has proved in practice:

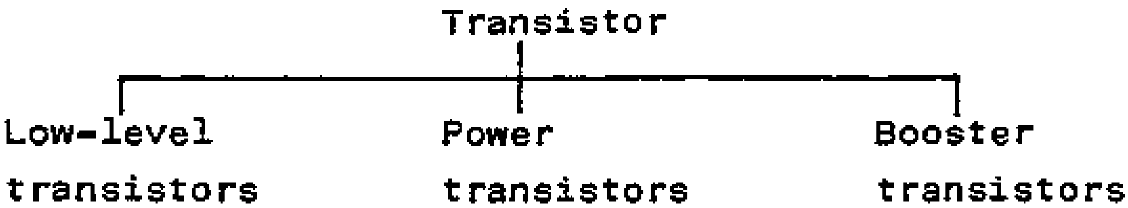


Table 13. Classification possibilities of transistors in practice

Low−power transistors

They have small collector loss power and are designed to be used as voltage amplifier. They are produced both as metal−encapsulated type and also as plastic−encapsulated type, with the latter one being designated as mini−plastic transistors, too. Different data for current amplification are given by the manufacturer.

$$h_{21e} = B_0 = \frac{\Delta I_C}{\Delta I_B}$$ short−circuit current amplification in emitter circuit

U_{CE} = const.

$$h_{21e} = B = \frac{I_C}{I_B}$$ d.c. amplification in emitter circuit

Power transistors

They can easily be recognized, since they have a special design due to their large basic area facilitating a good heat transfer when mounted on a heat sink.

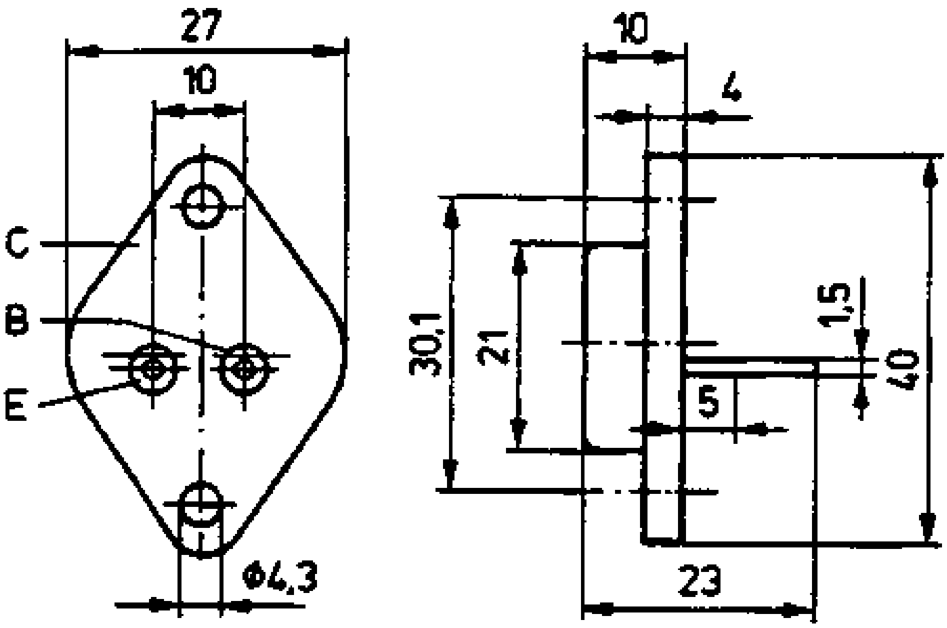


Figure 50. Common design for power transistors

The cooling problem plays a great part when power transistors are used. Spatial dimensions of p−n junctions are very small. Therefore, they have a low heat capacity. Already small electrical overloads result in an inadmissible heating which may lead to a thermal breakdown. Power transistors frequently have high current intensities causing, even during normal operation, a considerable transistor heating. Therefore local current density concentrations occur without overload, either, which lead to the 2nd type breakdown.

That is why the manufacturer indicates, in any case, the internal heat resistance R_{thje}. He describes the heat conduction proportions between the p−n junction and the casing. With this internal heat resistance, an external heat resistance R_{tha} is in series, recording heat output to the ambient.

The correlations between loss power and temperature are represented by the following equation:

$$P_V = \frac{t_j - t_{a\,max}}{R_{thje} + R_{thü} + R_{thk}}$$

t_j	admissible barrier−layer temperature
$t_{a\,max}$	highest occurring ambient temperature
R_{thje}	internal heat resistance
$R_{thü}$	heat transfer resistance
R_{thk}	cooling sink heat resistance

$R_{thü} + R_{thk} = R_{tha}$.

The equation was made in analogy to the electrical fundamental circuit.

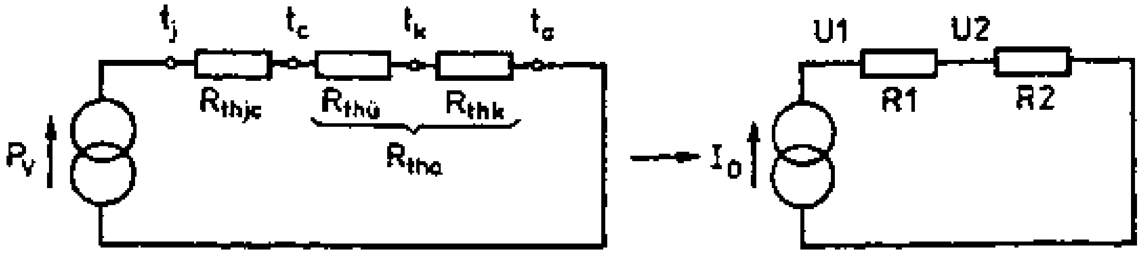


Figure 51. Thermal substitute circuit diagram for a power transistor with heat sink

t_K heat sink temperature,
t_c transistor casing temperature

The loss power P_V corresponds to the source current I_0, while the temperature corresponds to the partial voltage. The thermal heat−transfer resistance $R_{thü}$ is dependent on the assembly conditions of the transistor on the heat sink. It is approximately between 0.2 · W^{-1} (additional hard paper washer of 0.1 mm thickness without grease).

Is the transistor operated without heat sink, so the total heat resistance R_{thja} is to be applied to $R_{thje} + R_{tha}$. It is indicated by the manufacturer.

To improve heat output to the ambient, heat sinks or cooling plates are often used. Heat resistance is indicated for the heat sinks industrially produced. Mostly, cooling plates are made of aluminium sheets, because aluminium has a good heat conduction and is light. As for blank aluminium sheets, their vertical mounting and a thickness of 2 mm, the following approximate formula for the heat resistance has well proven:

$$R_{thk} \approx \frac{1}{1.5 \frac{mV}{cm^2 \cdot K} \cdot A/cm^2}$$

A surface (one side) of the sheet

Booster transistors (switch transistors)

They are an electronical version of the mechanical switches. Compared to them, they have the following advantages, among other things:

– no movable parts, therefore higher−reliability,

– essentially shorter switching times (mechanically speaking a few milli−seconds, electronically a few nano−seconds to microseconds).

– smaller volume.

But they have disadvantages, too:

– the resistance in the "open" state is smaller than in mechanical switches,
– the resistance in the "closed" state is bigger than in mechanical switches.

In case of higher current intensities, transistors cannot be used any more due to the thermal load.

Transistor marking is given in Table 14, while the marking of current amplification groups is shown in Table 15.

Table 14. Marking of transistors

Letter	at 1st place	at 2nd place	at 3rd place
A	germanium	–	–
B	silicon	–	–
C	–	LF−low−level transistor	–
D	–	NF−power transistor	–
F	–	HF−low−level transistor	–
G	germanium	–	–
K	silicon	–	–
L	–	HF−power transistor	–

M	–	Field effect transistor	–
P	–	Photo–transistor	–
S	silicon	Booster transistor	–
T	–	Thyristor	–
U	–	Power switch transistor	–
X	–	–	for commercial use
Y	–	–	
Z	–	–	

Table 15. Marking of current amplification group of transistors

Current amplification range	**Marking h_{21e}**	**h_{21E}**
–	–	–
18... 35	a	A
28... 71	b	B
56... 140	c	C
112... 280	d	D
224... 560	e	E
450... 1120	f	F

Unipolar transistors

As already mentioned earlier, MOSFETs are only described. Since both enrichment types and depletion types with p–or n–channel are produced, there are the following four versions:

n–channel–enrichment type

No channel exists without voltage U_{GS}, a small residual current flows between source and drain. If U_{GS} becomes bigger than U_{T0} (threshold voltage), an n–channel is induced, and a noticeable drain current flows, when $U_{DS} > 0$.

p–channel–enrichment type

The mode of operation is the same as with the n–channel, but it must be $U_{GS} < 0$ and $|U_{GS}| > |U_{T0}|$ so that a channel can be induced.

n–channel–depletion type

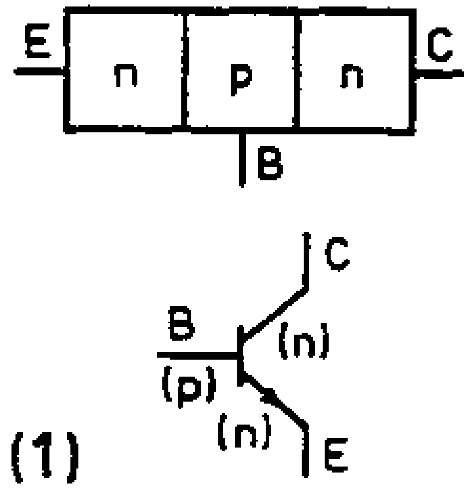
Already during production, an n–conducting channel is generated. A negative gate voltage ($U_{GS} < 0$) depletes charge carriers in the channel, and the drain current intensity is reduced ($U_{DS} > 0$). As to $|U_{GS}| = |U_{T0}|$ current flow is I_D ? 0 (measuring value of the manufacturer I_D = 10 µA).

p–channel–depletion–type

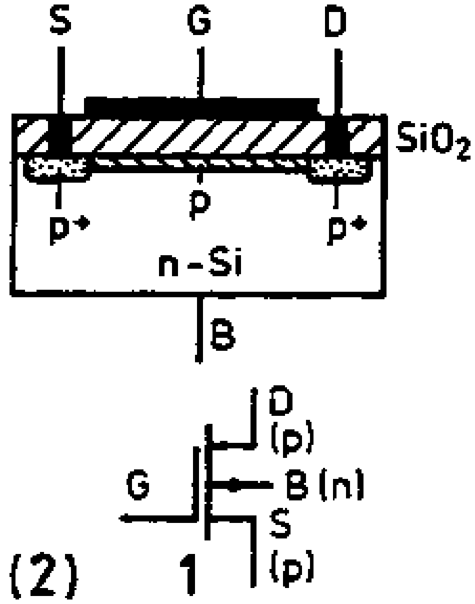
As for analogous mode of operation to the n–channel–depletion type, a positive gate voltage is, however, required to reduce the number of charge carriers in the channel.

The correct interpretation of the various circuit symbols is made easier when one considers that the arrow–head always shows from p to n in all p–n junctions. This also applies to bipolar transistors.

Figure 52. Representation of direction of arrow for p−n junctions



(1) for bipolar transistors,



(2) for unipolar transistors

1 p−conducting channel

The families of characteristic of the four fundamental types are the same in their form, therefore it is sufficient to explain one type only.

Figure 53 shows the output family of characteristics (right) and the input characteristic (left) for a p−channel−enrichment type. The pinch−off voltage U_{DSP} divides the output family of characteristics into the active (resistance) and saturation (amplifier) section. $I_D = f(U_{DS})$ in the active section, MOSFET acts like a resistor controllable by U_{GS}. In this case, the influence of U_{GS} is getting less and less with the drain voltage U_{DS} getting smaller and smaller.

In the saturation section, $I_D = f(U_{DS})$ = const. (approximately), MOSFET is operated in this section, if used as amplifier.

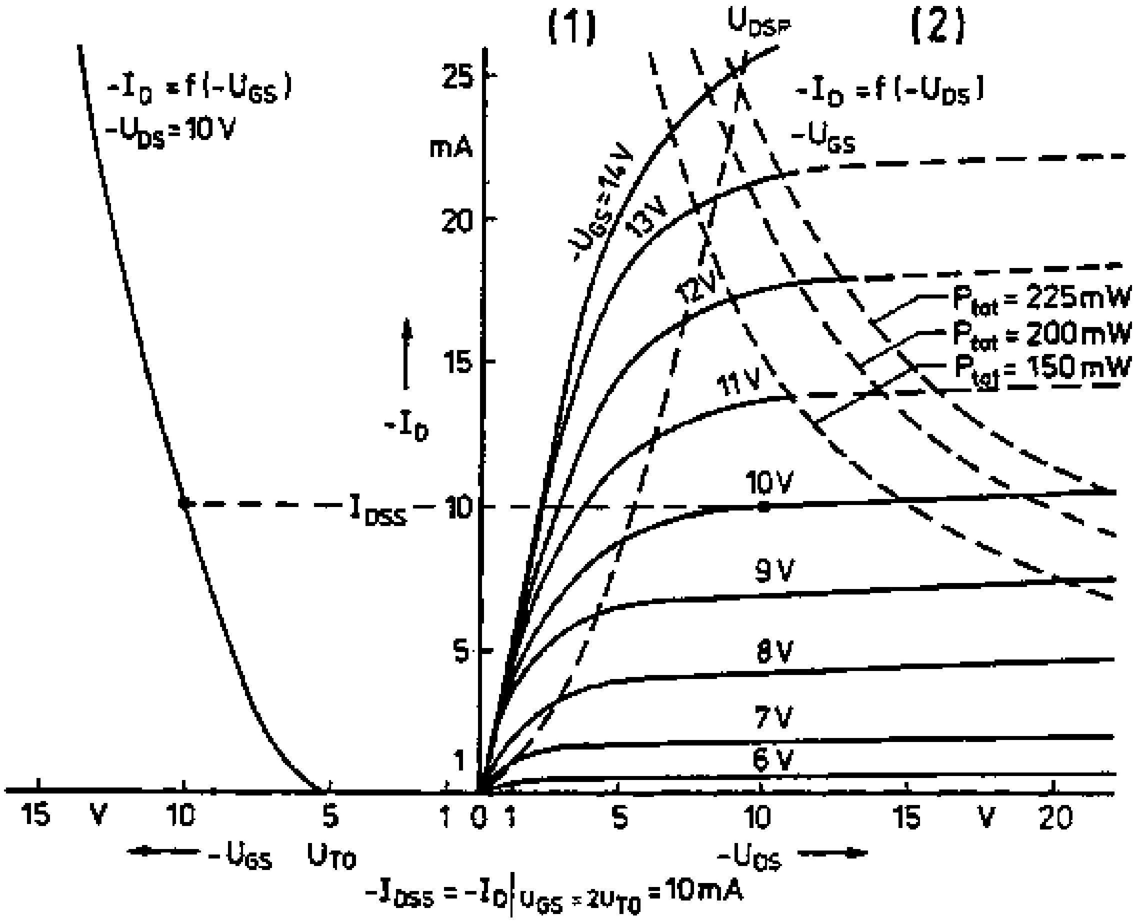


Figure 53. Characteristic fields for a p−channel enrichment type

(1) resistance range,
(2) amplification range,
U_{GS} in resistance range as parameter

Both the input characteristic and also the dependence of the channel resistance on the gate voltage make the influence of the threshold voltage U_{T0} evident.

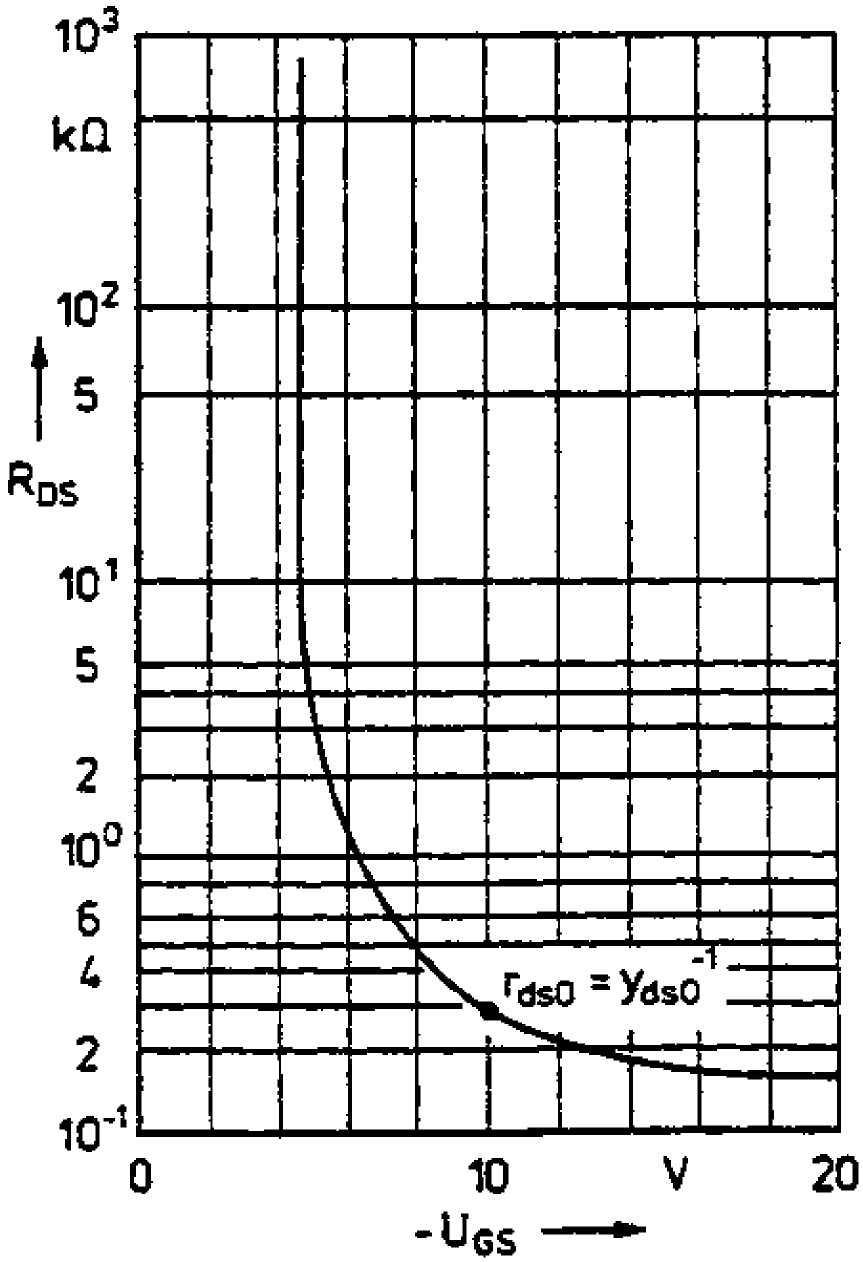


Figure 54. Dependence of channel resistance on gate voltage

U_{T0} = 3... 6V is assumed for the example shown. As well as for the bipolar transistor, characteristics can be given for a MOSFET, describing its action. As for automation technique, a reflection on low frequencies would be sufficient. The representation with y−parameters has been generally accepted.

The field effect transistors are equipped with integrated gate protection diodes (Z−diodes) draining off dangerous overvoltages from the gate. Their current load−carrying capacity is, however, low (0.1 mA), therefore they (diodes) must not be used in circuitry.

When MOS elements are used, the following recommendations are to be observed:

MOS elements are only processed on tables with conductive surfacing which has to be earthed! Do not take MOS elements out of the Manufacturer's packing material until they are immediately used. Do not touch MOS element connections with your hand or insulated instruments.

1.6.4. Thyristors

Not until the development of controllable rectifiers on semiconductor basis did industrial electronical engineering experienced as steep upturn. Higher reliability and shorter switching times make the thyristor superior to the mechanical switch. Current intensities and voltages switchable with a transistor are often not sufficient for operating the actuators, since mains voltage is mostly used. The thyristor offers a possibility to switch mains voltages.

