ELECTRONIC DEVICES AND CIRCUITS

Mod. MCM3/EV

Volume 1/2

THEORY AND EXPERIMENTS

TEACHER / STUDENT manual

ElettronicaVeneta

"Final English version provided by cambridge Open Learning"

CONTENTS

SAFETY RULES

Keep this handbook at hand for any further help.

After the packaging has been removed, set all accessories in order so that they are not lost and check the equipment integrity. In particular, check that it shows no visible damage.

Before connecting the equipment to the +/- 12V power supply, be sure that the rating corresponds to the one of the power mains.

This equipment must be employed only for the use it has been conceived, i.e. as educational equipment, and must be used under the direct supervision of expert personnel.

Any other use is not proper and therefore dangerous. The manufacturer cannot be held responsible for eventual damages due to inappropriate, wrong or unreasonable use.

LESSON B01: INTRODUCTION TO SEMICONDUCTORS

OBJECTIVES

- crystal structure of semiconductors
- Electronic conduction fundamentals

EQUIPMENT REQUIRED

- Base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- **The module may work in a stand-alone mode, the faults are inserted via the on-board DIP switches: When using the external management units, the 4 left DIP switches must be in the "ON" position, and the 8 right DIP switches must be in the "OFF" position.**
- Experimental module MCM3/EV
- Multimeter
- oscilloscope

B01.1 BASIC THEORY

The solid crystalline semiconductor

A semiconductor is a solid with a regular, 3 dimensional crystalline structure. It is obtained by the repetition of a cell or an elementary crystal. The atoms of the cell are connected by covalent bonds. The configuration is particularly stable, as the atoms continually exchange the electrons in their external orbits: these are known as the valence electrons.

Most semiconductors are elements in group 4 of the periodic table, and so have 4 valence electrons.

This is illustrated quite well by the crystal structure of germanium and silicon, which are the semiconductors used most often in electronics. In this structure you can note that each atom, set in the center of a tetrahedron, is surrounded by four other atoms at the corners. Each of these then shares an electron with the other. Each one also shares an electron with the central atom.

A 2-D representation of this is given in figure B01.1.

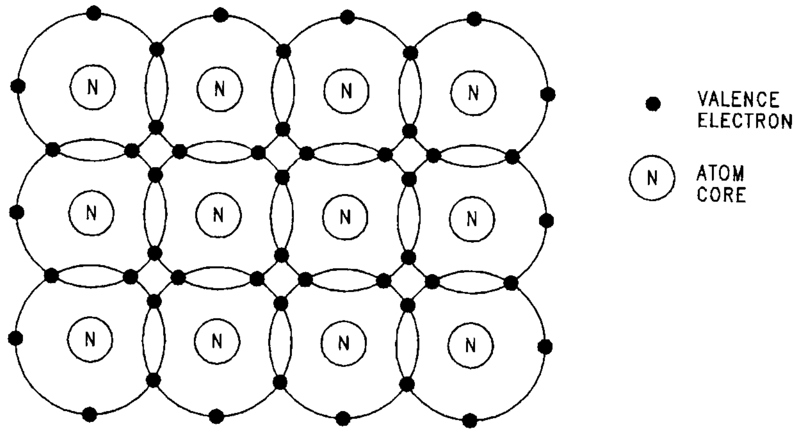


figure B01.1

The conductivity of semiconductors depends on temperature. As temperature increases, it causes some covalent bonds to break, and consequently a certain number of electrons are free or move under the action of an electrical field.
A semiconductor tends to behave as an insulator at low temperature, and a conductor at high temperature. At room temperature, its conductivity is somewhere inbetween, hence its name.

Conductivity mechanism

In the absence of electrical forces applied to a semiconductor, the overall movement of the electrons due to thermal agitation is zero, because there is no preferred direction of motion.
The electron in this case moves around a stable position and does not create an electrical current, which requires an overall flow of electrical charge.
If a potential difference is applied to the material, the weakly bound electrons can leave the atom and move towards the positive terminal.
When an electron separates from the atom, and is free, it produces a deficit of negative charge, a deficit which is called a "hole". A hole constitutes a positive charge carrier, comparable to a free electron. Both contribute to electrical conduction in a semiconductor.
The conduction mechanism can be described, by considering that the hole can easily be filled by a valence electron from a nearby atom. When this occurs, the electron which fills the hole leaves another deficit behind, ie another hole. The hole shift, in the reverse direction to that of the electrons, can be represented as the movement of a positive charge.

The electrical current of a semiconductor is then equal to the sum of positive holes and negative electrons moving across a plane per second. Figure B01.2 is a representation of this process.

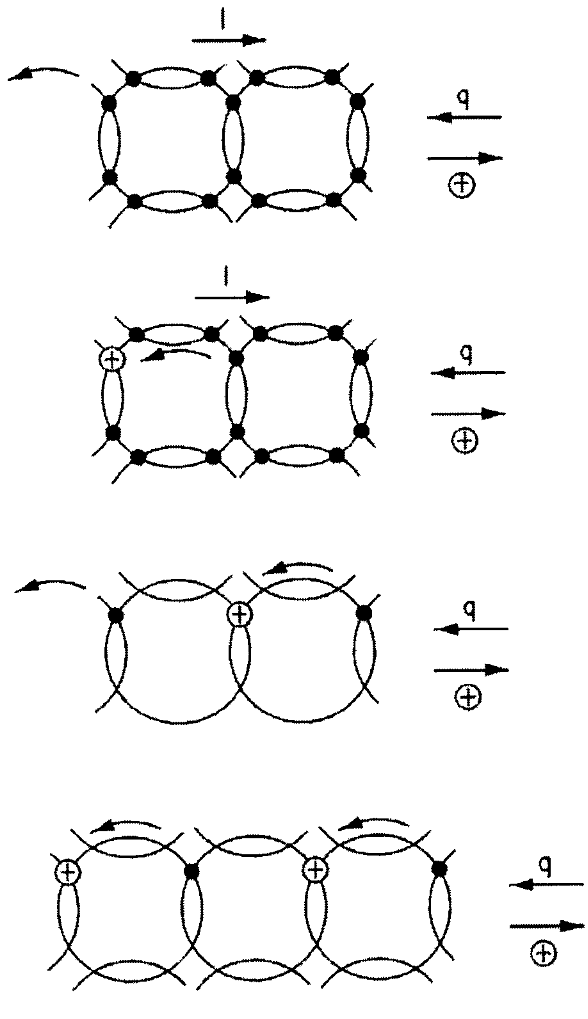


figure B01.2

Doped semiconductors

As the conductivity of a pure semiconductor is very low at room temperature, to increase it significantly, some impurities must be introduced into the crystal structure. These impurities are of two kinds.

In the first case, the impurities are atoms which can contribute an extra, free electron. A semiconductor doped in this way is called N (negative) type, because the "donor" atoms provide negative charges. Atoms of this kind belong to group V of the periodic table of elements, and examples are phosphorus (P), arsenic (As) or antimony (Sb).

The extra (or excess)electron is illustrated in figure B01.3.

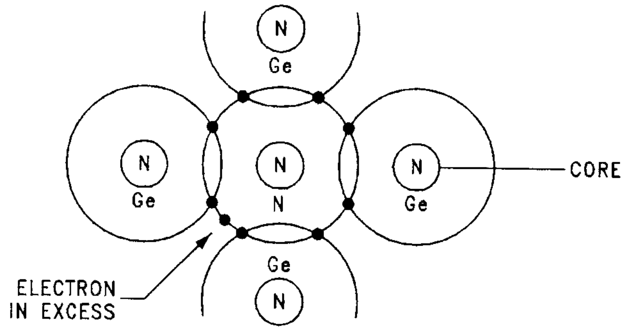


fig.B01.3

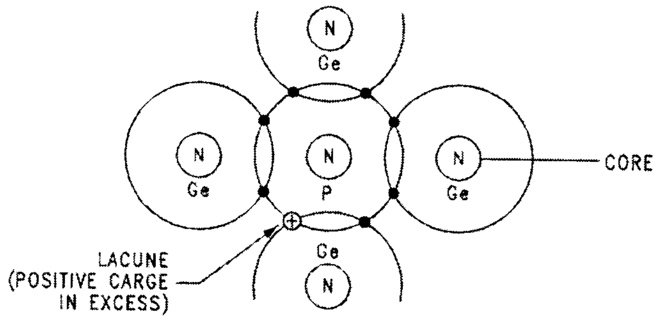


fig.B01.4

The second type of impurity consists of atoms having the capacity to capture a free electron. The semiconductor is then called type P type (positive) because the impurity atoms are "acceptors" of negative charges, ie they contribute a Positive hole.

The impurity atoms belong to group III of the periodic table of the elements (3 electrons in the valence band) and are e.g., boron (B), gallium (Ga), or aluminium (Al).

Note that both types of doped semiconductors are electrically neutral: although the added atoms contribute free carriers, the atoms themselves are electrically neutral.

Majority and minority charge carriers

In case of a doped semiconductor subjected to an emf, the current through it consists of the free carriers due to thermal agitation and also the free carriers supplied by the impurities. In the first case, they are provided by the crystal's own atoms and are called minority charge carriers.
In the second case the charges are due to the impurities added to the semiconductor. Such charges are called the majority charge carriers.

B01.2 QUESTIONS ON THIS CHAPTER

➲ ***MCM-3***	**Disconnect all jumpers**
➲ ***on-board SIS1***	**Set all switches "*OFF*"**
➲ ***SIS2***	**Insert lesson code: B01**

Q1 *The conductivity of a pure semiconductor is due to:*

SET
A B
1 5 electrons
2 3 holes
3 4 positive ions of the N regions and electrons
4 1 electrons and holes
5 2 positive ions of the P regions and holes

Q2 *A pure semiconductor is a good conductor when the temperature is:*

SET
A B
1 2 very high
2 2 very low
3 5 absolute zero
4 3 when ranging between 0 and 25 °K
5 4 it is not affected by temperature

Q3 *A P type semiconductor is obtained by adding impurities such as:*

SET

A B
1 2 those belonging to group V of the periodic table of the elements
2 4 those belonging to the group III of the periodic table of the elements
3 1 antimony only
4 5 gallium only
5 4 boron in the proportion of 25 %, and arsenic as 75 %

Q4 *An N type semiconductor is obtained by adding impurities such as:*

SET

A B
1 4 those belonging to group III of the periodic table of the elements
2 1 phosphorus only
3 3 boron only
4 5 aluminum and antimony together at 50 %
5 2 those belonging to group V of the periodic table of the elements

Q5 *Does a doped semiconductor have a higher conductivity than a pure semiconductor?*

SET

A B
1 4 no
2 5 yes, but only at a temperature of 0 °K
3 2 yes, but only if it is doped with N type impurities
4 1 yes
5 3 none of the above is correct

LESSON B02: THE P-N JUNCTION

OBJECTIVES

- To understand the operation of the PN junction

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).

B02.1 BASIC THEORY

Diffusion, field and power barrier currents

Suppose two doped semiconductor layers, one type P and the other type N, are brought together, forming a junction at their interface as illustrated in figure B02.1.

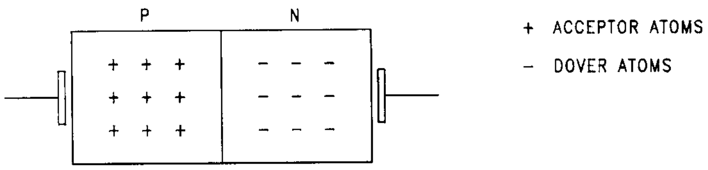


fig. B02.1

Due to the presence of acceptor atoms in the P region and donor atoms in the N, there is difference in charge concentration in the junction region. This causes a «spreading» or diffusion of free electrons from the N region to the P region, and a similar spreading of positive charges (holes) in the opposite direction.
The holes, having crossed the junction, combine with electrons of the N region, and likewise electrons crossing the junction combine with the holes on the other side.

Because a negative electron and positive hole «cancel out», there are no free carriers in the area adjacent to the junction . In other words there is an insulating region, or «depletion» layer around the junction.

Also, because of the charge migration, there is a negative charge on the P side, and a positive charge on the N side, as indicated in figure B02.2.

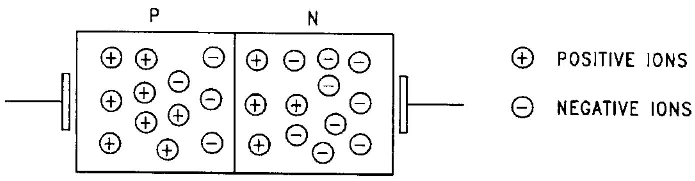


fig. B02.2

These charge layers produce an electrical field across the junction, and so a potential barrier, which opposes, and eventually stops the spreading process as shown in figure B02.3.

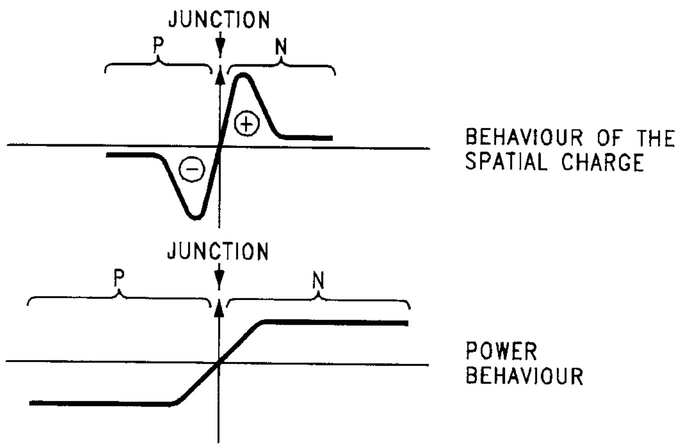


fig. B02.3

The voltage produced, with the polarity as shown in figure B02.3, will oppose the spreading of holes from P to N, and of the electrons from N to P, while it will assist the passage of holes from N to P and electrons from P to N.
Electrical charges of the latter type (minority carrier) generated thermally, can flow freely across the junction, creating an electrical current, called the minority carrier current or field current.
With this balance and with an open circuit, the two spreading and field currents are perfectly equal, so that the total resulting current I is zero.

Forward Bias on a P-N junction

The P layer in a P-N junction is called the "anode" and the N the "cathode". If a voltage difference is applied across the junction, with the cathode negative with respect to the anode (figure B02.4), the voltage barrier of the junction will be reduced. This occurs in forward bias.

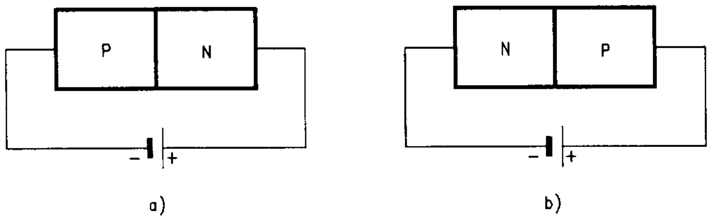


fig. B02.4

The free electrons of the N region are repelled by the negative terminal of the battery and sent to the junction. Simultaneously the holes of the P region are attracted towards the junction, by the positive terminal of the battery. There is a resulting current across the junction in the direction (P-N), whose value increases when the applied e.m.f. increases.

Reverse Bias on a P-N junction

Reversing the biasing of the applied voltage, the voltage barrier increases. As a result, both the positive charges of the P region as well as the electrons of the N region are repelled from the junction, and the spreading currents drop. The current across the junction consists only of the minority carriers, and is very small.
It has a negative direction (N-->P) and is called the "leakage current" or "reverse current".

It is almost independent of the applied voltage, and its maximum value is less than a few microamps for germanium and nanoamps for silicon.

The Avalanche Effect and Zener Effect

When the reverse bias voltage across the P-N junction takes very high values, there is a rapid rise in current, at almost constant voltage.

There are two causes of this: the "avalanche" effect, or the "Zener" effect, or both.

In the avalanche effect, the electrons acquire a high speed, due to the the applied voltage. As a consequence, the atoms hit by the high speed electrons are ionized, and extra electrons are freed. These charges, under the action of the high electrical field, can then ionize other atoms, starting a chain reaction which leads to a rapid current increase.

In the Zener effect, for a certain voltage value, the electrical field is such that some covalent bonds break, so producing a large increase in the minority carriers, and so in the reverse current.
The basic characteristic of a P-N junction as function of the bias voltage is as shown in figure B02.5.

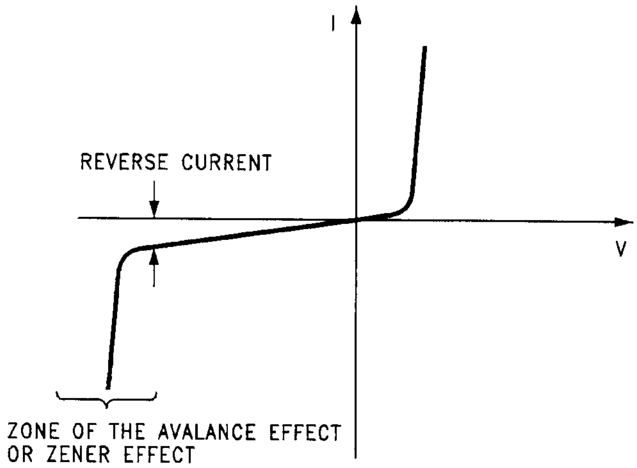


fig. B02.5

B02.2 QUESTIONS ON THIS CHAPTER

➲ *MCM-3*	**Disconnect all jumpers**
➲ ***on-board SIS1***	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B02**

Q1 *To forward bias a P-N junction you must* :

SET
A B
1 3 apply a positive voltage to the P region , and set the N to ground
2 1 apply a negative voltage to the N region, setting the P to ground
3 5 apply a positive voltage to the N region and a negative to the P
4 2 apply a positive voltage to the P region and a negative to the N
5 4 none of the above

Q2 *To reverse bias a P-N junction you must:*

SET
A B
1 5 apply a positive voltage between the P region and the N region
2 3 apply a positive voltage to the P region, setting the N to ground
3 4 apply a positive voltage to the N region and a negative to the P
4 1 apply a negative voltage to the N, setting the P to ground
5 2 none of the above

Q3 *What is the most evident effect in a forward biased P-N junction ?*

SET
A B
1 4 the current is zero
2 3 exponentially increases
3 1 the Zener effect
4 5 the avalanche effect
5 2 none of the above

Q4 *In a reverse biased P-N junction what is the most evident effect?*

SET

A B

1 3 the current is zero

2 5 the current increases exponentially

3 2 the junction starts conducting considerably after the threshold Voltage of 0.6v approximately

4 1 the current is low, at low to medium voltages, then it suddenly increases at an almost constant voltage

5 4 none of the above

LESSON B03: CHARACTERISTICS OF THE DIODE

OBJECTIVES

- To measure the forward and reverse resistance of a diode
- To measure the voltage-current characteristic
- To plot a graph of the voltage-current characteristic
- To study the half-wave rectifier.

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B03.1 BASIC THEORY

A diode is a semiconductor device consisting of a P-N junction. Its current-voltage characteristic is as shown in figure B03.1.

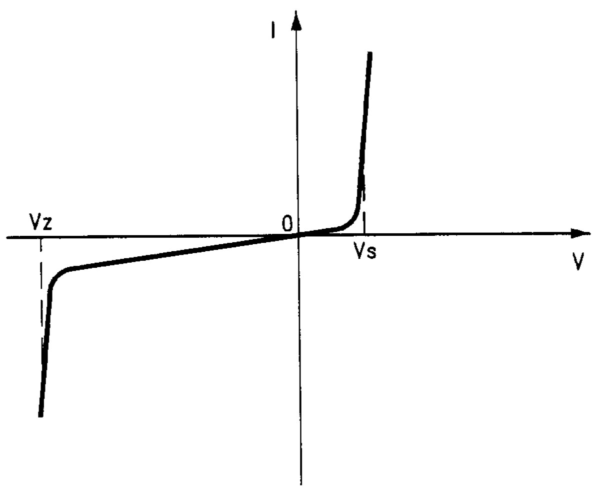


fig. B03.1

The key features of this graph are:

- the breakdown voltage V_Z, at which the avalanche effect occur. At this voltage there is a rapid increase in current which, if not properly limited, leads to the destruction of the diode.
- the threshold V_S at which the diode starts conducting easily. For forward bias voltage values above this value, the current rapidly increases. In forward bias the current can be defined by the equation:

$$I = Io \cdot \left(e^{\frac{q \cdot V}{n \cdot K \cdot T}} - 1 \right)$$

where:

Io is the reverse current
q is the electronic charge which is $1.63 \cdot 10^{-19}$ C
V is the anode-cathode voltage
n is a constant depending on the type of semiconductor
K is the Boltzmann's constant which is equal $1.38 \cdot 10^{-23}$ J/K
T is the temperature of the semiconductor in Kelvin.

It is important to note that the current through a diode is a function not only of the power supply voltage but also of temperature. This dependence is true for any semiconductor, and so the electronic properties are normally measured at a fixed temperature.

Another important parameter of a semiconductor diode is the differential resistance r_d. This is defined as the ratio between a small voltage variation and the corresponding current variation, around the operating point.

A diode is shown in figure B03.2, and underneath is the corresponding symbol.

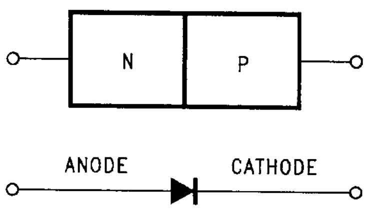


fig. B03.2

A diode conducts only when forward biased, and hardly at all in the reverse direction. If the diode is powered with ac, it is easy to see that only the positive half-wave causes current to flow in the circuit, as the negative component is blocked. The simplest circuit using the diode as a rectifier is represented in figure B03.3 a.

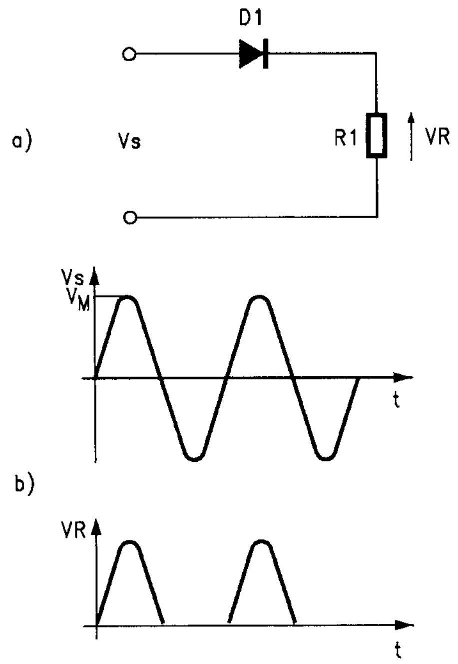


fig. B03.3

The current flows in the circuit during the half cycle (duration of a half-wave) and produces a positive half-wave voltage across the load. The average value V_m of the rectified voltage is:

$$\mathbf{V_m = V_M / \pi = 0.318 \cdot V_M}$$

The rms voltage is:

$$\mathbf{V_{rms} = V_M / 2}$$

B03.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches *OFF***
➲ *SIS2*	**Insert lesson code: B03**

N.B. Voltage and current measurements will be required on some circuits. If only a single multimeter is available this will need to be used sometimes as a voltmeter, and at other times as an ammeter. When used for voltage measurements, remember to short-circuit the points of the circuit where the ammeter can be inserted.

