4 quadrant
operation
Forward &
Reverse
- Motoring &
- Braking.

T1 D1 Va T3 D3
Vdc
T2 D2 R L T4 D4

M

a

Vdc

Forward Motoring

b

ia
t
Va

Reverse Braking

c

Vdc
ia
t
Va
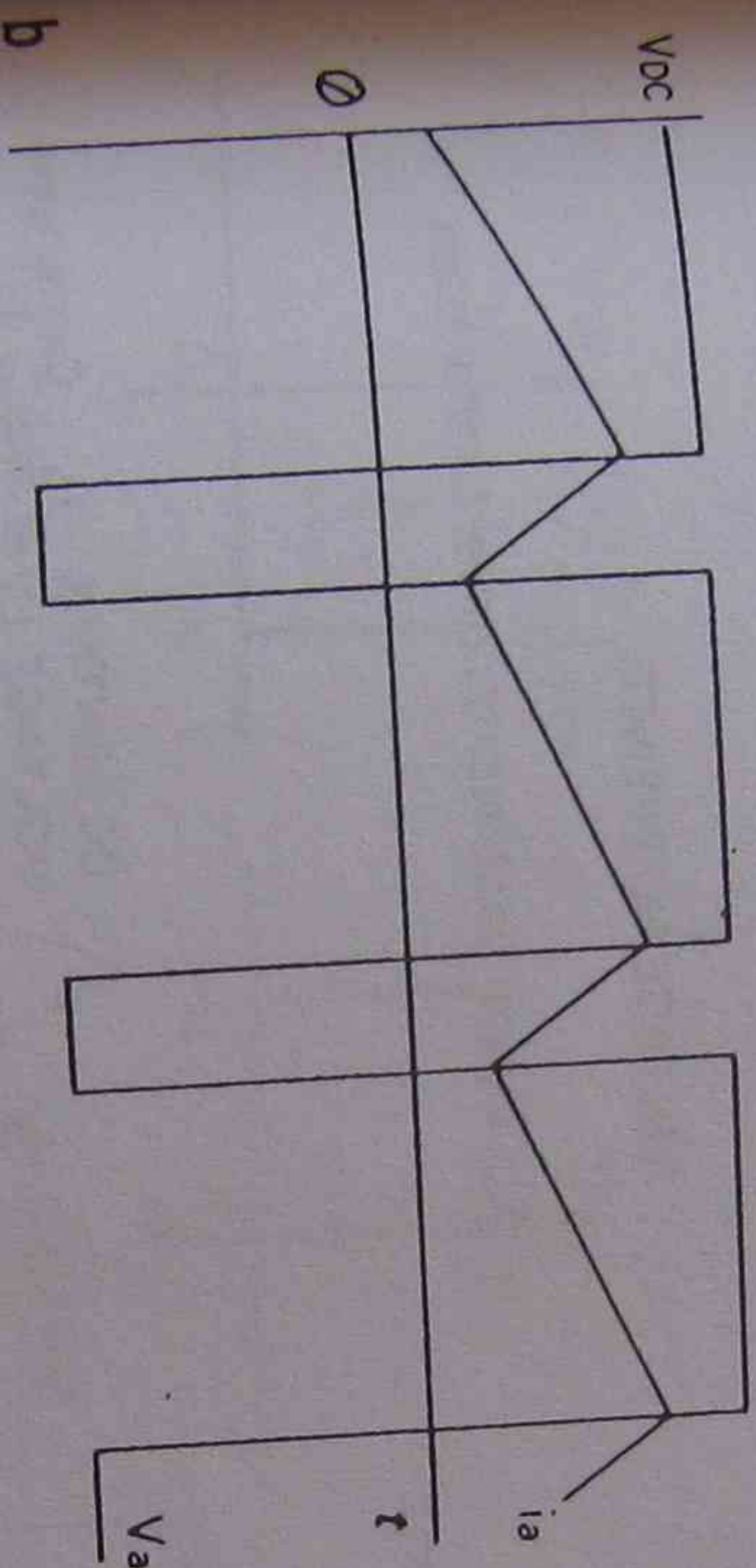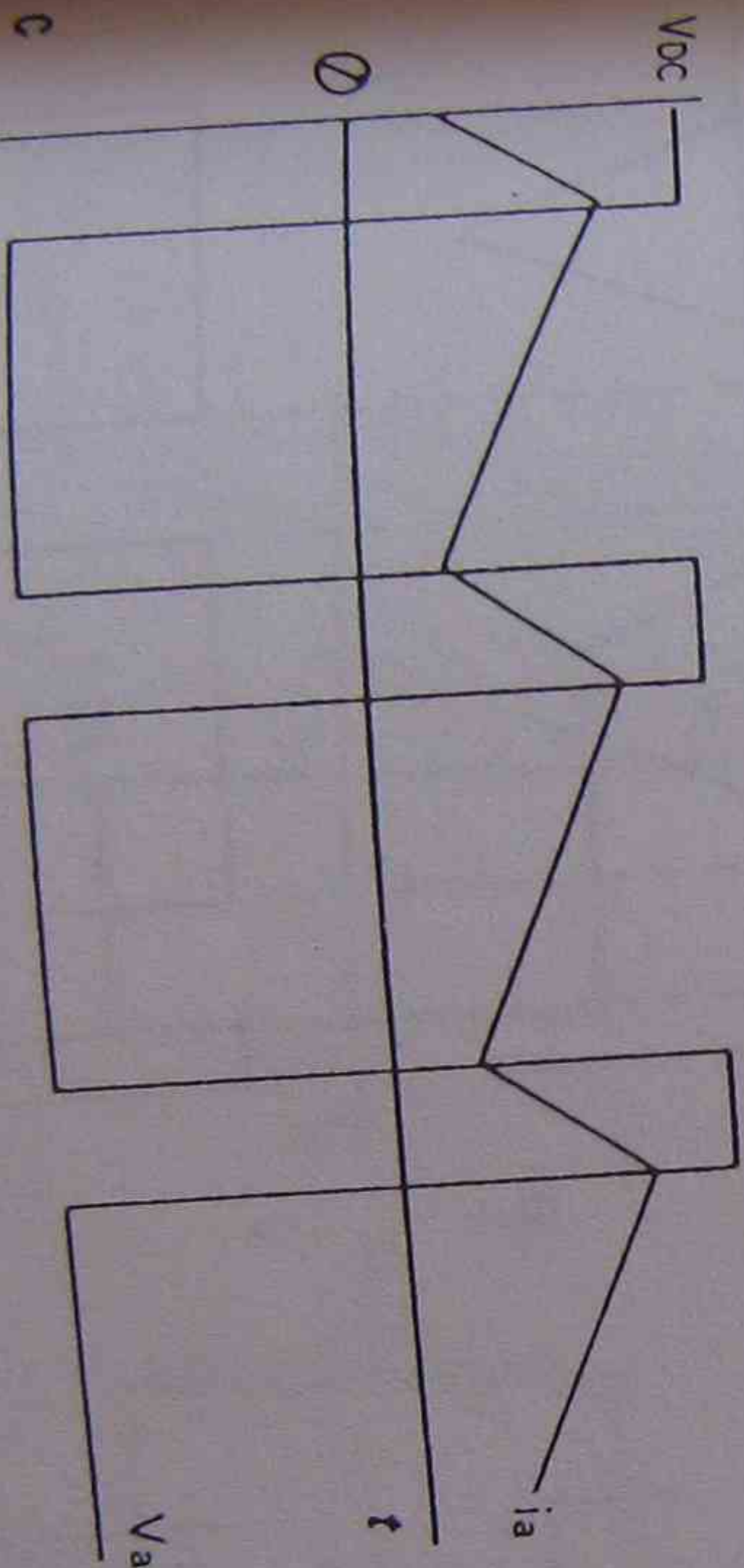
4 Four-quadrant dc dc converter; **a** circuit; **b** forward motoring; **c** reverse braking.