A thyristor consists of a four−zone sequence (p−n−p−n) in a crystal.

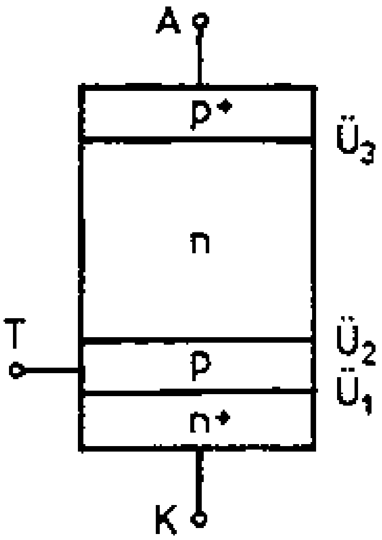


Figure 55. Schematic construction of a thyristor

Here, the centre n−zone is kept wide. This construction conditions three p−n junctions ($ü_1$ to $ü_2$). They make the following operating manners possible:

− Operation in barrier direction (positive pole of voltage source applied to cathode, negative pole of voltage source to anode) p−n junctions $Ü_1$ and $Ü_3$ are blocked, a small reverse current is only flowing. When the voltage is further increased, an avalanche breakdown is effected, destroying the element, if an external current limitation is not accomplished.

− Operation in blocking direction (positive pole of voltage source applied to anode, negative pole of voltage source to cathode) p−n functions $Ü_1$ and $Ü_3$ are open with this supply voltage polarity, and the centre junction $Ü_2$ is blocked. Even now, a small residual current is flowing. In this state, the thyristor can be "ignited" by a positive impulse at the gate electrode or by further increasing the anode voltage (supply voltage). In this connection it becomes low−resistive, the anode current intensity strongly increases, the voltage over the thyristor collapses to a small value (0.5... 1.5 V).

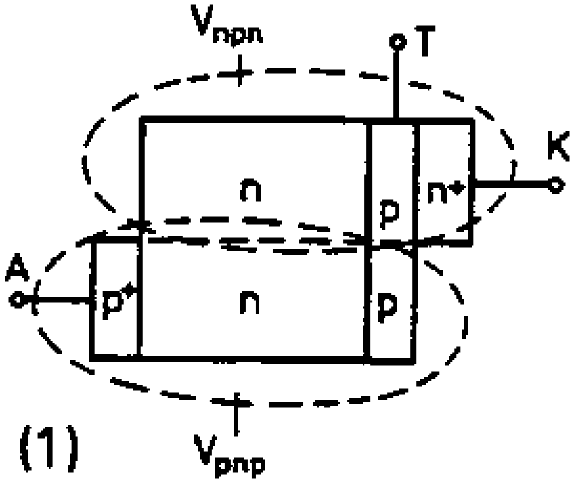
The thyristor acts now like a closed switch.

The transition from high−resistive to low−resistive state is performed very quickly and is, therefore designated as relaxation.

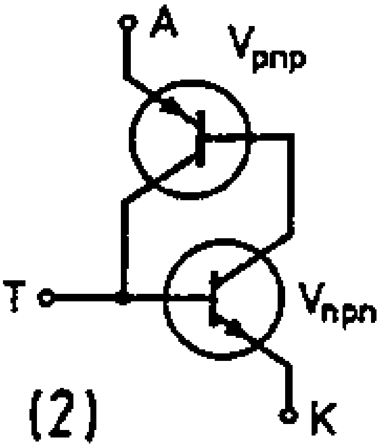
The relaxation process can be explained, when one imagines that the thyristor is composed of two transistors. These two transistors V_{pnp} and V_{npn} are so interconnected that the collector cur−rent of the one transistor is at the same time the base current of the other one, i.e. both transistors are completely coupled with each other.

In all transistors current amplification lowers with small collector "current intensities as well as with higher ones. With small values, the re−combination becomes noticeable and the base width increases. High collector current intensities bring about saturation effects.

Figure 56. Thyristor representation by two transistors



(1) deduced from schematic construction



(2) by circuit symbols

Technological measures (wide n−region) make it possible with the thyristor that the sum of current alterations (v_{ipnp} + v_{inpn}) becomes smaller than 1 with lower current intensities. With increasing current intensity the current amplifications will become also higher. When the sum has reached the value 1, both transistors become conductive. The other transistor's collector current acting as base current has become so strong that it can cover all losses (re−combination). The current intensity increases like an avalanche, the transistors V_{pnp} and V_{npn} are overmodulated.

In this connection, their collector−emitter voltage collapses to a small value. This process is designated as ignition (the term "ignition" is taken from vocabulary of the gas−discharge tube; they have the same properties, beginning of a noticeable current flow connected with the optical appearances − glowing, light−emitting).

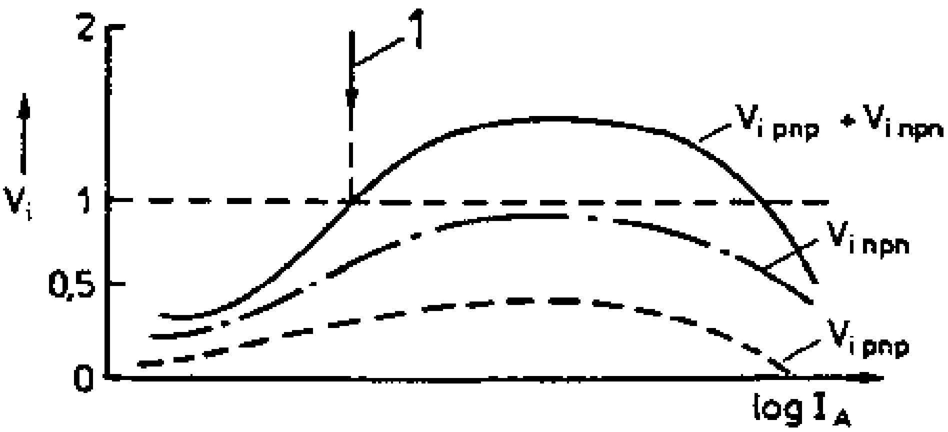


Figure 57. Dependence in principle of current amplification on anode current in transistor structures of thyristor

1 Ignition point

The current intensity needed for ignition appears when:

− the voltage between anode and cathode of the thyristor is so far raised that the reverse current takes on the necessary value for a total current amplification of more than 1 (this ignition is not allowed by the manufacturer).

− a voltage (ignition voltage) is applied to the control electrode (gate). The current now flowing in the control electrode is the base current of the npn−transistor and appears with its current amplification multiplied as collector current. Therefore, it may be much smaller than the future anode current and still release the ignition process.

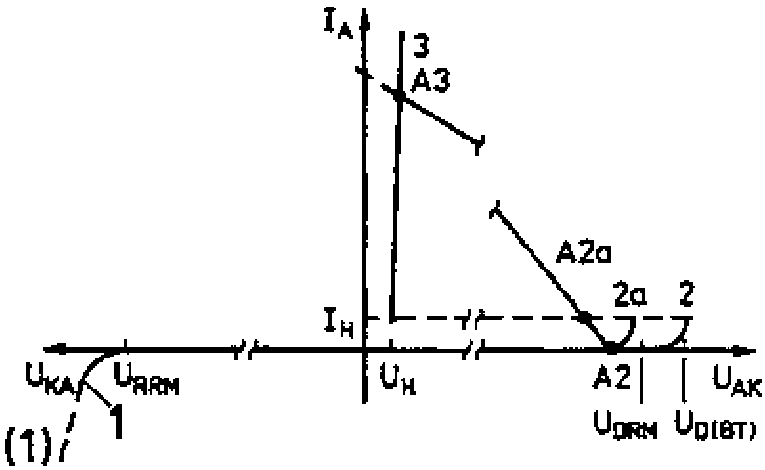
After ignition, the control current is not necessary any longer. The thyristor is only possible to be returned into the non−conductive state (off−state), when anode voltage and anode amperage are lowered below a certain value (holding current and holding voltage). That means, a blockage through the control electrode is hence not possible.

Up to the repeated application of an anode voltage in barrier direction, a certain time − recovery time − has to pass. It is at about 10... 100 µs. This time is needed for re−combining the charge carriers in the crystal.

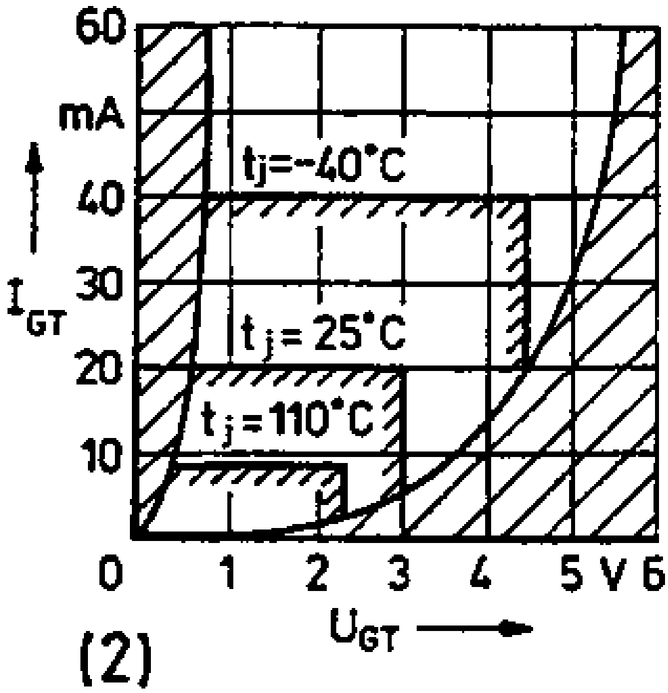
A thyristor can be ignited in barrier direction by a positive impulse at the control electrode. Here, the thyristor becomes low−resistive. The control electrode is ineffective after ignition.

The characteristics of a thyristor are represented in Figure 57. The static characteristic can be distributed to the non−conducting zone 1, the blocking zone 2 and the on−state zone 3 (Figure 58 (1)). Part 2a is an ignition over the gate. Here, the thyristor is switched to the on−state zone even with voltages $U_A < U_{D(Br)}$. The operating point jumps from point A2 to A3. Point A2a cannot be kept stable, it lies in a dropping part of characteristics, which is passed through quickly in any case. The input family of characteristics (Figure 58 (2)) represents the sections of possible ignition in dependence of the barrier layer temperature and the scattering of the input characteristic. Ignition is only performed in the unhatched section. An ignition is possible below the line marking the respective barrier layer temperature, it is certain above this line.

Figure 58. Thyristor characteristic



(1) static characteristic,



(2) input characteristic with the zones of a possible ignition

Along with the recovery time already mentioned, the dynamic characteristics

– voltage increase speed du/dt
– current increase speed di/dt

are to be considered when using a thyristor.

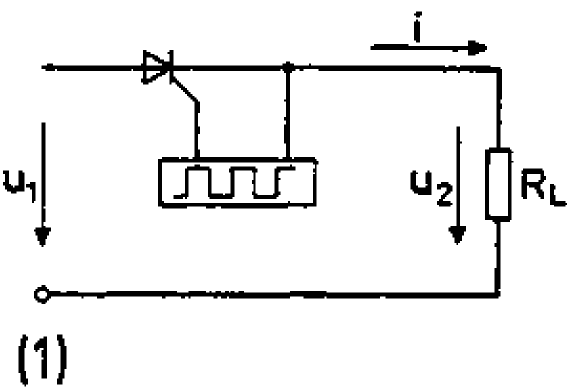
(For du/dt and di/dt, it is possible to place approximately ?u/?t and ?i/?t.)

The voltage increase speed must not exceed values of about 20 V/µs because the thyristor ignites, otherwise, in an uncontrollable (wild) manner.

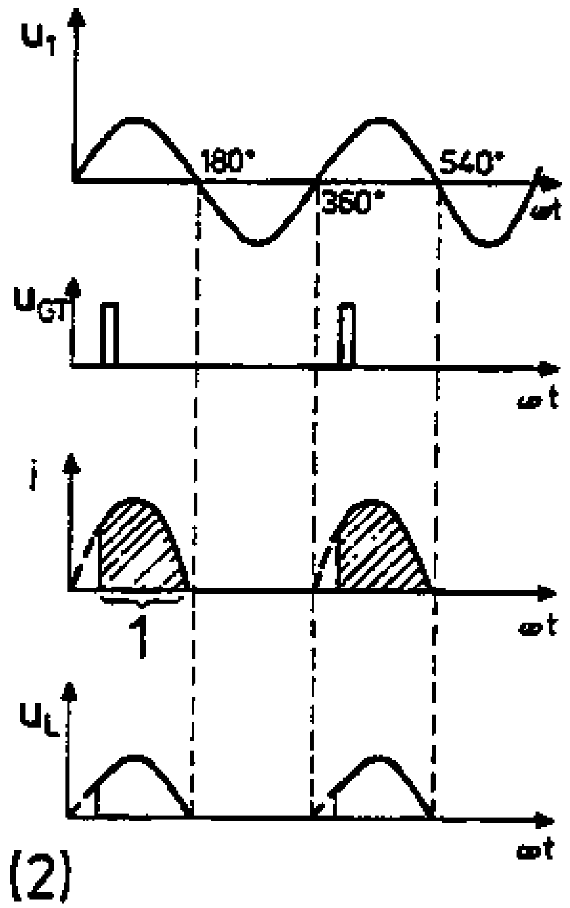
Too high a current increase speed (approximate value 10 A/µs) results in a local overload of the semiconductor wafer in the thyristor and in its thermal destruction.

The mode of action as a switch does not yet completely substantiate the versatile application of the thyristor. The real advantage is in the use as controlled switch, that means the ignition at a certain moment related to an alternating current half–wave. Depending on the ignition impulse length, the thyristor is live over a different time (indicated as hatched field in Figure 59).

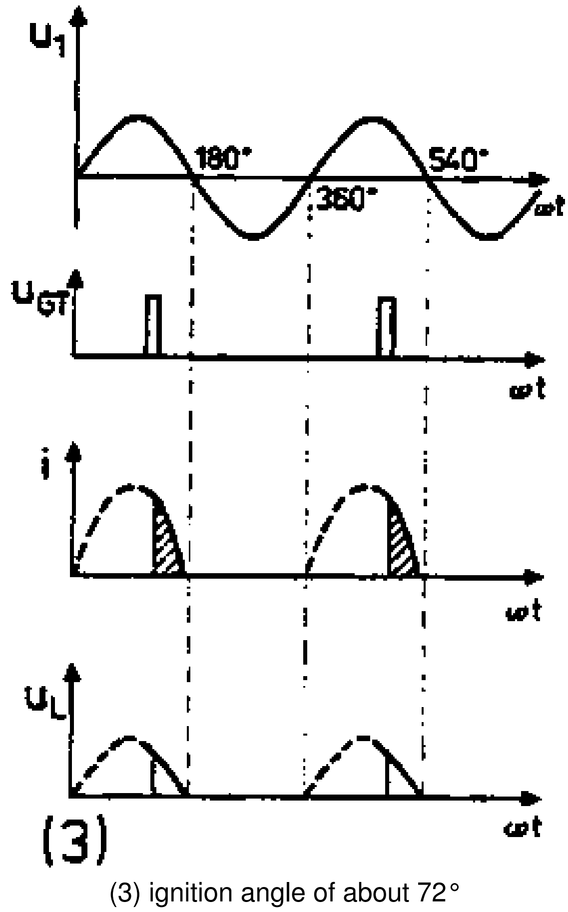
Figure 59. Application of thyristor as controlled switch



(1) circuit



(2) ignition angle of about 135°

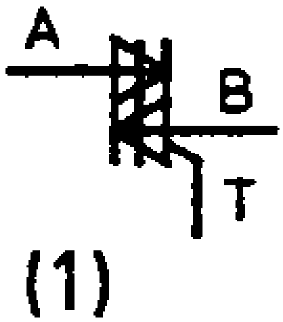


(3) ignition angle of about 72°

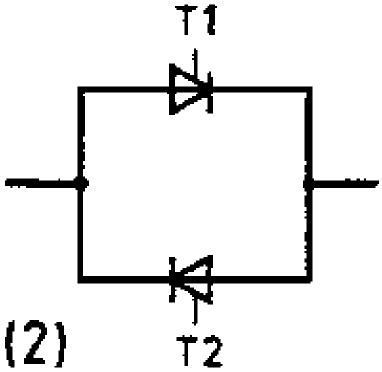
A consumer subsequently connected can only take up power in this time. By changing the moment of ignition of a thyristor, one can control the consumer's power input. This procedure is often called phase–angle control.

While the current flow is automatically interrupted at the end of each positive half−wave during operation with alternating voltage, it is not the case with direct voltage. If it is not possible to lower the direct voltage below the holding voltage, a special quenching circuit is needed. But also during operation with alternating voltage, one has to take note of the fact that the consumer is only triggered with a pulsing voltage − the positive half−waves. This is often not desired, because power drops to about half and, as for lighting facilities, flickering occurs. In such cases, the use of a bidirectional triode thyristor (triac) is required. This component can become conductive in both directions (anode − cathode and cathode − anode). Instead of a circuit with two anti−parallel thyristors, a simpler selection circuit can be used.

Figure 60 Symistor (triac)



(1) denomination of connections



(2) equivalent anti−parallel circuit of two thyristors

In principle, the construction of a triac is shown in Figure 61. The two thyristors are marked by dividing lines. Thus, the different zone sequence (npnp and pnpn) is made clear. Ignition through the control electrode T is possible with positive or negative impulses, because a p− and an n−doped field is arranged.

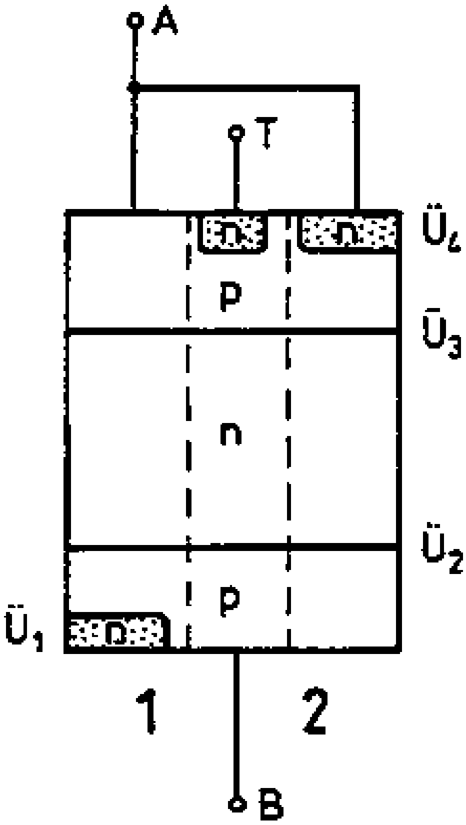


Figure 61. Construction of a triac in principle

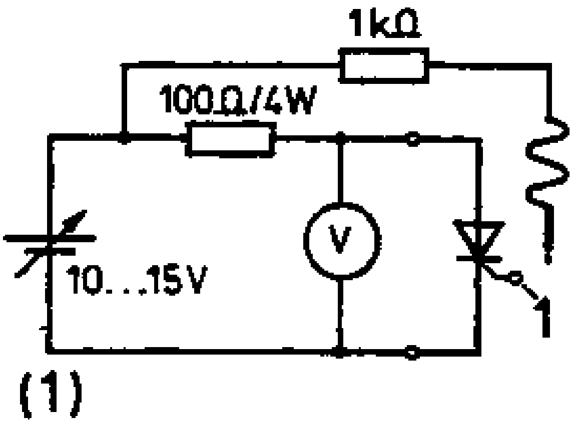
1 Thyristor 1, 2 Thyristor 2

To avoid voltage peaks (glitches) appearing when inductive loads are cut off and endangering the thyristor, an RC−element is connected to it in parallel (RC = resistance−capacitance). It is also called TSE−wiring (TSC carrier accumulation effect). Calculation of the values for R and C is only possible approximately, if the consumer is not exactly known. Practical values are between 0.022 µF and 0.47 µF or 10 ? and 470 ?.