Measurement of the forward and reverse resistance of a diode

- set the multimeter for resistance measurements
- measure the forward and reverse resistance (figure B03.4 and B03.5) of the diodes D_1 (silicon) and D_2 (germanium), and record the data in the table (note: in some multimeters, set for resistance, the red terminal is the negative, and the black the positive –check yours)

Si		Ge	
forward	rev	forward	rev

- (See 'note' inserted above)

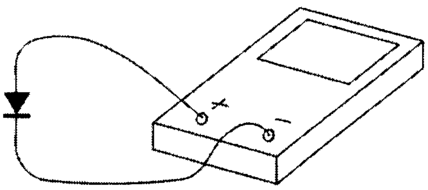


figure B03.4

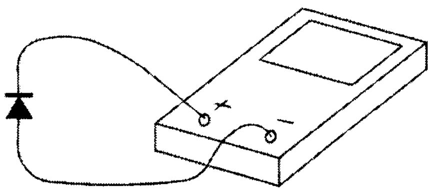


figure B03.5

Q1 *What are the differences between the germanium and silicon diodes?*

SET
A B
1 5 the forward and reverse resistance of the diodes is zero
2 3 the forward resistance of the silicon diode is low, but higher than that of the germanium diode. The two reverse resistances are high
3 1 the forward resistances are very high, and the reverse ones very low
4 2 the forward resistance of diode D_2 is very high, the reverse one very low; the diode D_1 has a completely opposite behavior
5 4 none of the above is true

Measurement of diode current as a function of the applied voltage

- Connect jumpers J2, J8, J9, J5 to produce the circuit of figure B03.6

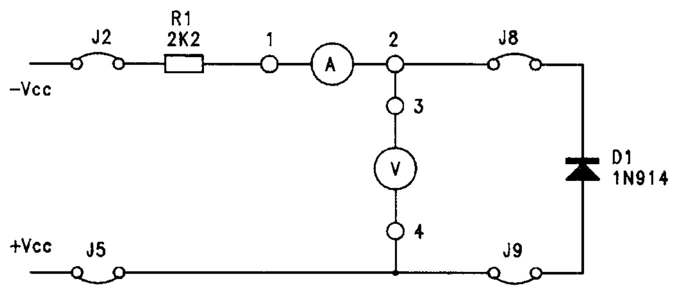


fig. B03.6

- steadily increase the supply voltage, and measure the voltage across the silicon diode D_1 for the current values shown in the following table

ma	I	.02	.05	.07	0.1	0.2	0.4	0.7	1	5	10
V	V_{diode} Si										
V	V_{diode} Ge										

- remove jumpers J8 and J9 and insert jumpers J10 and J11
- repeat the measurements for the germanium diode D_2, and record the data in the table
- disconnect all jumpers from the board
- connect jumpers J1, J8, J9, J6 and the ammeter across J7, to make the measurements when the diode is reverse biased

- for the voltage values shown in the following table, measure the current through the silicon diode D_1, and record the data into the table

V	V	5	10	20
μA	I_{diode} Si			
	I_{diode} Ge			

- disconnect jumpers J8 and J9, connect jumpers J10 and J11, and repeat the reverse bias measurements for the germanium diode D_2

Q2 *How does the diode behave as the supply voltage varies?*

SET
A B
1 2 in forward biasing the current is zero, in reverse biasing the current is constant at 100 mA
2 1 in forward biasing the current is very low, until the voltage reaches a characteristic value for the diode, then it increases exponentially. In reverse biasing the current is extremely low, and is difficult to measure
3 4 the current is always zero in forward as well as in reverse biasing
4 5 in forward biasing the current is constant at 120 mA, in reverse biasing it is zero
5 3 none of the above describes the behavior of the diode

Plotting the voltage-current curve of the diodes

- With the results obtained in this chapter, plot the voltage-current curves for both the germanium and silicon diodes (figure B03.7)

The curve obtained can be represented with broken lines, composed of a horizontal one overlaid on the voltage axis and by one almost parallel to the current axis.

From the threshold, or turning point of the straight line, estimate the threshold value V_S of the diode, (the voltage at which the diode starts to conduct reasonably well)

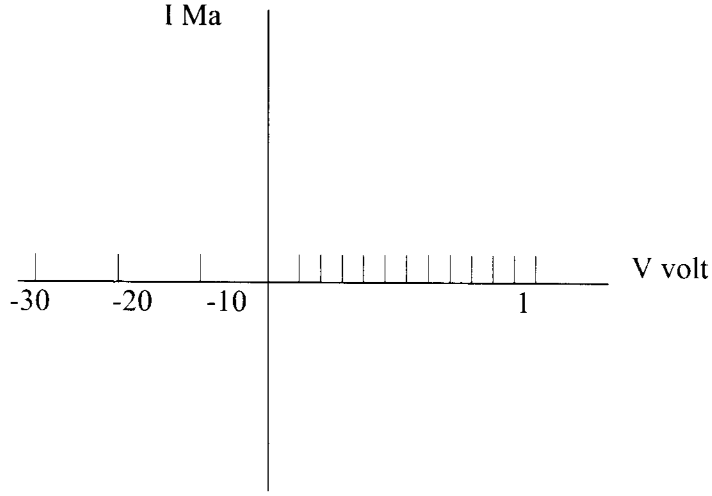


fig B03.7

Q3 *What is the threshold voltage for the diodes D_1 and D_2?*

SET

A	B	
1	5	0 V for D_1 and for D_2
2	3	5 V for D_2 and 7 V for D_1
3	2	0.2-0.3 V for D_2 and 0.5-0.7 V for D_1
4	1	0.5-0.7 V for D_2 and 0.2-0.3 V for D_1
5	4	3 V for D_2 and 0 V for D_1

Displaying the diode characteristic on the oscilloscope

- Disconnect all jumpers
- connect jumpers J3, J7, J8, J9, J4 to produce the circuit of figure B03.8

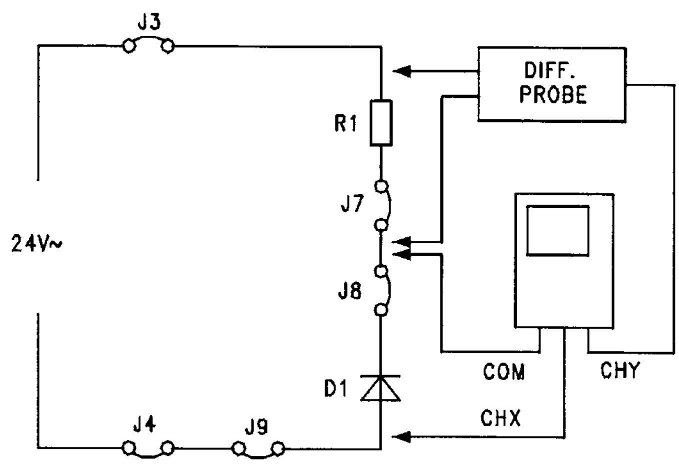


fig. B03.8

- connect channel 1of the oscilloscope to the cathode of D_1, (ground to anode) ground, to display the voltage across the diode, and channel 2 to display the voltage across R_1, as indicated
- invert channel 1 of the oscilloscope and select the XY display mode
- as the voltage V_{R1} is proportional to the current across the diode, this allows us to now observe the diode characteristic
- measure the threshold value and evaluate the curve in the forward direction
- disconnect jumpers J8, J9 and connect jumpers J10 and J11, and repeat the measurements for the germanium diode D_2
- the wave-forms displayed in the two cases should be similar to those in figure B03.9
- check if the threshold voltage values measured with the oscilloscope are similar to those obtained graphically in the last chapter.

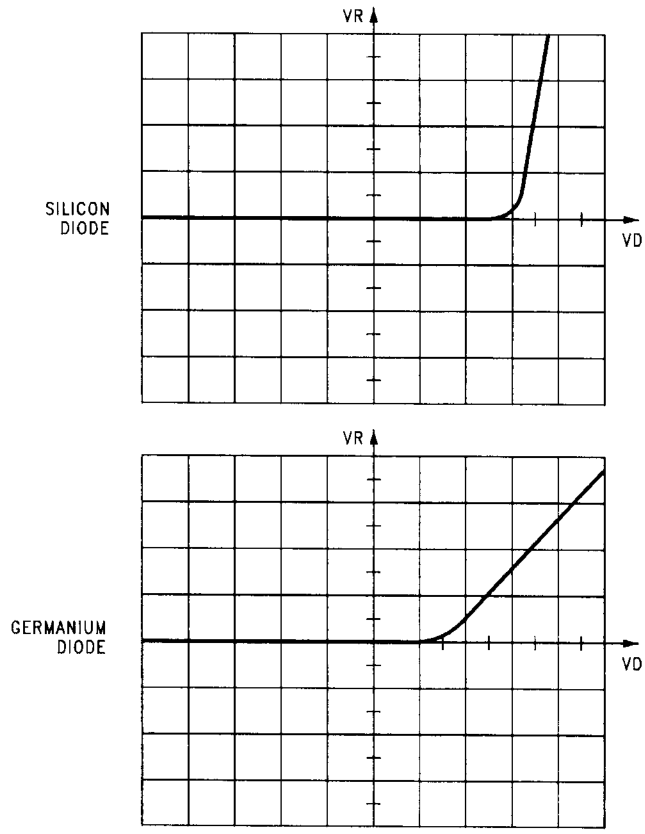


fig. B03.9

Analysis of the half-wave rectifier

- Connect jumpers J14, J24, J31, J27, J20 and the ammeter to produce the circuit of figure B03.10

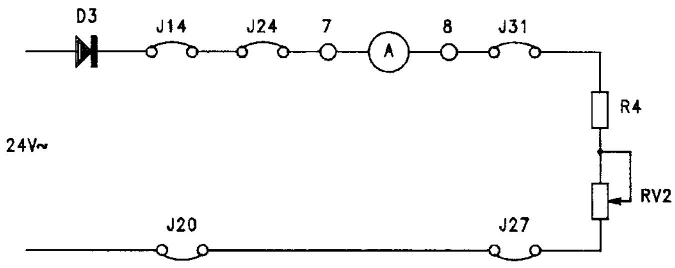


fig. B03.10

- adjust RV_2 to obtain the minimum current in the circuit
- connect the oscilloscope to display both the input voltage and the voltage across the load (R_4 with RV_2 in series)
- compare the 2 wave-forms and determine at which times the diode conducts

Q4 *What are the differences in the 2 displayed signals ?*

SET
A B
1 5 the input voltage has twice the amplitude of the one across the load
2 1 the input voltage has a frequency double that of the load voltage
3 4 the input voltage is shifted by 60° compared to the load voltage
4 3 the 2 signals are in phase, but the load signal lacks the negative half-wave, and the input one has slightly higher amplitude
5 2 none of the above

Note that although a real diode is a good conductor when forward biased , it does have a certain conduction threshold (about 0.7V).

➲ ***on-board SIS1***	**Turn switch S23 "*ON*"**
➲ ***SIS2***	**Press "INS"**

Q5 *What can you conclude from the changed readings on the instruments?*

SET
A B
1 6 the load resistance has increased
2 3 a further diode has been introduced in series
3 1 the circuit has become open-circuit
4 5 the supply voltage has been doubled
5 4 the load resistance r has been reduced
6 2 a capacitor has been connected in series with the load

➲ ***on-board SIS1***	**Turn switch S23 "*OFF*"**

B03.3 QUESTIONS ON THIS CHAPTER

Q6 *Which of these is the symbol for a diode:*

SET
A B
1 4


2 3


3 2


4 1


Q7 *Does the voltage-current characteristic of the diode depend on both the temperature and the type of semiconductor ?*

SET
A B
1 3 no, it depends only on temperature
2 4 no, it depends only on the type of semiconductor
3 2 yes
4 1 no, it does not depend on either one

LESSON B04: FULL-WAVE RECTIFIERS

OBIETTIVI

- To analyze the full-wave rectifier
- To analyze the Graetz (Bridge) rectifier

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B04.1 BASIC THEORY

The half-wave rectifier described in the last lesson has too low an average(or rms) value of output voltage, as it uses only half the input cycle. This is inconvenient, especially if the load requires a lot of power.
There are two alternatives to the simple rectifier, which rectify the whole of the input cycle, and so increase the average and rms value of the rectified voltage.
One circuit – the full-wave rectifier, uses two diodes, as seen in figure B04.1.

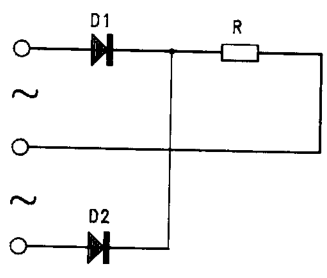


fig. B04.1

This dual diode rectifier requires two equal voltages, but 180° apart, on the anodes,. The average value V_m of the rectified voltage is :

$$\mathbf{V_m = 2 \cdot V_M / \pi = 0.636\ V_M}$$

The rms voltage is :

$$\mathbf{V_{rms} = V_M / \sqrt{2} = 0.707\ V_M}$$

The other circuit solution to rectify both half-waves of an ac source is the Graetz, or bridge rectifier. This circuit is shown in figures B04.2 and B04.3.
The Graetz bridge requires 4 diodes, instead of 2 as in the last case. During the positive half-wave the diodes D_1 and D_3 conduct, and during the negative half diodes D_2 and D_4 conduct. However it can be seen that the current in the load R has always the same direction, for both half cycles.

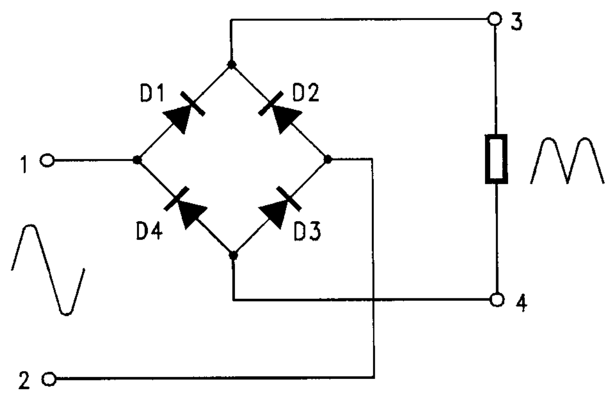


fig. B04.2

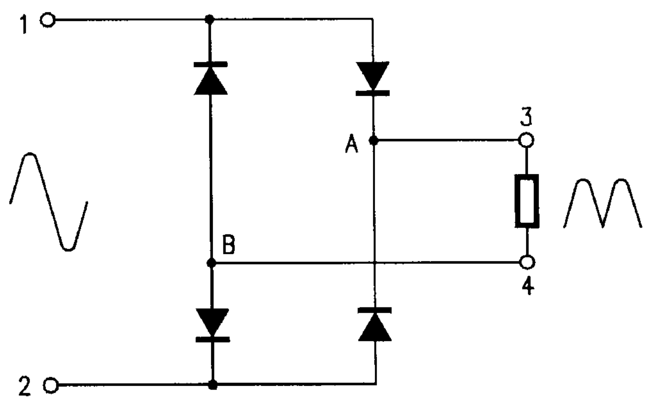


fig. B04.3

B04.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B04**

N.B. Voltage and current measurements will be required on some circuits. If only a single multimeter is available this will need to be used sometimes as a voltmeter, and at other times as an ammeter. When used for voltage measurements, remember to short-circuit the points of the circuit where the ammeter can be inserted.

Analysis of the full-wave rectifier

- Connect jumpers J14, J18, J24, J31, J27, J20 and the ammeter to produce the circuit of figure B04.4

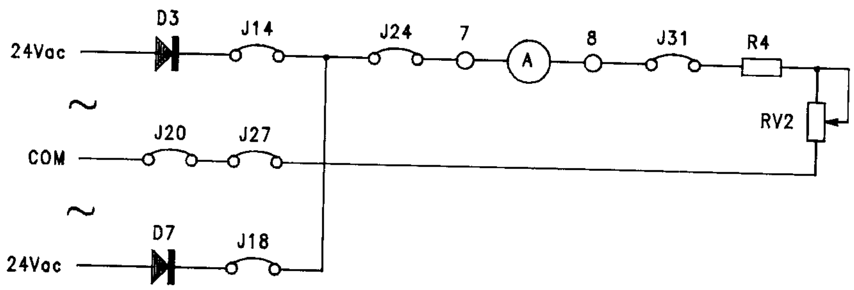


fig. B04.4

- connect the ground of the oscilloscope to the common point of the two ac input voltages (e.g. on the anode of the diode D5). Connect the probes to display the voltage across the load (of R_4 and RV_2 in series) and alternatively on the anodes of the diodes D3 and D7
- adjust RV_2 to obtain the maximum load current through the circuit

Q1 *What can be concluded from these measurements?*

SET
A B
1 3 the voltage on the cathode of D3 is always zero, the one on D7 has no positive halfwave, the one on the load has no negative half-wave
2 1 the voltage on the cathode of D3 has no positive half-wave, the one on D7 has no negative halfwave, so the voltage on the load is zero
3 4 the voltage on the anode of D3 has no negative half-wave, the voltage of D7 is zero, the one of the load has no positive half-wave
4 5 D3 and D7 rectify the half-wave with sign opposed to the input voltage. The voltage on the load consists only of positive pulses
5 2 none of the above is true

- Set the ammeter to dc, disconnect jumper J18 and measure the current
- connect jumper J18 and measure the current again

Q2 *Comparing the current values obtained, we note that:*

SET
A B
1 4 the results are identical in the two cases
2 3 the current in the first case is three times higher
3 2 the current in the second case is double
4 5 the current in the first case is double
5 1 the current is half in the second case

Graetz bridge rectifier

- Connect jumpers J14, J16, J24, J31, J17, J15 and the ammeter to produce the circuit of figure B04.5

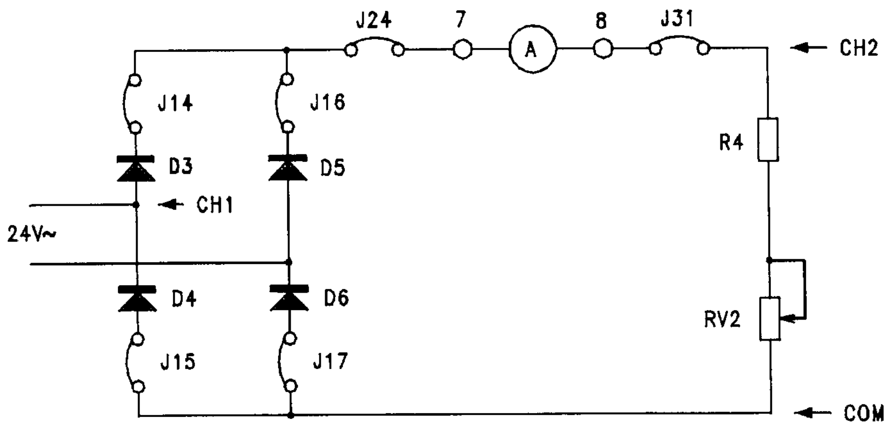


fig. B04.5

- adjust RV2 to obtain the maximum current in the circuit
- connect the ground of the oscilloscope to the anode of D4 (point COM in the figure) and probe 1 to the cathode of D4 and probe 2 across the load (of R_4 and RV_2 in series)
- measure the maximum value of the voltage across the diode D_4. This is the reverse voltage applied to the diode
- check the behavior of the voltage on the load when the following modifications are carried out on the circuit:

1 simultaneously disconnect jumpers J14, J15, J16
2 simultaneously disconnect jumpers J16, J14
3 disconnect jumpers J15, J16
4 disconnect jumpers J14, J17

Q3 *From the tests carried out, the operation of the Graetz bridge can be observed. Which of the following statements is true?*

SET
A B
1 2 during operation diodes D_3 and D_6 conduct alternately, while diodes D_2 and D_4 protect the load from over voltages
2 1 at any moment, one pair of diodes in the bridge are conducting
3 4 the signal on the load has a pulse behavior, consisting of the single negative half-waves of the input signal, as the diodes D_3, D_5, D_6 start conducting
4 5 the 4 diodes of the bridge simultaneously conduct and the output voltage is perfectly continuous
5 3 none of the above is true

In the Graetz bridge the voltage across the load is pulsing. The voltage half-waves are equal to the supply voltage, but reduced by the threshold values of the 2 diodes. As the supply voltage is usually much greater than the voltage drop across the diodes, it is not easy to notice the small difference on the oscilloscope.

- Connect the jumpers to produce the circuit of figure B04.5 again

➲ ***on-board SIS1***	**Turn switch S8 "*ON*"**
➲ ***SIS2***	**Press "INS"**

Q4 *The circuit has been modified. Examine the wave-forms across the load, and deduce which of the following is the modification.*

SET
A B
1 5 a 1 μF-capacitor has been connected in parallel with the load
2 4 a 1 mH inductor has been connected in series with the load
3 1 the diode D_3 has been short-circuited
4 2 the circuit has become open-circuit at D_5
5 3 none of the above

➲ ***on-board SIS1***	**Turn switch S8 "*OFF*"**

B04.3 QUESTIONS ON THIS CHAPTER

Q5 *What is the relation between the RMS output voltage of a full-wave rectifier, and a half-wave ?*

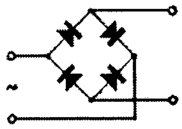
SET
A B
1 2 they are equal
2 1 the rms is double
3 4 the rms is half
4 5 the rms is √2 times bigger
5 3 the rms is 1/ √ 2 times smaller

Q6 *A full-wave rectifier is powered with 24V rms. What is the average current through a 1.2 KΩ resistor connected to the output of the rectifier?*

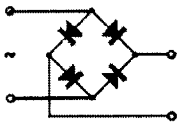
SET
A B
1 5 20 mA
2 1 10 mA
3 4 9mA
4 3 18 mA
5 2 50 mA

Q7 *Which of the following configurations is a Graetz bridge?*

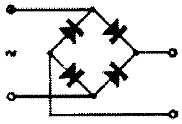
SET
A B
1 3



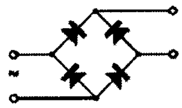
2 4



3 1



4 2



Q8 *What is the maximum reverse voltage across a diode in a Graetz bridge if the maximum value of the supply voltage is V_{iM}?*

SET
A B
1 2 V_{iM}
2 1 $(1/2)\ V_{iM}$

3 4 $2\ V_{iM}$

4 5 $\sqrt{2}\ V_{iM}$

5 3 $(1/\sqrt{2})\ V_{iM}$

LESSON B05: SMOOTHING FILTERS

OBIETTIVI

- To observe the voltages filtered with C, LC and CLC circuits on the oscilloscope
- To measure the peak-to-peak ripple voltage
- To measure the average rectified voltage
- To calculate the ripple voltage

EQUIPMENT REQUIRED

- base unit for the IPES system power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B05.1 BASIC THEORY

In the last chapter we saw how it is possible to rectify an ac signal. To obtain a continuous signal from a rectified signal, the dc voltage pulses must be smoothed out - a filter is able to do this.
The fluctuation of a rectified signal is defined as the "Ripple", (r), given by:

$$r = \frac{\text{RMS ripple voltage value}}{\text{Average voltage on the load}} \quad \%$$

For the raw, un-filtered signal, the ripple factor for a half-wave rectifier is: $\sqrt{(\pi/2)^2-1}$ (i.e. 121 %); for a full-wave rectifier it is : $\sqrt{(\pi/(2\cdot\sqrt{2}))^2-1}$ (i.e. 48%). To reduce the ripple it is necessary to smooth the voltage using filters.

Capacitive filters

This can be achieved by connecting a capacitor across the load, as in figure B05.1. The behavior of the smoothed voltage, and the current, with the capacitor are shown in figure B05.2 and B05.3.

fig. B05.1

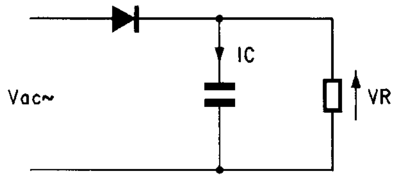


fig. B05.2

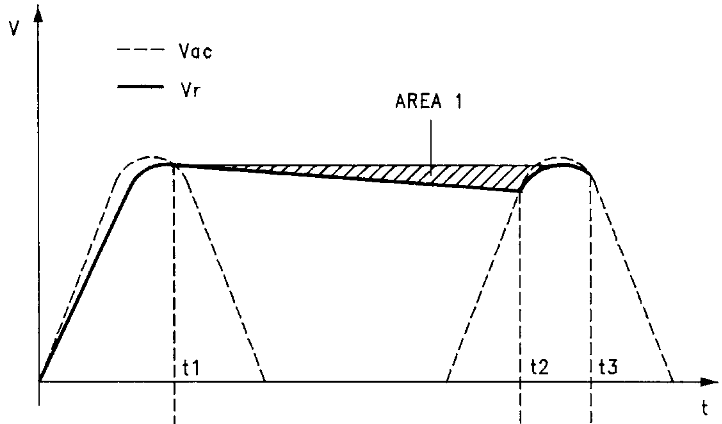
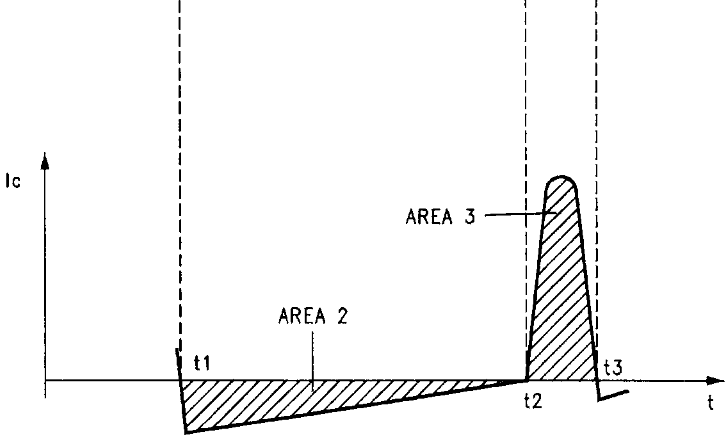


fig. B05.3



The capacitor charges up while the diode is conducting, until it reaches the maximum value of the rectified voltage.