Sydney Institute of Technology

School of Electrotechnology

Learners Theory

Work Book

Module NE76

A.C. Motor Control
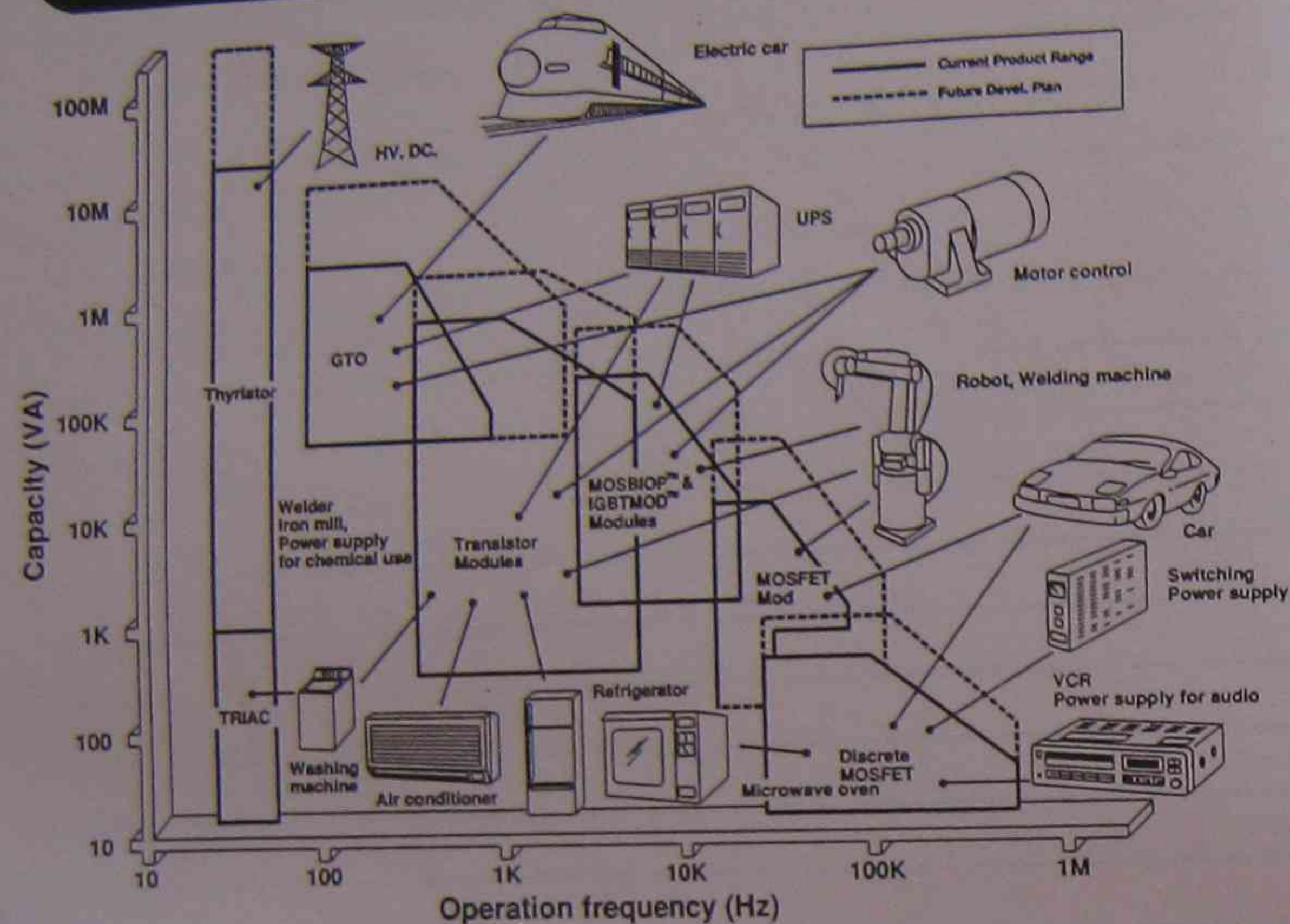
Area

Topic

Session No. 3·1

Figure 1-6 Applications of power devices. (Courtesy of Powerex, Inc.)

TABLE 1.2 RATINGS OF POWER SEMICONDUCTOR DEVICES

Type		Voltage/current rating	Upper frequency (Hz)	Switching time (μs)	On-state resistance (Ω)
Diodes	General purpose	5000 V/5000 A	1k	100	0.16m
	High speed	3000 V/1000 A	10k	2–5	1m
	Schottky	40 V/60 A	20k	0.23	10m
Forced-turned-off thyristors	Reverse blocking	5000 V/5000 A	1k	200	0.25m
	High speed	1200 V/1500 A	10k	20	0.47m
	Reverse blocking	2500 V/400 A	5k	40	2.16m
	Reverse conducting	2500 V/1000 A	5k	40	2.1m
	GATT	1200 V/400 A	20k	8	2.24m
	Light triggered	6000 V/1500 A	400	200–400	0.53m
TRIACs		1200 V/300 A	400	200–400	3.57m
Self-turned-off thyristors	GTO	4500 V/3000 A	10k	15	2.5m
	SITH	4000 V/2200 A	20k	6.5	5.75m
Power transistors	Single	400 V/250 A	20k	9	4m
		400 V/40 A	20k	6	31m
		630 V/50 A	25k	1.7	15m
	Darlington	1200 V/400 A	10k	30	10m
SITs		1200 V/300 A	100k	0.55	1.2
Power MOSFETS	Single	500 V/8.6 A	100k	0.7	0.6
		1000 V/4.7 A	100k	0.9	2
IGBTs	Single	500 V/50 A	100k	0.6	0.4m
MCTs	Single	1200 V/400 A	20k	2.3	60m
		600 V/60 A	20k	2.2	18m

TABLE 1.3 CHARACTERISTICS AND SYMBOLS OF SOME POWER DEVICES

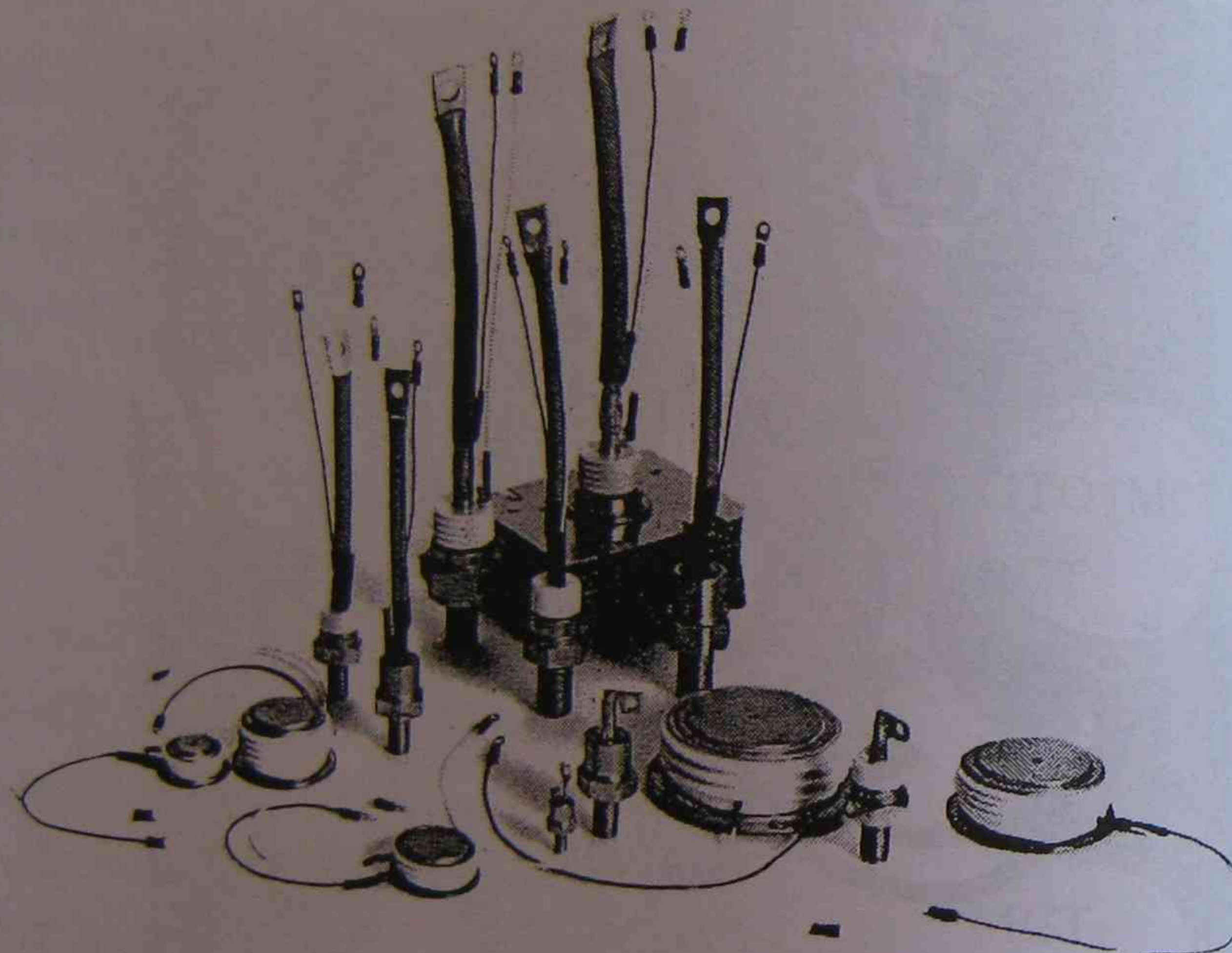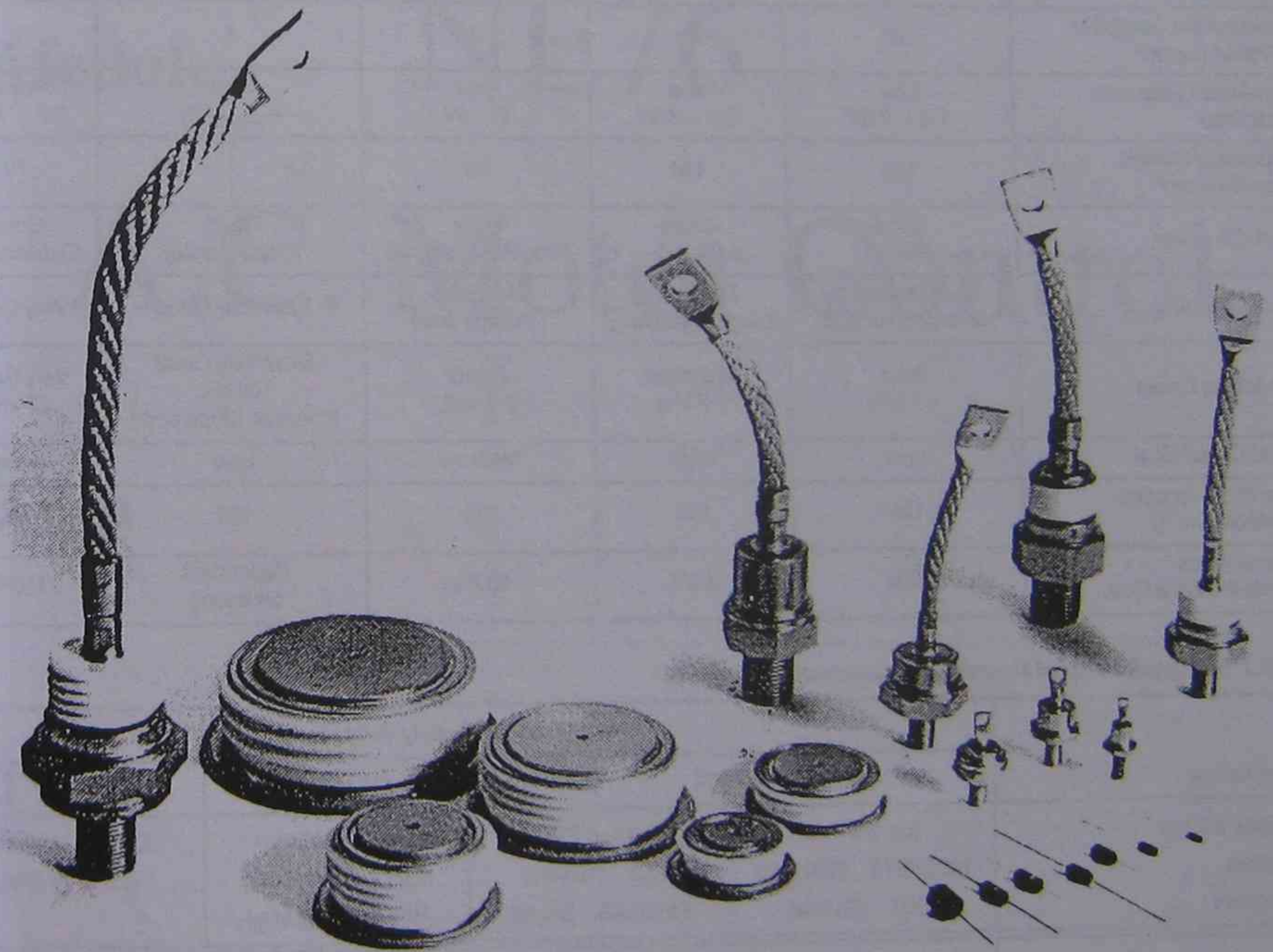| Devices	Symbols	Characteristics
Diode		
Thyristor		
SITH		
GTO		
MCT		
TRIAC		
LASCR		
NPN BJT		
IGBT		
N-Channel MOSFET		
SIT		

Figure 1-3 Various general-purpose diode configurations. (Courtesy of Powerex, Inc.)