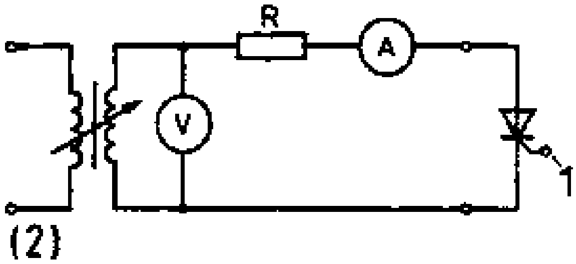
A simple possibility to check thyristors for serviceability is indicated in Figure 62. To test controllability, the thyristor is connected in series with a voltmeter to a direct voltage source so that it is loaded in blocking direction. Gate connections remains open. Through a resistor R ? 1 k? connected to the positive pole of the voltage source, the gate connection is shortly touched (tapped), and the thyristor ignites if it is serviceable. The voltmeter must indicate full service voltage before tapping and approx. zero after tapping (Figure 62.(1)). Blocking and reverse capability is checked with a circuit as per Figure 62.(2). Height of alternating voltage must be 10 to 50% above the future service voltage. When the thyristor is serviceable, the ammeter must indicate zero. If the thyristor breaks down, a current flow is indicated.

Resistance R is so to be measured that there will be a flow of about 0.1 A at the peak of voltage. Its load capacity must then amount to at least $U_{max} \cdot 0.1$ A. Purposefully, the voltage is being increased, starting from zero (adjusting transformer). Gate connection remains open in this circuit.

Figure 62. Circuit to check serviceability of thyristors



(1) to check controllability



(2) to check blocking and reverse capability

1 Specimen

1.7. Opto−electronic components

1.7.1. Determination of terms and requirements

Opto−electronic components convert light energy into electric energy or vice versa.

The following is differentiated as to the energy conversion direction:

− light receiver	optical	?	electrical	
− light transmitter	electrical	?	optical	
− optical coupler	electrical	?	optical	? electrical

A few kinds of components have only importance for automation technology.

Light has special properties as a transmitting medium, justifying the wide−ranged application of opto−electronic components. As known, light can be explained as a particle flow − here, one speaks of light quanta or photons − or as an electromagnetic wave (dualism of the light). Since energy is form of matter and this can also appear as a mass, the dualism is scientifically founded upon. Its practical significance is based on the fact that some processes, e.g. excitation of charge carriers by light, are only explicable when a particle structure is allocated to the light. Other properties, such as polarization or diffraction can only be explained by assuming the light wave properties. In general linguistic usage, the wavelength range ? = 390... 800 nm perceptible by man is called light. Physically speaking, this range is expanded towards shorter (ultraviolet) and also towards longer wavelengths (infrared). These ranges are used by many opto−electronic components. All electro−magnetic components can be concentrated when a reflector is used, whose diameter is essentially larger than the wavelength ?. With dependable technical expenditure, this can only be achieved with wavelengths ? < 10 cm. Light wavelengths are smaller by some decimal exponents, therefore, even small reflectors have as a result a sharp concentration (focussing), as can be proved with any flashlight being sufficient for transmitting over larger distances, too.

A conducting electrical connection is not necessary, the transmitting medium may be air. By applying light guide lines, they are thin glass fibres, light can be guided around the corner, through liquids or dull atmospheres. Influence of extraneous light is completely excluded. A thyristor laying on mains potential can be triggered, e.g. with the help of an optical coupler, by a circuit lying on earth potential without problems. Opto−electronic components help to indicate operational conditions, letters, figures or signs can be represented by an appropriate forming (alphanumerical representation).

The needed and released voltages permit a direct combination with semiconductor elements. Because of this fact, opto−electronic components are also used in a wider and wider range.

1.7.2. Light transmitters

Light transmitters convert electric energy into light energy.

They are also called light emitters.

In a p−n junction, through which current is flowing, the charge carriers are re−combined, resulting in setting energy free when electrons pass over to a lower energy level.

As already known, the electrons orbitting an atomic nucleus can only occupy trajectories being in a certain distance from the nucleus. A defined energy corresponds to each trajectory. The transition of an electron from one trajectory to another is only possible if there is a free place and energy is added (transition to an outer trajectory) or released (transition to an inner trajectory). This is also called higher or lower energy level. Energy is released as light. Energy quantity is dependent on the distance of trajectories (energy level) and decisive for the wavelength of light released.

<u>Light emitter diodes (LED)</u>

The afore−mentioned process of light generation is utilized by these constructional elements. By proper forming of the p−n junction, a part of light can emerge, light emission is effected. For that purpose, the p−n junction is placed closely to the surface as schematically represented in Figure 63.

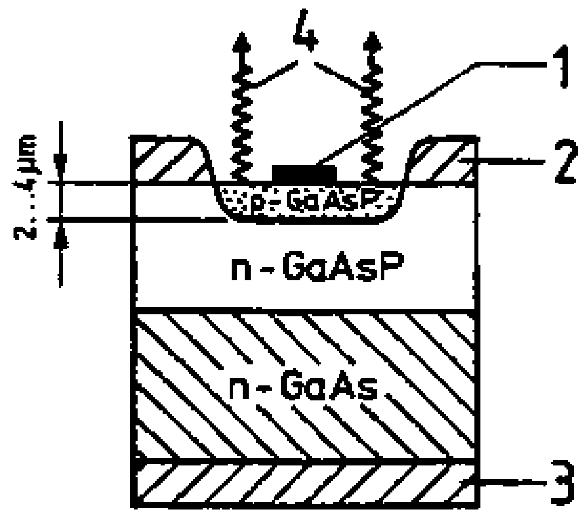


Figure 63. Schematic representation of a light emitter diode

1 Anode
2 Metal screen
3 Cathode
4 Light

The colour of the light emitted depends on the semiconductor material. Table 16 contains a few materials and their emission wavelengths.

<u>Table 16. Emission wavelengths of some materials for light emitter diodes</u>

Material	Wavelength for emission peak nm	Colour
GaAs	980	infrared
GaAP	660	red
GaP	565	green
GaAs PAL	580	yellow

Mostly, light is emitted in a concentrated form, therefore it is perceived from lateral direction. Concentration is ascertained by a lens−shaped plastic casing. If a concentration is not desired, types with diffuse emittance have to be used. In this simple form, light emitter diodes can only be applied to signalling operational conditions. Compared to incandescent lamps, they have an advantage of higher life and reliability. With a power input of 30 to 50 mW, they are energy−saving and superior to the majority of incandescent lamps.

Extended possibilities of application are obtained when several single diodes are put together for symbols. This may be a matrix arrangement in the most general case, as schematically represented in Figure 64. Thus, signs but also pictures can be represented optionally. They are made of individual luminous diodes and put together point by point. The resolution (smallest representable detail) depends on the number of diodes per unit area. A similar configuration is possible as solid−state picture tube for television sets. A 5 × 7 matrix is produced as alphanumerical display element.

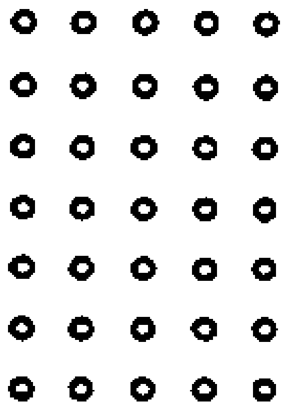


Figure 64. Matrix arrangement (5 × 7−matrix) of light emitter diodes

Practice has shown that a seven−segment configuration is sufficient to represent all figures and some letters and signs. These segments are arranged in the form of an eight (Figure 65). Each segment can be individually triggered, i.e. excited to glow. Depending on the segment size, one or several light emitter diodes are mounted in one line and electrically switched in series. Common displays have a height of 7 mm, but also greater heights are possible.

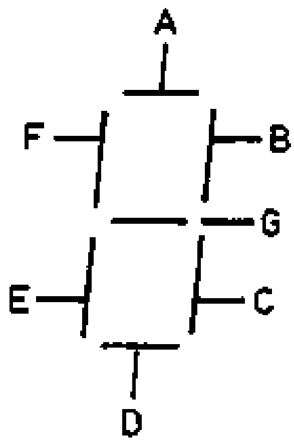
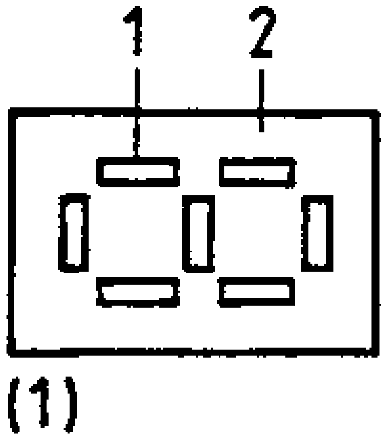


Figure 65. Principle of a seven−segment display (schematized)

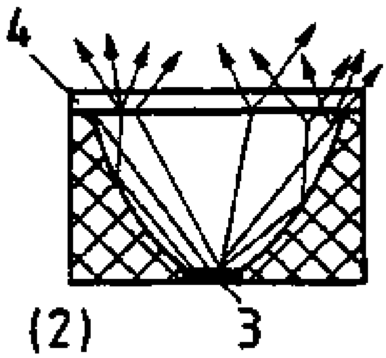
The use of several light emitter diodes for one segment requires from each individual diode the same luminosity with a defined current intensity. Selection of such diodes is costly, that is why one tries to manage with one diode per segment and enlarges the picture by a lens solidly linked with the component. Another method is used in the case of light tunnel displays. Individual diodes of high luminosity are assembled to a seven−segment configuration and the light is distributed by reflection on white−washed walls on a larger exit area.

Figure 66. Principle of a light tunnel display



(1) total representation,

1 Light outlet window
2 Duro−plastic body



(2) representation of a segment

3 Light emitter diode
4 Diffuser foil

A diffuser foil placed on the surface disperses the light and so permits symbol height of up to 20 mm.

Light emitter diodes have, due to the high doping, a small reverse voltage (this has to be observed in circuitry).

<u>Liquid crystal display (LCD)</u>

A number of chemical bonds has the property to physically behave like a liquid and optically like a crystal. They are called liquid crystals. They are technically used in an increasing manner.

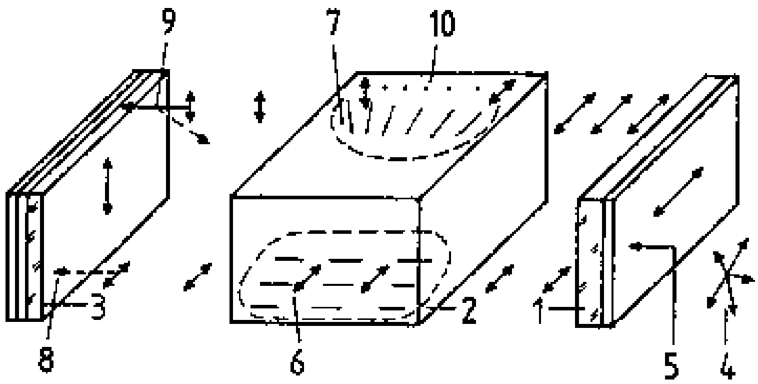


Figure 67. Principle of a liquid−crystal display

1 Upper panel glass with polarization foil, 2 Liquid crystal, 3 Lower panel glass with polarization and reflection foil, 4 Light, 5 Direction of view, 6 With electric field, 7 Without electric field, 8 A reflection, 9 Reflection, 10 turn of polarization direction

Filament−shaped molecules are inherent to liquid crystals, which change their position and form under influence of temperatures or electrical fields and at the same time joining together to structures. With this process various physical appearances are linked. Light is reflected spectrally, which can be noted as a change in colour. The refractive index changes or the polarization for light is modified. The latter is used on displays. Between two special glass panels, the liquid crystal with a thickness of about 10 µm is enclosed hermetically. The upper glass panel carriers the signs to be represented and evaporated as a metallic layer, e.g. a seven−segment configuration, and a fine dashed pattern aligning the adjacent filament−shaped crystals horizontally. The lower glass panel is evaporated with laminar counterelectrodes and has a dashed pattern aligning the filament molecules vertically. In the liquid molecule, a helical rotation of the molecules' position by 90° is effected. In addition, a reflection foil is glued to lower glass plate. Polarization foils polarize the light striking. The upper foil polarizes in a horizontal way, while the lower one does it vertically. The entering polarized light is turned by 90° due to the helical twist of the filament molecules, can penetrate the rear polarization foil, is reflected, egain turned by 90° in the liquid crystal and appears again on the upper foil. This surface shines brightly.

When voltage is applied between the evaporated electrodes, the molecules align themselves in the direction of the field lines, and their helical position disappears. The entering horizontally polarized light is not turned in the crystal and extinguished on the rear polarization foil − the surface appears as a dark area. By turning the polarization level of the rear polarization foil, the bright−dark impression can be exchanged.

The surfaces have then a dark effect without triggering and a bright effect with triggering.

Due to their high resistance, liquid crystals take up a very small power only (about 1 µW per segment). Therefore, they can also be operated with batteries of low capacity over a long period. The cause for the low power requirement is that no light is generated. In order to obtain a display with liquid crystals, an extraneous light source is needed. Thus, liquid crystals are not active, but only passive light emitters.

1.7.3. Light receivers

Light receivers convert light energy into electric energy.

They are also designated as photodetectors.

The photons striking a light−sensitive layer activate charge carriers increasing the electrical conductivity. This method is known as internal photo−electric effect.

Due to their small activating energy required, semiconductor materials are well suited for being applied as light receivers. They are used both in the polycrystalline and monocrystalline form.

Analogous to the light transmitters, there is a close correlation in the light receiver between the wavelength of the striking light and the number of the activated charge carriers. Therefore, all appropriate materials have a wavelength−dependent sensitivity peak. This has to be considered for application. Thus, it has been explained that some light receivers emit a signal in complete darkness and can, for instance, be used for proving the existence of heat radiation.

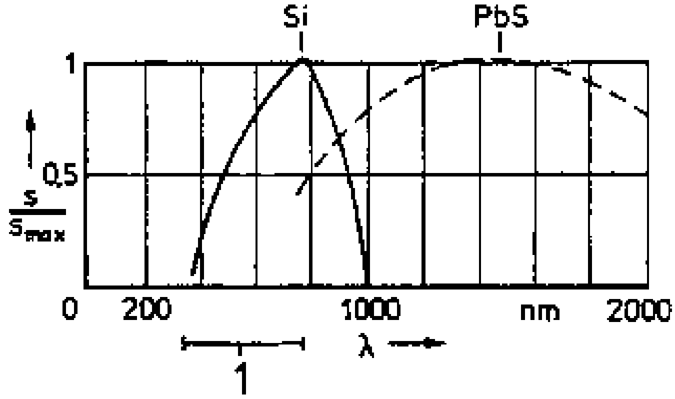


Figure 63. Dependence of relative spectral sensitivity on wavelength

1 Range of visible light

Photoresistors

Frequently, lead sulphide (PbS) or cadmium sulphide (CdS) is used as light−sensitive material. It is separated in a thin layer in a glass bulb and determines the spectral sensitivity. Photoresistors can be applied from the range of visible light up to far in the infrared zone. The position of the sensitivity peak is indicated by the manufacturer.

The striking light quanta set charge carriers free, the resistance reduces from about 10...10^8 ? in darkness to about 10^3 ? in bright illumination. The correlation between illumination intensity and change in resistance is mentioned in Figure 69.

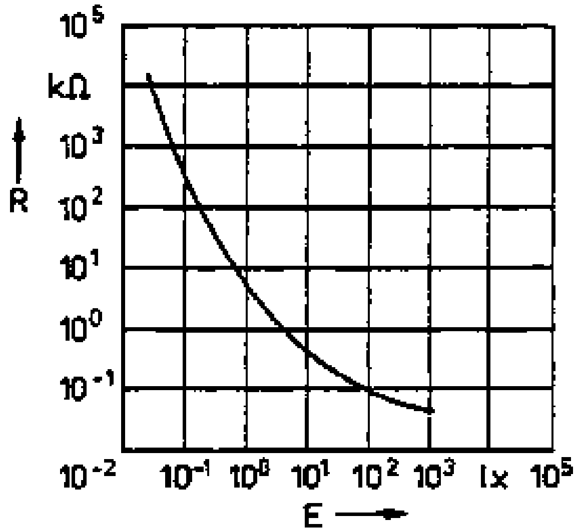


Figure 69. Dependence of resistance value on illuminating intensity of a photo−resistor

Rapid modifications of the illumination intensity cannot be followed up by photoresistors, for their high−frequency cut−off is at f_g ? 5...10 Hz. The cause for this inertia is the re−combination rate of the charge carriers.

This inertia is, in many cases, not troublesome in the equipment of automation systems, because mechanical components do not permit rapid sequences.

When photoresistors are used, the temperature coefficient of the resistor and the scattering width, dependent on manufacture, of the resistor's rated value of about 20% must be considered. They limit the application possibilities.

Photodiodes and phototransistors

In a p−n junction irradiated with light, charge carriers are activated, which increase the p−n junction conductivity. This is utilized for photodiodes and phototransistors.

The photodiode is operated in barrier direction. The activated charge carriers raise the reverse current intensity in dependence of the illumination intensity. The correlation is represented in Figure 70.

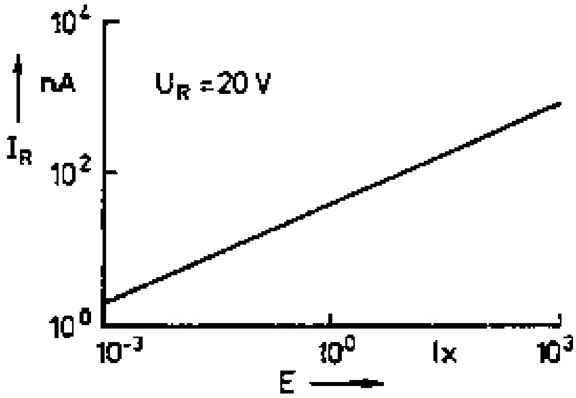


Figure 70. Dependence of reverse current of a photo−diode on illumination intensity

Light penetrates a glass window and strikes the flat p−n junction. As for the phototransistor, light is concentrated through a plastic casing acting as convergent lens onto the base zone. The charge carriers being released are multiplied with the current amplification and become effective as collector current. Thus, sensitivity is strongly increasing. The base is not separately established on phototransistors, that is why they only have two connections. The optical **axis** is not in conformity with the geometrical one of the casing in photodiodes and phototransistors. A respective correction possibility is, therefore, to be planned during assembly.

Because of their high reliability and small mechanical dimensions, these components are increasingly applied.

<u>Opto−electronic couplers</u>

The principle of riskless equipment and techniques as known in the field of labour safety, demands, for example, safety against getting in contact with parts lying on mains potential. For this reason special attention has to be paid to the coupling between operating elements and actuating units operated with mains voltage. The opto−electronic coupler (optical coupler) using light as transmitting medium offers a simple and almost ideal approach.

A light emitter diode and a phototransistor or a photodiode are optically coupled with each other. An insulating casing allows a permanent voltage difference of up to 1 kV approximately. Due to the double change in the form of energy (electrical – optical – electrical), the efficiency of the configuration is not very high.