When the supply voltage to the anode is less than the voltage on the cathode ,(i.e. the max. voltage of the capacitor), the diode is cut off.

The capacitor will then supply current to the load. This discharge current is shown as area 2 of figure B05.3. The capacitor discharges during the time interval (t_2-t_1). If the capacitor is small, and/or the resistance of the load is low, the capacitor will discharge very quickly, and the smoothing will not be very good.

When the input voltage to the anode, is higher than the voltage left across the capacitor, the capacitor charges up again (during interval t_3-t_2). The diode provides a current pulse to replace the charge lost by the capacitor. During the time t_3-t_2 the capacitor must restore the quantity of charge lost during t_2-t_1.

- Maximum current flowing in diodes:

$$I_M = V_M \pi \sqrt{(f R C)}$$

where V_M is the maximum voltage across the load
and f is the frequency of the ac signal

- Average current in diodes

$I_m = I_0/2$ with I_0 = average load current

- Average output voltage

$$V_m = V_M - I_M/(4.f.C)$$

- Output resistor:
  the output resistor will determine the drop in load voltage

$$R_0 = 1/(4.f.C)$$

- the ripple

$$r = 1/(4 f RC)$$

Low ripple requires a high resistance, a low current and a high capacitance. Capacitive filters are generally used in low power applications.

Inductive filters

With this circuit, an inductance is connected in series with the load (figure B05.4).
The inductance opposes the current variations and pulses from the diode, and produces a current I, which lags behind the voltage. The behavior of the current and voltages in this circuit are as in figure B05.5.
The insertion of an inductor after a full-wave rectifier greatly reduces the current ripple. The effect of the inductor in this case is represented in figure B05.6.

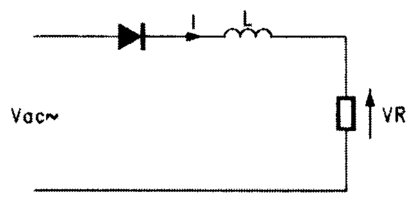


fig. B05.4

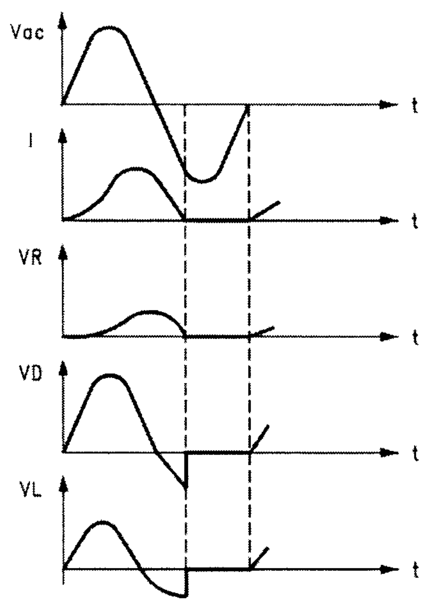


fig. B05.5

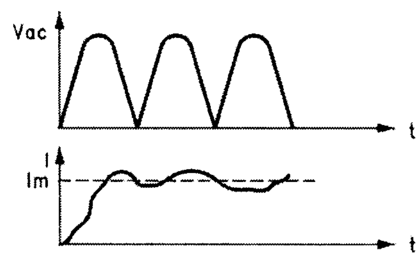


fig. B05.6

LC Filter

This type of filtering circuit, (also called an "L" section), is a common method of smoothing a rectified voltage (figure B05.7).

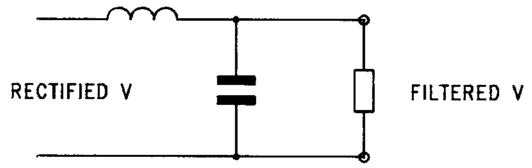


fig. B05.7

The inductance provides a first filtering of the current bumps, and then the capacitor provides a second filtering stage. The smoothing will be better, the higher the reactance of the coil is (compared to the parallel RC circuit), and the lower the reactance of C is, (compared to the load R).

CLC and CRC Filter

This circuit is a further improvement, obtained by connecting an extra capacitor across the input (fig.B05.8), which provides an extra stage of smoothing at the input. The average voltage output is then very close to the max. voltage of the power supply.
The advantages of this filter, (also called a "π" section filter), are: increased dc output voltage; and lower ripple. The main disadvantage, due to the capacitive filter is higher current peaks in the diodes.
If only small load currents are needed, an inductive filter is not necessary in the "π" filter. The inductor is normally expensive, and can be replaced with a resistor, making a CRC π section filter.

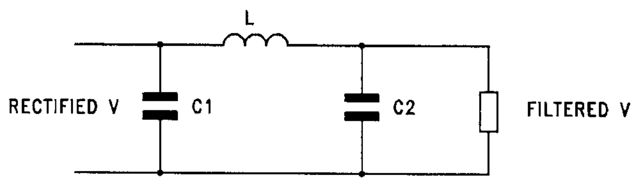


fig. B05.8

Full-wave rectification: useful formulae

filter	Condition for good smoothing	DC voltage	output impedance	ripple factor
C	$R >> 1/\omega C$	$V_M - I_m/4fC$	$1/4fC$	$1/(4\sqrt{3}. fRC)$
L	$\omega L >> R$	$2/\Pi.V_M - R_i . I$	R_{icoil}	$R_L/(3\sqrt{2}. \omega L)$
LC	$\omega L >> 1/\omega C$ $R > 1/\omega C$	$2/\Pi.V_M - R_i . I$	R_{icoil}	$\sqrt{2}/(12\omega^2 LC)$

B05.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches *OFF***
➲ *SIS2*	**Insert lesson code: B05**

C, LC, and CLC filters with a half-wave rectifier

- Connect jumpers J14, J24, J29, J27, J20 and the ammeter, for dc current measurements, to produce the circuit of figure B05.9.

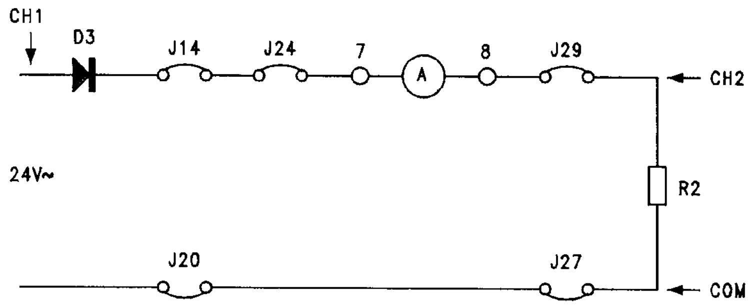


fig. B05.9

- Connect the oscilloscope to display the ac input voltage on channel 1, and the voltage across the load (resistor R_2) on channel 2
- observe the voltage across the load on the oscilloscope, and measure the current through the circuit
- connect jumper J23 to produce a capacitive filter with C_3
- measure the current through the load; observe and measure the peak-to-peak voltage of the ripple on the load
- disconnect jumper J29 and connect jumper J30, so increasing the load resistance

Q1 *What effect can be observed when the load resistance increases?*

SET

A B

1 3 the ripple in the output voltage drops

2 1 the ripple is unaltered, but the amplitude of the output signal increases

3 5 the ripple and amplitude of the output signal are constant

4 2 the ripple of the output signal increases, but its amplitude remains constant

5 4 none of the above is true

This observation can be explained by noting that the ripple is reversely proportional to the value of the load resistor.

- Take the circuit back to the last configuration, i.e. disconnect J30 and connect J29. Disconnect J23 and connect J25 to increase the capacitance of the filter
- measure the current through the circuit, observe and measure the peak-to-peak voltage of the ripple on the load

Q2 *This is the same type of filter as in the previous circuit, however the output voltage has changed. What is the change?*

SET

A B

1 2 the ripple has reduced

2 3 the maximum output voltage is reduced

3 5 the signal ripple is increased

4 1 no significant variation can be seen

5 4 the minimum voltage value is increased

➲ ***on-board SIS1***	**Turn switch S24 "*ON*"**
➲ ***SIS2***	**Press "INS"**

Q3 *What modification has been made to the circuit?*

SET
A B
1 6 the load resistance has dropped
2 3 the input signal to the filter is lower
3 5 no variation has been introduced
4 1 the capacitance of the filter is very much less
5 2 the load resistance has been reduced
6 4 none of the above

➲ *on-board SIS1*	**Turn switch S24 "*OFF*"**

- remove jumper J23 to produce the L C filter (figure B05.10)
- measure the dc current between test points 7-8, the average current in the circuit and observe and measure the peak-to-peak voltage of the ripple on the load connect jumper J23, to produce the CLC filter (figure B05.10)
- measure the average current through the circuit, observe and measure the peak-to-peak voltage of the ripple on the load

The addition of capacitor C3 provides the L C filter with a quite stable input voltage, with an average value near to the max. power supply voltage. Comparing the measured voltages in the different configurations, it can be seen that the dc output voltage increases with the dc voltage from the output of the filter, and also with the reduction of the ripple factor.

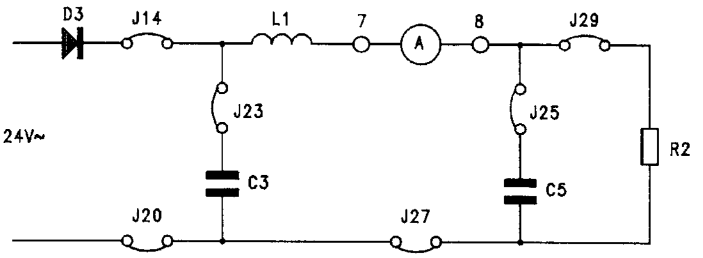


fig. B05.10

C, LC,and CLC filter circuits with full-wave rectifiers

- Connect jumpers J14, J16, J24, J29, J27, J17, J15, and the ammeter to produce the circuit of figure B05.11 (a Graetz or bridge rectifier)

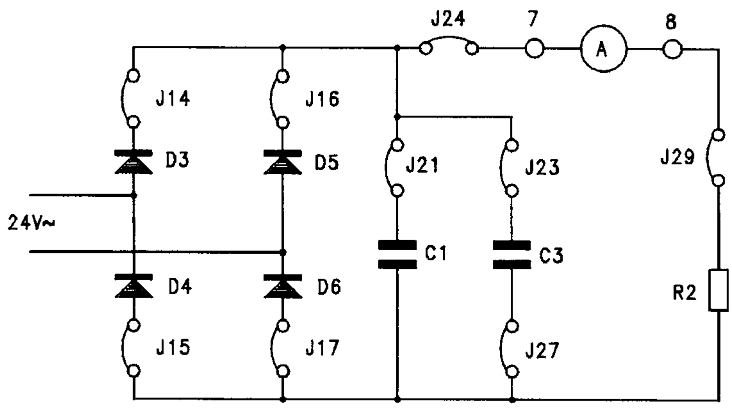


fig. B05.11

- for the following listed changes to the circuit, measure the dc current, the ripple voltage and dc voltage across the load:
- connect jumper J21 to produce a capacitive filter, using C_1
- connect J23 to increase the capacitance of the filter ($C_1//C_3$)
- remove J21 and J23 and connect J25 giving the capacitance of C_5
- disconnect J24 to create an L C filter as in figure B05.12
- connect J23 to produce a C L C filter

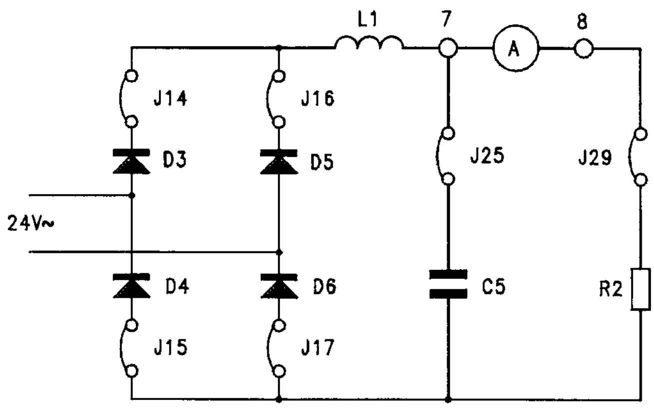


fig. B05.12

Q4 *Which of the circuits examined supplies the maximum current, with the least ripple?*

SET
A B
1 3 the one with C_1
2 5 the one with $C_1//C_3$
3 4 the one with C_5
4 2 the one with L C_5
5 1 the one with C_3 L C_5

B05.3 QUESTIONS ON THIS CHAPTER

Q5 *An inductance in series with a load will:*

SET
A.B
1 2 smooth the rectified voltage
2 5 increase the output voltage
3 4 smooth the voltage to the load
4 1 increase the ripple factor
5 3 do none of the above

Q6 *A capacitor in parallel with a load will:*

SET
A B
1 3 smooth the voltage across the load
2 1 increase the output frequency
3 5 reduce the current in the load
4 2 increase the ripple factor
5 3 short-circuit the load

Q7 *The ripple factor of a C L C filter depends on :*

SET
A B
1 5 the frequency of the alternating signal only
2 3 the value of the first capacitor
3 4 the value of the inductance and the load
4 2 the final capacitor only
5 1 all the components of the filter and the input frequency

LESSON B06: THE VOLTAGE DOUBLER

OBIETTIVI

- To examine the operation of a voltage doubler as the load and the capacitance are varied

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B06.1 BASIC THEORY

The «voltage doubler» circuit of figure B06.1 produces a dc voltage with twice that of the previous circuits, using the same ac supply.

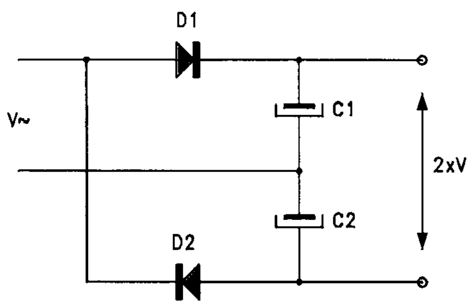


figure B06.1

Consider figure B06.2. During the first quarter period (t_0-t_1) of the input sine wave the diode D_1 conducts and capacitor C_1 charges to the maximum of V_M.

In the second quarter period (t_1-t_2) no diode conducts and the voltage remains the same, if there is no load present.

At the instant t_2, D_2 starts conducting and the current flows through C_2, which also charges to the maximum value V_M.

At instant t_3 the diode D_2 is cut off. From this moment on no diode is conducting and the voltage across the output terminals is equal to the sum of the two voltages on the capacitors, i.e. to a value of $2 \cdot V_M$.

When there is a load, the capacitors discharge slightly during the intervals (t_1-t_2) and (t_3-t_4), creating a ripple, which increases with the load current (reducing the load resistance).

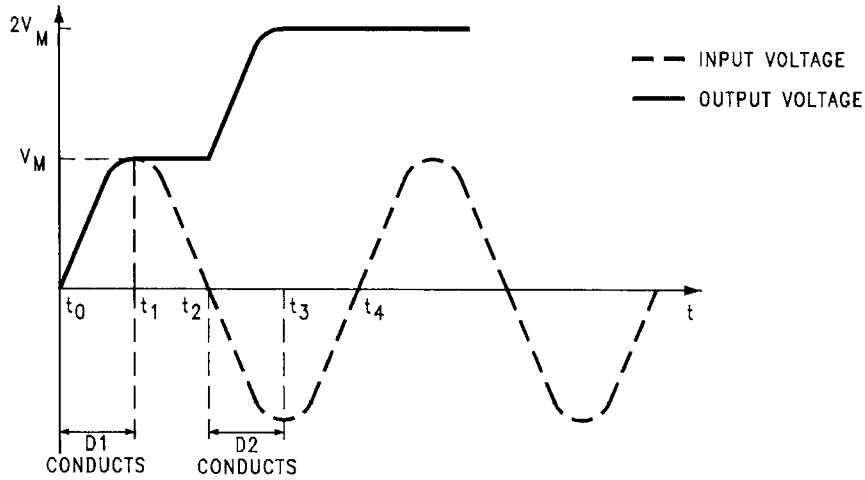


figure B06.2

B06.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B06**

- Produce the circuit of figure B06.3, connecting jumpers J14, J23, J20, J26, J24, J28, J31, J15

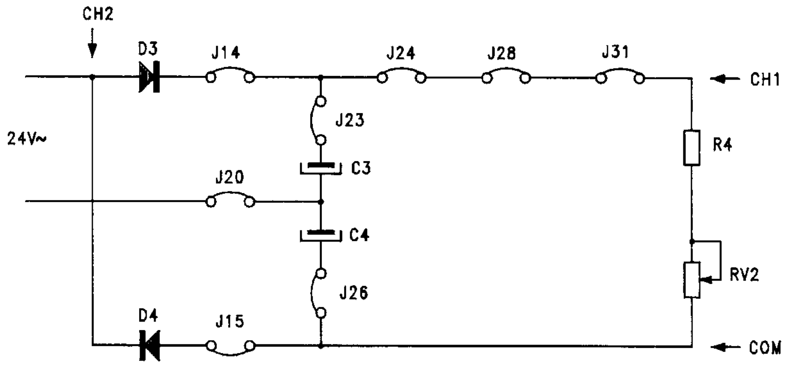


fig. B06.3

- connect the oscilloscope as shown in the figure
- check that the voltage across the load is about double the maximum value of the power supply voltage (24Vac)
- vary the load resistance, using RV_2, and check that the output voltage ripple increases as the load resistance decreases

Q1 *What happens if the capacitors have less capacitance?*

SET
A B
1 6 the ripple reduces
2 2 the voltage rises
3 4 the ripple increases and the voltage drops
4 3 the current through the load doubles
5 1 the voltage across the load is halved
6 2 none of the above

- disconnect jumpers J23, J26 and connect J21, J22 to replace C_3 and C_4 with C_1 and C_2. Vary the load resistance with RV_2 and examine the output voltage variation.

The results obtained indicate that in a voltage doubler, the ripple voltage on the load depends on the capacitor values

- disconnect jumper J31
- on channel 2 of the oscilloscope, observe the voltage present across diode D_4. Note any changes when the load is removed.

➲ ***on-board SIS1***	**Turn switch S23 "*ON*"**
➲ ***SIS2***	**Press "INS"**

Q2 *From an analysis of the circuit voltages, what modification has been applied to the circuit:*

SET
A B
1 5 a 1000µF-capacitor has been inserted as load
2 4 a 1MΩ-load has been inserted as load
3 1 a 1Ω-load has been inserted as load
4 2 the diode D_4 has been inverted
5 6 C_2 has been short-circuited
6 3 a 1KΩ-load has been inserted as load

- connect J31 again
- adjust the load resistance to its maximum value, using RV_2
- reduce the load resistance, and display the voltage across D_4 on channel 2 of the oscilloscope

➲ ***on-board SIS1*** **Turn switch S23 "*OFF*"**

Q3 *What happens to the voltage across D_4, as the load resistance drops?*

SET
A B
1 2 it gets lower
2 5 it stays constant
3 4 it increases in frequency
4 1 it gets higher
5 3 it goes to zero

B06.3 QUESTIONS ON THIS CHAPTER

Q4 *In a voltage doubler, does the ripple voltage depend only on the value of the capacitors?*

SET

A	B	
1	3	yes
2	1	it also depends on the load value
3	5	no, it always has a constant value
4	2	it depends on the threshold voltage of the diodes
5	4	it depends on the maximum value of the supply voltage

Q5 *The maximum reverse voltage across the diodes is equal to :*

SET

A	B	
1	5	the maximum voltage value of power supply
2	3	double the maximum value of the power supply
3	1	the average value of the power supply voltage
4	2	it is always zero
5	4	it is double the ripple voltage

Q6 *What is the output of a voltage doubler with a 15 V_{rms} supply?*

SET

A	B	
1	2	42.4 V
2	1	30 V
3	4	21.2 V
4	5	10.6 V
5	3	15 V

LESSON B07: LIMITERS AND CLAMPING CIRCUITS

OBIETTIVI

- Limit circuits tested with different loads
- To use a positive clamping circuit
- To use a negative clamping circuit
- To study the behavior of a clamping circuit as a function of the capacitance and the load resistance

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- function generator
- oscilloscope with differential probe

B07.1 BASIC THEORY

Limiter circuits

A limiter circuits is one in which the output is limited to some fixed, positive ,or negative value (or even both).

Figure B07.1 shows a limiter circuit with a limit which can be varied.

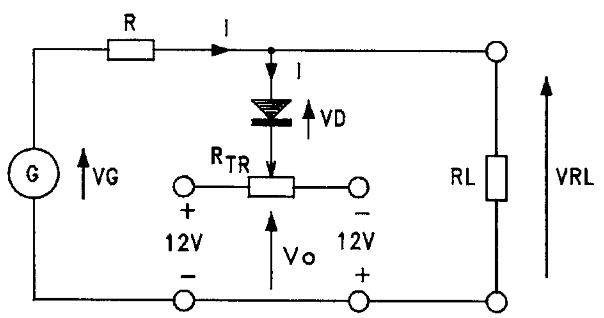


fig. B07.1

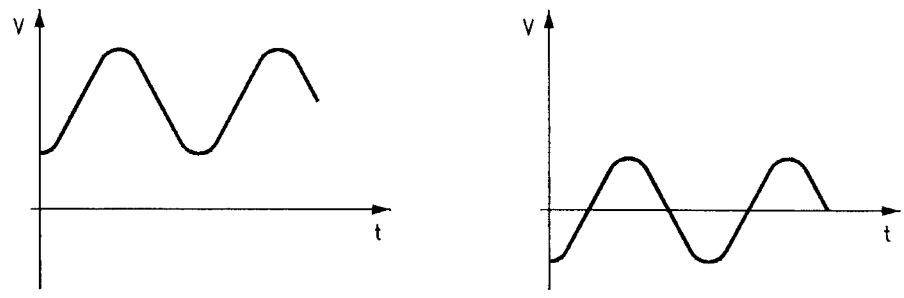
Supposing the load R_L has infinite resistance, and that the internal resistance of the diode is zero in forward bias and infinite in reverse biasing. The behavior of the limiter can then be explained as follows:

- taking V_G as positive, the diode conducts if $(V_G - V_O)$ is greater than the threshold voltage V_S. The voltage across the diode will stay at this voltage while $(V_G - V_O)$ is more than V_S. During all this time the voltage present across the load R_L is $(V_O + V_S)$
- however when $(V_G - V_O)$ is less than V_S, the diode does not conduct, there is no voltage drop across R and all the voltage V_G appears across the load
- this circuit is one with a positive limit. To obtain a negative limiter, simply reverse the diode
- the circuit supplying the voltage V_O consists of a trimmer and two dc power supplies, enabling V_O to vary from positive to negative values.

(these circuits are also known as «clippers», as they cut the top or bottom parts of a signal off).

Clamping circuits

In many electronic applications, with ac signals, the average value of the signals is zero, and the dc is not required. However, sometimes the dc is needed, as with a TV video signal for example. When such a signal (figure B07.2a), passes through coupling capacitor, it inevitably loses its dc component, leaving just the ac (figure B07.2b).



(a) (b)

fig. B07.2

To restore the dc component means that a dc voltage must be added to the ac signal. A clamping circuit (or restorer) is able to do this.

Clamping circuits consist basically of a capacitor which is charged up through a diode, as illustrated in the circuit of figure B07.3.
The capacitor charges up, to a fixed voltage if the load resistance is high, and this is the voltage which is added to the ac.