Sydney Institute of Technology

School of Electrotechnology

Learners Theory
## Work Book

Module   NE76

A.C. Motor Control

Area

Topic

The devices in the following converters are used to illustrate the basic princi-ples only. The switching action of a converter can be performed by more than one device. The choice of a particular device will depend on the voltage, current, and speed requirements of the converter.

Rectifiers.   A diode rectifier circuit converts ac voltage into a fixed dc voltage and is shown in Fig. 1-8. The input voltage to the rectifier could be either single-phase or three-phase.
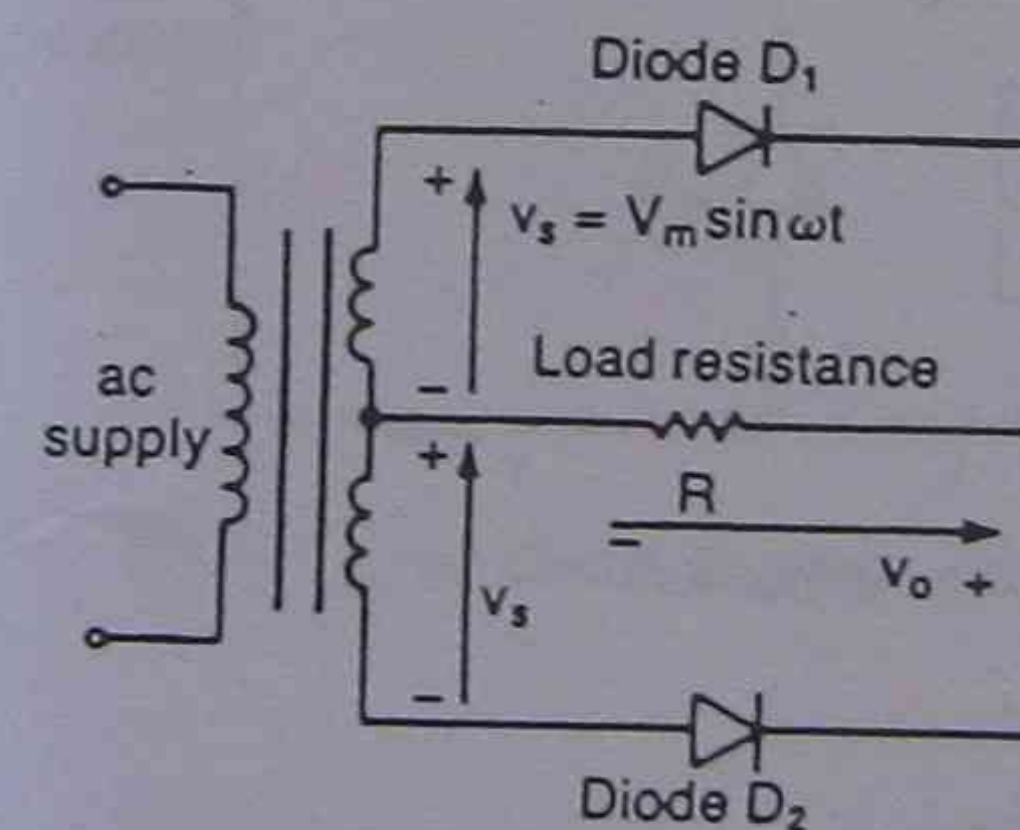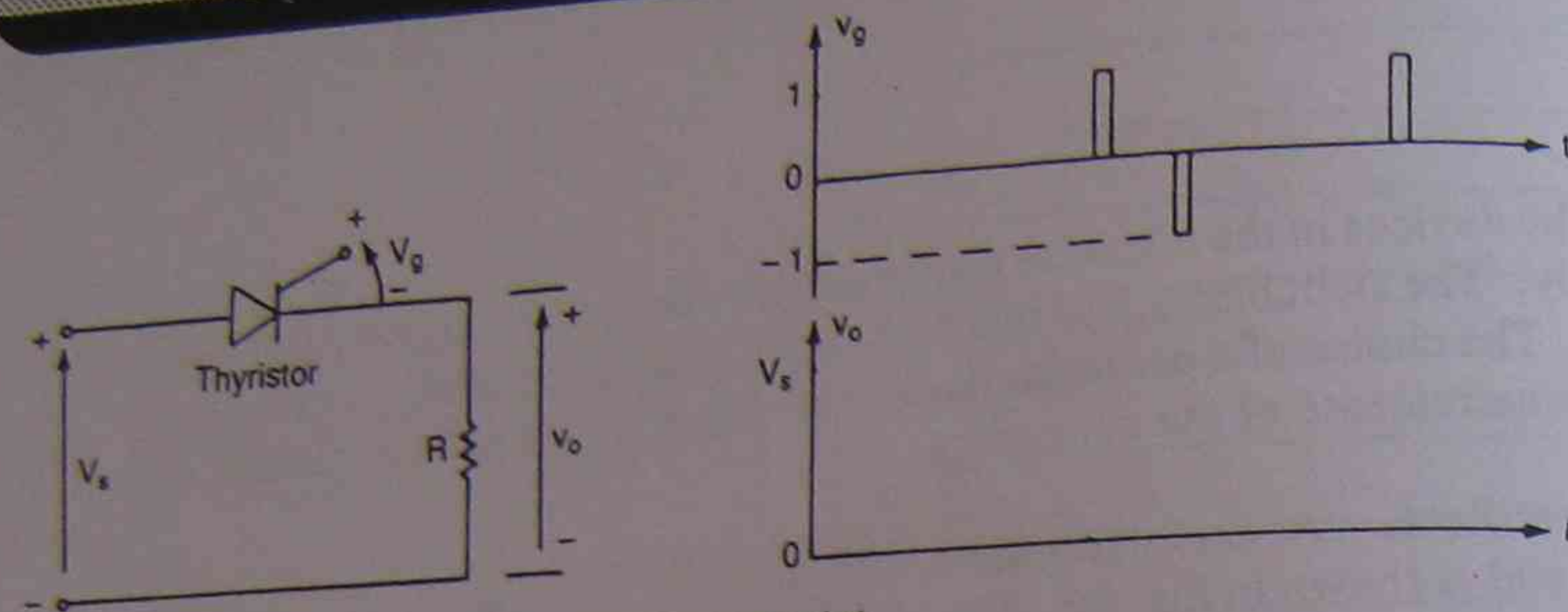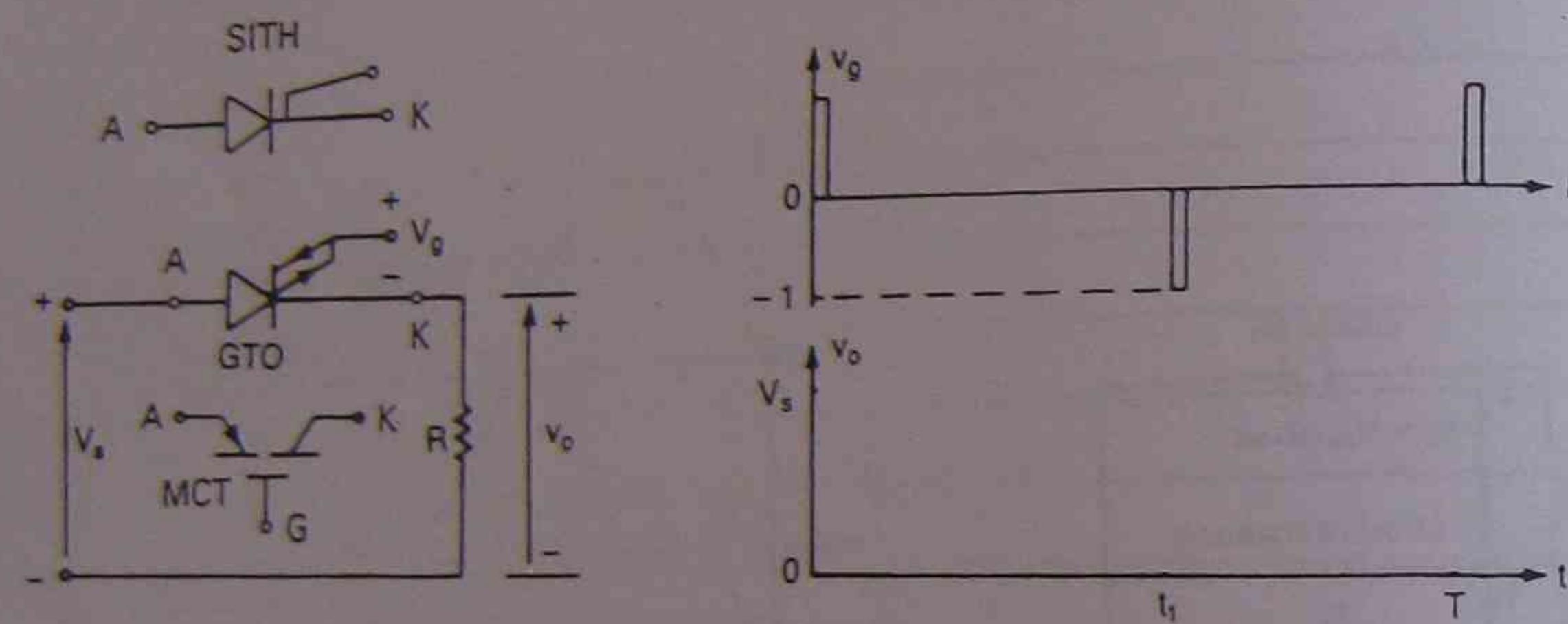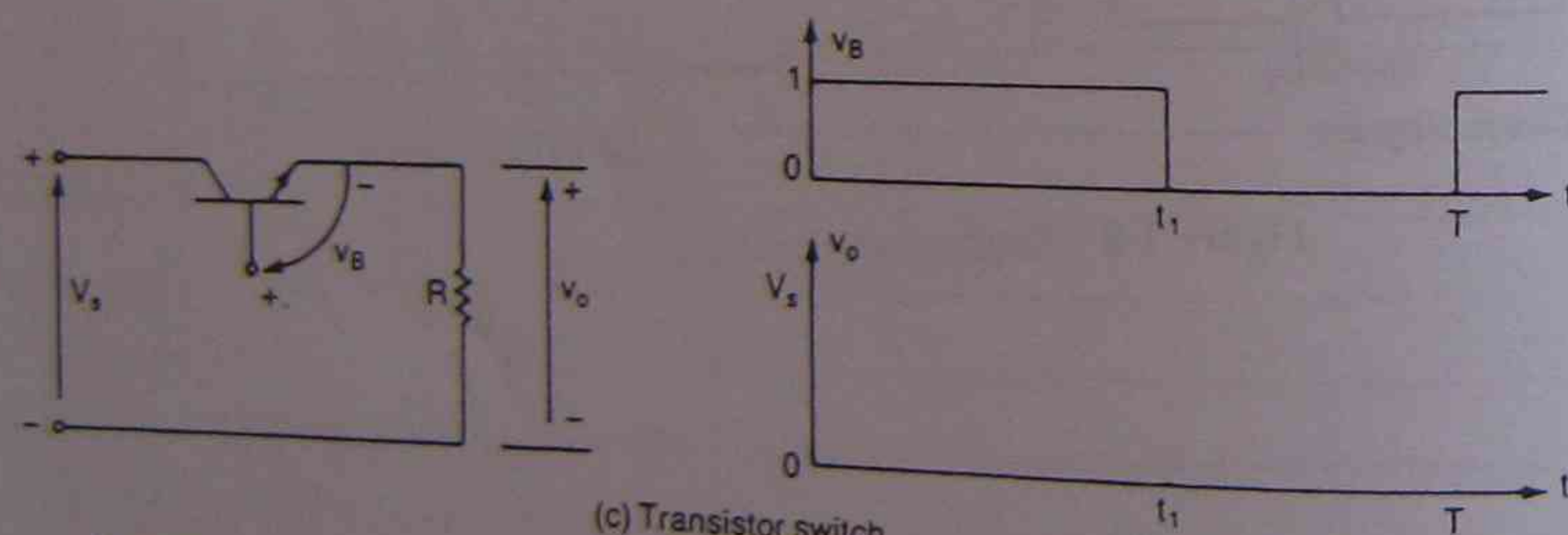