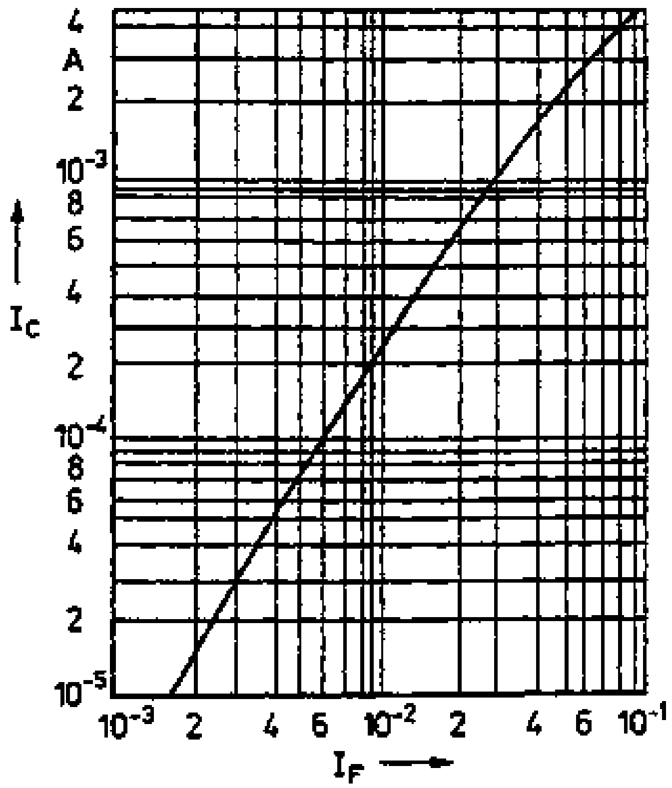


Figure 71. Transmission characteristic of an optical coupler

This is not decisive in systems for signal transmittance, either. Factors like reliability, speed, retaining the shape and others are in the foreground. Transmission losses can be re−compensated by a respective amplification.

1.8. Integrated circuits

1.8.1. Definition of terms and requirements

Electronical engineering is penetrating more and more all fields of economy. In this connection, microelectronics is of particular importance. It is the result of mastering, in a better and better way, the technology of producing semiconductors and introducing new circuit principles. Microelectronic components are the integrated circuits and, among them, especially the solid−state circuits. Here, several up to very many components (mostly transistors) are so inter−linked that a circuit comes into being to fulfill complex functions.

An integrated circuit may contain for example:

− a complete amplifier
− a decade counter
− an arithmetical and logical unit far the four fundamental operations of arithmetic
− the central unit of an electronic computer
− a complete mini−computer.

For that purpose, several hundred up to several hundred thousand transistor functions are required. They are produced in the crystal at the same time, and this not only for one circuit, but for many homogeneous ones at the same time. Thus, costs go down considerably. Many external connections (soldered joints) are shifted to the interior (in the crystal) and replaced by other joining techniques. The result is a considerable increase in reliability. Power input is already minimized when designing the circuit.

Integrated circuits make it possible, among other things,

– to strongly increase reliability
– to decrease power input and volume
– to considerably reduce the price of the finished product.

Particularly complex circuits can be programmed and thus, adapted to the most different tasks.

In automation technology, integrated circuits are more and more used for

– control and regulation
– process data control
– data compaction.

It is to be expected with great certainty that in a few years' time discrete (individual) components are only used in special cases for completion or adaptation and the majority of tasks arising in the production process will be solved by integrated circuits.

1.8.2. Digital circuits

Digital technique processes signals adopting only finitely many (discrete) values and being coded according to a declaration. These signals are called digital signals. Such signals are of special importance that can adopt two signals only. They are designated as binary signals. These two values can be represented very simply in electrical engineering (switch on – switch off; current is flowing – current is not flowing; voltage is connected – voltage is disconnected).

Compared to analogue signals, the use of digital signals has the following advantages:

– great accuracy
– possibility of signal regeneration
– few failures
– now failure due to noise, drift and the like.

Therefore, the use of digital and here mostly binary signals gains more and more importance and has led to the digital technique as an independent partial section of electronical engineering. Since diodes, transistors and thyristors can be operated as switches, electronic circuits were already constructed very early, which processed binary signals. The comprehensive application failed due to the prices of the components and the low reliability. Not until the integrated circuit had been applied, did a breakthrough happen there. Today, about 80% of all circuits are produced for being applied in digital technique. These are digital integrated circuits.

Digital circuits process digital signals.

In the course of time, defined circuitries have been formed as standards.

All circuits belonging to a circuitry – and thus logic – are designated as a family (logic family).

The most important families are compiled in Table 17. There, bipolar and unipolar circuits were not separated. But for further consideration, this separation is meaningful.

Table 17. Logic families

Denomination	Name	Remarks
TTL	Transistor−Transistor−Logic	Widely spread; standard family; very rapid and low−power design as special series
ECL	Emitter−coupled logic	Very short switching times (2 ns); higher power input
I^2L	Integrated injection logic	Due to simple production; method, also suited for large−scale integrated circuits
p−MOS	MOS−circuit with p−channel	Standard technology, simple production; longer switching times (500 ns approx.)

n−MOS	MOS circuit with n−channel	Shorter switching times (50 ns); developing to standard family
CMOS	Complementary MOS−method (p− and n−channel)	Very low power for watch/clock circuits, astronautics, etc.; requires much space.

Bipolar digital circuits

These circuits are predominantly produced as TTL−circuits.

I^2L−technique is increasingly used for large−scale integrated circuits. It only needs fewer manufacturing steps.

Frequently, the circuits are subdivided into groups as to the integration level.

Table 18 Integrations

Denomination	Complete name	Approx. values		
		Gate/chip	Component chip	Chip size
		–	–	mm^2
SSI	Small−scale integration	10	100	? 1
MSI	Medium−scale integration	100	1000	$\lessapprox$ 10
LSI	Large−scale integration	1000	10000	$\lessapprox$ 40
VLSI	Very large−scale integration	> 1000	> 10000	> 50

In this connection, the criterion is the number of fundamental circuits joined to a total circuit (gate) or the number of transistor functions. The TTL standard series (the circuit families are divided into series) is produced internationally. This series consists of a variety of single types being able to execute most different logic linkages. Basis for that are the logic conditions 0 and 1, to which the voltage levels L and H are allocated (L = low − H = high).

Table 19. Logic states/level

Logic state	Logic signal level	Voltage level		
		TTL V	p−MOS V	n−MOS V
0	L	? 0.4	? −10	? 0.8
1	H	? 2.4	? −1	? 2

Along with the increasing integration level, the internal construction becomes more and more complicated and cannot be represented as a circuit diagram any more in the case of MSI−circuits, Manufacturer's indications are limited to possible functions and allocation of pins. The circuit for the simplest gate (dual−NAND) is shown in Figure 72. This circuit is present four times on an area of 2 mm^2. There is an H−level at the output when both inputs (x_1 and x_2) are on L−level. V1 is a multi−emitter transistor.

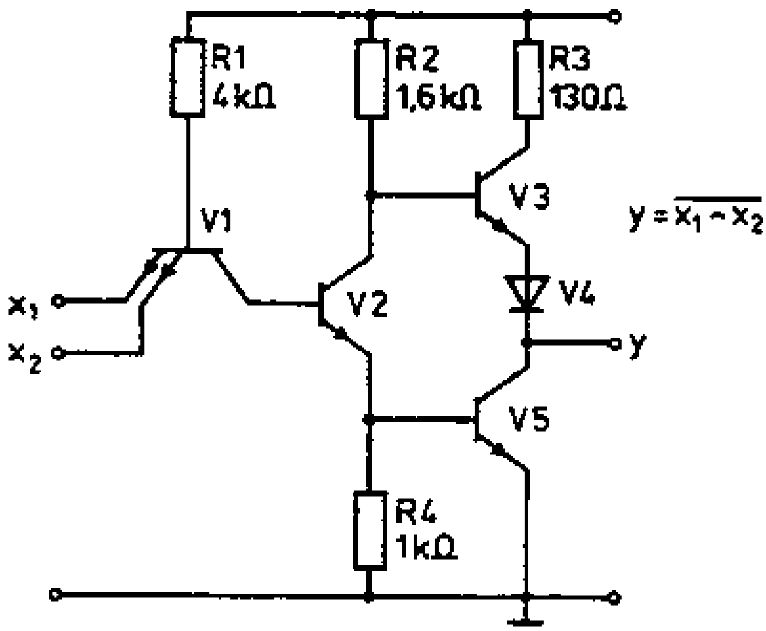
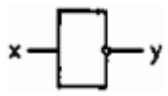
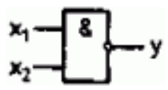
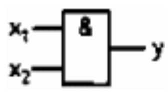
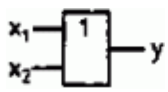
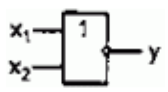
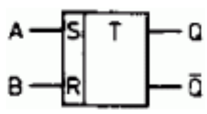
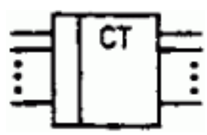
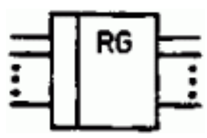


Figure 72. Circuit of dual–NAND gate

Table 20 contains a number of circuit functions.

<u>Table 20. Circuit functions (selection)</u>

Denomination	**Logic function**	**Symbol**
Negator	$y = \overline{x}$	
UND	$y = x_1 \wedge x_2$	
NAND	$y = \overline{x_1 \wedge x_2}$	
OR	$y = x_1 \vee x_2$	
NOR	$y = \overline{x_1 \vee x_2}$	
Trigger	–	
Counter	–	
Register	–	

The circuits are plastic– or ceramic–encapsulated and have several connections arranged in two lines. Therefore, this design; is designated as dual–in–line package (DIL–package)

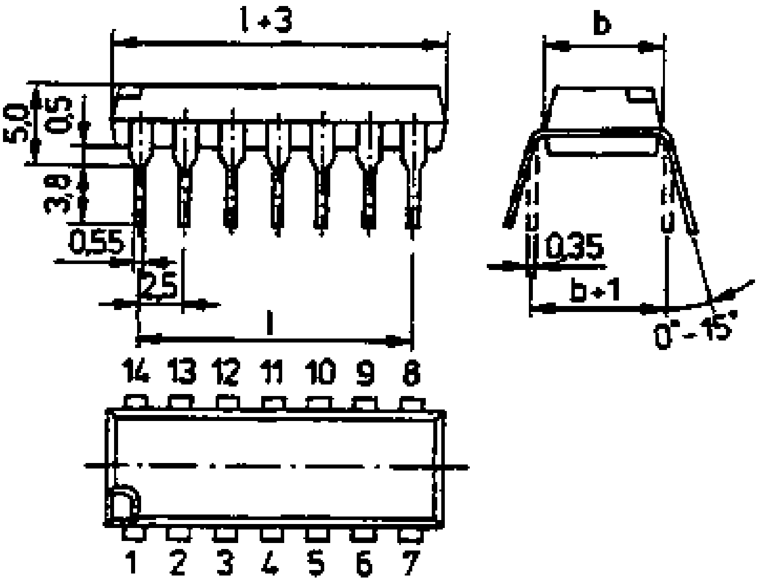


Figure 73. Dual−in−line casing

Unipolar digital circuits

Due to the simpler technology, compared to bipolar circuits, the unipolar type is preferred for the production of large−scale integrated circuits− Circuits produced as to n−channel technique can be used together with bipolar circuits. The n−channel technique offers the possibility to place the threshold voltage (which is the voltage at the gate, where the channel is opened or closed) in the regions of the logic voltage level of TTL−circuits. Such circuits are, then, called TTL−compatible.

LSI−circuits facilitate the manufacture of very complex circuits, such as data stores.

Table 21. Circuit to construct data stores (selection)

Denomination	Complete name
RAM	random access memory
ROM	read only memory
PROM	programmable ROM
EPROM	erasable PROM
µP	microprocessor

The highest level of integration at present is available in microprocessors. These components are a new generation of circuits. They use the principles of electronic data processing, can be programmed with a given instruction set and thus, adapted to different tasks.

Microprocessors are in the position to execute all the functions of the central unit of a digital computer. On a chip (semiconductor chip carrying the circuit) having a surface of 30 mm^2, approx. 10,000 transistors are integrated. Sub−assemblies are created with their proper inter−connection, such as shown in Figure 74.

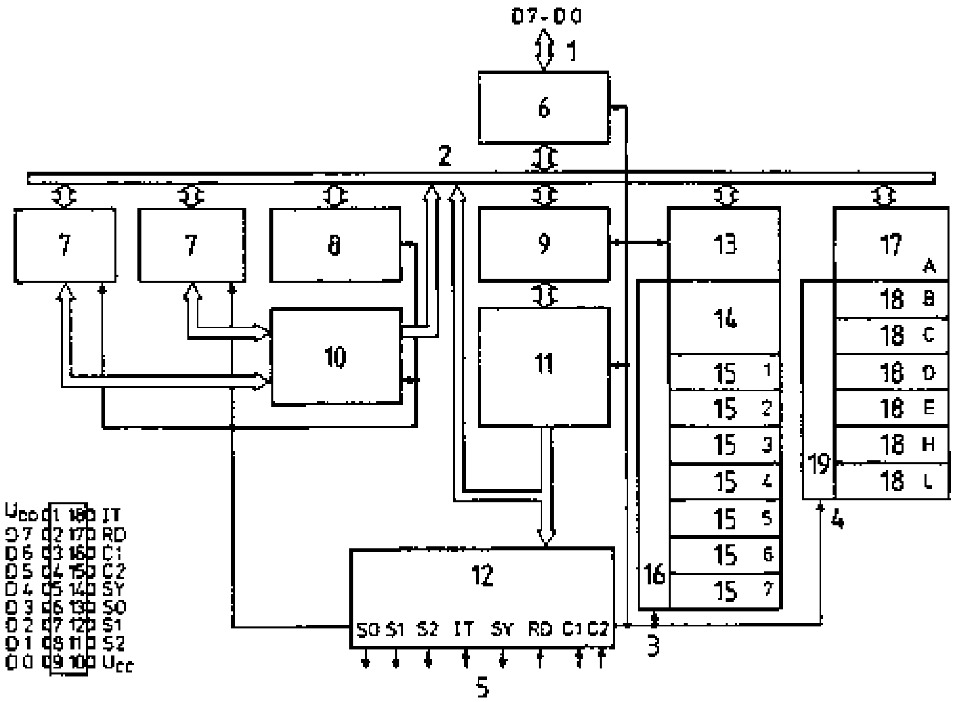


Figure 74. Functional units with the example of an 8−bit microprocessor

1 Bidirectional data bus, 2 Internal data bus, 3 Address stack, 4 Data register, 5 Coding (SO/ZVE; S1, S2/cycle; II/interrupt; SY/Sync.; RD/ready; C1, C2/cycle), 6 Data bus buffer, 7 Temporary register, 8 Operating flip−flop, 9 Instruction register, 10 Arithmetic logic unit (ALU), 11 Instruction decoder and machine cycle coding, 12 Time controller and ZVE control, 13 Stack multiplexer, 14 Program counter, 15 Stack level 1 to 7, 16 Stack pointer, 17 Accumulator, 18 Register B to L, 19 Register selection

When this circuit is added by a program memory, a data store and a clock generator, the fundamental design of a microcomputor is available. Such microcomputers are produced with increasing conveniences and already have the efficiency of modern minicomputers.

To what extent microelectronics has entered fields of daily life is self−evident with the use of pocket calculators and quartz watches/clocks.

Many circuits are available for being used in instrumentation technique.

1.8.3. Analogue circuits

Compared to a digital signal, an analogue signal can adopt any optional value between two final values. The deflection of a pointer−type meter is, for instance, an analogue signal. As known, the pointer may rest at any other place between its final positions. That means that not every intermediate value can be read, because the fineness of scale devision plays a great part in this connection.

The majority of quantities present in nature is available analogously. They are further processed by analogue circuits and frequently digitalized for a subsequent transmission.

Analogue circuits can process analogue signals.

At present, they are almost exclusively produced in bipolar technology.

Bipolar analogue circuits

There are only a few versatile applicable fundamental circuits in analogue technology, one being the amplifier for example. "Therefore, most of the analogue circuits have only a limited field of application, and such with a higher level of integration often a single possibility of application only (e.g. colour matrix for colour television sets).

However, the use of integrated circuits makes circuit concepts possible, which cannot be implemented in discrete technology due to the high expenditure or to the scattering width of obtainable parameters. Furthermore, there is the high reliability and, if sufficiently high numbers of pieces can be produced, the low price. Thus, these circuits have occupied a firm place in circuitry.

Only when the integrated technology with the close tolerances required had been developed, the operational amplifier very often applied could be produced. Other circuits such as voltage comparators, initiator circuits or threshold switch circuits can be advantageously used for many tasks in automation technology.

Unipolar analogue circuits

The advantages of unipolar circuits compared to bipolar circuits, simpler technology and thus a higher level of integration, are not decicise for analogue technology. For the reasons already mentioned in the previous section, large−scale integrated analogue circuits are only needed in exceptional cases. That is why unipolar analogue circuits are found only occasionally, e.g. as analogue delay conductor. Also the low operational speed of unipolar circuit limits their application.

Of greater importance is the mixture of unipolar and bipolar transistors in a circuit, because it permits to utilize the specific advantages of both kinds purposefully.

According to this method, operational amplifiers are produced for example, whose input stage becomes very high−resistive by using field effect transistors.

2. Selected basic circuits with components

2.1. Basic circuits of heavy−current electrical engineering/power electronics

The technical term "heavy−current electrical engineering/power electronics" means any circuit in which components are directly charged with high current, i.e. inserted in current paths in which high currents flow. These can be switching, rectification as well as controlling and adjustment works. The few examples specified in the following shall illustrate the multitude of applications offered by semiconductor components.

2.1.1. Example 1: Speed control with single−pulse rectification

An optimum adaptation to the technological task can be achieved by electronic speed control. It is especially important for hand drilling machines to adjust the speed to drill's diameter and the material to be machined. The following circuit can also be applied for other purposes (lamp control). In this connection, specific safety precautions in the case of coiled filament short circuit have to be provided for.

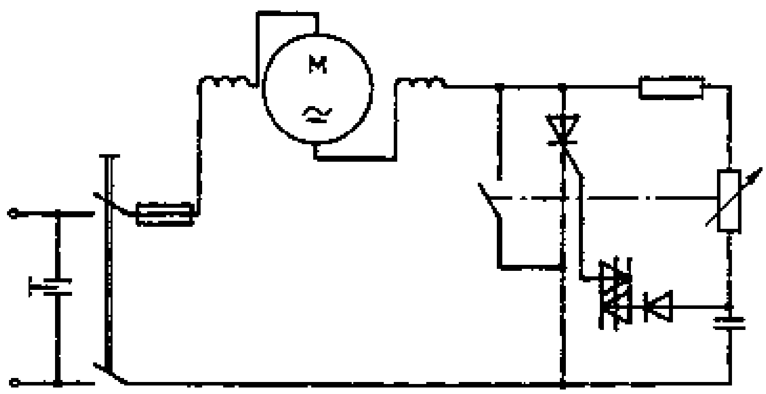


Figure 75. Speed control with single−pulse rectification

2.1.2. Example 2: Speed control for consumer goods

A constant speed is of great importance for the operation of the consumer good "universal cutter". In principle, mechanical load causes speed drop. By means of the modified basic circuit the voltage at the motor is increased at load. The capacitor **"C_2"** is charged via "R_3" from voltage drop – the point of ignition is shifted to smaller angles by this. Voltage drop "U_{R3}" is in its height a function of motor's load current, i.e. at increasing mechanical load the current I_B increases which itself causes an increase as to the formula $U_{V_{R3}} = R_3 \cdot I_B$

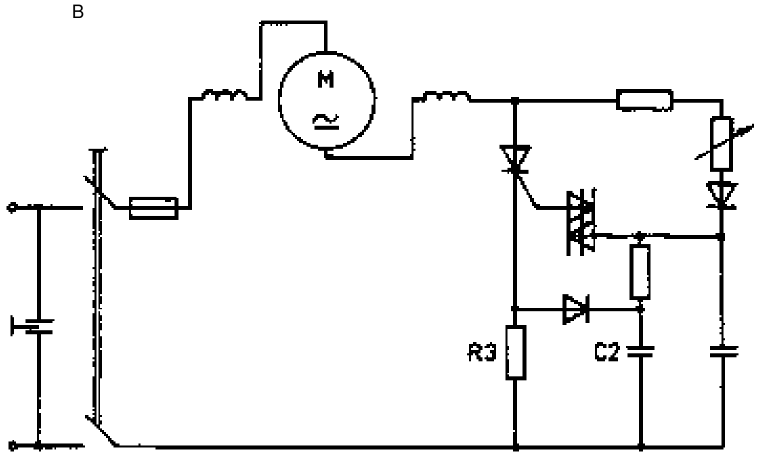


Figure 76. Speed control for consumer goods

2.1.3. Example 3: Starting circuit for single–phase motor

Several problems with drives can be solved by means of single–phase a.c. motors, e.g. for house water pumps, lawn–movers, circular saws, chaff–cutters, circulating pumps and compressors. So far, starting and operating capacitors as well as centrifugal switches or special auxiliary windings have been required for this. The following circuit replaces the a.m. auxiliary means. The circuit considers the inductive load. For this reason, TSE power components are wired up.