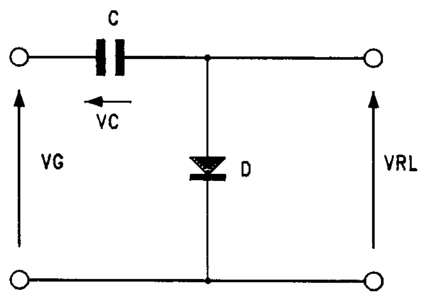


fig.B07.3

Suppose the applied signal is an ac sine wave: $v_G(t) = V_G \sin(w\ t)$, (see figure B07.4). The circuit operation, with no load, is as follows:

- at the very beginning, t = 0, the capacitor is completely discharged.
- when $v_G(t)$ becomes positive and more than the diode threshold voltage (0.7v) the diode starts to conduct and the capacitor C starts charging until its voltage is equal to the maximum amplitude of $v_G(t)$, i.e V_G
- as the capacitor cannot discharge through the diode, the voltage across the diode is equal to the difference between the input voltage and the capacitor voltage (figure B07.4)

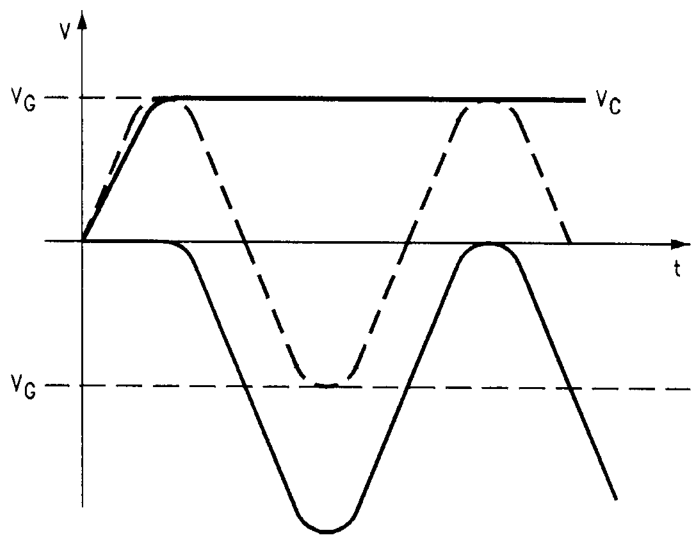


fig.B07.4

The output voltage has an average value equal to $-V_G$. If a dc voltage V_0 (figure B07.5a) is introduced in series to the diode, the new average value of the signal V_{RL} is not $-V_G$ but $-(V_G - V_0)$. In fact the capacitor can discharge only when the diode conducts, and this occurs when V_G is greater than V_0. In this case the different voltages are represented in the figure B07.5b, where

$$v_{RL}(t) = -V_G\,(1 - \sin(w\,t)) + V_0$$

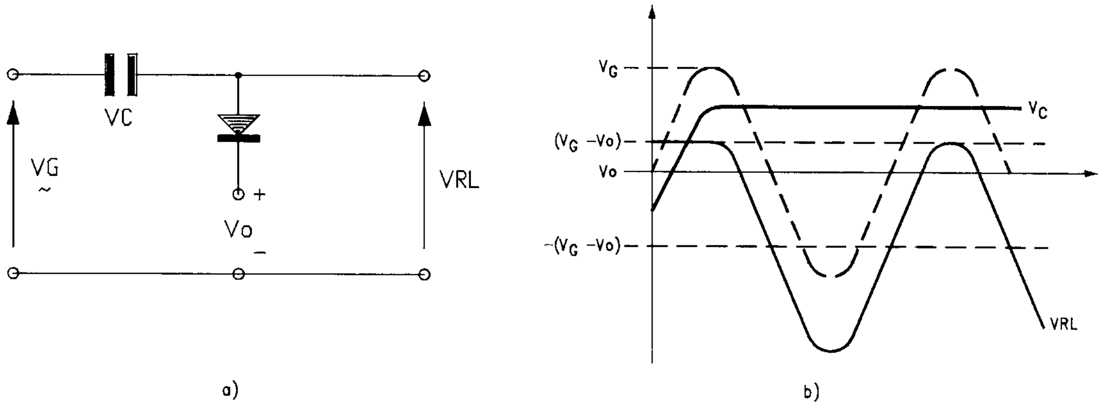


fig.B07.5

To keep the input signal fixed to level Vo when the input amplitude is fluctuating, a resistance is inserted in parallel with the diode (it can be the load resistance itself). This partially discharges the capacitor in each cycle, and enables its voltage V_C to follow variations in the input signal amplitude. The value of this resistance is usually a hundred times bigger than the equivalent forward resistance of the diode and so it takes effect only when the diode is non-conducting.

The limiting circuits examined so far have been ones with a positive limit, which «clipped» the wave above a certain level. Equally the clamping circuits have produced output signals mostly below 0V.
This situation can be reversed, ie the signal produced can have negative clipping, or one which is mainly above 0V simply by reversing the diode.
A clamping circuit with a variable negative limit is represented in figure B07.6.

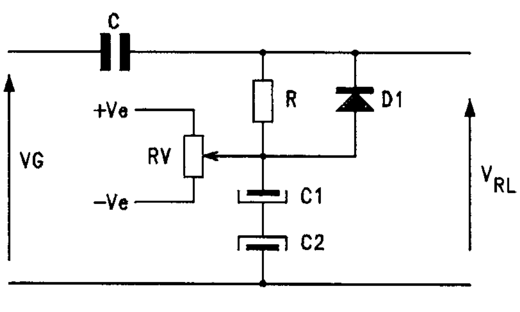


fig. B07.6

B07.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ ***on-board SIS1***	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code : B07**

Limiting circuits (with no load)

- Connect jumpers J32, J38, to produce the circuit of figure B07.7
- apply a sine signal with amplitude 20Vpp, zero average value and frequency of 200Hz, using a function generator

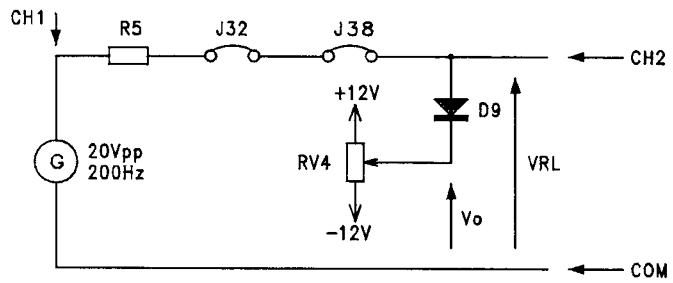


fig. B07.7

- Observe the behavior of voltage V_{RL} as a function of the position of the trimmer RV_4
- determine if the circuit has negative or positive limiting

➲ ***on-board SIS1***	**Turn switch S7 "*ON*"**
➲ *SIS2*	**Press "INS"**

Q1 *What is the new limiting level of the circuit?*

SET
A B
1 3 12 V
2 1 6 V
3 6 -5 V
4 5 5 V
5 4 none of the results listed
6 2 0 V

➲ ***on-board SIS1***	**Turn switch S7 "*OFF*"**

- disconnect jumper J38 and connect J37
- changing RV_4, determine the limit of this circuit, displaying the voltage on channel 2 of the oscilloscope

In the first case, the diode biasing produces a positive limit and in the second case a negative limit. You can observe that the voltage V_{RL} is attenuated compared to the power supply voltage. This is due to the input resistance of the oscilloscope which is not infinite and has a value of about 1 Megohm.

- adjust RV_4 to obtain a voltage V_o of 10 V
- check the way that the negative limit changes. Although resistor R_5 is much higher than the forward resistance of the diode there is an error on the limit. The reason is as follows:
  while the diode is non-conducting, the reference voltage remains stable. But when it starts conducting, the voltage drops as the amplitude of the ac input signal increases. This is due to the trimmer RV4 which is not a pure voltage generator, but has internal resistance, depends on the trimmer resistance and the position of its «wiper».

To overcome this, it is better to stabilize the reference voltage using capacitors with suitably large values

- connect the capacitors C_7 and C_8, with J35, as in figure B07.8.

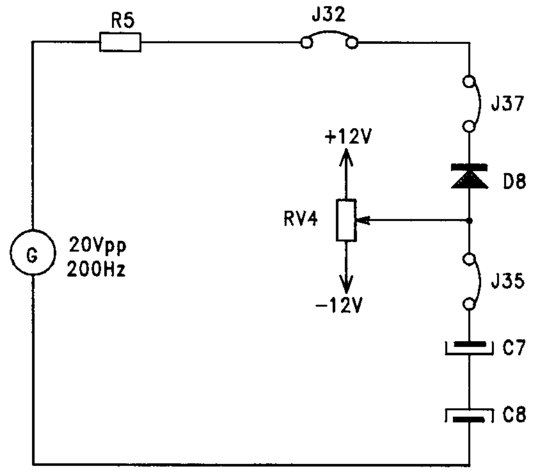


fig.B07.8

- Observe the reference voltage as RV_4 is varied, and compare it with the previous situation.

The reference voltage stability increases with the value of the filtering capacitors.

Limit circuits with a load connected

- Connect jumpers J32, J37, J35, J39 to produce the circuit of figure B07.9
- apply a sine signal of amplitude 20Vpp, zero average value and frequency 200Hz, using the function generator

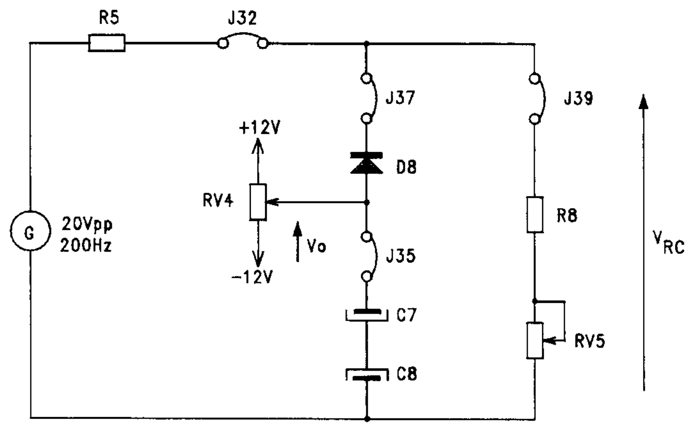


fig. B07.9

- adjust the negative limit V_o to - 5 V with RV_4
- vary the load with RV_5 and check the behavior of voltage V_{Rc}
- repeat measurements for V_o = O V, and then for V_o = +5 V

Q2 *Is the limit set by V_o dependent on the load resistance?*

SET
A B

1 3 yes, for these three tests and for all other values.
2 1 no, it is independent of the load
3 5 no, Vo does not vary, only the output signal amplitude varies
4 2 yes, when V_o = 0 V
5 4 yes, when V_o = 0 V and the load R_c = 50 KΩ

Clamping circuit

- Produce the circuit of figure B07.10 connecting jumpers J33, J34, J35, J38 and connect the oscilloscope to the points marked with CH1, CH2 and COM
- Set the function generator for a sine wave of 20 Vpp and 200 Hz

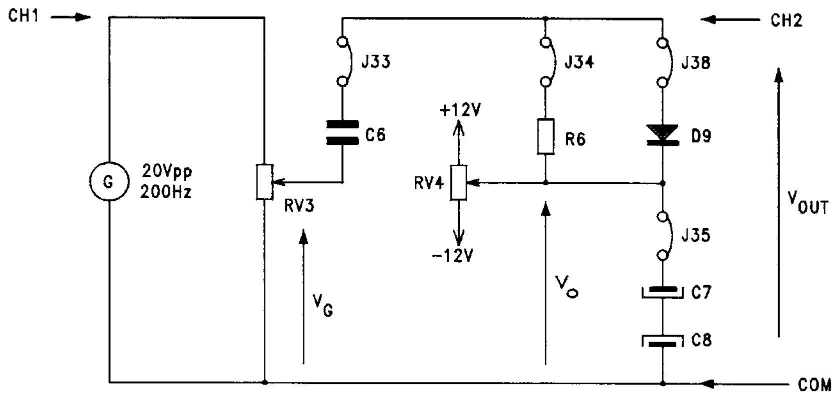


fig. B07.10

- adjust the signal amplitude to the maximum, using RV_3
- vary the clamping voltage V_O, with RV_4

Q3 *Does the clamping circuit have a positive or negative limit ?*

SET
A B

1 2 negative
2 3 positive
3 1 the circuit is not clamping

- use a diode in the reverse direction, by disconnecting J38 and connecting J37. This way, the type of limit is changed
- adjust V_O to about - 10 V, then vary the amplitude of the voltage V_G across RV_3. Check that the output signal remains locked to V_O
- repeat the measurements after disconnecting R_6, by removing J34, and note the signal behavior.

With R_6 removed, the output signal may drift slowly until it settles at Vo. The capacitance in this case is discharging through the oscilloscope, which does not have infinite input resistance (generally 1 Mohm).

Q4 *What must be done to make the new input voltage lock to the limit Vo?*

SET
A B
1 2 reinsert R_6 or increase V_G
2 5 reduce V_G
3 1 short-circuit D_8
4 3 remove the oscilloscope
5 4 short-circuit C_7 and C_8

B07.3 QUESTIONS ON THIS CHAPTER

Q5 *Which component produces the limit in a limiting circuit ?*

SET
A B
1 5 the generator
2 3 the diode and its connection
3 4 the input capacitor
4 1 the output load
5 2 none of the above

Q6 *What determines the quality of a clamping circuit ?*

SET
A B
1 5 the time constant R C which must be much greater than the input signal period
2 4 the distortion of the input signal
3 1 the supply voltage to the diode
4 2 the capacitor biasing
5 3 the input impedance

Q7 *What must be done to change from a positive limiting to a Negative limiting circuit?*

SET
A B
1 4 to invert the diode
2 5 to invert the input voltage
3 1 to remove the diode
4 3 to invert the voltage V_o
5 2 to remove the load

LESSON B08: ZENER DIODES and VOLTAGE STABILIZERS

OBJECTIVES

- To obtain the voltage-current characteristic curve of a Zener
- To use a voltage stabilizer, consisting of resistor and Zener diode, and observe the voltage stability as the input voltage varies
- To check the circuit operation as a function of the load

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B08.1 BASIC THEORY

The Zener diode is a diode which is designed to be used in reverse bias, in the «breakdown» region.

The Zener diode operates basically as follows: (fig.B08.1)

- in FORWARD bias it behaves like a normal diode
- in REVERSE bias it behaves like a normal diode until the «breakdown» voltage is reached (normally called the Zener voltage, Vz). At this point, the reverse current rapidly increases, while the voltage across it remains almost constant.
  (The term «breakdown» is not really appropriate for this type of diode: the diode is designed (originally by Zener) to work continually in this region, without any damage at all to the diode.)

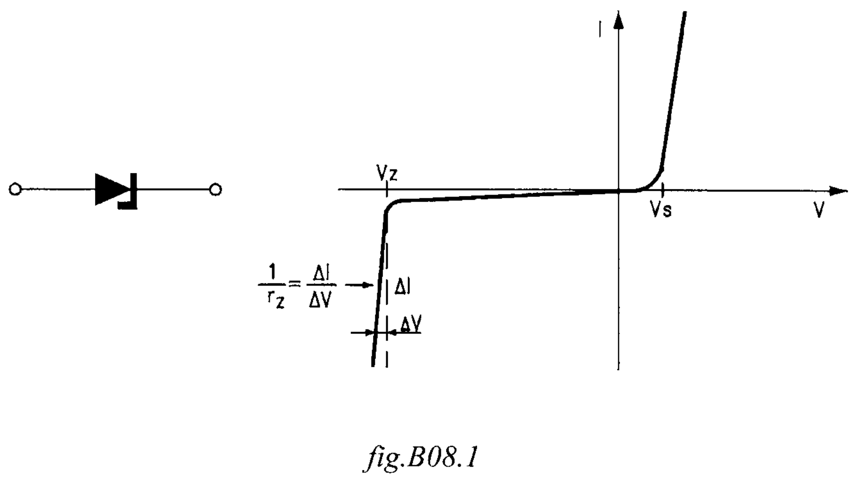


fig.B08.1

Differential resistance

In a real Zener the voltage in the Breakdown region is not quite constant, but it increases slightly, as the current increases.

The slope is almost vertical, and has the inverse dimensions of a resistance, known as the "differential resistance r_Z".

The Zener diode can be represented, when biased in this normal region of operation, by a battery V_Z (the Zener voltage) in series with the resistance r_Z (fig.B08.2). In this region of operation the Zener resistance r_Z is only a few ohms.

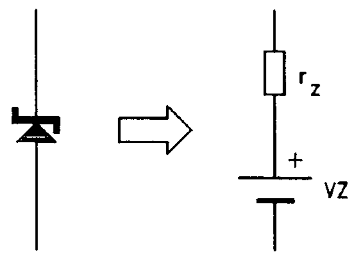


fig.B08.2

Voltage stabilizer

The basic stabilizer circuit using a Zener diode is shown in fig.B08.3. The Zener is reverse biased in the breakdown zone by the voltage Vi through the resistance R. For an ideal Zener, the voltage V_O across the load R_L does not vary, and is the same as the Zener voltage, Vz.

The main points of the stabilizer operation are :

- if the load current I_L increases, the current I_Z, through the Zener drops
- if I_L drops, I_Z increases
- if the input voltage V_i increases, I_Z also increases
- if V_i decreases, I_Z also decreases

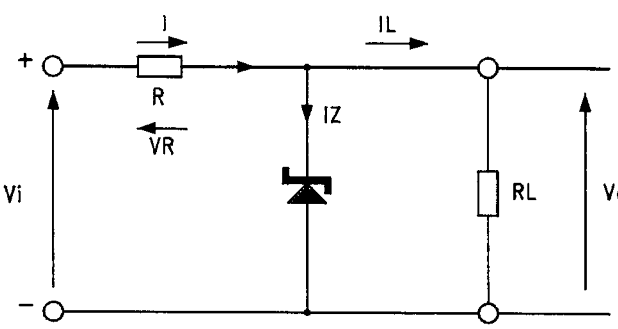


fig. B08.3

Voltage stability with change of load

Refer to fig.B08.4, and assume that the Zener is ideal. The voltage V_o across the load is constant, so the supply current I is constant and is equal to:

$$I = (V_i - V_o)/R$$

A change in the load current I_L causes an equal, but opposite change in the Zener current I_Z: (the supply current I is constant, to a first approximation)

$$\Delta I_L = -\Delta I_Z$$

For a real Zener, this current change causes a small change in output voltage due to the effect of r_Z:

$$\Delta V_o = r_Z \cdot \Delta I_Z = -r_Z \cdot \Delta I_L$$

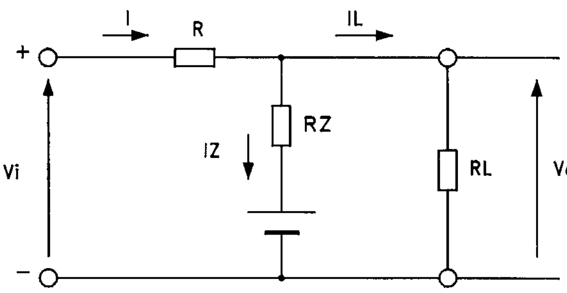


fig.B08.4

Voltage stability with change of input voltage

Refer to fig.B08.4. For an ideal Zener, as the input voltage V_i varies, the output voltage V_o stays constant, and so does the current I_L through the load.

A change in V_i causes a change in the supply current I, and consequently a change in I_Z:

$$\Delta I = \Delta V_i/R = \Delta I_Z$$

And the change in the output voltage is :

$$\Delta V_o = r_Z \cdot \Delta I_Z = (r_Z/R) \cdot \Delta V_i$$

B08.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B08**

N.B. Voltage and current measurements will be required on some circuits. If only a single multimeter is available this will need to be used sometimes as a voltmeter, and at other times as an ammeter. When used for voltage measurements, remember to short-circuit the points of the circuit where the ammeter can be inserted.

Measurement of the Zener current as a function of the input supply voltage

- Connect jumpers J2, J12, J5, the ammeter and the voltmeter to produce the circuit of figure B08.5

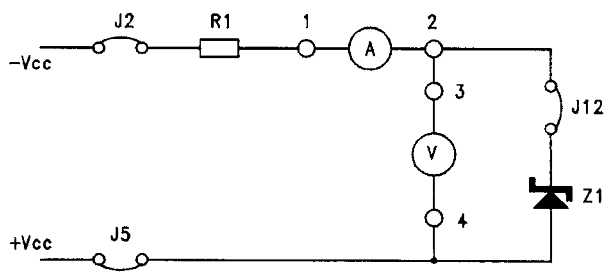


fig.B08.5

- in forward bias, measure the current through the Zener diode Z_1 as function of the voltage across it
- now reverse bias the diode by removing jumpers J2 and J5 and connecting J1 and J6
- measure (in reverse bias) the voltage across the diode as the supply voltage Vcc is varied

Q1 *What is the Zener voltage ?*

SET
A B
1 6 10 V
2 5 3.5 V
3 1 1 V
4 3 0.7 V
5 4 6.2V
6 2 8.7 V

Displaying the V-I characteristics of a Zener diode on the oscilloscope

- Connect jumpers J3, J7, J12, J4 and connect the oscilloscope as in the circuit of figure B08.6

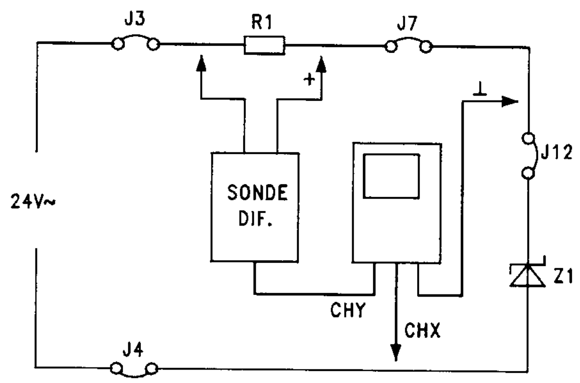


fig.B08.6

- Set the oscilloscope to the X-Y mode. As the voltage V_{R1} is proportional to the current through the diode, you can directly observe the characteristic of the Zener diode
- Note that the threshold voltage is 0.7 V, and the Zener voltage is about 6.2 V. Note also the almost vertical slope when the diode is conducting, which means a low resistance value.

➲ *on-board SIS1*	**Turn switch S2 "*ON*"**
➲ *SIS2*	**Press "INS"**

Q2 *What modification to the characteristic can be seen on the oscilloscope?*

SET
A B
1 2 the threshold voltage has changed
2 3 the current through the diode has increased
3 4 the current through the diode has dropped
4 5 the Zener voltage has increased
5 1 no change has occurred

➲ *on-board SIS1*	**Turn switch S2 "*OFF*"**

Voltage stabilizer with a variable load

- Connect jumpers J1, J6, J13, an ammeter across J7 and one across J12, and the oscilloscope as shown in figure B08.7

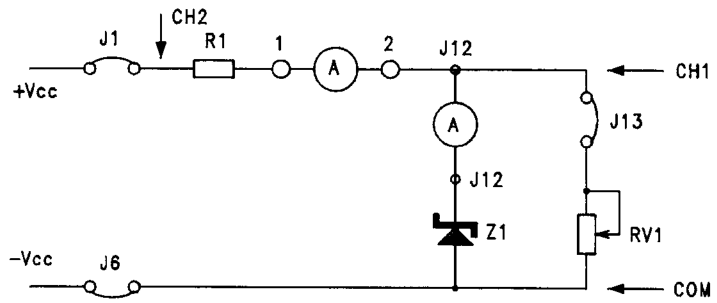


fig.B08.7

- adjust the variable power supply V_{CC} to maximum, about 30V checking the current through the diode
- vary RV_1 and observe that when the diode is conducting the supply current is about 10 mA , for $V_Z = 6.2$ V
- move the ammeter from J7 to J13, (and consequently connect jumper J7 and remove J13)
- vary RV_1 and observe the current changes in the load and the diode

Q3 *How do the currents in the diode and the load change?*

SET
A B
1 2 the current in the load is inversely proportional to the current trough the diode (with the diode conducting)
2 5 both currents increase
3 4 both currents drop
4 1 they cancel
5 3 the current in the load is directly proportional to the current through the diode (with the diode conducting)

- reduce RV_1 until the voltage across it is voltage lower than the Zener voltage
- note the current through the diode. It can be seen that when the diode is non-conducting ($I_Z = 0$ A), it does not stabilize the voltage anymore
- adjust RV_1 again to the maximum resistance value, then reduce the supply voltage until you reach the stabilization limit

Q4 *What is the stabilization limit in this case?*

SET
A B
1 5 30 V
2 1 3.5 V
3 2 10 V
4 3 20.5 V
5 6 5 V
6 4 7.5 V

B08.3 QUESTIONS ON THIS CHAPTER

Q5 *What is the Zener voltage?*

SET

A	B	
1	4	it is the maximum dc voltage of a diode
2	5	it is the voltage between cathode and anode in reverse bias
3	2	it is the forward threshold voltage of a diode
4	1	it is the reverse voltage which in certain conditions remains constant across a diode
5	3	it is a fixed voltage for all kinds of diodes

Q6 *Consider the circuit of fig.B08.3, with Vz = 7.5 V, R = 5.6 KΩ, R_L = 12 KΩ and an ideal Zener diode. What is the minimum input voltage which will ensures a voltage across the load equal to the nominal Zener voltage ?*

SET

A	B	
1	6	23.57 Volt
2	5	7.5 Volt
3	2	11 Volt
4	1	3.5 Volt
5	3	13.6 Volt
6	4	32 Volt

Q7 *What is the minimum value of R which ensures that the Zener diode is conducting, if: R_L=27KΩ; Vi=32 V, Vz = 16 V*

SET

A	B	
1	6	27 KΩ
2	5	54 KΩ
3	4	13.5 KΩ
4	1	6.5 KΩ
5	2	30.6 KΩ
6	3	1 KΩ

LESSON B09: The Uni junction Transistor (UJT)

OBJECTIVES

- The physical structure of a UJT
- To measure the interbase resistance R_{BB}
- To measure the voltages and currents in the peak and valley points V_P, I_{PP}, V_V, I_V
- To calculate the intrinsic stand-off ratio
- To use the UJT as a pulse generator

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope

B09.1 BASIC THEORY

UJT means "Uni junction Transistor", ie it is a component with a single junction, like the diode.
Its structure, however, is different. It is composed of a doped silicon bar N (or P) across which there are two ohmic contacts, called base 1 and base 2. In the bar, nearer to base 2, there is a PN junction as shown in the figures B09.1 a and b. The third electrode is called the "emitter". The symbol for a uni junction transistor is shown in figure B09.2 a and b.