(a) Circuit diagram
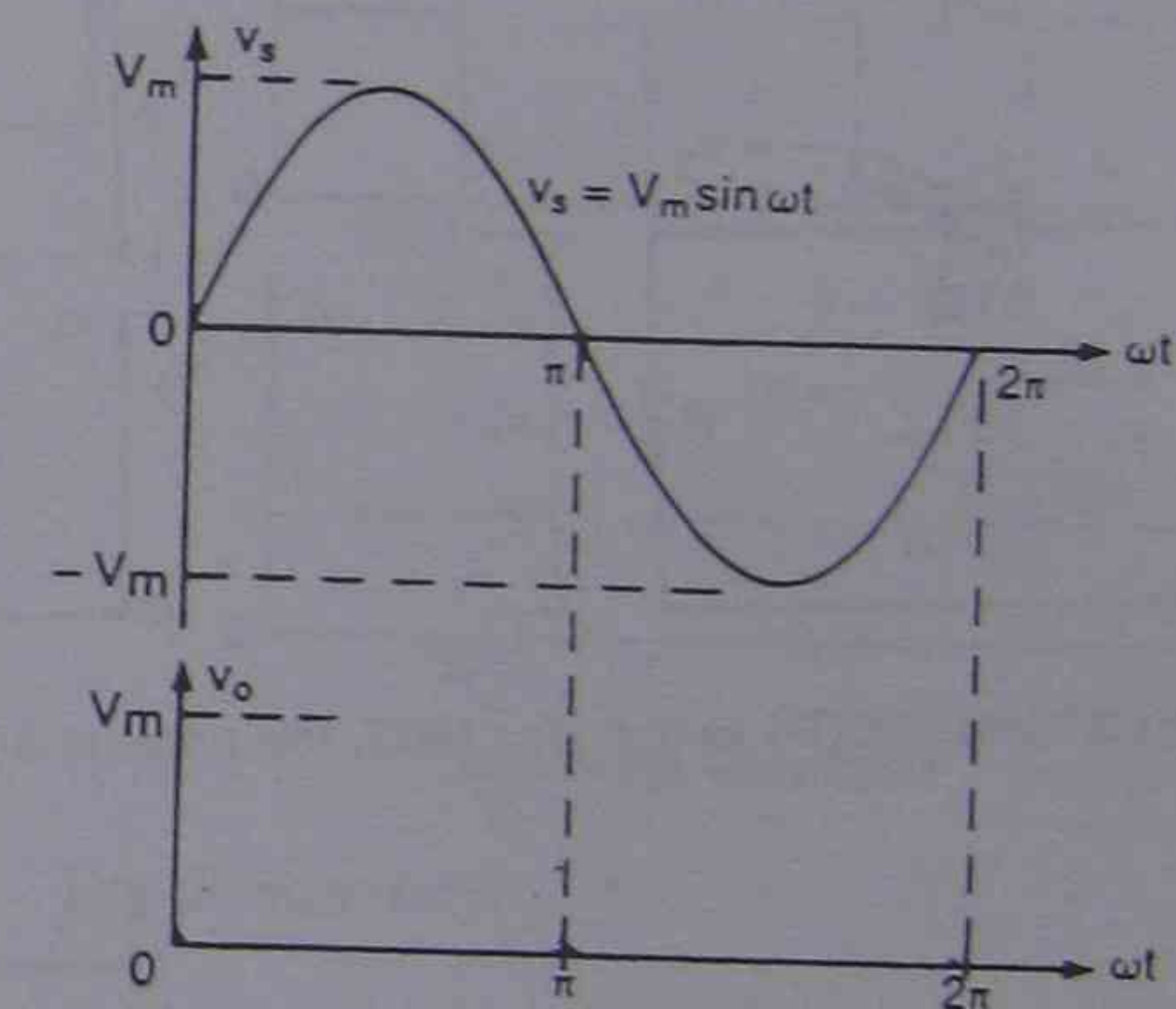
(b) Voltage waveforms

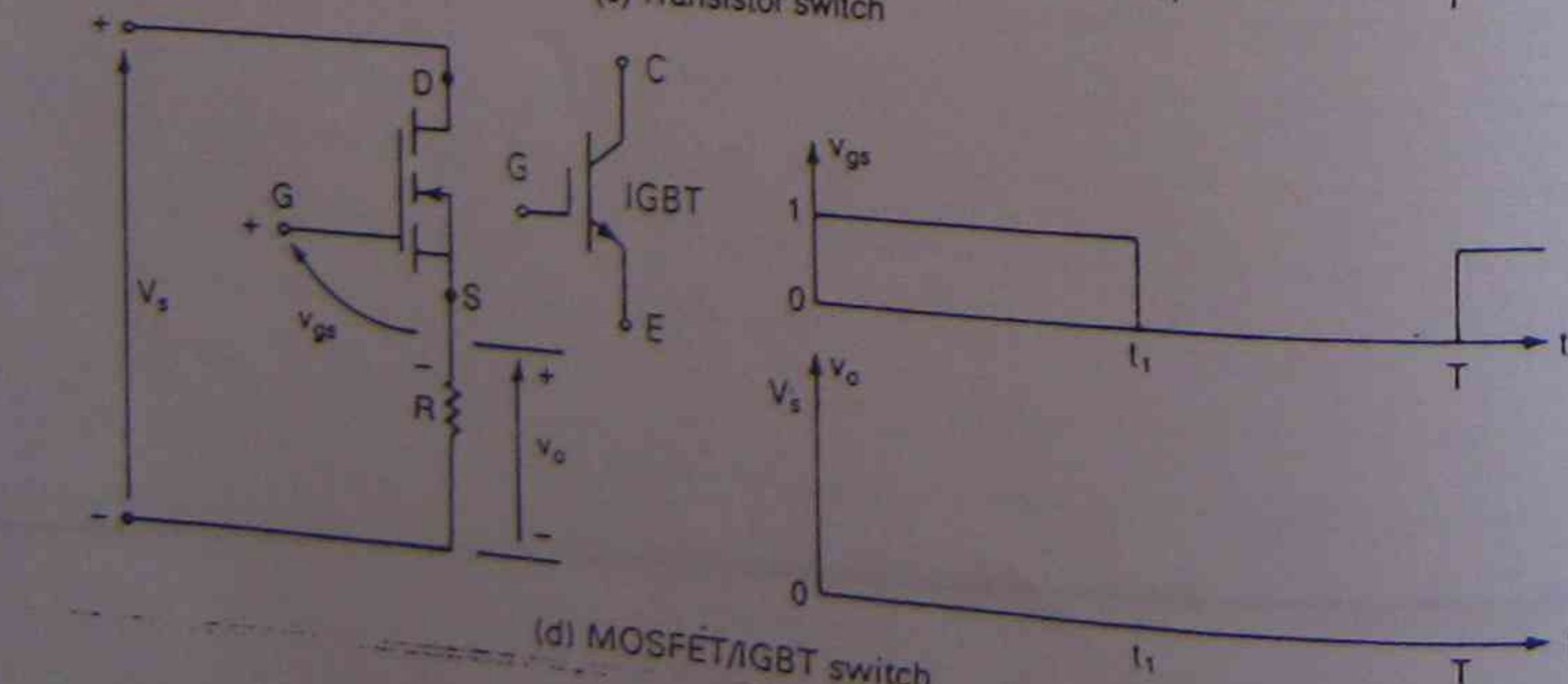**Figure 1-8**   Single-phase rectifier circuit.