The present circuit shows a starting control with a triac in the auxiliary phase. Its ignition circuit is so adjusted to the main circuit that there flows out–of–phase current, compared with the main circuit, by means of which the motor is capable of generating a rotating field. If more than two thirds of nominal speed is reached, the current in main circuit drops back and the current transformer (1) does no more supply necessary voltage to the ignition circuit – the auxiliary phase becomes ineffective. The starting torques achieved by this circuit are within the range of those attained by means of traditional technical equipment.

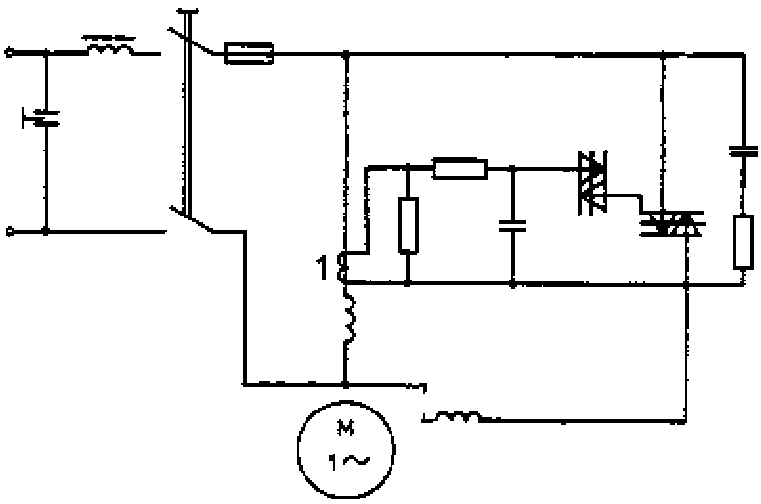


Figure 77. Starting circuit for single–phase motors

1 Current transformer

2.1.4. Example 4: Photoelectric lighting circuit

The following example represents to some extent an automatic switch.

Photoresistance (1_F) is so high at darkness that the impulses are directed to the control electrode. When lightness is increasing, resistance drops back, and the capacitor is not able to acquire the breakover voltage of diac due to low voltage.

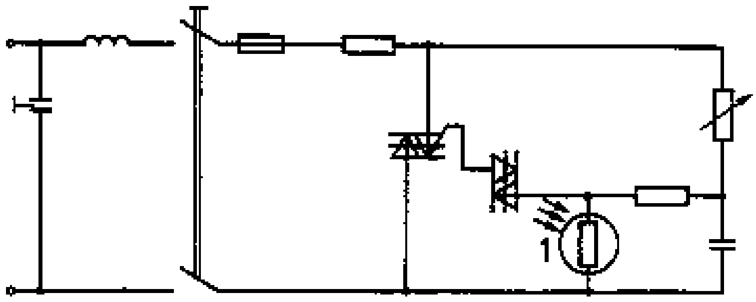


Figure 78. Photoelectric lighting circuit

1 Photoresistor

2.2. Basic circuits of information electrotechniques/electronics

The term information electrotechniques/electronics comprises any component, unit and module used to gain, transmit, store, process and apply signals in communication, control, computer engineering.

We can only represent a small selection because of application's variety.

2.2.1. Example 1: Car aerial as part of a high−frequency circuit

A car aerial is a high−frequency generator with high−resistive source resistance. It has also a considerable capacitance (abt. 60 pF). Respectable receiving results are only reached when the aerial is part of the input circuit.

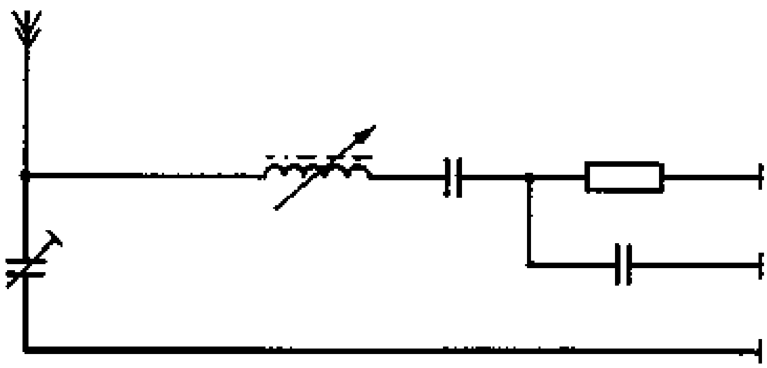


Figure 79. Car aerial (part of a high−frequency circuit)

The high self−capacitance of aerial requires the application of a variometer because with it is possible to adjust the variational ratio to the medium−frequency precircuit independently of circuit capacity.

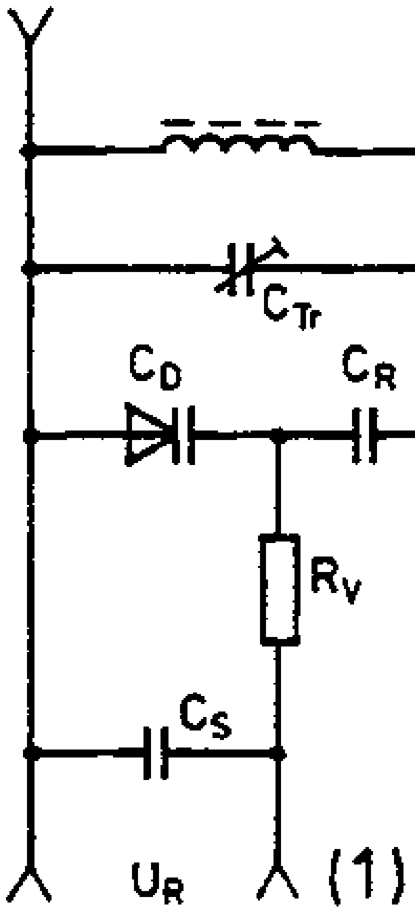
Most of the radio receivers are adjusted by means of variable capacitors. Latest technical findings however result in the application of electronical components, e.g. C diodes (capacitance diodes).

They are operated in reverse direction and exclusively effective as parallel capacitances. Circuit alternatives are specified under Example 2 (tuned oscillating circuits).

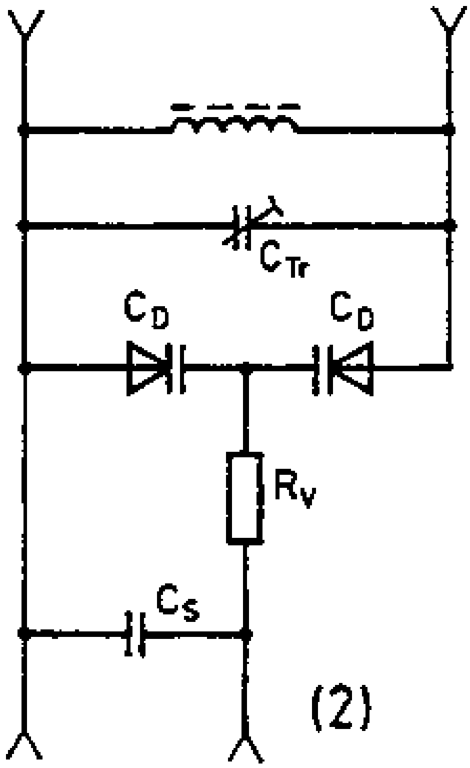
2.2.2. Example 2: Diode−tuned oscillating circuits

The C_R capacitance is originally quite high, compared to diode capacitance. Its influence to frequency remains small. U_R is kept free of high frequency and hum voltage by means of the resistance−capacitance (RC) element (Cs, Rv). At the same time, short circuit of resonance voltage is prevented via the source resistance.

Figure 80. Diode−tuned oscillating circuits



(1) with one



(2) with two capacitance diodes

2.2.3. Example 3: Voltage stabilization

An automatic voltage stabilization can be realized by means of electronical components.

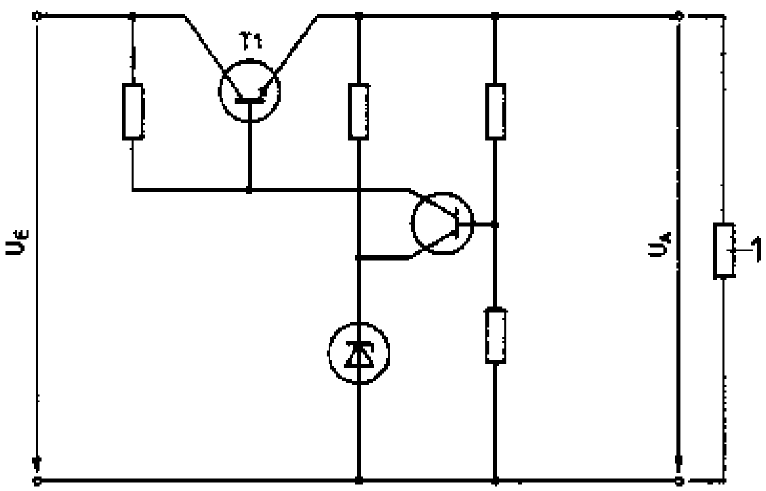


Figure 81. Voltage stabilization

1 External resistance

The T_1 transistor is an adjustable series resistor for the external resistance (1).

When the resistance of T_1 drops back, dropping back of U_1 is opposed.

3. Semiconductor component measurements

If semiconductor component measurements have to be carried out, it is not necessary to use "latest" measuring technique. Therefore, this section applies to measuring instruments and methods of electrical and electronical measuring technique for specific matters of semiconductor components.

Semiconductor component measurement are above all aimed at

- examining performance,
- determining selected characteristic values,
- ascertaining selected limit values.

3.1. Diode measurements

3.1.1. Performance test

For many practical concerns it is important and sufficient to execute a survey measurement furnishing good/bad assertion. The test−field or after−sales−service specialist must be able to ascertain certainly, by means of simple instruments and methods, if possible, whether a diode is working, without being forced to determine characteristic values or curves as to quantity.

Rectifier diodes

Here, it is to be checked whether the diode has valve action.

Prior to measurement, surely inform about pin connections!

Direction of flux

By means of the circuit shown in Figure 82, an I_F forward current can be determined. In this connection, voltage U must be higher than the lock voltage of diode, i.e. 1.5 V.

The multiplier R_V limits the forward current. R_V is a function of the voltage applied and the maximum admissible forward current of diode.

For U >> U_S there applies

$$R_V \approx \frac{U}{I_F}.$$

Results:

The diode is working towards forward direction when current of

$I \approx \frac{U}{R_V}$ flows.

The diode is defect when current, which cannot be measured, or current of

$I << \frac{U}{R_V}$ flows.

Reverse direction

The circuit represented in Figure 83 can be applied to check rejection characteristic. It is recognizable that the Figures 82 and 83 only differ from each other by the opposite polarity of the U voltage source. In this connection, the series resistor only protects the voltage source in case of a defect diode.

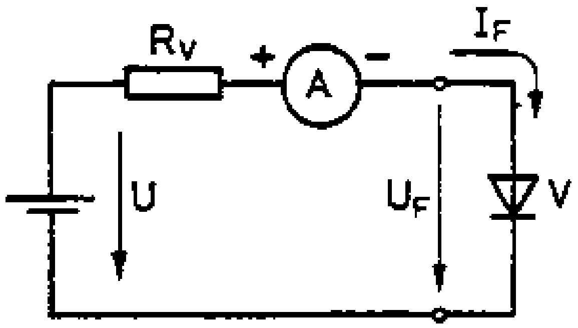


Figure 82. Measuring circuit of diode in forward direction

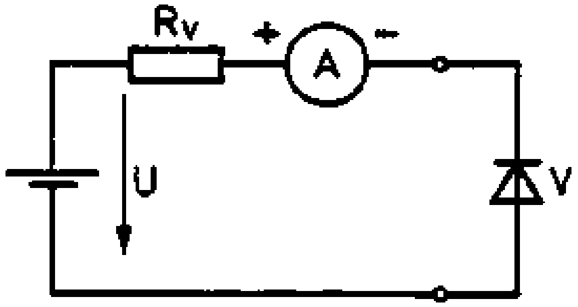


Figure 83. Measuring circuit of diode in reverse direction

The U voltage shall be higher than at measurement towards forward direction, in order to detect faults surely.

Results:

The diode is working towards reverse direction when current, which cannot be measured, flows and/or when

– loss power is $I_R < 0.1$ µA for diodes up to 1 W
– $I_R <$ 1 mA for power rectifier diodes.

The diode is defect when the reverse current is considerably increasing above the a.m. values.

For critical cases, take the admissible reverse current for the appropriate component from a catalogue or data sheet.

In principle, the performance test is a determination of the resistance in forward and reverse direction. It is however not advisable to apply any resistance measuring instrument, since the components could be damaged or the results are indefinite.

Voltage−regulator (Z) diodes

Z diodes are Si diodes for stabilization purposes and, in direction of flux, rectifiers. In reverse direction, there will be a breakdown near the specified Zener voltage. A very low reverse current (? 1 µA) shall only flow below breakdown voltage. Near the Zener voltage, current is quickly increasing and must be limited, since the admissible loss power would then be exceeded. A performance test is effected in the same way as for rectifiers, when the voltage is kept below Zener voltage.

Light−emitting diodes

They emit light. As to performance test, it is in most cases sufficient to apply low voltage in the direction of flux and check light emission. In this connection, take care that the maximum admissible loss power will not be exceeded.

3.1.2. Plotting of characteristics

Diode characteristics are specified in characteristic sheets and manufacturers' catalogues. These characteristics represent mean values. If the actual course of characteristic is of interest, it must be measured.

As to diodes, the relation between current and voltage is measured and plotted in forward direction and reverse direction as well.

Plotting of characteristics requires

- – measuring circuit,
- – measuring instruments,
- – voltage sources.

<u>Forward direction</u> $I_F = f(U_F)$

Prior to measurement, the maximum admissible forward current or the maximum admissible loss power must be known. Measurements shall be recorded at ambient temperatur without considerable variations.

By means of the a.m. values, limits of measurement can be entered in a prepared diagram.

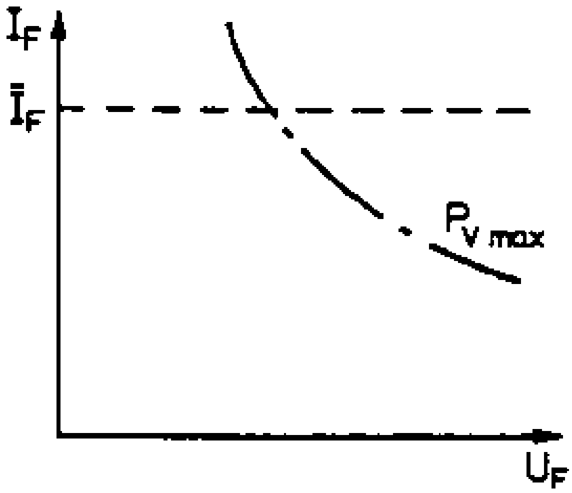


Figure 84. Prepared diagram

Line verification (anode/cathode) can be taken from data sheets or catalogues. Figure 85 shows a measuring circuit for the characteristic in forward direction.

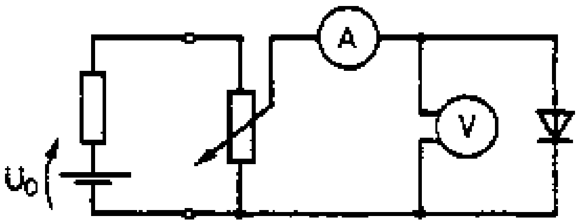


Figure 85. Measuring circuit for plotting a diode characteristic in forward direction

The open−circuit voltage of voltage source must be approx. 6 V for Si and Ge diodes. It is favourable when there is a controlled power pack with continuously adjustable output voltage available. Power rating of source must correspond to the maximum admissible loss power of the diode to be tested. If there is only a fixed voltage available, adjustment will be realized by means of a voltage divider, as shown in Figure 85.

Multipurpose instruments may be applied for current and voltage measurement. Therefore, the correct circuit as to voltage must be used, since diode's resistance in forward direction is low, compared to the resistance of voltmeter.

Measuring starts with U = 0. Voltage is increased step by step and the measured values for current and voltage should immediately be entered in the prepared diagram, if possible.

As to all discrete semiconductors (diodes and transistors), connection diagrams are given with a view of connections (from below).

If P_{tot} is assumed to be 150 mW in the circuit, Figure 85, the tot following measuring instruments have to be used:

A multipurpose instrument (D = 20 k?/V) for measuring ranges between 10 mA and 50 mA and a multipurpose instrument (D = 100 k?/V) for measuring range of 1.5 V.

The measured characteristic is as drawn in Figure 86.

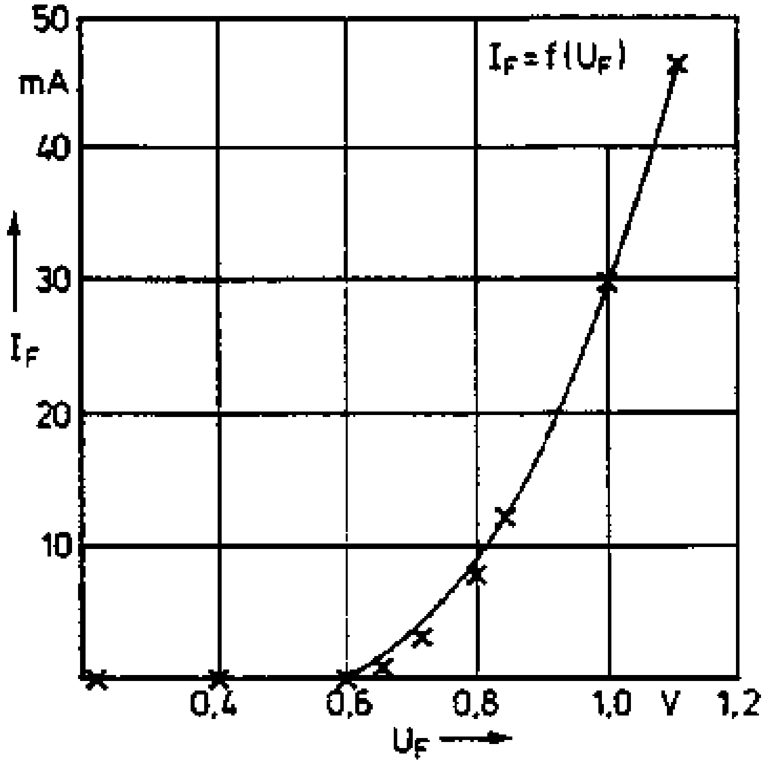


Figure 86. Diode characteristic in forward direction for P_{tot} = 150 mW

<u>Reverse direction</u> $I_R = f(U_R)$

The reverse characteristic is mainly important for Z diodes. Reverse current below breakdown is very low for Si diodes (in most cases < 0.1 µA) and hence difficult to be measured.