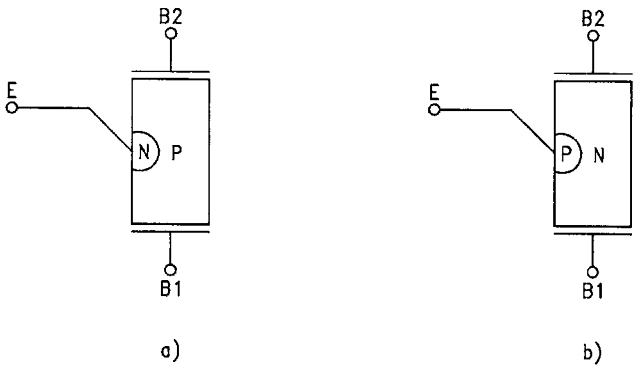


fig. B09.1

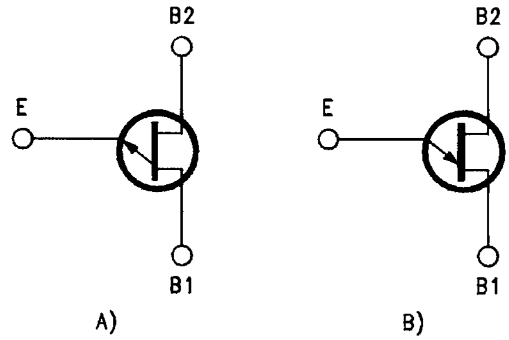


fig. B09.2

The resistance between base 1 and base 2, measured with zero emitter current is called the "interbase resistance" R_{BB}, and is typically between 5 and 10 KΩ.

Figure B09.3 shows the simplified equivalent circuit of a UJT with a P base. The interbase resistance is divided by the PN junction (represented by a diode) into two resistors R_{B1} and R_{B2}, whose sum is equal to R_{BB}.

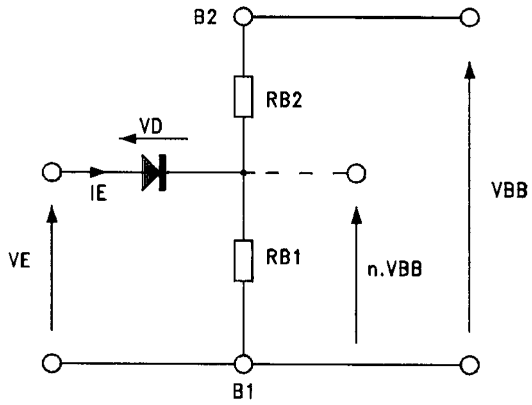


fig.B09.3

In normal operation of the transistor a voltage V_{BB} is applied between base 1 and base 2, with base 2 positive with respect to 1. With no emitter current I_E, the silicon bar behaves like a simple voltage divider, and a certain fraction of voltage V_{BB} appears across R_{B1}. The ratio n is called the " intrinsic stand-off ratio" and its value generally ranges between 0.5 and 0.9. The ratio is given by :

$$n = \frac{R_{B1}}{R_{B1} + R_{B2}}$$

The voltage V_{BB} makes the cathode of the diode positive with respect to B_1, at a voltage of n V_{BB} . If the emitter voltage V_E is less than this, the junction is reverse biased, and only a small reverse emitter current flows.
If V_E is more than $(n \cdot V_{BB} + V_D)$, where V_D is the junction threshold voltage, the diode is forward biased and a forward emitter current I_E flows. This current is due to holes which, entering the lower part of the bar, increase its conductivity (because the number of free charges increases). The causes the resistance R_{B1} to drop. When R_{B1} decreases, so does the voltage n V_{BB}, and so there is an increase of the forward voltage across the diode, with a further increase of the diode current. This cumulative process continues until a value of current I_E is reached which saturates the silicon bar in the R_{B1} region.
Starting from these conditions, the voltage V_E, which has reached the minimum value V_V (valley voltage), starts rising with the current following the normal characteristic of a diode.
These features of the voltage-current characteristic of a UJT, are shown in figure B09.4.

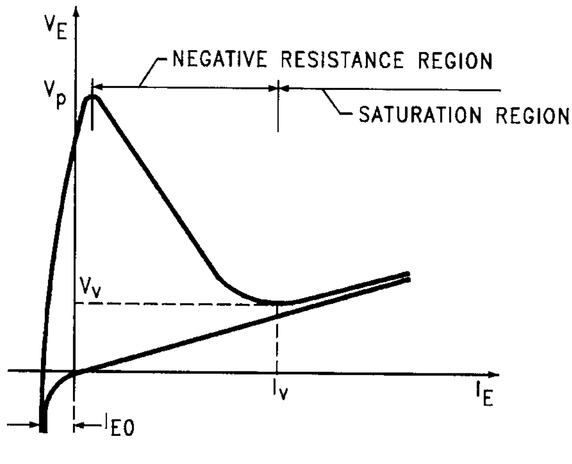


fig.B09.4

In this curve there are 3 operating regions:

1. $0 < V_E < V_P$: the current I_E is very small and the input resistance is very high.
2. $V_P < V_E < V_V$: the input resistance is negative. ie an increase of current produces a decrease of voltage
3. $V_E > V_V$: the input resistance becomes positive again and has a value similar to that of a diode in conduction.

The characteristic points are:

1. V_P is called the peak voltage and is equal to:
   $V_P = n\ V_{B2B1} + V_D$.
2. V_V is called the valley voltage
3. I_V is the valley current

The uni junction transistor is generally used in switching, timing, trigger circuits and as a pulse generator.

Sawtooth generator

The circuit of the figure B09.5 can be used as pulse generator, as a trigger circuit or as a sawtooth signal generator.

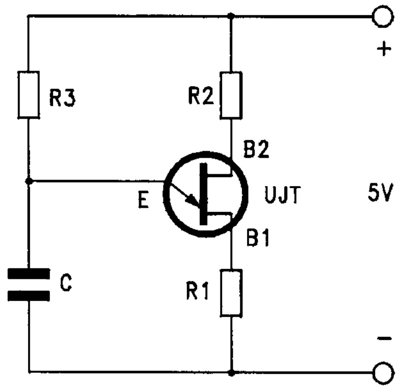


fig.B09.5

At the beginning of the cycle, the capacitor is discharged, and so the emitter is reverse biased because of the voltage on R_1. Then the capacitor charges through R_3 with a time constant of $R_3 \cdot C$. When the voltage across C reaches the peak voltage of the UJT, it starts conducting, enabling the capacitor to discharge through R_{B1} and R_1 to reach the minimum voltage which is slightly different to the valley voltage. At this point the UJT blocks, and the cycle can start again.
The signals at different points of the circuit are shown in figure B09.6.

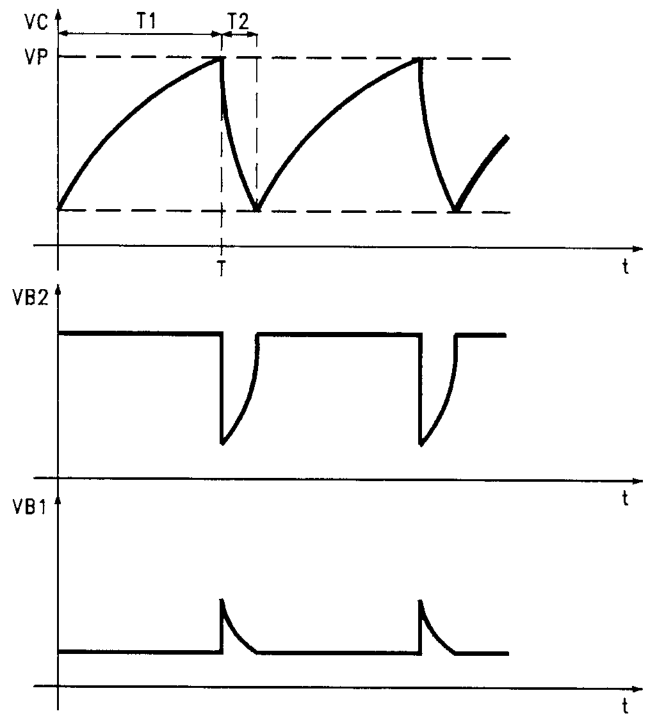


fig.B09.6

As can be seen in this figure, the capacitor discharge causes positive pulses across R_1 and negative pulses across R_2, whose duration depends on the time constant $(R_1 + R_{B1})\cdot C$.

The dc components of V_{R1} and V_{R2} are determined by the normal or «quiescent» current, flowing through these two resistors with no input signal on the emitter. The amplitudes of the pulses V_{B2} and V_{B1} can be different as they are determined by the resistors R_1, R_2, R_{B2}.

The frequency f of the signal, (if the discharge time is negligible compared to the charging time), is found using $(T = T_1 + T_2 \approx T_1)$:

$$f = \frac{-1}{R_3 \cdot C \cdot \ln(1 - n)}$$

From this relation it can be seen that the frequency is independent of the power supply voltage

Square-wave generator

The previous circuit can be changed to obtain a square wave generator (figure B09.7)

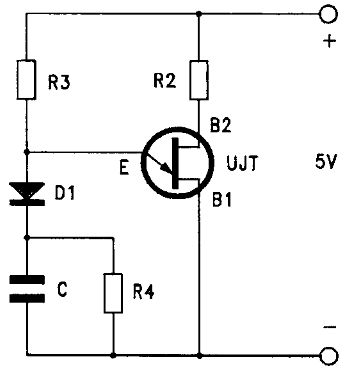


fig.B09.7

At the beginning of the cycle, the UJT is cut off because C is discharged. Then the capacitor charges through R_3 and D_1 until its voltage reaches the peak voltage. At that instant, the UJT starts conducting as it is connected to the power supply through R_3. The capacitor, which is isolated from the UJT due to D_1, discharges through the resistor R_4.

When the voltage across R_4//C falls below the valley voltage, the UJT cuts off and the cycle can begin again. The signals at different points of the circuit are represented in figure B09.8.

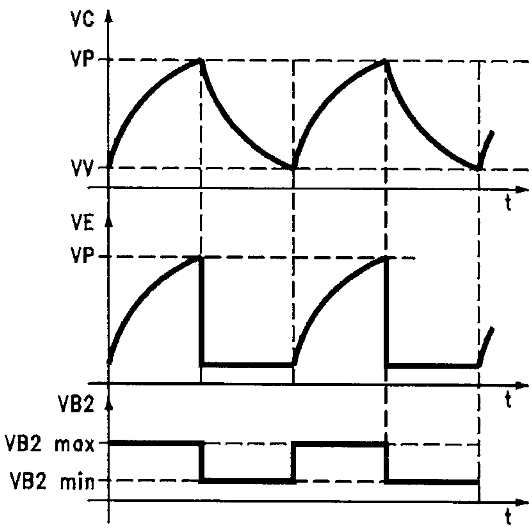


fig.B09.8

The period T of this signal is function of the charge and discharge times of the capacitor. So, it depends on C, R_3 and R_4 as follows:

$$T = R_3 C \ln \left(\frac{E - V_V}{E - V_P}\right) + R_4 C \ln \left(\frac{V_P}{V_V}\right)$$

$$\approx R_3 C \ln \left(\frac{1}{1 - n}\right) + R_4 C \ln \left(\frac{V_P}{V_V}\right)$$

B09.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B09**

Measurement of the interbase resistance R_{BB}

The pin out of the UJT 2N2646 used in these exercises is shown in figure B09.9

pin 1 = emitter
pin 2 = base 1
pin 3 = base 2

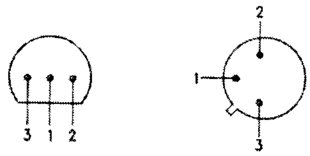


fig. B09.9

- Set the multimeter to the 100 Ω resistor range, and measure the resistances $R_{2\text{-}3}$ and $R_{3\text{-}2}$

Q1 *Are the 2 obtained results equal? And what are they?*

SET
A B
1 5 they are not equal; $R_{23} = 1$ KΩ, $R_{32} = 0$ Ω
2 3 they are equal , and about 1MΩ
3 1 no, they are not equal; $R_{23} = 1$ KΩ, $R_{32} = 1$ MΩ
4 2 they are equal and their value is between 2KΩ and 10KΩ
5 4 they are different with $R_{32} = 0$ and $R_{23} = 1$ KΩ

This result should be typical of the interbase resistance R_{BB} (see earlier description)

Measurement of the peak voltage V_P, and the valley voltage and current, V_V and I_V

- Connect jumpers J45, J46, J42, the voltmeter between emitter and ground to produce the circuit of figure B09.10

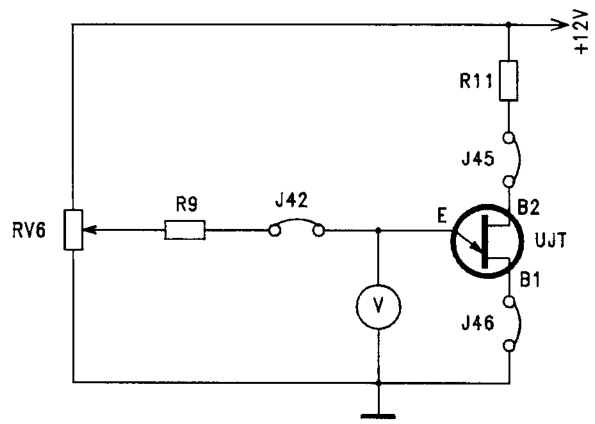


fig.B09.10

- Begin with RV_6 adjusted to the minimum (emitter voltage to 0 V). Slowly increase the voltage to reach and measure the peak voltage V_P (when this value is reached there is a sudden drop of the voltage indicated by the voltmeter)
- measure the voltage indicated by the instrument (if necessary, repeat the last operation)
- Reset the emitter voltage to 0V
- connect a milliammeter in the place of jumper J42
- adjusting the trimmer RV_6, first increase the voltage to reach the peak voltage, then reduce the voltage and check the emitter current behavior I_E

Q2 *How does the emitter current behave?*

SET

A B

1 5 the current increases linearly

2 3 the current is very small until it reaches the peak voltage, then it rapidly increases until the voltage reaches the valley voltage

3 4 the current I_E remains at zero

4 1 the current stays constant at 50 mA

4 2 none of the above describes what happens

- Measure the valley current and voltage
  To measure these variables you must slowly reduce the emitter voltage by adjusting the trimmer RV_6, and check the behavior of the current I_E. The current I_E drops, in fact, to reach a minimum value, then instantly drops to zero. The valley current corresponds to this minimum value, and the valley voltage must be measured in correspondence with this minimum.

Calculation of the intrinsic stand-off ratio

The last measurements gave the peak voltage value of the UJT. As this voltage satisfies the equation $V_P = n \cdot V_{B2B1} + V_D$, with V_D = threshold voltage of a silicon junction (0.5 V), calculate the intrinsic stand-off ratio n

Q3 *What* is the calculated ratio?

SET

A B

1 6 n = 0

2 1 n = 0.5 - 0.8

3 5 n = 1

4 2 n = 10

5 3 n = 100

6 4 n = 5 - 8

Pulse generation circuit

- Remove all the jumpers connected before and connect jumpers J40, J43, J45, J47 to produce the circuit of figure B09.11

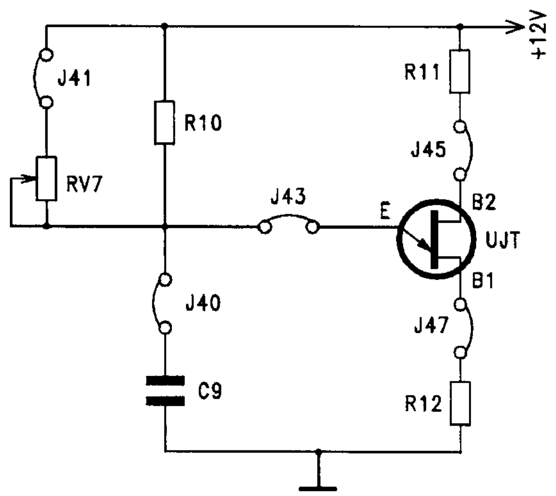


fig.B09.11

- connect the oscilloscope to display the wave-form across the capacitor C_9

Q4 *What is the behavior of the displayed voltage?*

SET

A	B	
1	2	a square-wave signal
2	4	a triangular-wave signal
3	1	a dc voltage
4	3	a saw-tooth voltage

The voltage behavior approximates to the charge and discharge law of a capacitor, across the resistors R_{10} (charging), and $R_{12}+R_{B1}$ (discharging)

- Measure the period of the displayed signal, and calculate the corresponding frequency
- Use the theoretical formulas to calculate the periodic time of the RC circuit and check if this data agrees with the measured period
- Measure the peak voltage of the displayed signal and check if this value corresponds to the one calculated theoretically, using the value of n obtained in the last chapter (differences will be due to

the voltage drops across the resistances R_{11} and R_{12})

- In the circuit, insert jumper J41 to connect trimmer RV_7 in parallel with R_{10}
- vary the resistance of RV_7, and check if this changes the frequency f of the signal V_{C9}
- keeping the value of RV_7 constant, disconnect jumper J40, and connect jumper J44, and check if the frequency has varied

Q5 *From these tests, we can say that the frequency of the signal depends on:*

SET

A	B	
1	3	the supply voltage
2	5	the resistor only
3	1	the capacitor only
4	2	the capacitor and the resistance
5	4	none of the above

- Connect the oscilloscope to display the voltages on the emitter and across R_{12}
- change the oscilloscope probes to display the voltages across R_{12} (V_{B1}) and on Base2

Q6 *What are the waveforms of the voltages V_{B1} and V_{B2}?*

SET

A	B	
1	4	V_{B1} has a triangle waveform, V_{B2} a sine one
2	1	V_{B1} has a saw-tooth waveform, V_{B2} a square one
3	2	V_{B1} has a pulse waveform with positive peaks, V_{B2} has a pulse waveform with negative peaks
4	3	V_{B1} has a sine waveform, V_{B2} a triangle one

➲ ***on-board SIS1***	**Turn switch S9 "*ON*"**
➲ ***SIS2***	**Press "INS"**

Q7 *The circuit does not operate. What is the reason?*

SET
A B
1 2 the supply voltage is missing
2 4 there is a short-circuit between emitter and Base1
3 1 there is a short-circuit between emitter and Base2
4 3 there is a short-circuit between Base2 and Base1

➲ ***on-board SIS1***	**Turn switch S9 "*OFF*"**

B09.3 QUESTIONS ON THIS CHAPTER

Q8 *In a UJT, the stand-off intrinsic ratio is used to calculate*:

SET
A B
1 5 the valley voltage
2 3 the peak voltage
3 1 the interbase resistance
4 2 the valley current
5 4 none of the above

Q9 *A saw tooth generator (fig. B09.5) has a 4.7 KΩ-resistance, a 68 nF-capacitor, with a 12V power supply voltage. What is the period of the signal generated if n = 0.6 ?*

SET
A B
1 4 32 μs
2 3 3.2 ms
3 5 320 μs
4 1 32 ms
5 2 3.2 μs

LESSON B10: THE PUT (Programmable UJT)

OBJECTIVES

- The physical structure of a PUT
- To measure the typical resistances of a PUT
- Behavior of the characteristics I_A-V_{AK}
- To use the PUT as a frequency divider

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope
- function generator with differential probe

B10.1 BASIC THEORY

The PUT (Programmable Uni junction Transistor) operates like a UJT but, unlike it, its starting current can be programmed with external components. It is composed of 3 junctions (PN-NP-PN) and has 3 terminals: Anode (A), Cathode (K) and Gate (G). The internal structure and symbol for the PUT are shown in figure B10.1. The PUT starting condition , i.e. for maximum conduction between Anode and Cathode, depends on the Gate voltage. The Gate is the terminal by which the PUT is programmed.

fig. B10.1

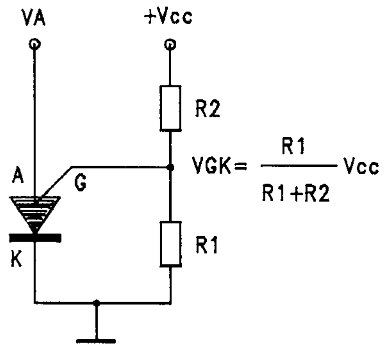
Refer to fig.B10.2.

In the normal operation of a PUT there is a fixed voltage V_{GK} between Gate and Cathode. When the voltage of the Anode V_{AK} varies there are 3 operating regions:

BLOCKING: V_{AK} is less than a voltage V_P - the "peak voltage" (V_P is approximately equal to V_{GK} plus 0.5V). In this region the anode current is very low

NEGATIVE RESISTANCE: if V_{AK} is more than V_P, I_A increases, the resistance between A and K drops and consequently so does V_{AK}

SATURATION: here V_{AK} is higher than the "valley voltage", V_V. The resistance between A and K is positive again. The PUT remains on until the anode current I_A drops below the valley current, I_V.



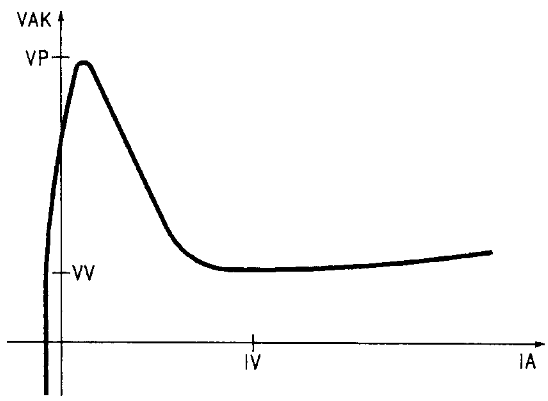


fig.B10.2

PUT applications

The typical applications of a PUT are similar to a UJT. In this lesson we'll examine the frequency divider circuit.

Consider the circuit of fig.B10.3.

Section A is an ac voltage doubler. This provides a voltage on capacitor C_2 equal to twice the power supply voltage, as illustrated in figure B10.4.

The connection of a PUT, with an adjustable starting voltage, to this circuit, enables capacitor C_2 to discharge when the threshold voltage of the PUT is reached. As this discharge produces a voltage pulse across resistance R, the frequency of these output pulses is proportional to the frequency of the input signal (figure B10.5)

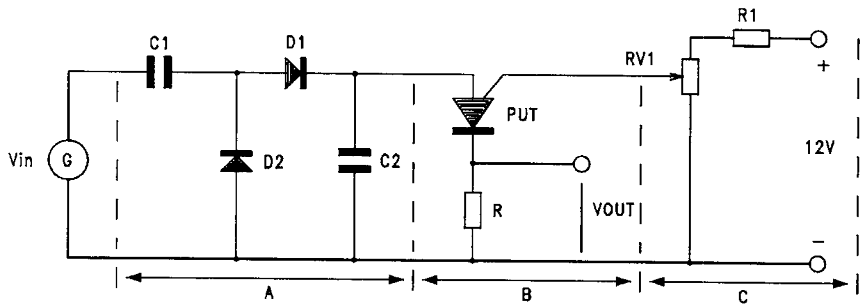


fig. B10.3

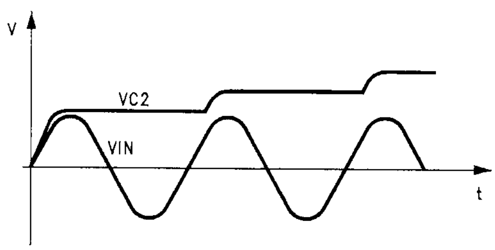


fig. B10.4

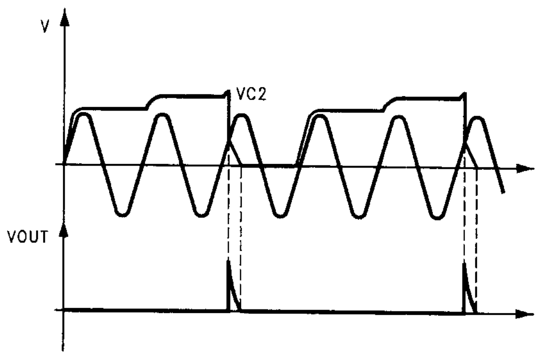


fig. B10.5

B10.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ *on-board SIS1*	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B10**

N.B. Voltage and current measurements will be required on some circuits. If only a single multimeter is available this will need to be used sometimes as a voltmeter, and at other times as an ammeter. When used for voltage measurements, remember to short-circuit the points of the circuit where the ammeter can be inserted.