(a) Thyristor switch

(b) GTO/MCT/SITH switch (For MCT, the polarity of V_g is reversed as shown

(c) Transistor switch

(d) MOSFET/IGBT switch

Dc–dc converters. A dc–dc converter is also known as a *chopper* or *switching regulator* and a transistor chopper is shown in Fig. 1-11. The average output voltage is controlled by varying the conduction time t, of transistor Q_1. If T is the chopping period, then $t_1 = \delta T$. δ is called as the *duty cycle* of the chopper.
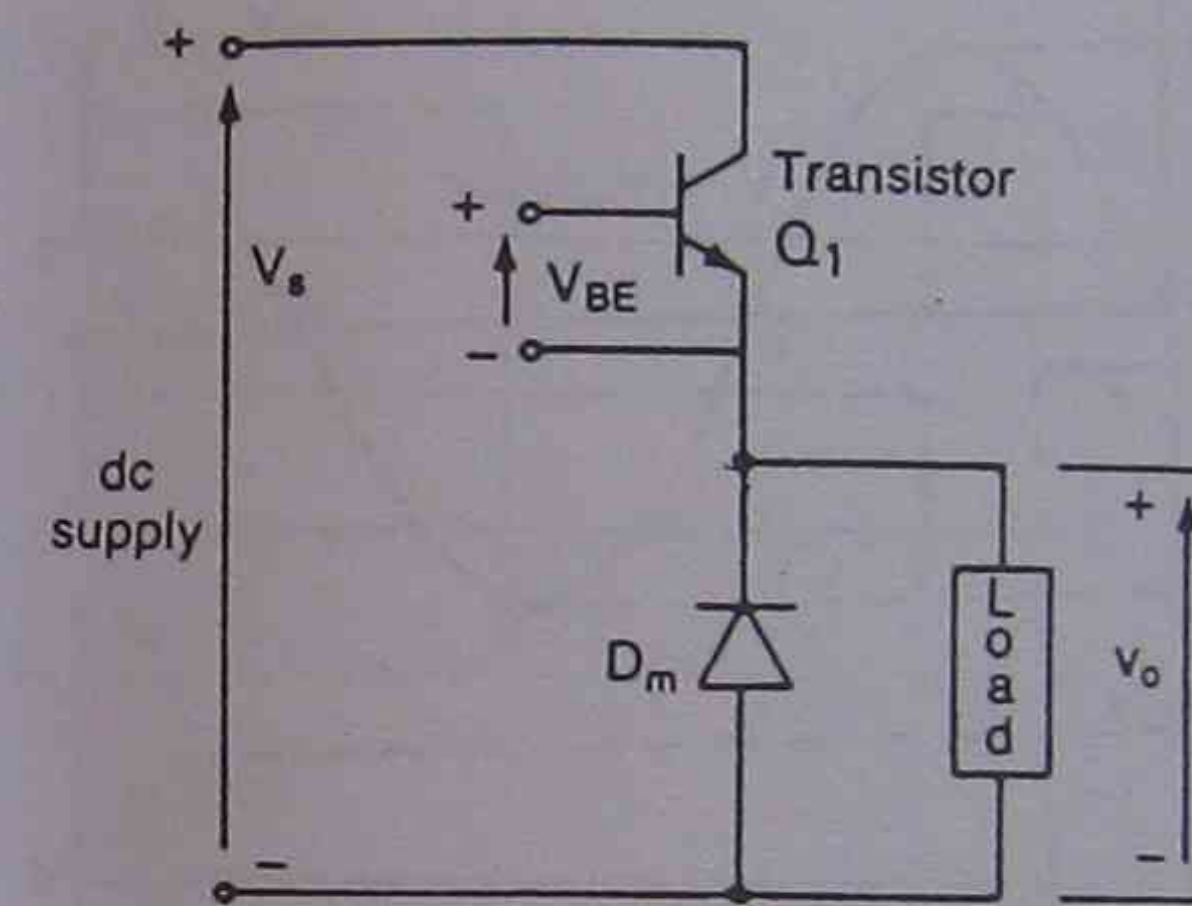
(a) Circuit diagram
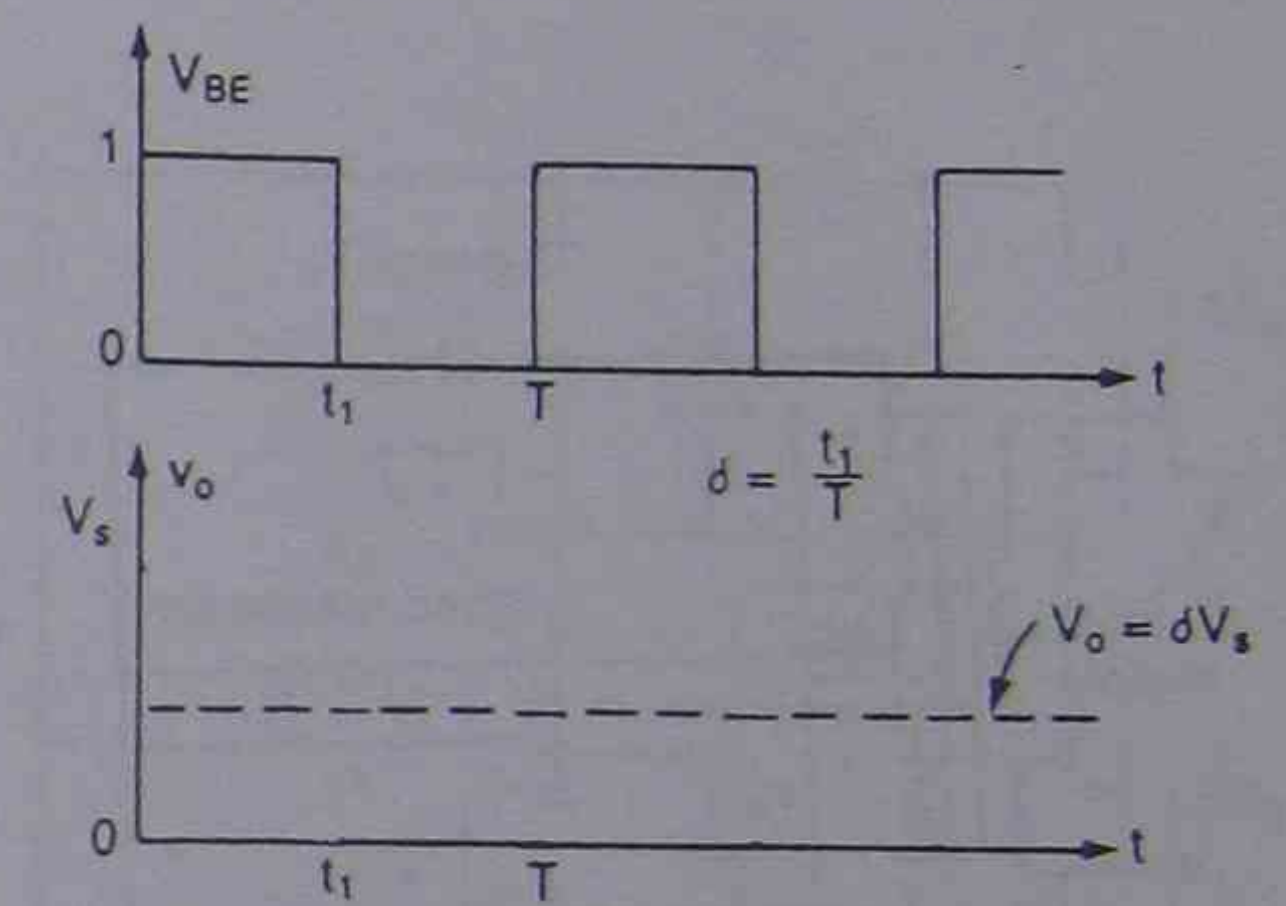
(b) Voltage waveforms

Figure 1-11 Dc–dc converter.

Ac–dc converters. A single-phase converter with two natural commutated thyristors is shown in Fig. 1-9. The average value of the output voltage can be controlled by varying the conduction time of thyristors or firing delay angle, α. The input could be a single or three-phase source. These converters are also known as *controlled rectifiers*.

Dc–ac converters. A dc–ac converter is also known as an *inverter*. A single-phase transistor inverter is shown in Fig. 1-12. If transistors M_1 and M_2 conduct for one-half period and M_3 and M_4 conduct for the other half, the output voltage is of alternating form. The output voltage can be controlled by varying the conduction time of transistors.
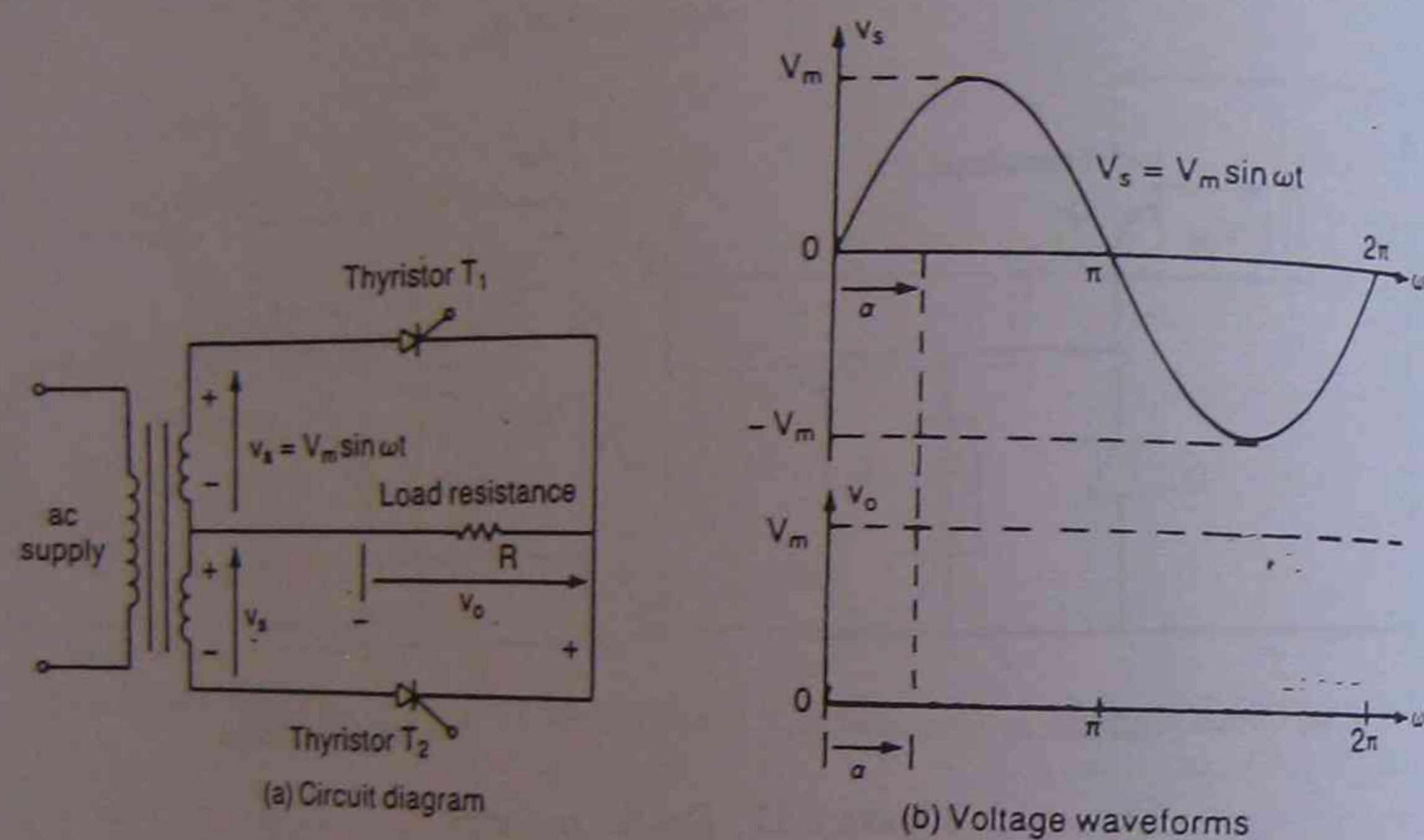
Figure 1-9   Single-phase ac–dc converter.