In most cases, this range is however unimportant for the application of Z diodes and can consequently be neglected. Multipurpose instruments can be applied for measurement, with taking this limitation in consideration.

It is here also favourable to prepare a diagram; it is vital to enter characteristic's limit in order to avoid damages on components.

Figure 87 shows a circuit for receiving Z diodes' reverse characteristic.

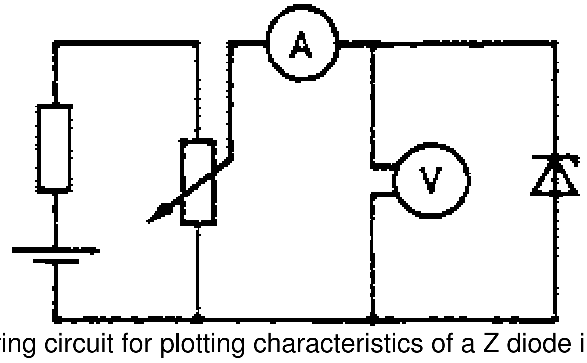


Figure 87. Measuring circuit for plotting characteristics of a Z diode in reverse direction

It differs from Figure 85 in Z diode being arranged in reverse direction. The internal voltage depends on the Zener voltage of the object to be measured and must exceed it. Zener voltages between 1 V and 24 V are normal; a suitable, controlled power pack with continuously adjustable output voltage renders the voltage divider of Figure 87 superfluous.

The characteristic is correctly measured as to voltage, since resistance within the interesting range is low. Below the breakdown there will be a considerable systematic measuring error – the current measured is, on the whole, the current flowing through the voltmeter, if multipurpose instruments are used. If the reverse current below breakdown is of interest, in exceptional cases, measurement must be carried out in correct circuit as to current by means of a sensitive galvanometer – because of high resistance.

3.1.3. Measurement of characteristic values

The following section deals with the measurement of three important characteristic values.

<u>Alternating–current resistances r_F and r_Z</u>

The dynamic internal resistance r_F and the Zener impedance r_Z (differential Zener impedance) can be measured with the same installation.

Possibility 1

If there is a circuit according to Figure 87 available for receiving the characteristic, the required operating point of diode or Z diode is adjusted by it.

A voltage variation ?U around this operating point causes a current change ?I. r_F and/or r_Z can be determined by these values:

$$r_Z = \frac{\Delta U_Z}{\Delta I_Z}$$

$$r_F = \frac{\Delta U_F}{\Delta I_F}$$

The little expenditure of circuit is favourable; the limited measuring accuracy proves a disadvantage because there is the demand for ?U_Z << U. By means of the measuring instruments used this can be reached only approximately.

Possibility 2

As to a more favourable measuring accuracy and rational measurement a circuit according to Figure 88 is suitable.

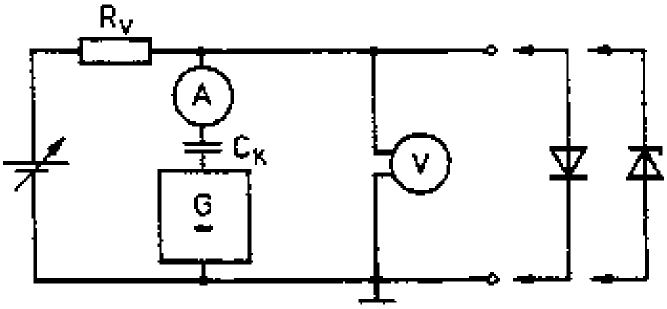


Figure 88. Measuring circuit for plotting characteristics of differential impedances

The operating point is adjusted by the power pack. A low a.c. voltage superimposes the d.c. values. The a.c. values u_F (u_Z) and i_F (i_Z) can be selected as well as measured sufficiently low so that resistance can directly be read from the amplifier voltmeter through a tailored equation:

$$r = \frac{u}{i}$$

with i = 0.10 mA

$$\frac{r}{\Omega} = \frac{U}{mV} \cdot 100$$

C_K and R_V decouple the two voltage sources.

Barrier−layer capacitance

The most important characteristic value of capacitance diodes is their barrier−layer capacitance.

The well−known processes of capacitance measurement fail, since the barrier−layer capacitance depends on the reverse voltage applied. Therefore, another process is represented here.

Capacitance is indirectly measured by detuning a resonance circuit.

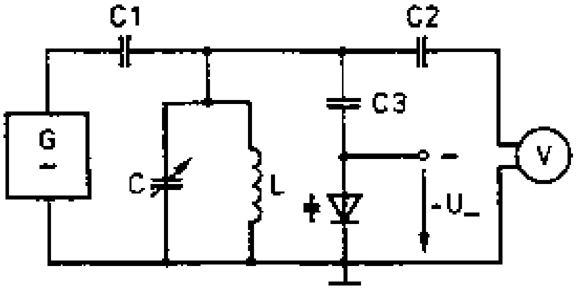


Figure 89. Measuring circuit for plotting characteristics of capacitance diodes

Resonance frequency of a parallel oscillating circuit results to

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

Instead of f_0 there develops a voltage maximum. If C changes by one value + ?C, e.g. by connecting a capacitor in parallel, resonance frequency is changing and the voltage maximum disappears. If it is possible, as shown in Figure 89, to change C by a value −?C, the old condition is produced again. The unknown barrier−layer capacitance can be read from the graduated scale of the C capacitor.

X_{C1}, X_{C2} and R_V must be great against the resonance resistance of the oscillating circuit.

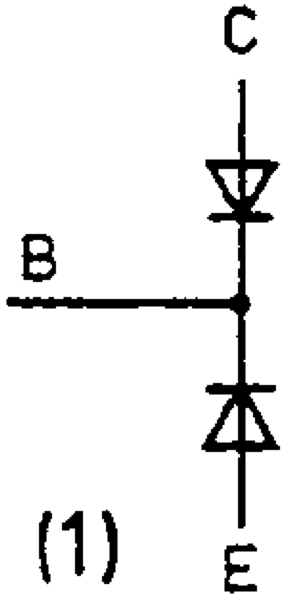
X_{C3} must be low, compared to X_{Cs}. There are no specific requirements made on the indicator; it has to indicate a voltage maximum within the frequency range selected. The U voltage is adjustable, in order to measure the barrier−layer capacitance as a function of reverse voltage.

3.2. Measurements on transistors

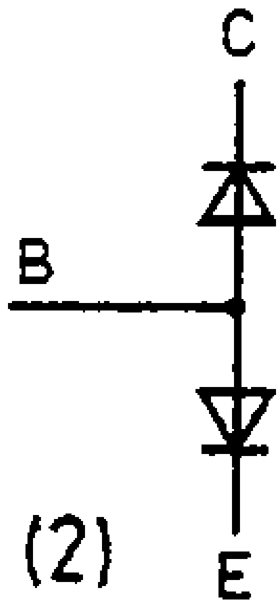
3.2.1. Function test

A function test for bipolar transistors can be explained by a diode test by means of a simplified equivalent circuit diagram. From Figure 90 it can be seen that the tracks emitter − base and collector − base are like diodes.

Figure 90. Transistor equivalent circuit



(1) p−n−p transistor



(2) n−p−n transistor

Measuring circuits are Figures 82 and 83. The amount of voltages and resistances depends on the limit values of the transistors to be tested. A voltage of 3 V is favourable to carry out this test.

Series resistors depend on the voltage and admissible currents

$R_V \geq \frac{U}{I_{Bmax}}$ or $R_V \geq \frac{U}{I_{Cmax}}$.

For example, if U is 3 V and $I_{B\,max}$ is 5 mA, so is R_V = 600 ?.

As to reverse direction, test voltage must not be more than the reverse voltage!

(Ge−high−frequency transistors have a very low basis/emitter reverse voltage: U_{EBO} ? 0.2 V)

Table 22 summarizes the results to be expected for transistors without errors, with taking the a.m. sizing into account.

<u>Table 22. Test values for transistors</u>

Sequence of zones	Currents	
	$U_{BE} > 0$ $U_{BC} > 0$	$U_{BE} < 0$ $U_{BC} < 0$
p–n–p	Off–state currents < 10 µA	Forward currents in mA, limited by R_V
n–p–n	Forward currents in mA, limited by R_V	Off–state currents < 1 µA

The described test is distinguished by little expenditure.

By means of this arrangement, only rough errors can however be detected. It is indeed possible to test transistors in some circuits, without unsolder them, if one has gained appropriate experience.

It is not possible to test unipolar transistors by means of this simplified arrangement.

3.2.2. Plotting of characteristics

<u>Bipolar transistors</u>

As to bipolar transistors, a representation in four quadrants has been proven favourable for statical characteristics.

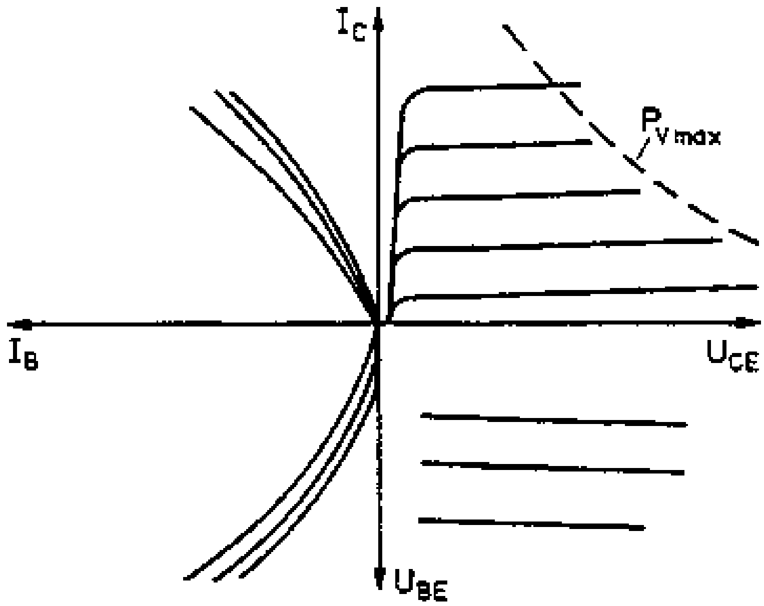


Figure 91. Transistors' families of characteristics

Since operating points will be determined within these families of characteristics, plotting of families of characteristics is very important.

Four functions are to be plotted and represented in a rational way, if possible:

– $I_C = f(U_{CE}, I_B)$
– $I_C = f(I_B, U_{CE})$
– $U_{BE} = f(I_B, U_{CE})$
– $U_{BE} = f(U_{CE}, I_B)$

Preparatory works

– Determine sequence of zones of transistors (npn or pnp)!

– Make familiar with transistor's connection diagram!

– Take important limit values from data sheets or catalogues!

– Prepare diagram!

– Enter the maximum admissible loss power as most important limit value into the diagram (Figure 91)!

Measurement

The measuring circuit according to Figure 92 has been drawn for npn transistors. The voltages U_1 and U_2 can be taken from two separate and adjustable voltage sources. If there is only one suitable voltage source available, select a voltage supply according to Figure 93.

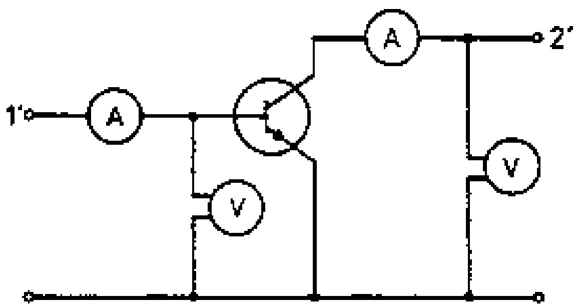


Figure 92. Measuring circuit for plotting characteristics of n–p–n transistors

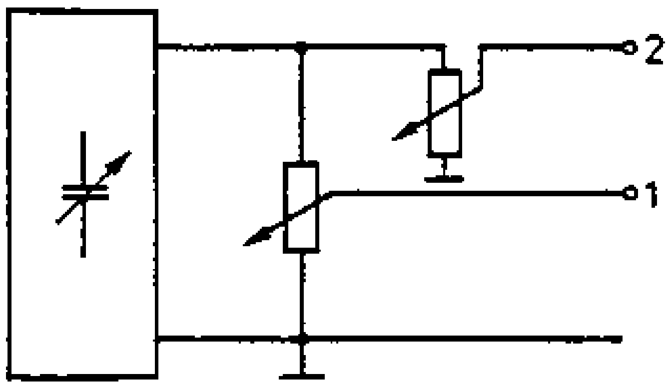


Figure 93. Voltage supply for measuring circuit

Measuring instruments may be of multipurpose design. For the measurement of I_B and U_{BE}, a measuring instrument with D = 100 k?/V should be applied because of the smaller systematic measuring error. As to U_{CE} and I_C, a measuring instrument with D = 20 k?/V would be sufficient. They make it possible to be connected as ammeter and also as voltmeter, so that only two instruments are required.

It is favourable to select the measuring points from the output family of characteristic $I_C = f(U_{CE})$ with I_B being parameter. At the same time, U_{BE} is at hand, so that each measuring point can immediately be entered into any of the four quadrants.

Error possibilities

A systematic measuring error arises by the finite resistance of voltmeter, especially for U_{BE}.

This can be prevented by means of a d.c. voltage amplifier voltmeter. Near the loss–power hyperbola there could be a change of measuring values by heating (runaway). The respective heat must be eliminated by means of suitable cooling elements – by forced cooling, if necessary.

For plotting of characteristics of pnp transistors, the voltage sources and measuring instruments must be changed in polarity.

Unipolar transistors

Within the range of unipolar transistors or field effect transistors there exist many types which differ from each other by their production technology and kind of charge carrier effecting the current flow. In principle, the measuring method of characteristics' plotting is however not different to that for bipolar transistors. The most important family of characteristics are the output family of characteristic $I_D = f(U_{DS}, U_{GS})$ and the transfer family of characteristic $I_D = f(U_{GS}, U_{DS})$.

I_D drain current

U_{DS} voltage drain – source

U_{GS} voltage gate – source

Preparatory works

Determine conductivity type of transistors!

For 2nd to 5th dashes, please refer to bipolar transistors.

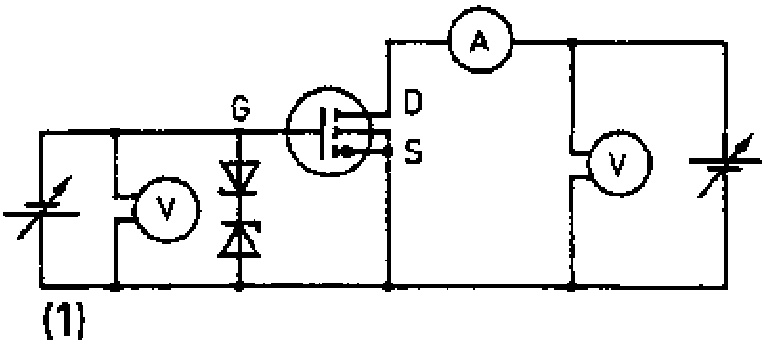
For unipolar transistors with insulated control electrode (IGFET), adhere to manufactuer's operating instructions!

Because of control electrodes' susceptibility to high voltages (> 50 V), which could already be exceeded by influence, the terminals are short–circuited appropriately during transportation. The short circuit shall be eliminated not until after having been installed into the measuring circuit! The polarity of voltages to be applied must be known prior to the plotting of characteristics of metal–insulator semiconductor field effect transistors.

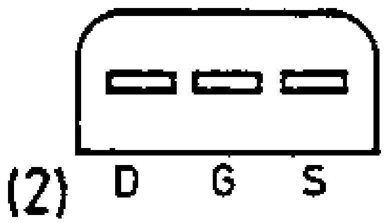
Measurement

The measuring circuit by two separate voltage sources has been represented in Figure 94 (1). Two separate voltage sources are, in this connection, favourable, since the voltages U_{DS} and U_{GS} can be oppositely poled and the voltage U_{GS} must run from negative to positive values.

Figure 94. To plotting of characteristics of unipolar transistors



(1) measuring circuit



(2) connection diagram of a unipolar transistor

The same measuring instruments as for bipolar transistors are suitable.

Take care that the admissible limit values and loss powers are not to be affected.

In the measuring circuit according to Figure 94 (1), the gate terminal is protected by means of two Z diodes being in counter–connection.

Short circuit of electrodes and arrangement of measuring set−up are to be observed (conducting linings, earthed equipment)!

Automatic plotting of characteristics

The characteristic measurements dealt with so far had to be effected point by point. The values were changed by the observer. The uncontested advantage of this method is the great accuracy which can be attained.

Disadvantage is that

− the measurements are time−consuming,
− qualified observers must be employed.

Hence follows that an automatic process is desirable for quick plotting of characteristics of many transistors. So−called characteristic curve tracers supply either an oscillogram or a diagram on paper. In this connection, oscilloscopes operate quicker, a measurement protocol can only be prepared by devious means.

Essential requirements made on a characteristic curve tracer are as follows:

− The rate of change of values must be low, but create closed curves and fixed, flicker−free pictures on a screen.

− The values shall only be changed towards one direction. Sine naive−waves are a simple method for this.

− Screen's coordinates must be furnished with scales.

By means of the simple measuring circuit, represented in Figure 95, it is possible to plot a curve of the family of output characteristic I_C = f (U_{CE}) on the screen at a time.

U_{CE} can be changed with positive sine halve−waves by the diode V. The I_C current is proportional to the voltage via R_M.

The parameter I_B must still be adjusted to the value concerned by hand, in this case.

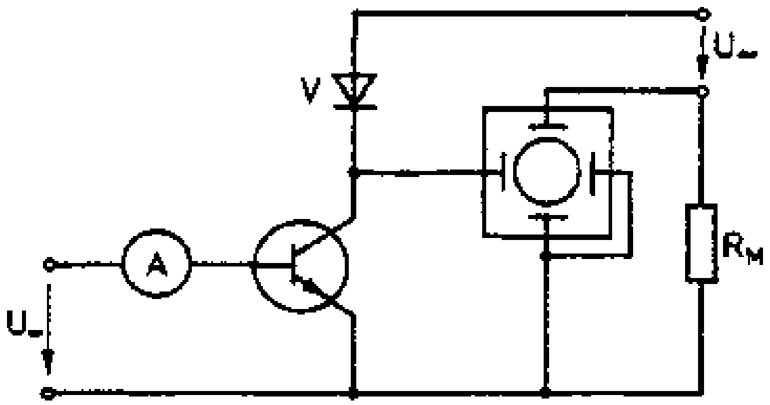


Figure 95. Circuit principle for plotting of a characteristic by means of an oscilloscope

A stationary picture can be adjusted without difficulties by means of the internal synchronization of oscilloscope.

A circuit according to Figure 96 makes it possible to plot the entire family of output characteristic. Here, base current is changed step by step by a staircase generator. It is important to change synchronization between oscilloscope, staircase generator and sawtooth generator time−linear with U_{CE}.

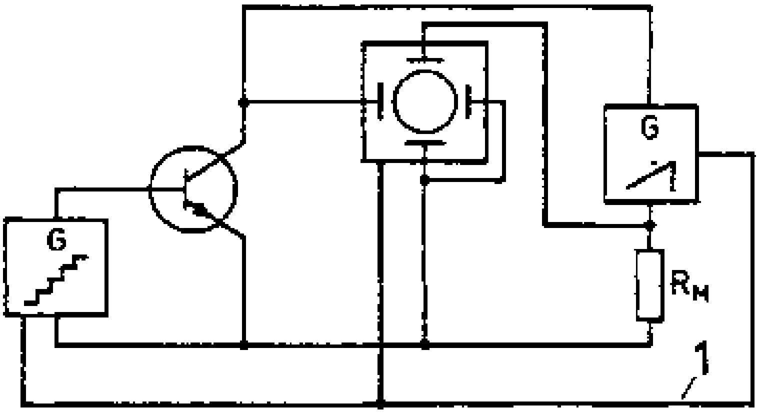


Figure 96. Circuit principle for plotting families of characteristics 1 Synchronization

3.2.3. Characteristic value measurements

A list of known characteristic values of transistors is given in Table 23. The user must only measure a part of these characteristic values.