- The pin out of the PUT 2N 6027 used in these exercises is shown in figure B10.6

pin 1 = A
pin 2 = G
pin 3 = K

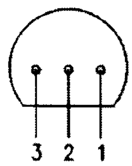


fig. B10.6

Current – voltage characteristics I_A-V_{AK}

- Connect J48, J49, J53, J50 and the ammeter to produce the circuit of figure B10.7

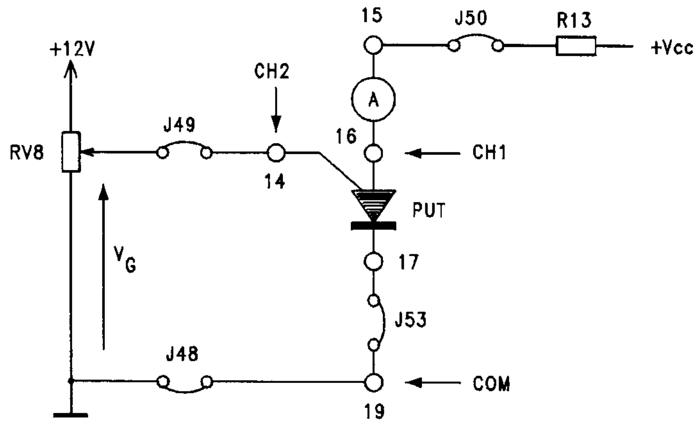


fig.B10.7

- Connect the oscilloscope to display the PUT gate voltage on channel 2, and the anode voltage on channel 1
- adjusting RV_8 vary the Gate voltage V_G, and for the different values of V_{CC} and V_G, shown in the following tables, measure the anode-cathode voltage V_{AK} and the anode current I_A , recording your results in the table

$V_G = 4V$	V_{cc} (V)	0	2	4	4.5	8	12
	V_{AK} (V)						
	I_A (ma)						
$V_G = 8V$	V_{cc} (V)	0	2	4	4.5	8	12
	V_{AK} (V)						
	I_A (ma)						

Q1 *What conclusions can be drawn from these measurements?*

SET
A B
1 2 the currents always remains constant
2 4 the current increases linearly
3 4 the current is very small until the voltage V_{AK} is slightly greater than V_G, after which the current increases considerably
4 3 the current is zero for any voltage applied
5 1 none of the above

- Note that the voltage V_{AK} across the PUT, when it is conducting, is almost constant and independent of the gate voltage V_G. The conduction voltage or "valley voltage" is about 1 V

Frequency divider circuit

- Connect jumpers J51, J52, J54, J49, J48, the voltmeter between the gate of the PUT and the ground, to produce the circuit of figure B10.8

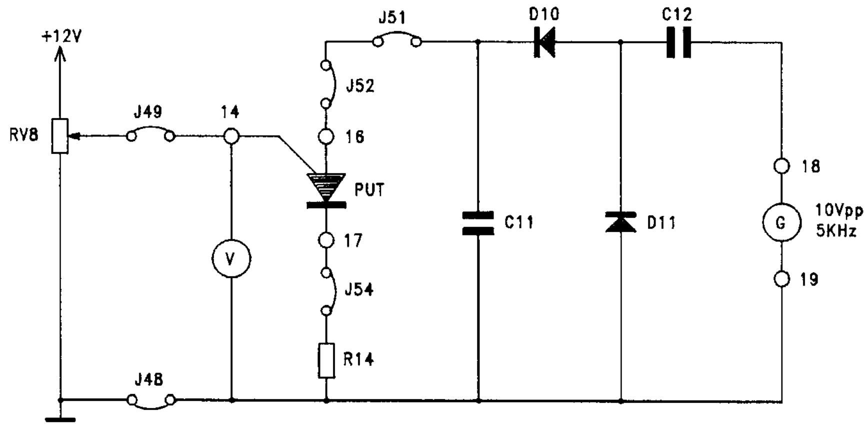


fig. B10.8

- across the input apply a sine signal with a frequency of 5 KHz and amplitude 10V peak to peak
- connect channel 1 of the oscilloscope across the generator
- adjusting RV_8 increase the Gate voltage until a wave-form is displayed across R_{14}

Q2 *What is the behavior of the displayed signal?*

SET

A	B	
1	5	the voltage is strictly continuous
2	3	the voltage has a square-wave behavior
3	4	the voltage is zero
4	1	the voltage has a pulse behavior
5	2	none of the above

The PUT starts conducting when the voltage across the capacitor C_{11} is greater than the Gate voltage.

- Slowly reduce the voltage V_G and check the frequency of the pulse on R14

For V_G less than a critical value, the PUT conducts for each cycle of the input signal. So the frequency of the output pulses is equal to the input frequency.

➲ ***on-board SIS1***	**Turn switch S11 "*ON*"**
➲ *SIS2*	**Press "INS"**

Q3 *The pulse wave-form across R_{14} has disappeared. Why ?*

SET

A	B	
1	5	the resistance R_{14} has been increased
2	3	the diode D_{10} has been short-circuited
3	2	the capacity C_{11} has been increased
4	1	the capacity C_{11} has been reduced
5	4	none of the above

➲ ***on-board SIS1***	**Turn switch S11 "*OFF*"**

B10.3 QUESTIONS ON THIS CHAPTER

Q4 *The PUT starts conducting when:*

SET

A	B	
1	4	the Anode voltage is greater than the Gate
2	5	the Anode currents drops
3	2	the Cathode voltage ripples
4	1	the Anode voltage is greater than the Gate by about 0.5 Volt
5	3	none of the above

Q5 *The PUT starting is programmed by which pin?*

SET

A	B	
1	2	the Cathode
2	1	the Anode
3	5	the emitter
4	3	the Base 2
5	4	the Gate

Q6 *The voltage across a PUT in strong conduction is:*

SET

A	B	
1	3	$\approx$ 1V
2	5	$\approx$ 10V
3	1	equal to 0V
4	2	equal to the power supply voltage
5	4	none of the above

LESSON B11: The SCR (Silicon Controlled Rectifier)

OBJECTIVES

- Fundamentals of SCR's
- To measure the maintenance current
- Switching with anode-gate and anode-cathode connection
- Starting characteristics

EQUIPMENT REQUIRED

- base unit for the IPES system supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B20.1 BASIC THEORY

The SCR (Silicon Controlled Rectifier) is also known as a **thyristor**.
It is an electronic component with 2 stable operating states:
- In the OFF state, the current through it is very low and the SCR can be compared to an open circuit
- in the ON state the current is high (limited only by external resistors) and the SCR is practically a short-circuit.

The SCR is composed of 3 junctions and has 3 terminals: Anode (A), Cathode (K) and Gate (G) (fig.B11.1).
The SCR operation can be summed up as follows:

1. A pulse of current is required on the gate to control the start of heavy conduction between the Anode and Cathode
2. To keep the SCR conducting, a minimum current is required called the "maintenance» or "holding" current
3. reducing the anode current below the maintenance value, or reversing the bias between Anode and Cathode, cuts the device off.

fig.B11.1

Figure B11.2 shows the main voltage-current characteristic for an SCR with no signal on the Gate.

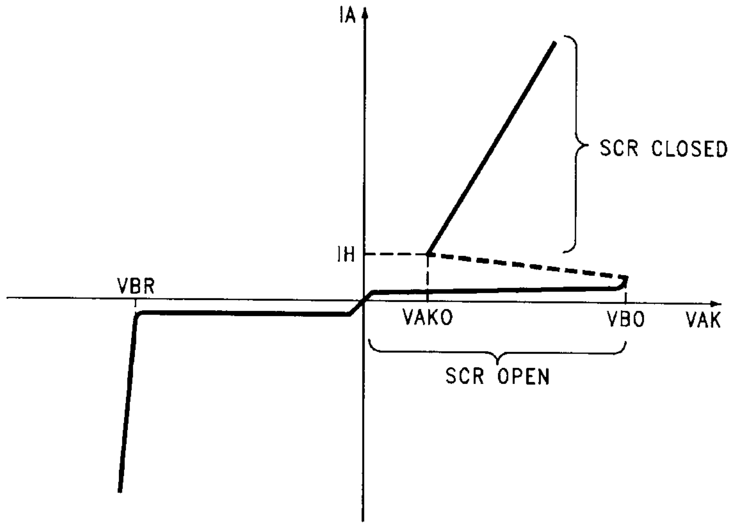


fig.B11.2

As you can see in the figure, the operation of a reverse biased SCR is similar to a diode.
In forward bias (positive anode with respect to the cathode) a small leakage current flows across the SCR in the open state. When the forward voltage increases, a value V_{BO} (break-over) is reached at which the current starts growing rapidly, and the voltage VAK across the SCR decreases suddenly to a very low value called the forward ON voltage (V_{AKO}). When the thyristor conducts, it has a very low impedance, the voltage across it is very small (a few Volt) and slightly dependent on the current. The use of the gate provides control of the break-over voltage. Figure B11.3 shows the break-over curves as function of the gate current, while figure B11.4 represents the voltage-current curve of the gate.

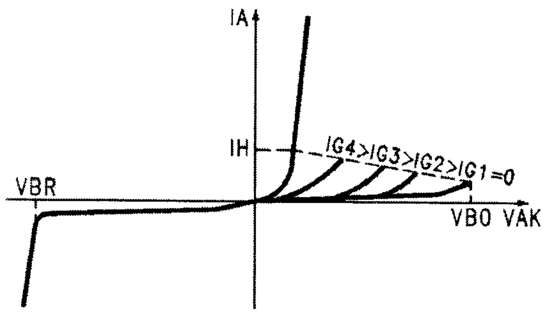


fig. B11.3

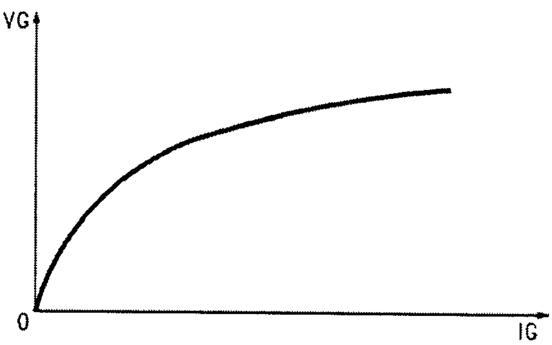


fig. B11.4

B11.2 EXERCISES

➲ *MCM-3*	**Disconnect all jumpers**
➲ ***on-board SIS1***	**Set all switches "*OFF*"**
➲ *SIS2*	**Insert lesson code: B11**

N.B. Voltage and current measurements will be required on some circuits. If only a single multimeter is available this will need to be used sometimes as a voltmeter, and at other times as an ammeter. When used for voltage measurements, remember to short-circuit the points of the circuit where the ammeter can be inserted.

- SCR's, like transistors, can have different containers. For the SCR used in the experiments the pin out is as follows:

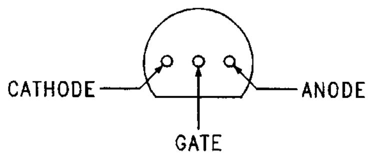


fig.B11.5

With the ohmmeter, set to minimum range, measure the resistance R_{AK} between anode and cathode of the SCR, connecting the positive of the ohmmeter to the gate and the negative to the cathode

- reverse the bias and measure R_{KA}

Q1 *What are the measured resistances?*

SET
A B
1 5 they are close to zero
2 4 they are practically infinite
3 1 RAK is high and and RKA is low
4 2 RAK is low and and RKA is high
5 3 they are between 1 and 10 KΩ

Measurement of the maintenance current I_H

- Connect jumper J59, the ammeter and the oscilloscope to obtain the circuit of figure B11.6

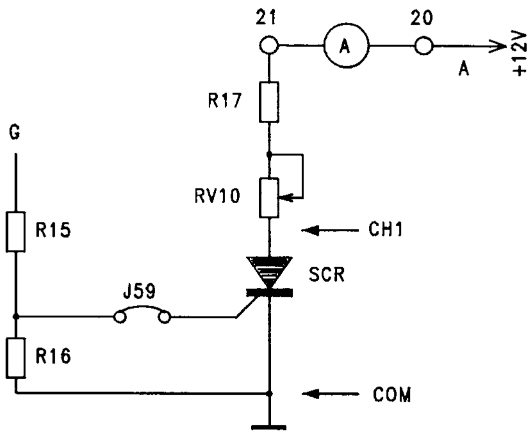


fig.B11.6

- Adjust RV_{10} to the minimum resistance value

As the Gate is not powered yet, the SCR is still cut off, and so the current I_A is zero

- apply a voltage to the Gate for an instant, temporarily connecting jumper J55, and check the state of the SCR
- measure the current I_A and the voltage V_{AK} when the SCR is conducting
- watching the ammeter, gradually increase RV_{10} (and so reducing the current I_A) until the thyristor goes open circuit
- measure the minimum holding current before this cut-off occurs
- measure the voltage across the SCR when it is off

The voltage V_{AK} across the SCR is about 0.7 V when the device is conducting, and 12 V when it is blocking. These values confirm the fact that the SCR behaves as a PN junction when conducting, and as an infinite resistance when cut off.

➲ ***on-board SIS1***	**Turn switch S13 "*ON*"**
➲ ***SIS2***	**Press "INS"**

- Insert and remove jumper J55 to pulse the gate

Q2 *In which condition is the SCR now and why ?*

SET
A B
1 2 the current I_A has been increased and the SCR is conducting
2 5 the power supply has been disconnected and the SCR is OFF
3 4 there is a short-circuit between Gate and Cathode: the SCR is OFF
4 1 I_H has been diminished and the SCR is ON
5 3 the connection between R_{17}-RV_{10} has been disconnected and the SCR is OFF

➲ ***on-board SIS1***	**Turn switch S13 "*OFF*"**

Switching the SCR ON and OFF using the anode-gate and anode-cathode connections

- Change the previous circuit by disconnecting J55, and selecting the minimum resistance for RV_{10}
- briefly short-circuit the points Anode-R_{15}, by temporarily connecting the jumper J58

Q3 *What is the result of this ?*

SET
A B
1 3 the thyristor is conducting
2 4 the thyristor conducts for short periods
3 1 the thyristor conducts but slowly turns off
4 5 the thyristor remains blocked
5 2 none of the above

- examine the effect of short-circuiting the Anode and the Cathode by connecting J61

In OFF state, the Anode is at +12 V and a connection to the Gate provides the pulse which makes the SCR conduct. After switching on, the Anode drops to 0.7 V. Keeping the connection, the voltage of 0.7 V on the Gate is sufficient to guarantee the ON state, and the current can take values high enough to damage the SCR. The current I_G is limited by the resistance R_{15}. A short-circuit between anode and cathode removes the anode current, causing the SCR to turn off.

Connect jumper J60, and repeat these operations evaluating the state of the SCR with the help of the lamp in the circuit.

Switch-on characteristics

- Produce the circuit of fig.B11.7, connecting jumpers J56, J57, J60, the ammeter and the voltmeter (or the oscilloscope)
- adjust trimmer RV_9 to the minimum, to obtain zero V_{GK}
- increase the value of V_{GK} adjusting the trimmer RV9 until the SCR starts conducting (lamp on)
- measure the threshold voltage V_{GT} which makes the thyristor switch
- when the SCR conducts, disconnect RV_9 by removing J56, and note that there is a current through R_{16} from gate to cathode

The voltage present across the G-K junction causes a leakage current through the resistance R_{16} from the gate to the cathode.

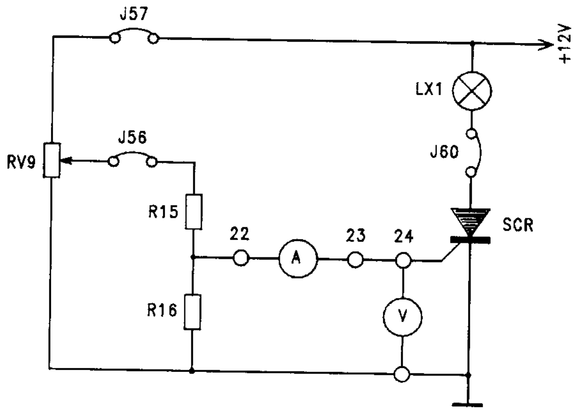


fig. B11.7

B11.3 QUESTIONS ON THIS CHAPTER

Q4 *An SCR starts conducting when:*

SET
A B
1 5 the voltage V_{AK} is greater than the Breakover voltage V_{BO}
2 3 the voltage V_{AK} is less than V_{BO}
3 2 $I_G < 0$
4 1 $I_A < I_H$
5 4 $I_A < 0$

Q5 *Which switch must be pressed to switch the SCR on and off in figure B11.8 ?*

SET
A B
1 2 I4
2 4 I3
3 1 I2
4 3 I1

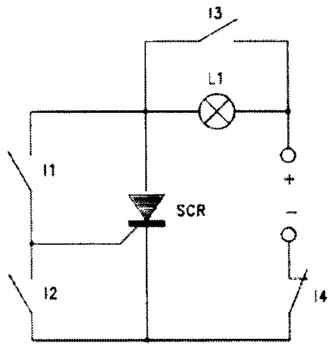


fig.B11.8

Q6 *The SCR is different from a common rectifier diode because:*

SET
A B
1 3 it conducts between anode and cathode as well as in the reverse direction.
2 1 It conducts if, with a positive anode compared to the cathode, there is a sufficient positive pulse between gate and cathode
3 5 it can handle larger currents
4 2 it conducts only for voltages less than the threshold voltage
5 4 it conducts only for negative voltages

Q7 *A thyristor turns off, if :*

SET
A B
1 4 the anode-cathode current takes high values
2 1 the anode-cathode current drops below the maintenance current I_H
3 2 the gate pulse is removed
4 5 a capacitor is connected in parallel
5 3 a 10Ω-resistance is connected in series with the SCR

LESSON B12: DIACS and TRIACS

OBJECTIVES

The DIAC:
- Physical structure
- To determine the characteristic of a DIAC
- To display the voltage-current characteristic on the oscilloscope
- To use a pulse generator DIAC

The TRIAC:
- To check the bidirectional conduction
- To test the switching modes

EQUIPMENT REQUIRED

- base unit for the IPES system (power supply mod.PS1-PSU/EV or PSLC/EV, module holder structure MU/EV), Individual Control Unit mod.SIS1/SIS2/SIS3 (optional).
- experiment module MCM3/EV
- multimeter
- oscilloscope with differential probe

B12.1 BASIC THEORY

The DIAC

The DIAC is a device consisting of two PNPN sections connected in anti-parallel, as indicated in figure B12.1a

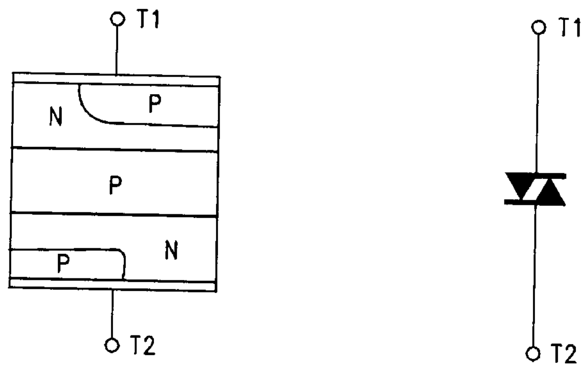


fig. B12.1

The two differences compared to a SCR are:

1. DIAC conduction does not require a pulse applied to the gate, but only on a voltage threshold between terminals T_1 and T_2

2. in a DIAC, conduction can be in both directions.

These characteristics are shown in the voltage-current curve of figure B12.2.

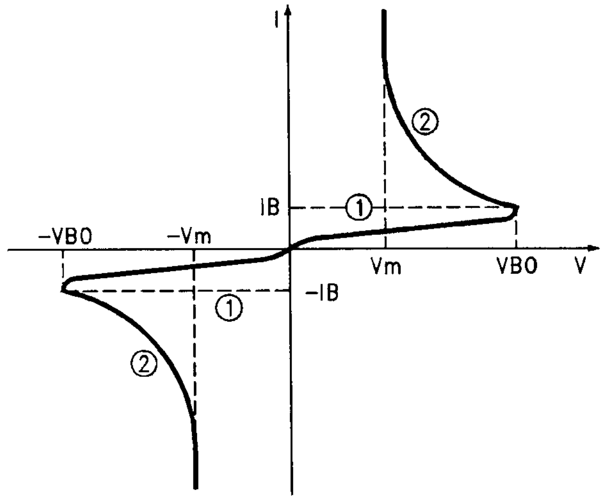


fig. B12.2

In the segment (1) of the characteristic, the DIAC behaves as open switch, for either bias direction. When the voltage exceeds the value V_{BO} (Break over), the current starts increasing and the voltage drops to V_m.

In segment (2) of the characteristic, the voltage drop occurs in a very short time, during which the DIAC has a negative resistance. When the voltage becomes lower than the minimum value V_m the DIAC becomes open circuit again.

The circuit of figure B12.3 shows an oscillator circuit using a DIAC.

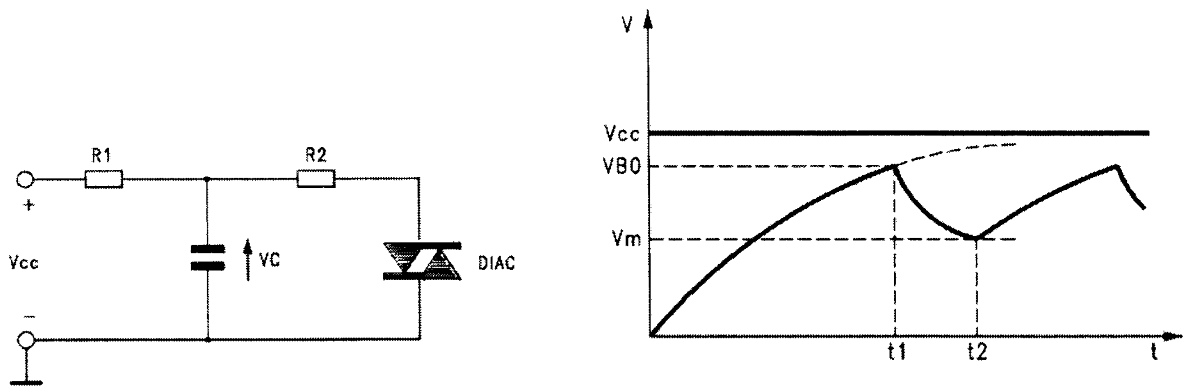


fig. B12.3

The capacitor charges through R_1 up to the instant t_1. At this instant the voltage of the capacitor equals the voltage V_{BO} and the DIAC starts conducting strongly. The capacitor discharges down to the value V_m (instant t_2), when the DIAC switches back to open circuit. The cycle can now start again.

The TRIAC

A TRIAC is also different from the SCR, being bidirectional, ie it can conduct in both directions. The symbol for a TRIAC is represented in figure B12.4 and its characteristic V-I is shown in figure B12.5.

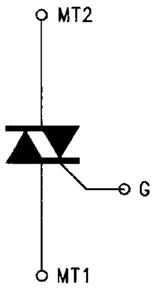


fig. B12.4

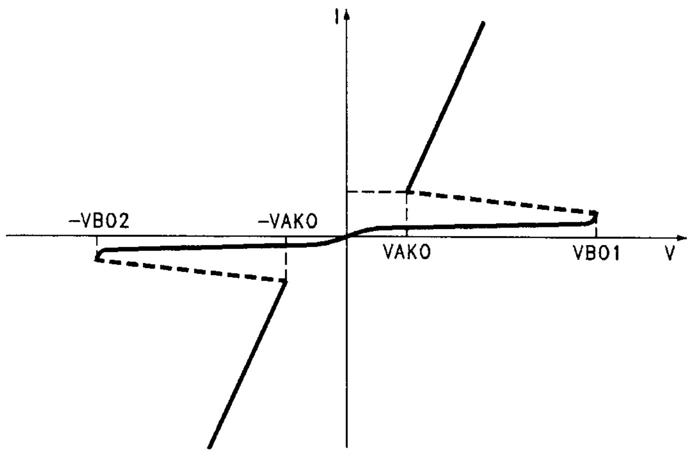


fig. B12.5

As shown in figure B12.6, the TRIAC can be represented as the union of two SCRs, a P type and an N type.