Figure 1-12   Single-phase dc–ac converter.

Ac–ac converters. These converters are used to obtain a variable ac output voltage from a fixed ac source and a single-phase converter with a TRIAC is shown in Fig. 1-10. The output voltage is co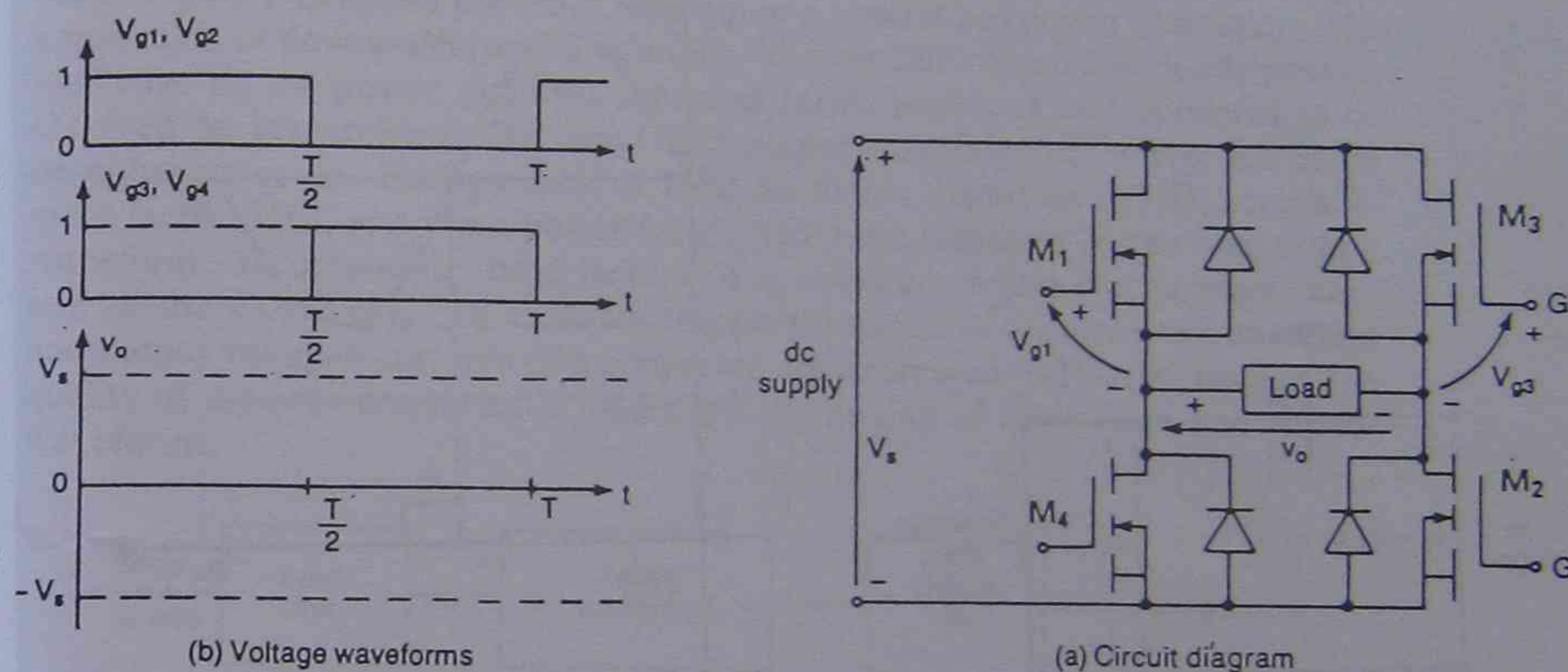ntrolled by varying the conduction time of a TRIAC or firing delay angle, α. These types of converters are also known as *ac voltage controllers*.
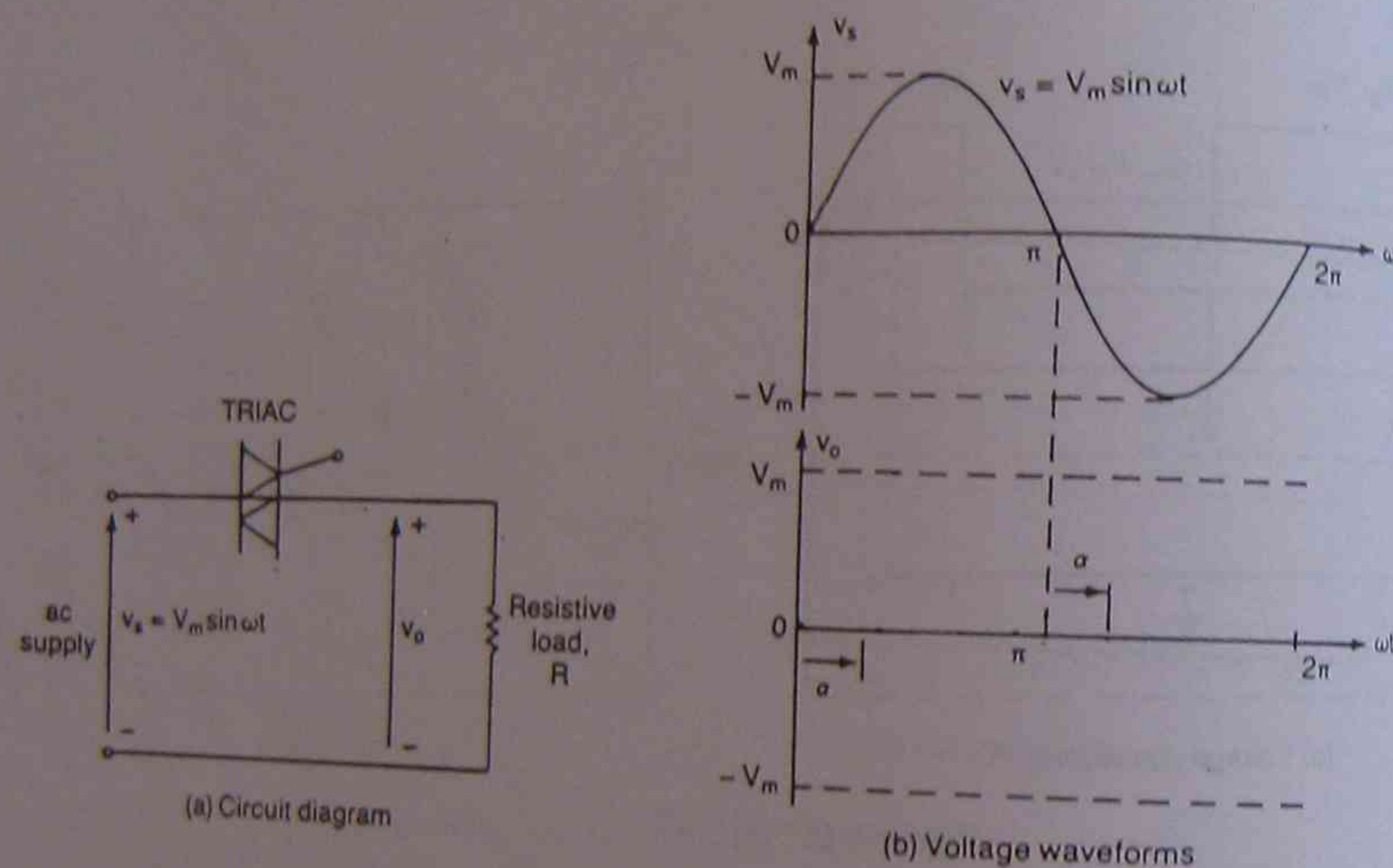

(a) Circuit diagram

(b) Voltage waveforms

Figure 1-10 Single-phase ac–ac converter.