Table 23. Transistor parameters

Statical	Dynamical	Thermal	Variation
Parameters (I_{CES}, U_{CEsat})	Small–signal parameters (h, y)	Temperatures (t_j, max.)	Noise figures
Limit values (U_{CEO}, P_{tot}, U_T)	Limiting frequencies (f_r, f_T, f_1) Large–signal parameters (k, B) Switching times	Temperature coefficient (TK)	

The following shows measuring processed for selected important characteristic values.

Statical characteristic values

Collector/emitter residual current I_{CES}

Residual currents are reverse currents and basically to be measured as such currents.

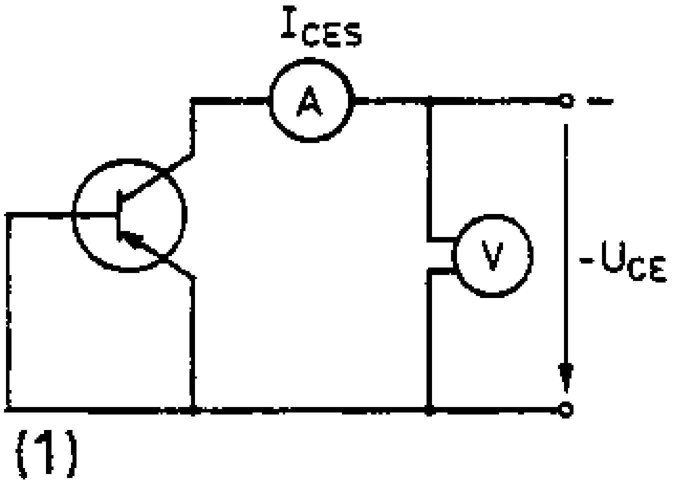
I_{CES} is the collector/emitter current for UBE = 0.
I_{CES} is important for transistors applied in switch and amplifier operation.

In principle, the same preparatory works as for plotting of characteristics are to be carried out for measuring of characteristic values. In this connection, the admissible voltage U_{CE}, which must not be exceeded, is of particular importance.

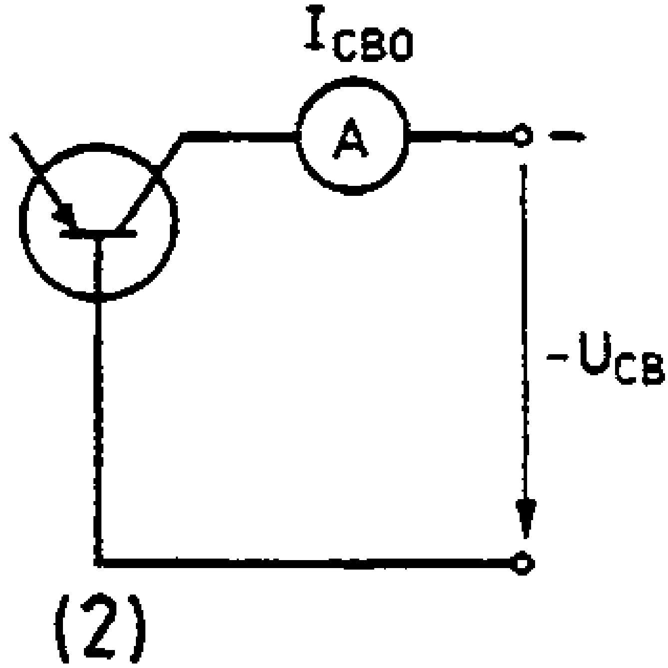
In the measuring circuit according to Figure 97 (1) I_{CES} can be measured without difficulties by means of a multipurpose instrument (D = 20 k?/V), as long as the current remains measurable, e.g. in case of Ge power transistors.

Currents I_{CES} < 1 µA can only be measured with sufficient accuracy by means of sensitive galvanometers. The figures 97 (2), (3), (4) show how I_{CEO}, I_{CBO} and I_{EBO} can also be measured in the same way.

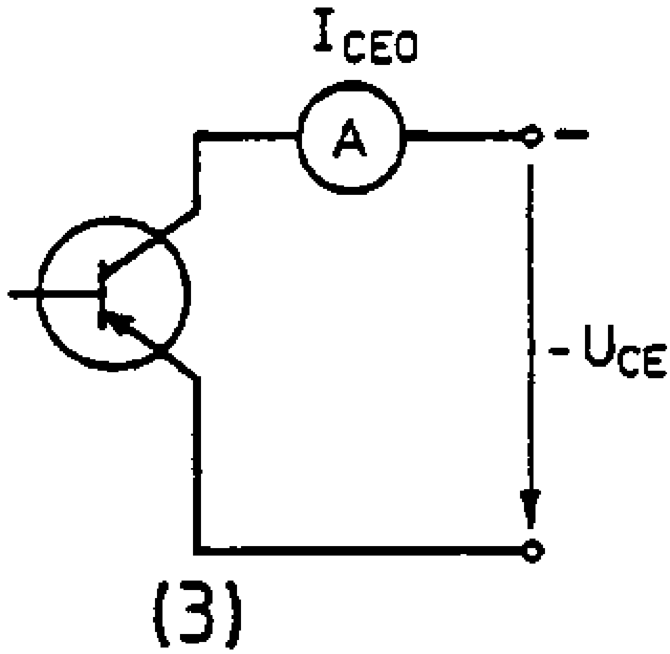
Figure 97. Measuring circuits to determine residual currents



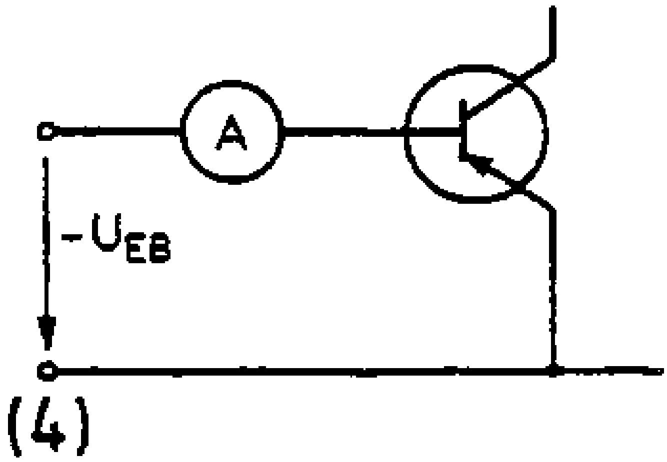
(1) I_{CES}



(2) I_{CBO}



(3) I_{CEO}



(4) I_{EBO}

Collector/emitter saturation voltage $U_{CE\ sat}$

The characteristic $U_{CE\ sat}$ is important for the transistor being a switch and also for transistors in amplifier operation because of its meaning as limit of modulation.

The saturation voltage can be measured as a function of the collector current with $U_{CB} = 0$ being provided for. A measuring circuit is shown in Figure 98.

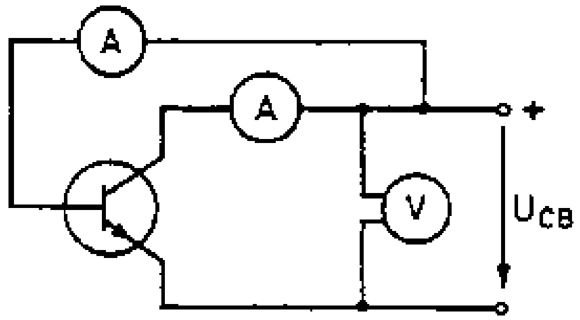


Figure 98. Measuring circuit to determine the saturation voltage U_{CEsat}

Limit values

Limit values being of interest to a transistor are its breakdown voltages. When, for example, a transistor shall switch an inductive load (relay), glitches occur in reverse direction due to the self−inductance, which might destroy the transistor as soon as its breakdown voltage is exceeded. In this connection, the process of constant−current supply is applied. $U_{BR(CEO)}$, $U_{BR(CES)}$ and $U_{BR(CBO)}$ can be measured in dependence of the position of switches S1 and S2.

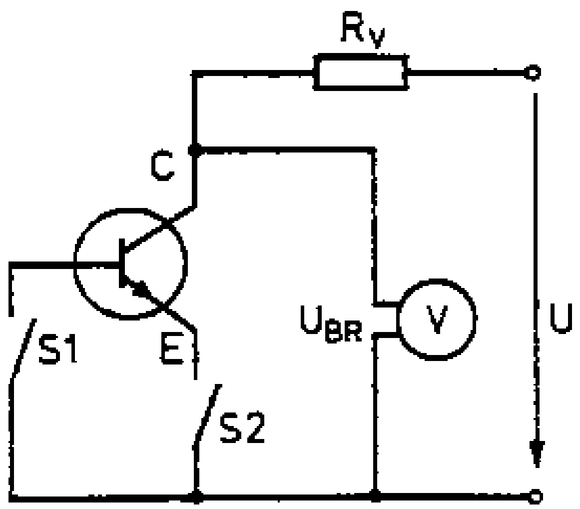


Figure 99. Measuring circuit to determine the limit values

$U_{BR(CEO)}$, $U_{BR(CES)}$, $U_{BR(CBO)}$

With U = 600 V and R_V = 10 M ?, a current of I ? 60 µA sets. The transistor is safely driven into the breakdown, because of the high voltage. A breakdown voltage adjusts over the loaded track, in Figure C − E.

<u>Dynamical characteristic values</u>

The quadripole characteristic values are used to determine the behaviour of transistors in amplifier operation.

These are for

- low−frequency applications: h−parameters
- high−frequency applications: y−parameters.

These characteristic values have been generally accepted, since they describe the transistor completely and can be acquired favourably. Quadripole characteristic values exist for all the three basic transistor circuits. Since the characteristic values of the individual circuits can be converted into one another, the measurements of h−parameters for the high−frequency range are only presented.

h−Parameter

Prior to the measurement of h−parameters, an operating point must be adjusted. The measuring circuit must, hence, ensure to set each operating point within the limit values of transistor. In the measuring circuit according to Figure 100, R1 and the service voltage can be adjusted for this.

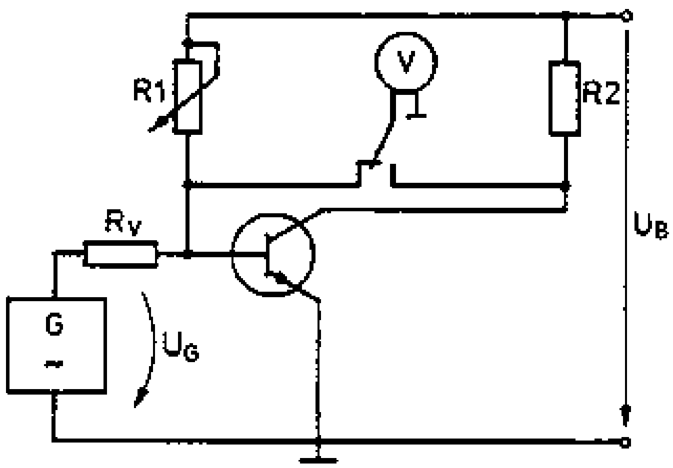


Figure 100. Measuring circuit to determine the h−parameters h_{11} and h_{21}

The measuring conditions for h−parameters can easily be read from its definition:

$h_{11} = \frac{u_1}{i_1}$ at $u_2 = 0$.

Input alternating current and voltage must consequently be measured. The measuring result is given by their quotient. A favourable simplification is given when i_1 is constant and known.

Then, it becomes

$h_{11} \sim u_1$,

i.e. the voltmeter for u_1 can be graduated in values for h_{11}. Secondary condition for the measurement is that the transistor is at $u_2 = 0$, i.e. short circuit is operated.

In practice, this can be reached only approximately by selecting the load resistance much lower than transistor's output resistance. Moreover, it must be ensured that the drive of transistor is very little, compared to the values of the operating point. The measuring circuit according to Figure 100 is fed by a sine−wave generator with low source resistance.

With R_V = 100 k? and U_G = 1 V,

$$i_1 = \frac{U_G}{r_{on}}$$ is approximately 10 µA.

$$r_{on} = R_V + (r_{BE} \,||\, R_1)$$

with r_{BE} ? 1 k?; R_1 > 1 M?, r_{on} becomes = R_V ? 100 k?

In the drawn switch position, u_1 is measured:

$$h_{11} = \frac{u_1}{10\,\mu A}$$

$$\frac{h_{11}}{\Omega} = \frac{u_1}{mV} \cdot 10^2$$

The R2 resistance in the circuit as load resistance with 10? serves to measure the short−circuit current gain h_{21}:

$$h_{21} = \frac{i_2}{i_1}$$ at $u_2 = 0$.

The secondary condition (boundary condition) of $u_2 = 0$ is the same as for h_{11}, the circuit remains unchanged.

i_1 is determined with 10 µA.

i_2 is the output alternating current. For a sufficiently good short circuit $R_2 << 1/h_{22}$ it can be assumed that i_2 flows through R2. Then, it is as follows:

$$i_2 = \frac{u_2}{R_2} = \frac{u_2}{10\Omega}$$

$$h_{21} = \frac{u_2}{10\Omega \cdot 10^{-5} A}$$

$$h_{21} = \frac{u_2}{mV}$$

The output admittance h_{22} refers to

$$h_{22} = \frac{i_2}{u_2}$$ at $i_1 = 0$.

A measuring circuit must fulfill the term of "open input" ($i_1 = 0$, i.e. no−load running). In this connection, the operating point must also be adjustable in wide limits, as shown in Figure 100.

Figure 101 shows the possibility of determining h_{22} with the switch position drawn.

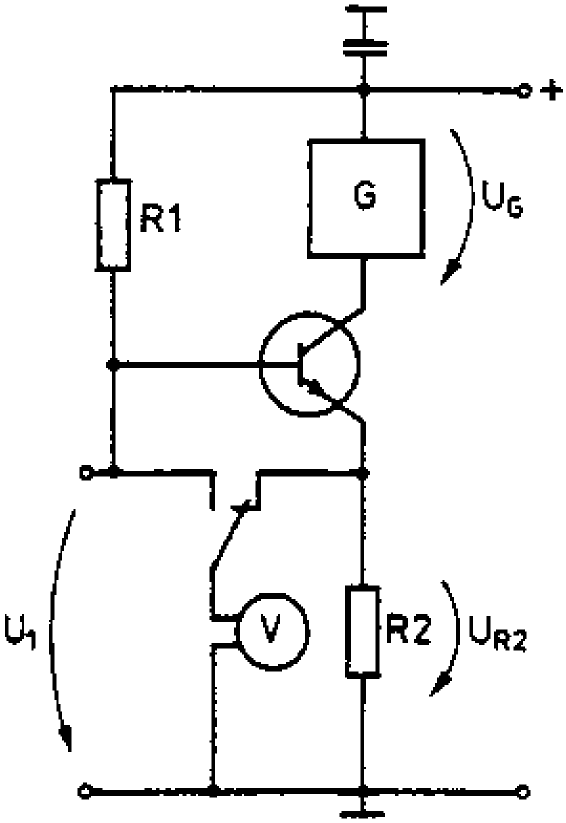


Figure 101. Measuring circuit to determine the h−parameters h_{22} and h_{11}

In this respect, the source resistance of generator and R2 must be small compared with $1/h_{22}$. Then, it is

u_C ? U_{CE} ? u_2 = constant = U_G.

i_2 is indireclty determined via R2, so that it can be written

$$h_{22} \approx \frac{u_{R2}}{R_{2u_G}}$$.

$h_{22} \sim u_{R2}$, i.e. the measuring instrument can be graduated in admittances.

For example, with U_G = 0.2 V and R2 = 50 ? we have

$$h_{22} = \frac{u_{R2}}{10\,V \cdot \Omega}$$

$$\frac{h_{22}}{mS} = \frac{u_{R2}}{mV} \cdot 0.1$$.

In the same circuit, Figure 101, voltage reaction can be measured.

$$h_{12} = \frac{u_1}{0.2\,V}$$ at i = 0

With the constant generator voltage u_2, voltage reaction can be indicated immediately

$h_{12} \sim u_1$

The rating for h_{12} is given by

$$h_{12} = \frac{u_1}{0.2\,V} = \frac{u_1}{mV} \cdot 5 \cdot 10^{-3}$$

The voltmeters used in the measuring circuits are amplifier voltmeters, which guarantee an adequate response and a high input resistance.

Because of clearness, the operating point settings in the Figures 100 and 101 were outlined, only. In general, the operating point is to be measured together with the h−parameters, at the same time. The rating of circuit and selection of measuring instruments must ensure that statical measurement (operating point) and dynamical measurement (h−parameters) do not affect each other.

y−Parameters

The measurement of high−frequency characteristics meets with various difficulties which increase the expenditure for the measurement.

− As for high frequencies, little capacitance and inductances of measuring circuit become apparent. These disturbances must be eliminated or reduced to a minimum.

− The characteristic values of transistor can no more be seen as ohmic resistances or conductances, but are made up by effective and reactive part as impedances and/or admittances, respectively.

− As for measuring generators and voltmeters, questions of adaptation must be clariefied.

The parameter y_{21} is, according to its definition, a conductance. In many cases, it is also specified as transconductance in forward direction:

$$y_{21} = \frac{i_2}{u_1}$$

Data in manufacturer's brochures quote in this connection the measuring frequency and the operating point, since the characteristic value depends on these conditions.

The output short circuit ($u_2 = 0$) is sufficiently fulfilled with

$$R_2 << \frac{1}{h_{22}}.$$

The operating point must be set in an appropriate way at the sockets B, E, C (Figure 102). In order to have definite mass ratios, the sockets B, E, C are connected through relatively great C1 and C2 capacitors (? 1 µF) against earth connection. With a constant input voltage u_1 the current i_2 can indirectly be determined via u_{R2}.

Then, it is

$$y_{21} = \frac{u_{R2}}{R_2\,u_1} \sim u_{R2}.$$

The parameter y_{21} can immediately be read from the voltmeter. In this connection, the value of parameter is measured. By this simple process it is possible to measure effective and reactive part separately.

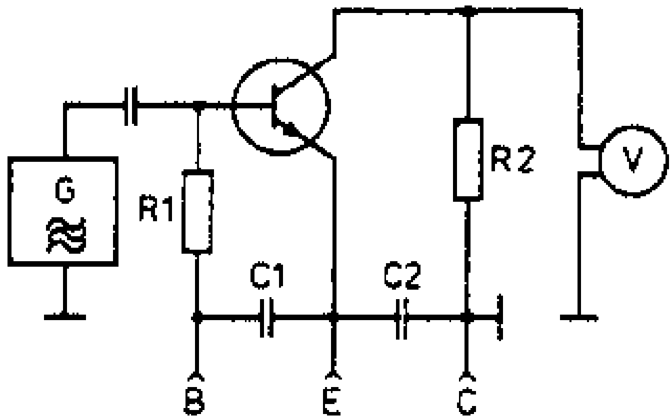


Figure 102. Measuring circuit to determine the y−parameters

Transistor cut−off frequency

The most important frequency characteristic is the transition frequency f_T of a transistor. Essential conclusions regarding the total frequency response of a transistor in amplifier operation can be drawn from the transition frequency.

f_T is an internationally standardized characteristic, which can be measured easily.

As for high measuring frequency (in most cases f = 100 MHz),

$$f_T = |h_{21e}| f$$
.

The value of short−circuit current gain must be multiplied by a high measuring frequency.

By means of a measuring set suitable for high−frequency (as for y_{21}), current gain can be measured, as described.

3.2.4. Transistor measuring devices

Transistor test sets

Transistor test sets give information about the condition of transistors, with little expenditure. In most cases, this is effected by measuring the residual currents and indicating the current gain. Test sets work either with a fixed preset operating point for all test pieces or permit the setting of two or three operating points.