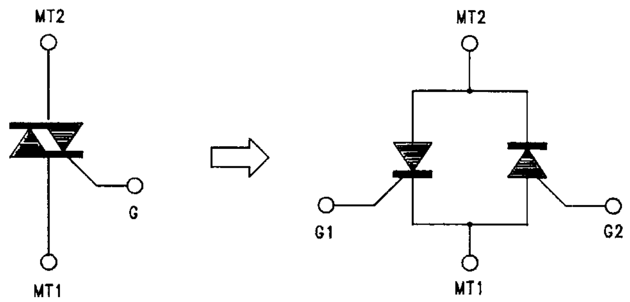


fig. B12.6

the internal structure is shown in figure B12.7, which shows the P and N regions, and also the three electrodes : G, MT_1 and MT_2.
The region between two terminals MT_1 and MT_2 is composed of a PNPN structure, connected in parallel with a similar NPNP structure (figure B12.8), like joining two SCRs in anti-phase.

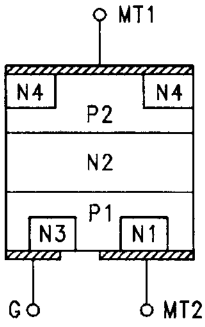


fig. B12.7

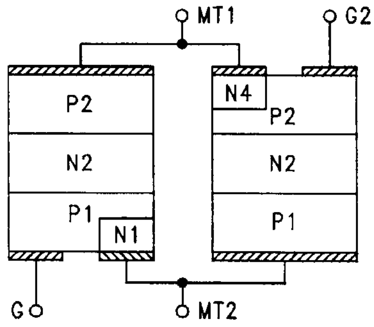


fig. B12.8

With no signal to the gate, the device is always cut off, because there is always a reverse biased diode:
If $V_{MT2} > V_{MT1}$ the junction N_2P_1 guarantees the blocking state. In the reverse direction cut off is ensured by the junction N_2P_2.
Conduction can start when the voltage between the electrodes MT_1 and MT_2 exceeds the threshold value, on the application of a positive or negative current pulse to the control electrode. Conduction can occur in both directions: when MT_1 is positive with respect to MT_2, the layers $P_2N_2P_1N_1$ provide the conduction path, while when MT_2 is positive with respect to MT_1, current flows in the layers $P_1N_2P_2N_4$ (figure B12.9).

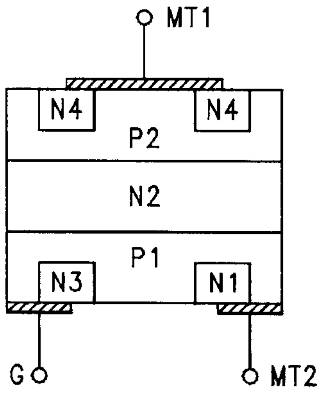


fig. B12.9

«Firing» the TRIAC (ie starting conduction)can be achieved with the bias voltages seen in figure B12.10.

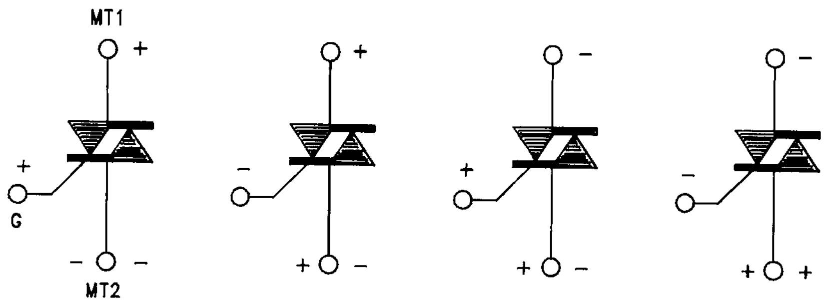


fig. B12.10

TRIAC characteristics

The TRIAC characteristics are similar to those of the SCR (figure B12.11).

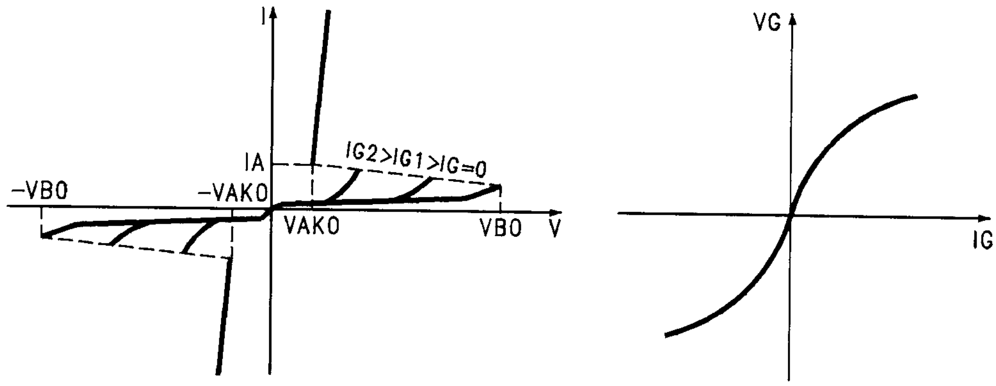


fig. B12.11

B12.2 EXERCISES

➲ ***MCM-3***	**Disconnect all jumpers**
➲ ***on-board SIS1***	**Set all switches "*OFF*"**
➲ ***SIS2***	**Insert lesson code: B12**

Determining the characteristics of a DIAC

- Connect jumpers J73, J72, J74, the ammeter across J68, the oscilloscope across the DIAC (to measure the voltage) to produce the circuit of fig.B12.12

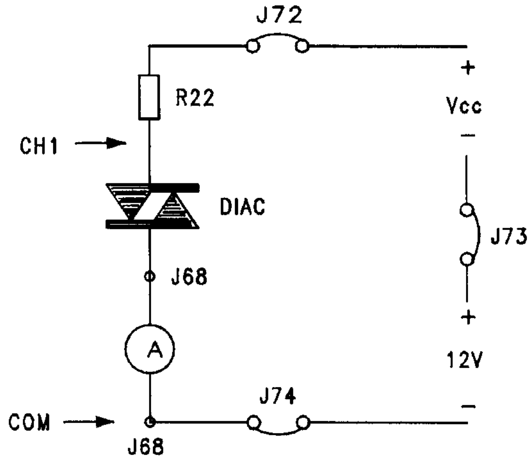


fig.B12.12

- with the power supply in the circuit, the circuit voltage can be varied from 12 to 42 Vdc
- measure the current and voltage of the DIAC for different values of the power supply voltage as in the following table:

Vdc (V)	12	20	28	30	32	34	36	38	40
I (ma)									
VD (V)									

- note the avalanche voltage V_{BO} for which the DIAC starts conducting. Check if the ON voltage across the DIAC depends on the current.

Q1 *At what voltage values does the DIAC start conducting?*

SET

A	B	
1	6	-2 V
2	4	2-4 V
3	1	4-8 V
4	5	8-10 V
5	3	10-25 V
6	2	25-35 V

Displaying the DIAC V-I characteristic on the oscilloscope

- Connect jumpers J71, J68, J75, and connect the oscilloscope as indicated in the figure B12.13

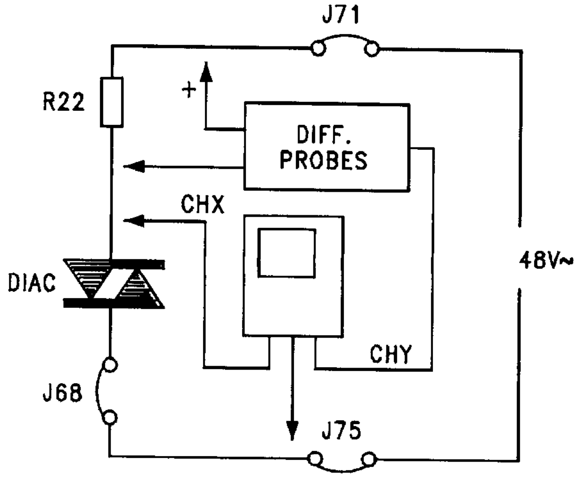


fig.B12.13

- set the oscilloscope to X-Y mode; 10 V/div on the Y-axis; 10 V/div on the X-axis; center the trace on the screen
- the X-axis shows the voltage across the DIAC, while the Y-axis represents the current through the circuit (proportional to the voltage present across R_{22})

Q2 *What are the features of the displayed characteristics?*

SET
A B

1 5 it is a straight line with a positive slope
2 1 it is a straight line with negative slope, and only for V<0
3 2 the current becomes zero only when V reaches V_{BO}
4 3 the current is zero until the supply voltage reaches the avalanche voltage VBO
5 4 it has a sine wave behavior.

- Measure the positive and negative amplitudes of V_{BO}
- calculate the difference between V_{BO+} and V_{BO-}

(As a DIAC is not perfectly symmetrical, there can be a difference of a few volts between the size of V_{BO+} and V_{BO-})

➲ *on-board SIS1*	**Turn switch S3 "*ON*"**
➲ *SIS2*	**Press "INS"**

Q3 *The voltage across the DIAC has changed. What has happened?*

SET
A B
1 2 the power supply voltage has dropped
2 4 the circuit is powered by a dc voltage
3 5 the load resistance has been increased
4 1 the load resistance has been reduced
5 3 the power supply voltage has increased

From this we can note that when the DIAC is conducting, its voltage drops when the load resistance drops, ie more current is supplied.

➲ *on-board SIS1*	**Turn switch S3 "*OFF*"**

The DIAC pulse generator

- Produce the circuit of fig.B12.14, connecting the jumpers J69, J70, J72, J73, J74

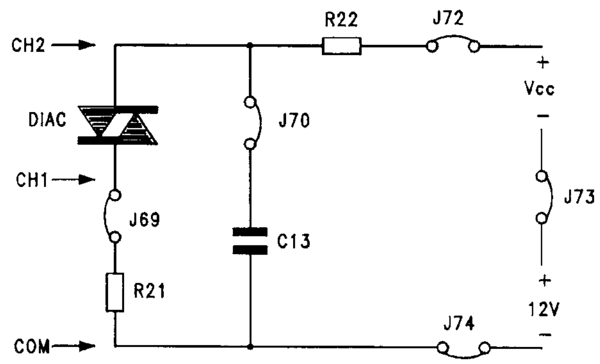


fig.B12.14

- Measure the frequency and amplitude of the voltage pulses present across the C13

The frequency of the pulses is determined by the charging of capacitor C_{13} through R_{22}. The current pulses through the DIAC are limited by the resistance of R_{21}

Q4 *What happens if the power supply is inverted?*

SET
A B
1 6 the DIAC is damaged
2 4 the power supply will overheat
3 1 the frequency of the pulses increases
4 5 the frequency of the pulses decreases
5 2 the amplitude of the pulses doubles
6 3 the circuit produces negative pulses

Checking bidirectional conduction in a TRIAC

- Produce the circuit of fig.B12.15 connecting jumpers J66, J65, J76 and connect the oscilloscope as indicated

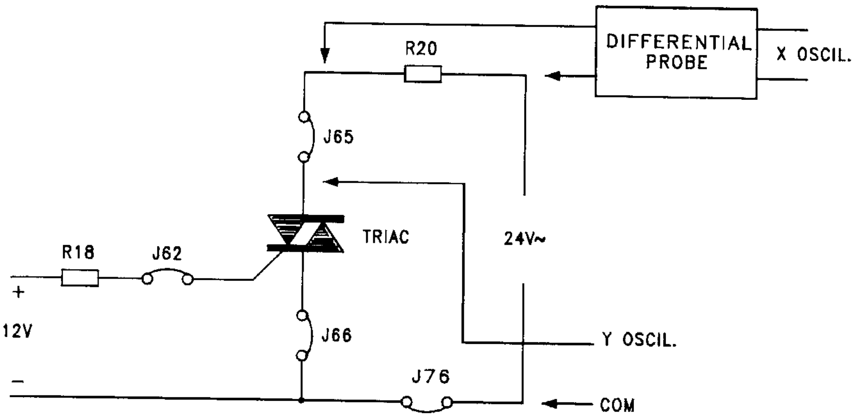


fig.B12.15

- connect jumper J62 and observe how and when the TRIAC is conducting
- disconnect the gate by removing the jumper J62

Q5 *How does the TRIAC behave?*

SET
A B
1 2 it conducts up to the first zero crossing point of the supply voltage
2 5 it remains conducting always
3 4 it conducts only for the positive half-waves
4 3 it conducts only for the negative half-waves
5 6 it turns off instantly
6 1 none of the above

- Connect jumpers J65, J66, J76 to produce the circuit of fig. B12.16

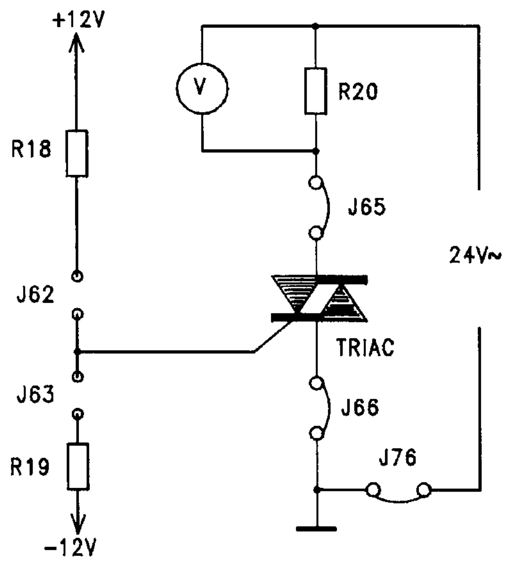


fig.B12.16

- connect jumper J62 and check the reading on the voltmeter

➲ *on-board SIS1*	**Turn switch S20 "*ON*"**
➲ *SIS2*	**Press "INS"**

Q6 *What can you conclude from the voltages observed across the TRIAC and the resistance R_{20} ?*

SET

A	B	
1	2	the power supply voltage is on and the TRIAC conducts
2	1	the gate circuit has been disconnected
3	5	the circuit between the TRIAC and R_{20} has been disconnected
4	3	the TRIAC has been short-circuited
5	4	the value of R_{20} has been doubled

➲ *on-board SIS1*	**Turn switch S20 "*OFF*"**

- remove all jumpers in the card
- connect jumpers J64, J67, J76 to reverse the terminals MT_2 and MT_1
- connect jumper J62, and observing the voltages across the circuit, see if the TRIAC conducts
- disconnect jumper J62 and connect J63 and examine the operation of the circuit.

B11.3 QUESTIONS ON THIS CHAPTER

Q7 *The DIAC consists of two PNPN sections which are connected:*

SET		
A	B	
1	2	in series
2	3	in parallel
3	1	in antiparallel

Q8 *A TRIAC is a switch which can be controlled:*

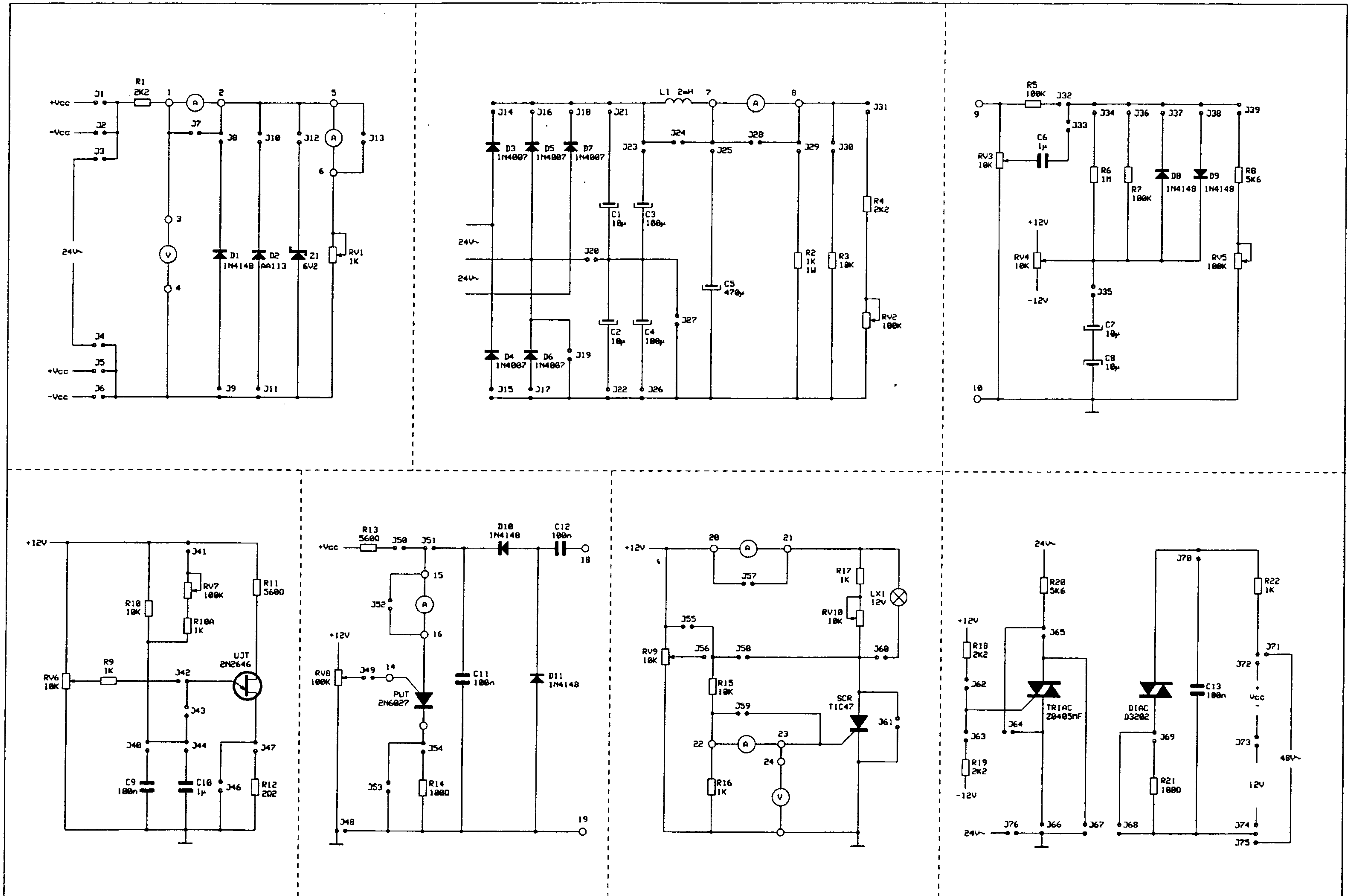
SET		
A	B	
1	3	only with positive pulses
2	5	only with negative pulses
3	1	with alternating positive and negative pulses
4	2	with negative or positive pulses
5	4	only with high frequency pulses

Q9 *A TRIAC can be thought as:*

SET		
A	B	
1	5	two Zener diodes in antiparallel connection
2	1	two germanium diodes and silicon diodes in series
3	4	two inductances connected in parallel
4	3	two SCR diodes connected in antiparallel
5	6	two UJT diodes connected in antiparallel
6	2	two PUT diodes connected in antiparallel

Q10 *Conduction in a DIAC is caused by :*

SET		
A	B	
1	4	a voltage threshold has been exceeded
2	3	a current threshold has been overcome
3	5	applying a sine wave ac voltage
4	1	the power supply circuit being interrupted
5	2	the zero crossing point of the power supply voltage



ELETTRONICA VENETA MOTTA DI LIVENZA - TV ITALY	DESCRIPTION : ELECTRONIC DEVICES AND CIRCUITS I		REPLACES: --	DWG Nº: MC031D01.FSH	DRAWN :
	EQUIPMENT : IPES MODULE MCM-3/EV		REPLACED BY: --	P.C.B.: MCM3	CHECKED :
	T.C. FILE : --	SCALE : --	REVISION: 0	SHEET : 1 OF 1	DATE : [illegible]-97

APPENDIX A : DATA SHEETS

- Germanium diode: OA91
- Silicon diode: 1N914
- UJT : 2N2646
- PUT : 2N6027
- SCR : TIC 47
- TRIAC : T2301D
- DIAC : D3202

OA91

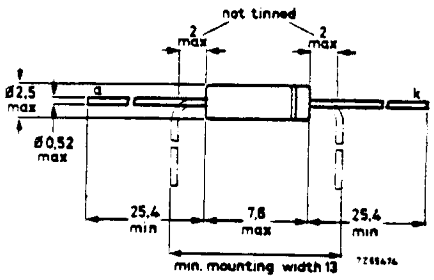
POINT CONTACT DIODE

Germanium diode in all-glass DO-7 envelope intended for general purposes.

MECHANICAL DATA

Dimensions in mm

DO-7



The coloured band indicates the cathode

RATINGS Limiting values in accordance with the Absolute Maximum System (IEC 134)

Average reverse voltage (averaged over any 50 ms period)	V_R	max.	90	V
Repetitive peak reverse voltage	V_{RRM}	max.	115	V
Average forward current (averaged over any 50 ms period)	I_F	max.	50	mA
Repetitive peak forward current	I_{FRM}	max.	150	mA
Non-repetitive peak forward current ($t < 1$ s)	I_{FSM}	max.	500	mA
Storage temperature	T_{stg}		−55 to +75	°C
Operating ambient temperature	T_{amb}		−55 to +75	°C

THERMAL RESISTANCE

From junction to ambient in free air $R_{th\ j\text{-}a}$ = 0.55 °C/mW

CHARACTERISTICS

		T_{amb} = 25 °C	T_{amb} = 60 °C	
Forward voltage				
I_F = 0.1 mA	V_F	typ. 0.18	typ. 0.1	V
		0.1 to 0.25	0.05 to 0.2	V
I_F = 10 mA	V_F	typ. 1.2	typ. 1.05	V
		0.65 to 1.9	0.55 to 1.8	V
I_F = 30 mA	V_F	typ. 2.1	typ. 1.9	V
		1.0 to 3.3	0.9 to 3.15	V
Reverse current				
V_R = 1.5 V	I_R	typ. 1.5	typ. 15	µA
		0.3 to 7	6 to 45	µA
V_R = 10 V	I_R	typ. 4	typ. 20	µA
		0.5 to 11	9 to 60	µA
V_R = 75 V	I_R	typ. 40	typ. 115	µA
		5.5 to 180	35 to 260	µA
V_R = 100 V	I_R	typ. 75	typ. 190	µA
		10 to 275	60 to 450	µA

TYPES 1N914, 1N914A, 1N914B, 1N915, 1N916, 1N916A, 1N916B, 1N917
SILICON SWITCHING DIODES

BULLETIN NO. DL-S 7311954, MARCH 1973

FAST SWITCHING DIODES

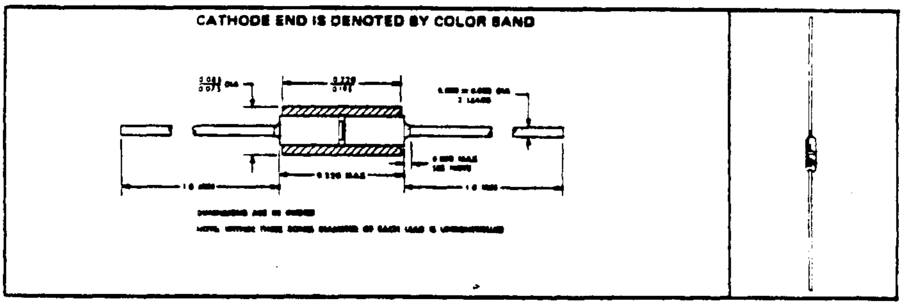
- Rugged Double-Plug Construction

Electrical Equivalents

1N914 . . . 1N4148 . . . 1N4531
1N914A . . . 1N4446
1N914B . . . 1N4448
1N916 . . . 1N4149
1N916A . . . 1N4447
1N916B . . . 1N4449

mechanical data

Double-plug construction affords integral positive contacts by means of a thermal compression bond. Moisture-free stability is ensured through hermetic sealing. The coefficients of thermal expansion of the glass case and the dumet plugs are closely matched to allow extreme temperature excursions. Hot-solder-dipped leads are standard.



absolute maximum ratings at specified free-air temperature

		1N914 1N914A 1N914B	1N915	1N916 1N916A 1N916B	1N917	UNIT
Working Peak Reverse Voltage from −65°C to 150°C		75*	50*	75*	30*	V
Average Rectified Forward Current (See Note 1)	at (or below) 25°C	75*	75*	75*	50*	mA
	at 150°C	10*	10*	10*	10*	mA
Peak Surge Current, 1 Second at 25°C (See Note 2)		500*	500	500*	300	mA
Continuous Power Dissipation at (or below) 25°C (See Note 3)		250*	250	250*	250	mW
Operating Free-Air Temperature Range		−65 to 175				°C
Storage Temperature Range		−65 to 200*				°C
Lead Temperature 1/16 Inch from Case for 10 Seconds		300				°C

NOTES: 1. These values may be applied continuously under a single-phase 60-Hz half-sine-wave operation with resistive load.
2. These values apply for a one-second square-wave pulse with the devices at nonoperating thermal equilibrium immediately prior to the surge.
3. Derate linearly to 175°C free-air temperature at the rate of 1.67 mW/°C.