The operations of the power converters are based mainly on the switching of power semiconductor devices; and as a result the converters introduce current and voltage harmonics into the supply system and on the output of the converters. These can cause problems of distortion of the output voltage, harmonic generation into the supply system, and interference with the communication and signaling circuits. It is normally necessary to introduce filters on the input and output of a converter system to reduce the harmonic level to an acceptable magnitude. Figure 1-13 shows the block diagram of a generalized power converter. The application of power electronics to supply the sensitive electronic loads poses a challenge on the power quality issues and raises problems and concerns to be resolved by researchers. The input and output quantities of converters could be either ac or dc. Factors such as total harmonic distortion (THD), displacement factor (HF), and input power factor (IPF) are measures of the quality of a waveform. To determine these factors, it is required to find the harmonic content of the waveforms. To evaluate the performance of a converter, the input and output voltages/currents of a converter are expressed in Fourier series. The quality of a power converter is judged by the quality of its voltage and current waveforms.
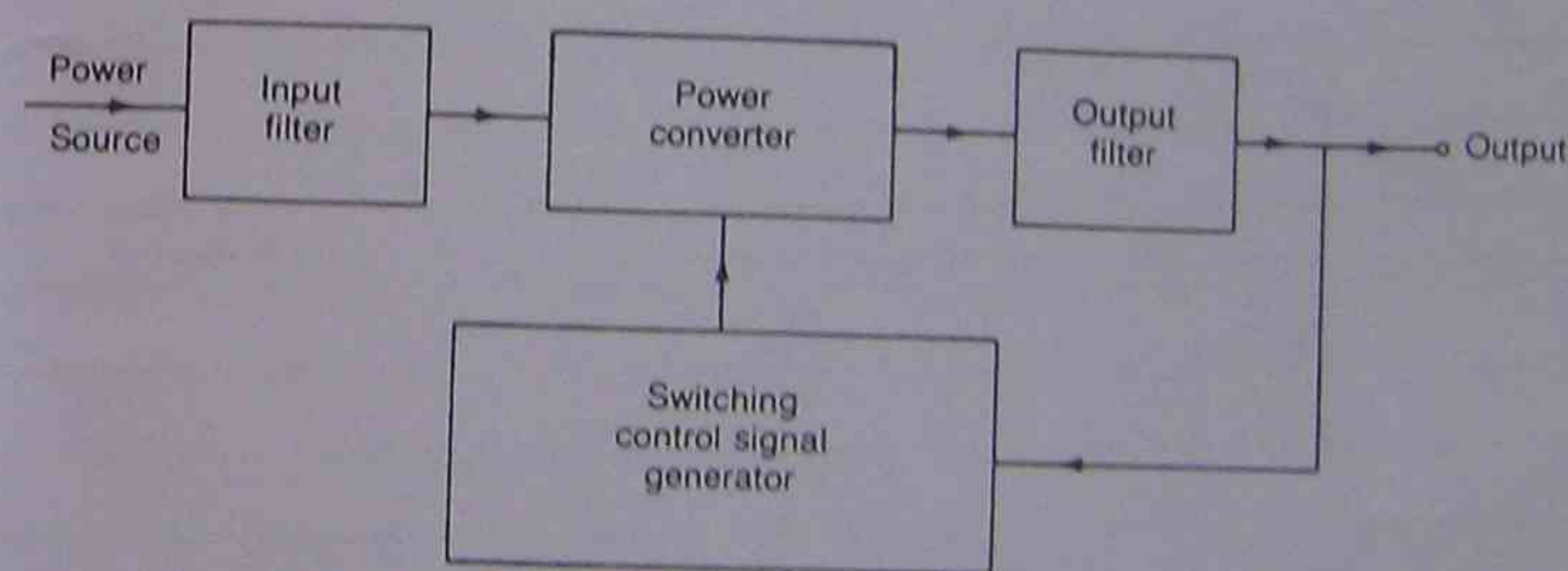

Figure 1-13 Generalized power converter system.

The control strategy for the power converters plays an important part on the harmonic generation and output waveform distortion, and can be aimed to minimize or reduce these problems. The power converters can cause radio-frequency interference due to electromagnetic radiation and the gating circuits may generate erroneous signals. This interference can be avoided by *grounded shielding*.

Sydney Institute of Technology

School of Electrotechnology
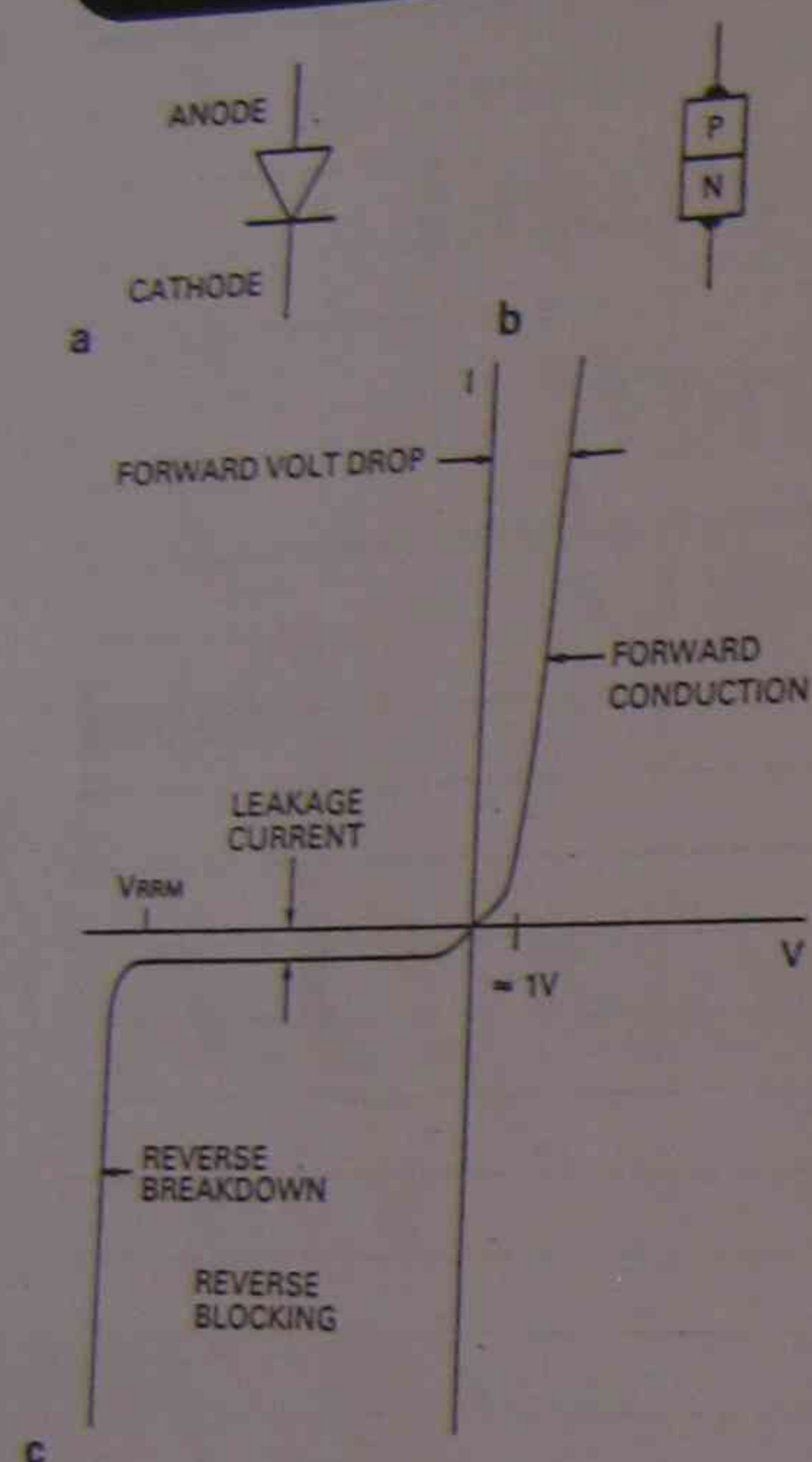
Learners Theory
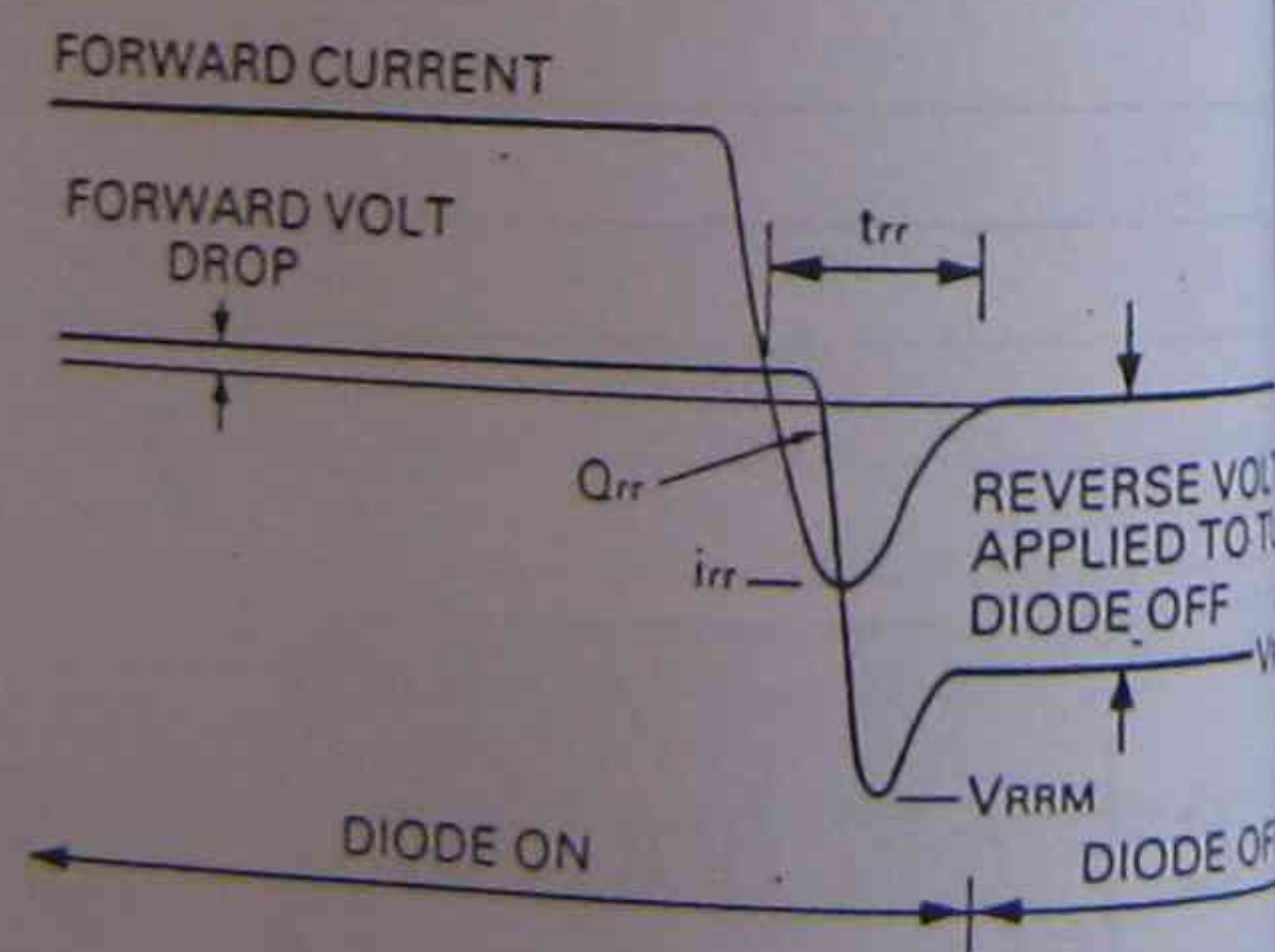
Work Book