Current gain is statically be determined, because of little expenditure. A low, definite base current is additionally fed to a preset operating point which is determined by the rating. The appropriate collector−current increase is indicated. The scale of test set can then be graduated in B−values, for it is

$$B = \frac{I_C}{I_B}$$

with I_B = constant

$B \sim I_C$.

Parameter measuring devices

In most cases, parameter measuring devices permit the measurement of residual currents, h−parameters and partly of values of y−parameters. In this connection, the operating point can be selected optionally within the characteristic values of transistor. A general circuit diagram is shown in Figure 103. The operating point is set and measured by the current supply 1 (U_{CE}, I_C are measured). A generator 2 generates the modulation signal and will be connected to the test piece 3, dependently on the characteristic value. The indicator 4, designed as amplifier voltmeter, indicates the selected characteristic value.

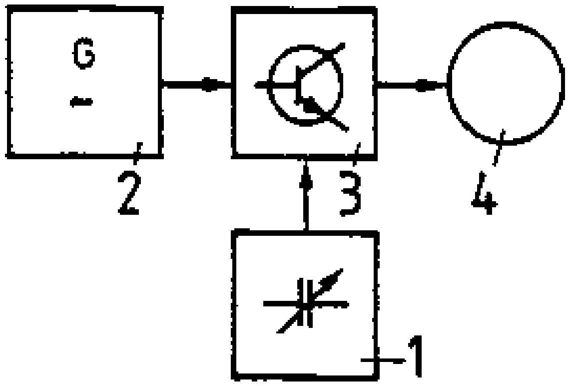


Figure 103. General circuit diagram of parameter measuring device

1 Current supply
2 Generator
3 Test transistor
4 Indicator

Automatic measuring units

Automatic measuring units are high−grade and high−duty units. Automatic measuring units are mainly applied by transistor manufacturers. In most cases, they are computer−controlled units.

1. Several essential characteristic and limit values are measured very quickly.
2. These values are compared with control values, very quickly.
3. The components are classified very quickly (e.g. as to current amplification groups).
4. The components are sorted very quickly.

3.3. Measurements on integrated circuits

3.3.1. Measurements on digital circuits

The user of digital circuits is especially interested in the proper logic function of the components. Furthermore, it must be possible to measure individual characteristic values, not only of statical but also of dynamical kind. The following describes measurements on circuits of the TTL−series (transistor−transistor logic), since these circuits are common.

The measurements and processes are stipulated in standard specifications.

Steady−state measurements

NAND gate

Steady−state measurements on TTL−circuits shall be demonstrated by means of the NAND gates.

Service current I_S

An important characteristic is the service current I_S of a gate. Each gate of a circuit is individually measured according to a standardized circuit (Figure 104).

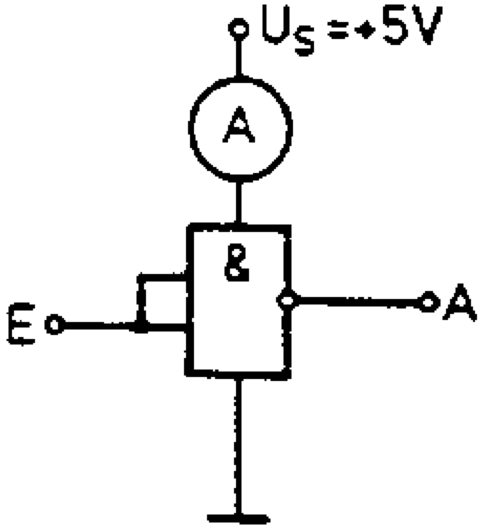


Figure 104. Example of a circuit for steady−state measurement of circuits

The measurable variable is determined at

- – open output
- – service voltage U_S = 5 V
- – input level H (5 V) and L (0 V).

For the gate specified in Figure 104, the following is valid, for example:

I_{SH} ? 4 mA and I_{SL} ? 14 mA.

If a higher service current is measured than specified, it does not necessarily mean inefficiency. These circuits are, however, not suited to be used in industries, since the higher service current results in an inadmissible heating affecting reliability.

Input current I_1

According to the standard specification, the following is prescribed, for example:

- – service input is to be measured individually;
- – every input is to be measured individually;
- – the output of gate remains open;
- – the values of input voltages shall be U_{IL} = 0.4 V and U_{IH} = 2.4 V.

The free inputs are applied to the voltages specified. Measuring circuits are shown in Figure 105 for U_{IL}, on input and in Figure 106 for U_{IH} on input.

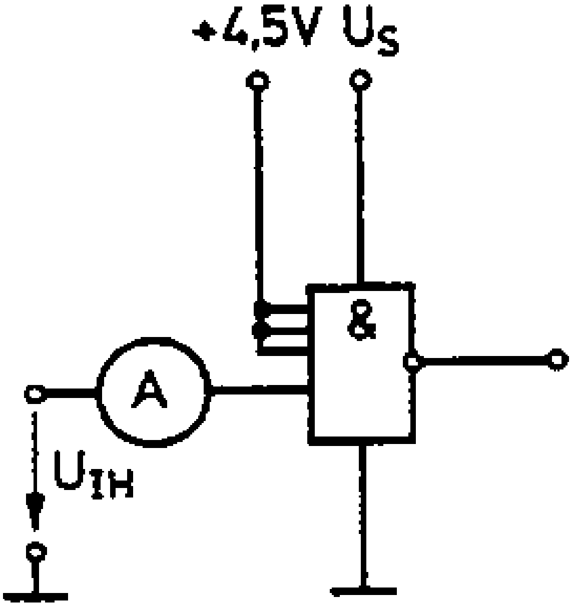


Figure 105. Circuit for measurement of the input level U_{IL}

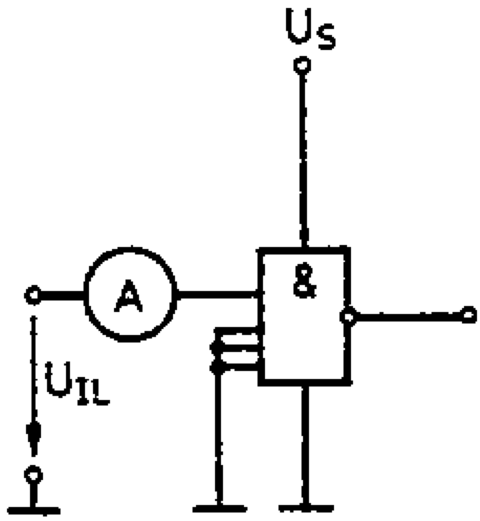


Figure 106. Circuit for measurement of input level U_{IH}

According to the input level, the input currents show different directions!
L level on input: current flows to source (negative counting direction);
H level on input: current flows to gate (positive counting direction).

For example,

I_{IH} = 40 µA, I_{IL} = – 1.6 mA

are admissible for gates of this series.

These currents can be measured by means of multipurpose instruments.

Output voltage U_0

Conditions to measure the output voltage of a gate are as follows:

– Output voltages must be kept within admissible limits for the logical levels of circuit series.

– On the outputs, appropriate fan−outs are to be reproduced by resistors or constant−current sources.

– As for U_{OH}, every input is measured individually, free inputs are applied to U_S.

– As for U_{OL}, the inputs are connected in parallel.

– The most disadvantageous (minimum) service voltage U_S = 4.75 V shall be selected.

– The most unfavourable input levels U_{IH} = 2 V, U_{IL} = 0.8 V shall be applied.

The measuring circuits are represented in Figures 107 and 108.

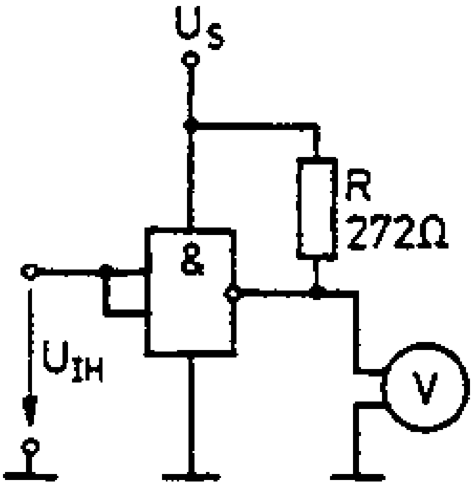


Figure 107. Circuit of measurement of the output level U_{OL}

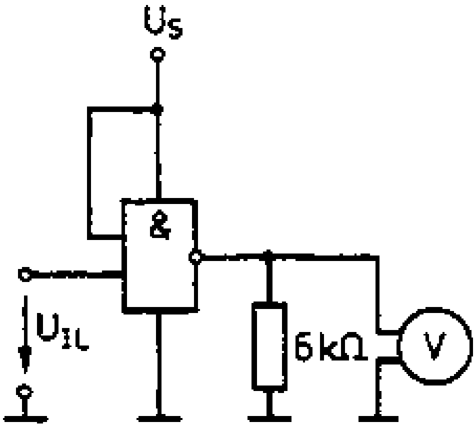


Figure 108. Circuit for measurement of the output level U_{OH}

Limit values for U_0 of this series are for example:

U_{OH} ? 2.4 V and U_{OL} ? 0.4 V.

The output currents can be measured easily by inserting voltmeters into the output line.

The following is admissible, e.g.

I_{OL} – = 16 mA and I_{OH} = – 0.4 mA.

Logical functions

The measurement of logical functions gives complete evidence about the static functionability of a circuit, in connection with the parameter measurement described before.

It is a common practice to enter the results in a circuit table or compare them with it.

In this connection,

– the outputs shall be open,
– the most disadvantageous input levels U_{IO} = 0.8 V, U_{IL} = 2 V shall be applied.

The allocation for a gate of the circuit is given in Table 24. It is the most ordinary logical function of the TTL series, it contains four lines. In case of multivibrator modules, the allocation scheme comprises even 15 lines. Such or other higher−integrated circuits are measured by means of so−called testers, which automatically (quickly) finish the allocation sheme and immediately reach a good/bad statement.

Table 24. Allocation of a circuit of the TTL series

A	B	Y
L	H	H
L	L	H
H	L	H
H	H	L

Dynamical measurements

Dynamical parameters of logical circuits are logical symbols. As for gates of the TTL−series, the standard specification specifies the measuring conditions. They include:

– the amplitude of input signals,
– the rise times of input signals,
– the pulse length of input signals,
– the output load.

In Figure 109, the general circuit diagram for the measurement of dynamical parameters is shown. A pulse generator 1, which must transmit pulses with rise times of t ? 10 nsec., is on the input of the gate to be measured. (Gate 2). Free inputs shall be applied to a voltage of U = 2.4 V. The output load 3 creates the input of additional TTL−gates with parasitic capacitances.

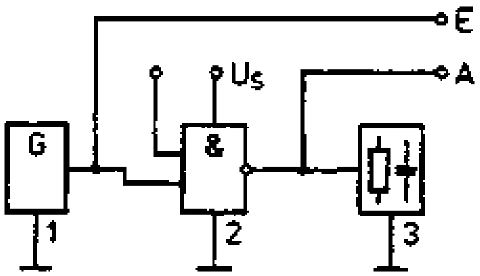


Figure 109. General circuit diagram for measurement of dynamical parameters of integrated circuits

1 Pulse generator
2 Circuit to be measured
3 Output load

Quantities to be measured are the turn−out time t_D and the turn−out time t_{DLH}.

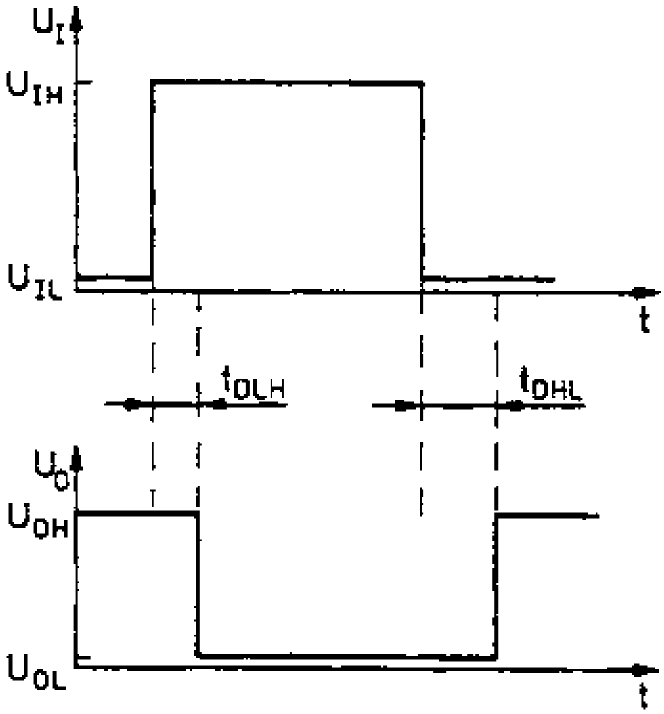


Figure 110. For the determination of turn−on and turn−out time

Dual−beam oscilloscopes or pulse counters are used as measuring instruments. Both the generator and the measuring instruments require a considerable expenditure. Therefore, measuring sets of this kind are not utilized excessively.

3.3.2. Measurements on analogue circuits

The manufacturers of analogue circuits offer a multitude of different types. With increasing integration level, application possibilities limit more and more. That means − a certain circuit, e.g. a power amplifier, can only be used as power amplifier. For these complex circuits, the manufacturer specifies parameters measured under the operating conditions to be expected. In principle, a standard measuring circuit is specified in the data sheets for the parameters.

The operational amplifier has mostly been used out of the small−scale−integrated circuits, due to its universal applicability. For this, measurement of selected parameters shall be presented.

Operational amplifier

Prior to the measurement, limit values (e.g. for U_S, R_L) must be known and, as for other semiconductor components, the connection diagram must be at hand.

An important parameter is the open−loop voltage gain V_U.

The ratio between input voltage and output voltage must be determined

$$V_U = \frac{U_I}{U_O}.$$

Difficulties emerge from the high amplification of $15 \cdot 10^3$ up to $25 \cdot 10^3$.

The measuring set must be arranged interference−proof.

An estimate for the input voltage results from

$$U_I = \frac{U_O}{V_U}$$

$U_{O\ max.} = 10$ V

$U_I < 1$ mV.

The voltage divider R1/R2, shown in Figure 111, shall be so rated that the generator voltage amounts to 1 V. R2 becomes then low−resistant and ensures good interference suppression on input.

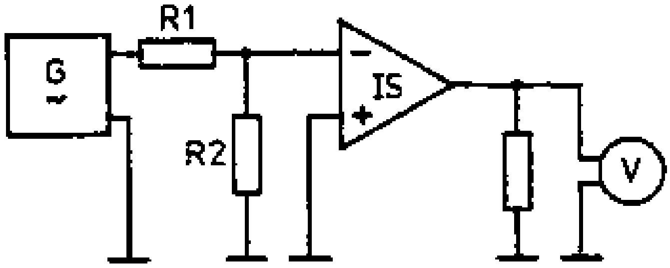


Figure 111. Circuit to determine the parameters of integrated operational amplifiers

The output shall be loaded with $R_L = 2$ k?. The frequency of input voltage must lie below 100 Hz, for measurement will be possible to be effected on the flat part of frequency response. An amplifier voltmeter is used as voltmeter. In case of many applications it is necessary to know the modulability $U_{O\ max}$ in dependence of service voltage. In this connection, it is necessary to make both service voltages (+ U_S, − U_S) variably available. The circuit according to Figure 111 can be applied for this. An oscilloscope or a distortion analyzer can serve as measuring instrument, in order to measure the distortion of output voltage.

Power amplifier

A measuring circuit is given in the standard sheet for an integrated power amplifier.

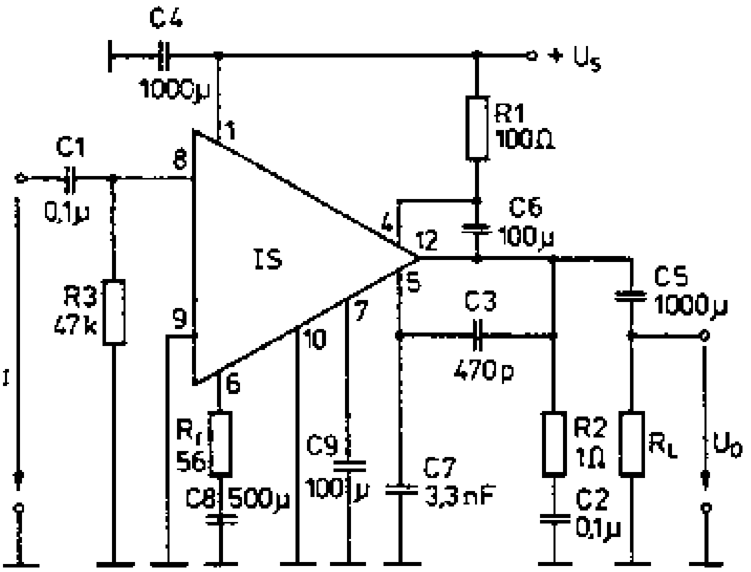


Figure 112. Circuit example to determine the parameters of integrated power amplifiers

The expenditure for such a measuring circuit is, however, only profitable when parameters of integrated circuits shall be verified frequently.

A sine−wave generator must then be connected to the input of circuit. According to the measuring task, the output must be terminated by R_L and connected to amplifier voltmeter, distortion analyzer and oscilloscope. Then, output power, distortion factor and voltage gain can be measured.

Questions and tasks for recapitulation and control

1. Which climatic protection class must at least a component have which shall be applied

– in a laboratory device (10°C ? t ? 25°C)

– in an outdoor installation (−25°C ? t ? 50°C)?

2. Which climate investigation test is especially required for a component used under tropical conditions?

3. Which stability is improved when a component is tightly soldered into a metal case?

4. What is the technical importance of the tolerance?

5. What is the economical importance of the tolerance?

6. Which conditions must capacitors meet applied in automatic control engineering?

7. At the end of a line, which carries a d.c. voltage measuring signal, disturbing pulses occur. They can be bypassed by connecting a capacitor with C = 1 µF in parallel. Which type of capacitor is to be applied if ambient temperature varies between 10 and 35°C and aggressive vapours emerge?

8. What is to be observed when applying electrolytic capacitors?

9. How is it possible to prevent sticking of the armature of a relay or capacitor?

10. Which component is to be used with an exciter magnet for alternating current to diminish the power input to holding current intensity?

11. Which specific conditions are to be met by a protective transformer?

12. What is to be observed when applying an isolating transformer?

13. What hazard occurs if two devices are connected to an isolating transformer?

a) with non−earthed secondary winding; b) with earthed secondary winding?

14. What is an electrical contact?

15. Of what is the electrical resistance of a contact composed?

16. Which possibilities are used in practice to remove the contamination layer on contact surfaces?

17. Which are the disadvantages of silver as contact material?

18. Why is the dual interruption preferred in power electronics?

19. What is a p−n junction?

20. Which essential requirements are to be fulfilled by a reactifier diode?

21. Explain the amplifying effect on a bipolar transistor!

22. Which minimum dielectric strength must a thyristor have when it shall be connected to a mains voltage (220 V)?

23. Why is the current flow interrupted after every positive half−wave, when operating a thyristor with alternating voltage?

24. What are the reasons for the great advance of opto−electronics?

25. Where does the denomination "seven−segment indication" come from?

26. Which segments (A to G) must be triggered for a seven−segment indication in order to represent the numbers 0 to 9? What letters can be displayed?

27. What difference is between photodiode and phototransistor?

28. Of what is an optoelectronical coupler composed?

29. Designate the advantages/disadvantages of the application of integrated circuits!

30. What is the importance of applying integrated circuits?

31. What does "integration level" mean, and which importance does have it for the classification of circuits?

32. Explain the difference between digital and analogue signals!

33. Explain the contractions "RAM" and "ROM!"

34. What is a microprocessor?