*JEDEC registered data

2N2646 (SILICON)
2N2647

SILICON ANNULAR PN UNIJUNCTION TRANSISTORS

designed for use in pulse and timing circuits, sensing circuits and thyristor trigger circuits. These devices feature:

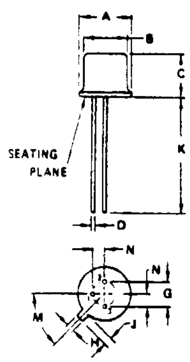
- Low Peak Point Current – 2.0 μA (Max)
- Low Emitter Reverse Current – 200 nA (Max)
- Passivated Surface for Reliability and Uniformity

PN UNIJUNCTION TRANSISTORS

***MAXIMUM RATINGS** (T_A = 25°C unless otherwise noted.)

Rating	Symbol	Value	Unit
Power Dissipation (1)	P_D	300	mW
RMS Emitter Current	$I_{E(RMS)}$	50	mA
Peak Pulse Emitter Current (2)	i_E	2.0	Amp
Emitter Reverse Voltage	V_{B2E}	30	Volts
Interbase Voltage	V_{B2B1}	35	Volts
Operating Junction Temperature Range	T_J	-65 to +125	°C
Storage Temperature Range	T_{stg}	-65 to +150	°C

*Indicates JEDEC Registered Data.
(1) Derate 3.0 mW/°C increase in ambient temperature. The total power dissipation (available power to Emitter and Base-Two) must be limited by the external circuitry.
(2) Capacitor discharge – 10 μF or less, 30 volts or less.



STYLE 1:
PIN 1. EMITTER
2. BASE 1
3. BASE 2

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	5.31	5.84	0.209	0.230
B	4.52	4.95	0.178	0.195
C	4.32	5.33	0.170	0.210
D	0.41	0.48	0.016	0.019
G	2.54 TYP		0.100 TYP	
H	0.91	1.17	0.036	0.046
J	0.71	1.22	0.028	0.048
K	12.70	–	0.500	–
M	45° TYP		45° TYP	
N	1.27 TYP		0.050 TYP	

CASE 22A

2N2646, 2N2647 (continued)

*ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted.)

Characteristic		Symbol	Min	Typ	Max	Unit
Intrinsic Standoff Ratio (V_{B2B1} = 10 V) (Note 1)	2N2646 2N2647	η	0.56 0.68	– –	0.75 0.82	–
Interbase Resistance (V_{B2B1} = 3.0 V, I_E = 0)		r_{BB}	4.7	7.0	9.1	k ohms
Interbase Resistance Temperature Coefficient (V_{B2B1} = 3.0 V, I_E = 0, T_A = -55°C to +125°C)		α_{rBB}	0.1	–	0.9	%/°C
Emitter Saturation Voltage (V_{B2B1} = 10 V, I_E = 50 mA) (Note 2)		$V_{EB1(sat)}$	–	3.5	–	Volts
Modulated Interbase Current (V_{B2B1} = 10 V, I_E = 50 mA)		$I_{B2(mod)}$	–	15	–	mA
Emitter Reverse Current (V_{B2E} = 30 V, I_{B1} = 0)	2N2646 2N2647	I_{EB2O}	– –	0.005 0.005	12 0.2	µA
Peak Point Emitter Current (V_{B2B1} = 25 V)	2N2646 2N2647	I_P	– –	1.0 1.0	5.0 2.0	µA
Valley Point Current (V_{B2B1} = 20 V, R_{B2} = 100 ohms) (Note 2)	2N2646 2N2647	I_V	4.0 8.0	6.0 10	– 18	mA
Base-One Peak Pulse Voltage (Note 3, Figure 3)	2N2646 2N2647	V_{OB1}	3.0 6.0	5.0 7.0	– –	Volts

*Indicates JEDEC Registered Data.

Notes:

(1) Intrinsic standoff ratio, η, is defined by equation:

$$\eta = \frac{V_P - V_F}{V_{B2B1}}$$

Where V_P = Peak Point Emitter Voltage
V_{B2B1} = Interbase Voltage
V_F = Emitter to Base-One Junction Diode Drop ($\approx$ 0.5 V @ 10 µA)

(2) Use pulse techniques: PW ≈ 300 µs, duty cycle ≤ 2% to avoid internal heating due to interbase modulation which may result in erroneous readings.

(3) Base-One Peak Pulse Voltage is measured in circuit of Figure 3. This specification is used to ensure minimum pulse amplitude for applications in SCR firing circuits and other types of pulse circuits.

FIGURE 1
UNIJUNCTION TRANSISTOR SYMBOL AND NOMENCLATURE

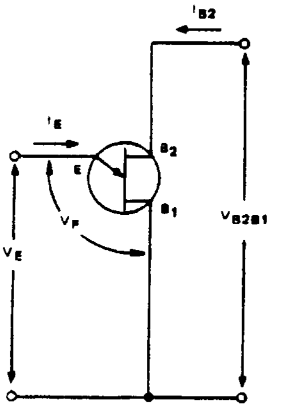


FIGURE 2
STATIC EMITTER CHARACTERISTIC CURVES
(Exaggerated to Show Details)

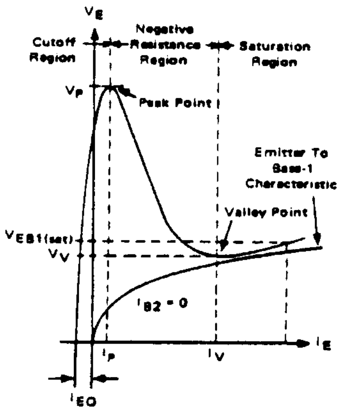
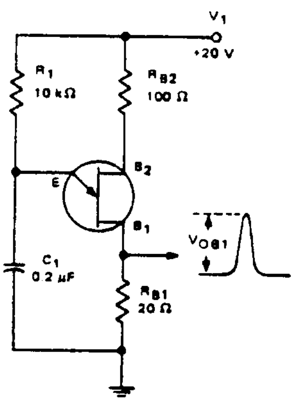
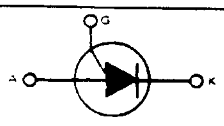


FIGURE 3 – V_{OB1} TEST CIRCUIT
(Typical Relaxation Oscillator)

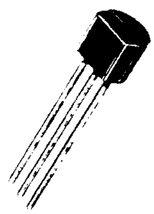


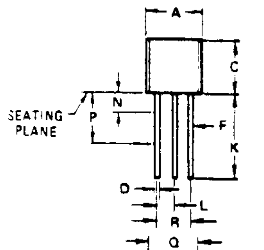
2N6027 (SILICON)
2N6028



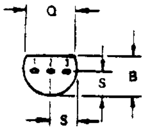
SILICON PROGRAMMABLE UNIJUNCTION TRANSISTORS

40 VOLTS
375 mW





STYLE 16.
PIN 1 ANODE
2. GATE
3. CATHODE



	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	4 450	5 200	0.175	0.205
B	3.180	4.190	0.125	0.165
C	4 320	5.330	0.170	0 210
D	0 407	0.533	0.016	0 021
F	0 407	0.482	0.016	0 019
K	12.700	–	0.500	–
L	1 150	1 390	0.045	0.055
N	–	1 270	–	0.050
P	6 350	–	0.250	–
Q	3 430	–	0.135	–
R	2.410	2 670	0.095	0 105
S	2.030	2.670	0 080	0.105

CASE 29-02
TO 92

SILICON PROGRAMMABLE UNIJUNCTION TRANSISTORS

. . . designed to enable the engineer to "program" unijunction characteristics such as R_{BB}, η, I_V, and I_P by merely selecting two resistor values. Application includes thyristor-trigger, oscillator, pulse and timing circuits. These devices may also be used in special thyristor applications due to the availability of an anode gate. Supplied in an inexpensive TO-92 plastic package for high-volume requirements, this package is readily adaptable for use in automatic insertion equipment.

- Programmable – R_{BB}, η, I_V and I_P.
- Low On-State Voltage – 1.5 Volts Maximum @ I_F = 50 mA
- Low Gate to Anode Leakage Current – 10 nA Maximum
- High Peak Output Voltage – 11 Volts Typical
- Low Offset Voltage – 0.35 Volt Typical (R_G = 10 k ohms)

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Power Dissipation (1) Derate Above 25°C	P_F $1/\theta_{JA}$	375 5.0	mW mW/°C
DC Forward Anode Current (2) Derate Above 25°C	I_T	200 2.67	mA mA/°C
*DC Gate Current	I_G	±50	mA
Repetitive Peak Forward Current 100 µs Pulse Width, 1.0% Duty Cycle *20 µs Pulse Width, 1.0% Duty Cycle	I_{TRM}	 1.0 2.0	 Amp Amp
Non-Repetitive Peak Forward Current 10 µs Pulse Width	I_{TSM}	5.0	Amp
*Gate to Cathode Forward Voltage	V_{GKF}	40	Volt
*Gate to Cathode Reverse Voltage	V_{GKR}	-5.0	Volt
*Gate to Anode Reverse Voltage	V_{GAR}	40	Volt
*Anode to Cathode Voltage	V_{AK}	±40	Volt
Operating Junction Temperature Range	T_J	-50 to +100	°C
*Storage Temperature Range	T_{stg}	-55 to +150	°C

*Indicates JEDEC Registered Data
(1) JEDEC Registered Data is 300 mW, derating at 4.0 mW/°C.
(2) JEDEC Registered Data is 150 mA.

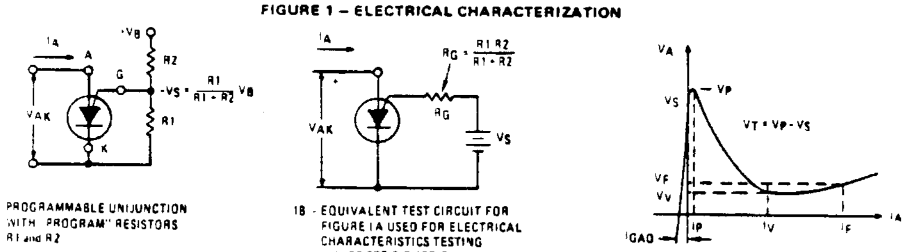
2N6027, 2N6028 (continued)

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Figure	Symbol	Min	Typ	Max	Unit
*Peak Current		2,9,11	I_P				μA
(V_S = 10 Vdc, R_G = 1.0 MΩ)	2N6027			–	1.25	2.0	
	2N6028			–	0.08	0.15	
(V_S = 10 Vdc, R_G = 10 k ohms)	2N6027			–	4.0	5.0	
	2N6028			–	0.70	1.0	
*Offset Voltage		1	V_T				Volts
(V_S = 10 Vdc, R_G = 1.0 MΩ)	2N6027			0.2	0.70	1.6	
	2N6028			0.2	0.50	0.6	
(V_S = 10 Vdc, R_G = 10 k ohms)	(Both Types)			0.2	0.35	0.6	
*Valley Current		1,4,5,	I_V				μA
(V_S = 10 Vdc, R_G = 1.0 MΩ)	2N6027			–	18	50	
	2N6028			–	18	25	
(V_S = 10 Vdc, R_G = 10 k ohms)	2N6027			70	270	–	
	2N6028			25	270	–	
(V_S = 10 Vdc, R_G = 200 Ohms)	2N6027			1.5	–	–	mA
	2N6028			1.0	–	–	
*Gate to Anode Leakage Current		–	I_{GAO}				nAdc
(V_S = 40 Vdc, T_A = 25°C, Cathode Open)				–	1.0	10	
(V_S = 40 Vdc, T_A = 75°C, Cathode Open)				–	3.0	–	
Gate to Cathode Leakage Current (V_S = 40 Vdc, Anode to Cathode Shorted)		–	I_{GKS}	–	5.0	50	nAdc
*Forward Voltage (I_F = 50 mA Peak)		1,6	V_F	–	0.8	1.5	Volts
*Peak Output Voltage (V_B = 20 Vdc, C_C = 0.2 μF)		3,7	V_o	6.0	11	–	Volts
Pulse Voltage Rise Time (V_B = 20 Vdc, C_C = 0.2 μF)		3	t_r	–	40	80	ns

*Indicates JEDEC Registered Data

FIGURE 1 – ELECTRICAL CHARACTERIZATION



1A PROGRAMMABLE UNIJUNCTION WITH "PROGRAM" RESISTORS R1 and R2

1B - EQUIVALENT TEST CIRCUIT FOR FIGURE 1A USED FOR ELECTRICAL CHARACTERISTICS TESTING (ALSO SEE FIGURE 2)

1C - ELECTRICAL CHARACTERISTICS

FIGURE 2 – PEAK CURRENT (I_P) TEST CIRCUIT

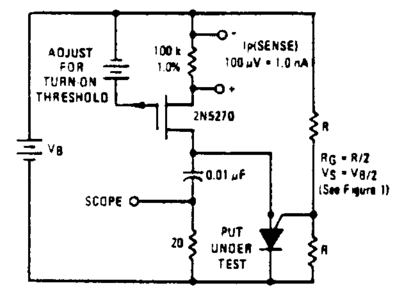
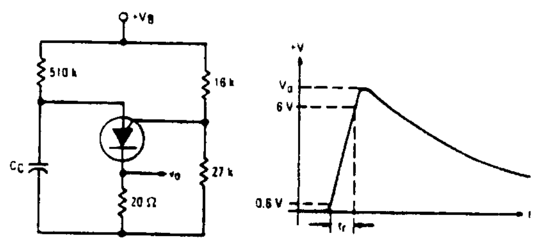


FIGURE 3 – V_o AND t_r TEST CIRCUIT



TYPES TIC44, TIC45, TIC46, TIC47
P-N-P-N PLANAR SILICON REVERSE-BLOCKING TRIODE THYRISTORS

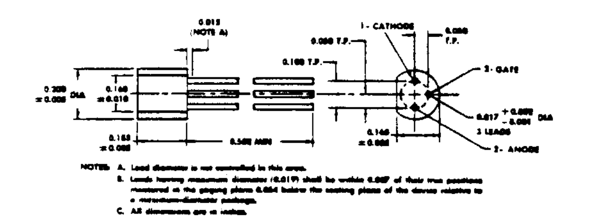
TYPES TIC44, TIC45, TIC46, TIC47
BULLETIN NO. DL-S 669051, SEPTEMBER 1966

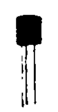
SILECT† THYRISTORS

600 mA DC • 30 thru 200 VOLTS
Rugged, One-Piece Construction with Standard TO-18 100-mil Pin Circle

mechanical data

These thyristors are encapsulated in a plastic compound specifically designed for this purpose, using a highly mechanized process developed by Texas Instruments. The case will withstand soldering temperatures without deformation. These devices exhibit stable characteristics under high-humidity conditions and are capable of meeting MIL-STD-202C method 106B. The thyristors are insensitive to light.





absolute maximum ratings over operating free-air temperature range (unless otherwise noted)

	TIC44	TIC45	TIC46	TIC47	UNIT
Continuous Forward Blocking Voltage, V_{FO} (See Note 1)	30	60	100	200	V
Peak Forward Blocking Voltage (See Note 1)	30	60	100	200	V
Continuous Reverse Blocking Voltage, V_{RO} (See Note 1)	30	60	100	200	V
Peak Reverse Blocking Voltage (See Note 1)	30	60	100	200	V
Continuous Anode Forward Current at (or below) 55°C Case Temperature (See Note 2)	600				mA
Continuous Anode Forward Current at (or below) 25°C Free-Air Temperature (See Note 3)	300				mA
Average Anode Forward Current (180° Conduction Angle) at (or below) 55°C Case Temperature (See Note 4)	430				mA
Peak Anode Surge Current (See Note 5)	6				A
Peak Gate Reverse Voltage	8				V
Peak Gate Forward Current (Pulse Width ≤ 300 μs)	1				A
Peak Gate Power Dissipation (Pulse Width ≤ 300 μs)	4				W
Operating Free-Air Temperature Range	−55 to 125				°C
Storage Temperature Range	−55 to 150				°C
Lead Temperature 1/16 Inch from Case for 10 Seconds	260				°C

NOTES: 1. These values apply when the gate-cathode resistance $R_{GK} \leq 1\ k\Omega$.
2. These values apply for continuous d-c operation with resistive load. Above 55°C derate according to Figure 5.
3. These values apply for continuous d-c operation with resistive load. Above 25°C derate according to Figure 6.
4. This value may be applied continuously under single-phase, 60-Hz, half-sine-wave operation with resistive load. Above 55°C derate according to Figure 5.
5. This value applies for one 60-Hz half sine wave when the device is operating at (or below) rated values of peak reverse blocking voltage and anode forward current. Surge may be repeated after the device has returned to original thermal equilibrium.

†Trademark of Texas Instruments.

TYPES TIC44, TIC45, TIC46, TIC47
P-N-P-N PLANAR SILICON REVERSE-BLOCKING TRIODE THYRISTORS

PARAMETER MEASUREMENT INFORMATION

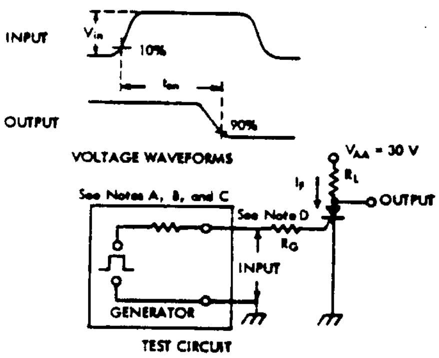


FIGURE 1 — TURN-ON TIME

NOTES: A. V_{in} is measured with gate and cathode terminals connected as shown and anode terminal open.

B. The input waveform of Figure 1 has the following characteristics: $t_r \leq 40$ ns, $t_p \geq 20$ μs.

C. Waveforms are monitored on an oscilloscope with the following characteristics: $t_r \leq 14$ ns, $R_{in} \geq 10$ MΩ, $C_{in} \leq 12$ pF.

D. R_G includes the total resistance of the generator and the external resistor.

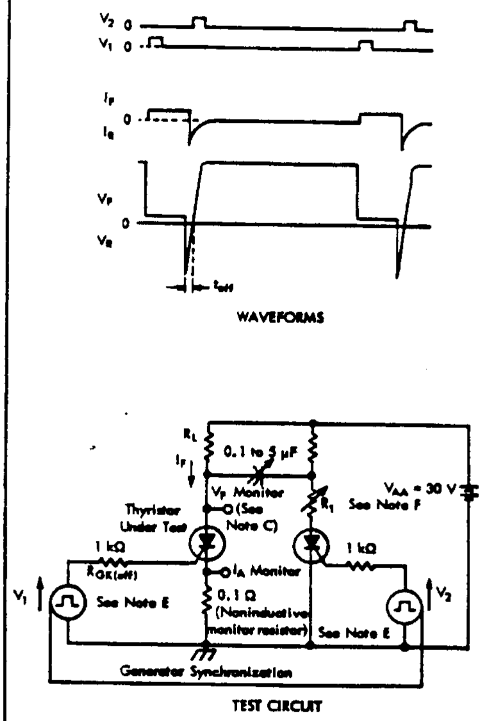


FIGURE 2 — COMMUTATING TURN-OFF TIME

NOTES: E. Pulse generators for V_1 and V_2 are synchronized to provide an anode current waveform with the following characteristics: t_p = 50 to 300 μs, duty cycle = 1%. The pulse widths of V_1 and V_2 are $\geq$ 10 μs.

F. Resistor R_1 is adjusted for I_R = 1 A.

T2300, T2301, T2302 Series

File Number **911**

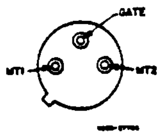
2.5-A Sensitive-Gate Silicon Triacs

Modified TO-205 Package for AC Power Switching

Features:

- *800V, 125 Deg. C T_J Operating*
- *High dv/dt and di/dt Capability*
- *Low Switching Losses*
- *High Pulse Current Capability*
- *Low Forward and Reverse Leakage*
- *Sipos Oxide Glass Multilayer Passivation System*
- *Advanced Unisurface Construction*
- *Precise Ion Implanted Diffusion Source*

TERMINAL DESIGNATIONS



Modified TO-205

The RCA-T2300, T2301, T2302, series triacs are gate-controlled full-wave silicon ac switches that are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

The gate sensitivity of these triacs permits the use of economical transistorized control circuits and enhances their use in low-power phase-control and load-switching applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

3 mA Gate	**T2300F**	**T2300A**	**T2300B**	**T2300D**	**T2300M**	**T2300N**	
4 mA Gate	**T2301F**	**T2301A**	**T2301B**	**T2301D**	**T2301M**	**T2301N**	
10 mA Gate	**T2302F**	**T2302A**	**T2302B**	**T2302D**	**T2302M**	**T2302N**	
V_{DROM}▲: T_J = −40 to 125°C	50	100	200	400	600	800	V
$I_{T(RMS)}$: T_C = 95°C			2.5				A
For other conditions			See Figs. 3,4,5				
I_{TSM}: For one cycle of applied principal voltage							
60 Hz (sinusoidal)			25				A
50 Hz (sinusoidal)			21				A
More than one cycle of applied principal voltage			See Figs. 6,7				
di/dt: $V_D = V_{DROM}$, I_G = 50 mA, t_r = 0.1 μs			100				A/μs
I^2t (At T_C shown for $I_{T(RMS)}$):							
t = 20 ms			4.3				A^2s
= 2.5 ms			2				A^2s
= 0.5 ms			1				A^2s
I_{GTM}•: For 1 μs max.			1				A
P_{GM}: Peak (For 1 μs max., $I_{GTM} \leq$ 1 A(peak)			10				W
$P_{G(AV)}$:							
T_C = 60°C			0.15				W
T_A = 25°C			0.05				W
T_{stg}■			−40 to 150				°C
T_C■			−40 to 125				°C
T_T■:							
During soldering for 10 s maximum at distance ≥ 1/16 in. (1.58 mm) from seating plane			225				°C

▲For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

•For either polarity of gate voltage (V_G) with reference to main terminal 1.

■For temperature measurement reference point, see Dimensional Outlines.

T2300, T2301, T2302 Series

ELECTRICAL CHARACTERISTICS
At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	LIMITS FOR ALL TYPES Except as Specified Min.	Typ.	Max.	UNITS
I_{DROM}▲: Gate open, T_J = 125°C, V_{DROM} = Max. rated value	–	0.2	0.75	mA
V_{TM}▲: i_T=10 A(peak), T_C=25°C	–	1.7	2.2	V
I_{HO}▲: *(See Figs. 9 & 10)* Gate open, Initial principal current=150 mA (dc), v_D=12 V, T_C=25°C				
(T2300, T2301 series)	–	2	5	mA
(T2302 series)	–	7	15	mA
dv/dt (Commutating)▲ *(See Fig. 14)* v_D=V_{DROM}, $I_{T(RMS)}$=2.5 A, commutating di/dt=1.33 A/ms, gate unenergized, T_C= 70°C	0.5	–	–	V/µs
dv/dt (Off-state)▲: v_D=V_{DROM}, exponential voltage rise, gate open,				
T_c = 115°C (T2300, T2301 series)	3	5	–	V/µs
T_c = 125°C (T2302 series)	6	10	–	V/µs
I_{GT}▲●: *(See Figs. 11 & 12)* v_D=12 V dc, R_L=30 Ω, T_C=25°C				
Mode / V_{MT2} / V_G				
I+ positive positive				
T2300 series	–	1	3	mA
T2301 series	–	1	4	mA
T2302 series	–	3.5	10	mA
III− negative negative				
T2300 series	–	1	3	mA
T2301 series	–	1	4	mA
T2302 series	–	3.5	10	mA
I− positive negative				
T2300 series	–	2	3	mA
T2301 series	–	2	4	mA
T2302 series	–	7	10	mA
III+ negative positive				
T2300 series	–	2	3	mA
T2301 series	–	2	4	mA
T2302 series	–	7	10	mA
V_{GT}▲●: *(See Fig. 13)*				
v_D=12 V dc, R_L=30 Ω, T_C=25°C	–	1	2.2	V
v_D=V_{DROM}, R_L=125 Ω, T_c = 125°C	0.15	–	–	V
t_{gt}: *(See Fig. 16)* v_D=V_{DROM}, I_{GT}=60 mA, t_r=0.1 µs, i_T=10 A(peak), T_C=25°C	–	1.8	2.5	µs
$R_{\theta JC}$: Steady-state	–	–	8.5	°C/W
$R_{\theta JA}$: (T2300 Series)	–	–	150	°C/W

▲For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

●For either polarity of gate voltage (V_G) with reference to main terminal 1.

ElettronicaVeneta

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