Module   **NE76**

A.C. Motor Control

Area

Topic

ANODE

CATHODE

a

b

P
N

FORWARD VOLT DROP

FORWARD CONDUCTION

LEAKAGE CURRENT

V_{RRM}

$\approx 1V$

V

REVERSE BREAKDOWN

REVERSE BLOCKING

c

1 Diode: **a** circuit symbol; **b** structure; **c** characteristic.

FORWARD CURRENT

FORWARD VOLT DROP

t_{rr}

Q_{rr}

i_{rr}

REVERSE VOL APPLIED TO T DIODE OFF

V_{RRM}

DIODE ON

DIODE OF

2 Switching characteristics of a diode

20.4   POWER DIODES

There are a number of diodes designed specifically to handle the high-power and high-temperature demands of some applications. The most frequent use of power diodes occurs in the rectification process, in which ac signals (having zero average value) are converted to ones having an average or dc level. As noted in Chapter 2, when used in this capacity, diodes are normally referred to as *rectifiers*.

The majority of the power diodes are constructed using silicon because of its higher current, temperature, and PIV ratings. The higher current demands require that the junction area be larger, to ensure that there is a low forward diode resistance. If the forward resistance were too large, the I^2R losses would be excessive. The current capability of power diodes can be increased by placing two or more in parallel and the PIV rating can be increased by stacking the diodes in series.

Various types of power diodes and their current rating have been provided in Fig. 20.12a. The high temperatures resulting from the heavy current require, in many cases, that heat sinks be used to draw the heat away from the element. A few of the various types of heat sinks available are shown in Fig. 20.12b. If heat sinks are not employed, stud diodes are designed to be attached directly to the chassis, which in turn will act as the heat sink.
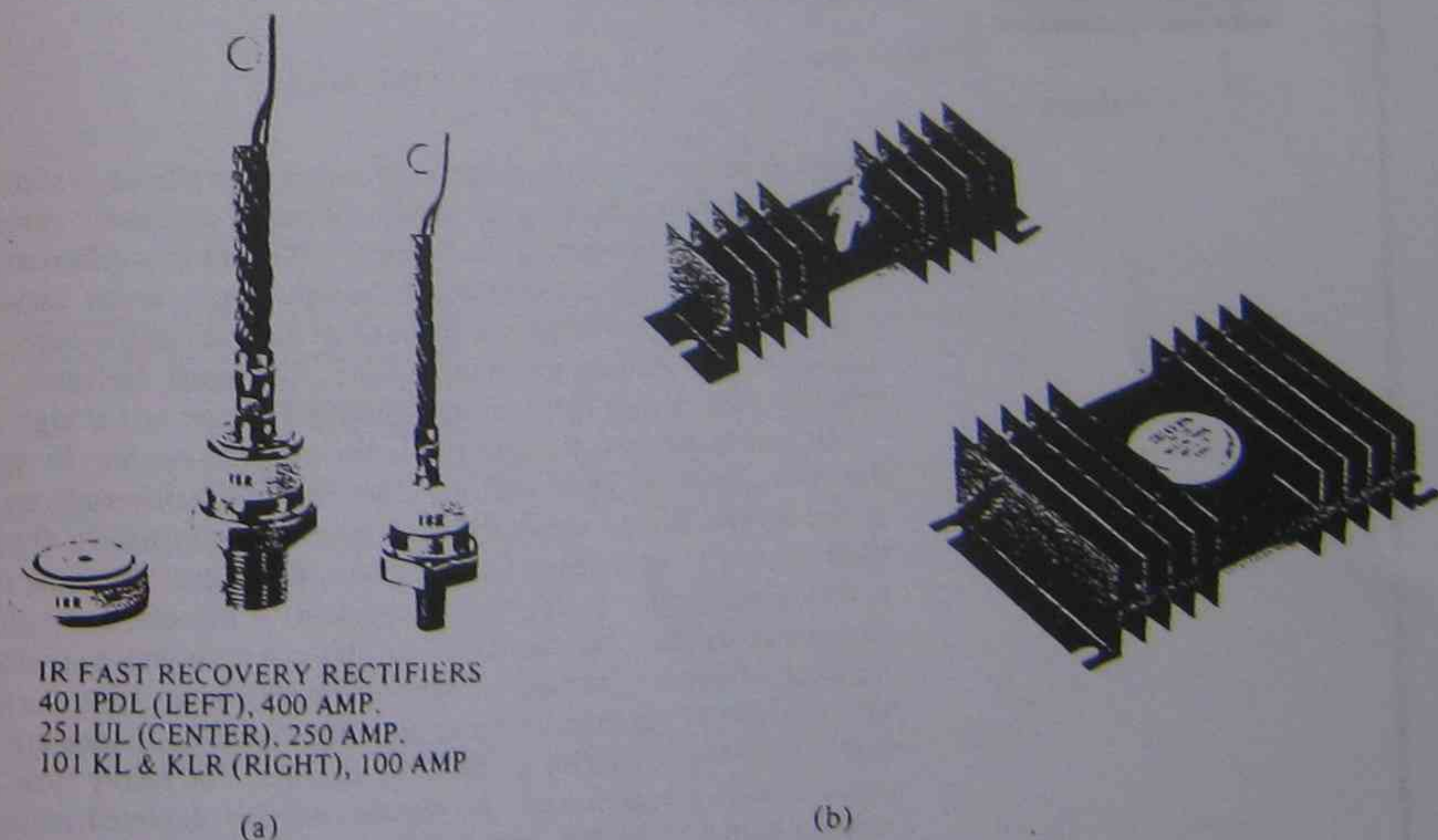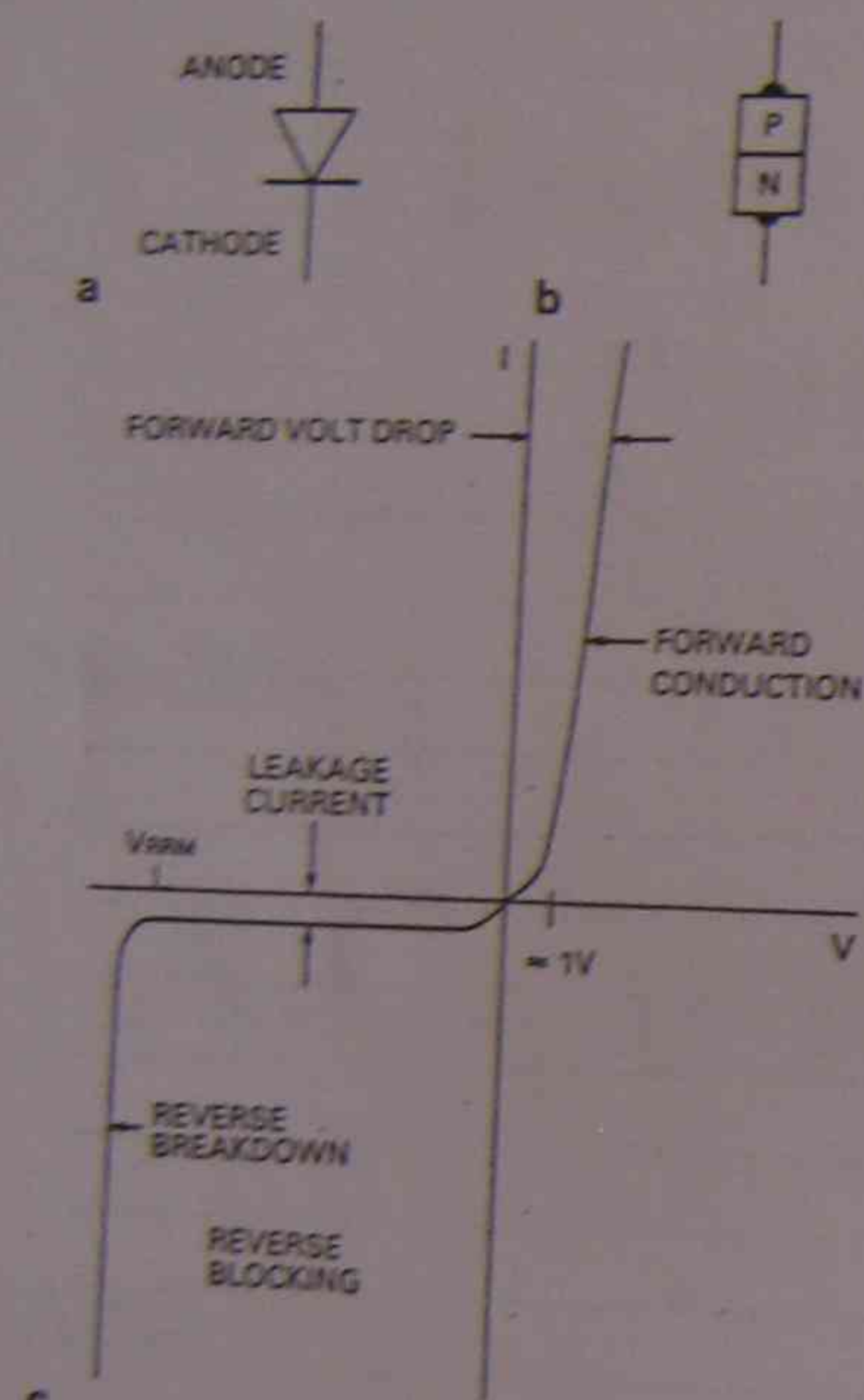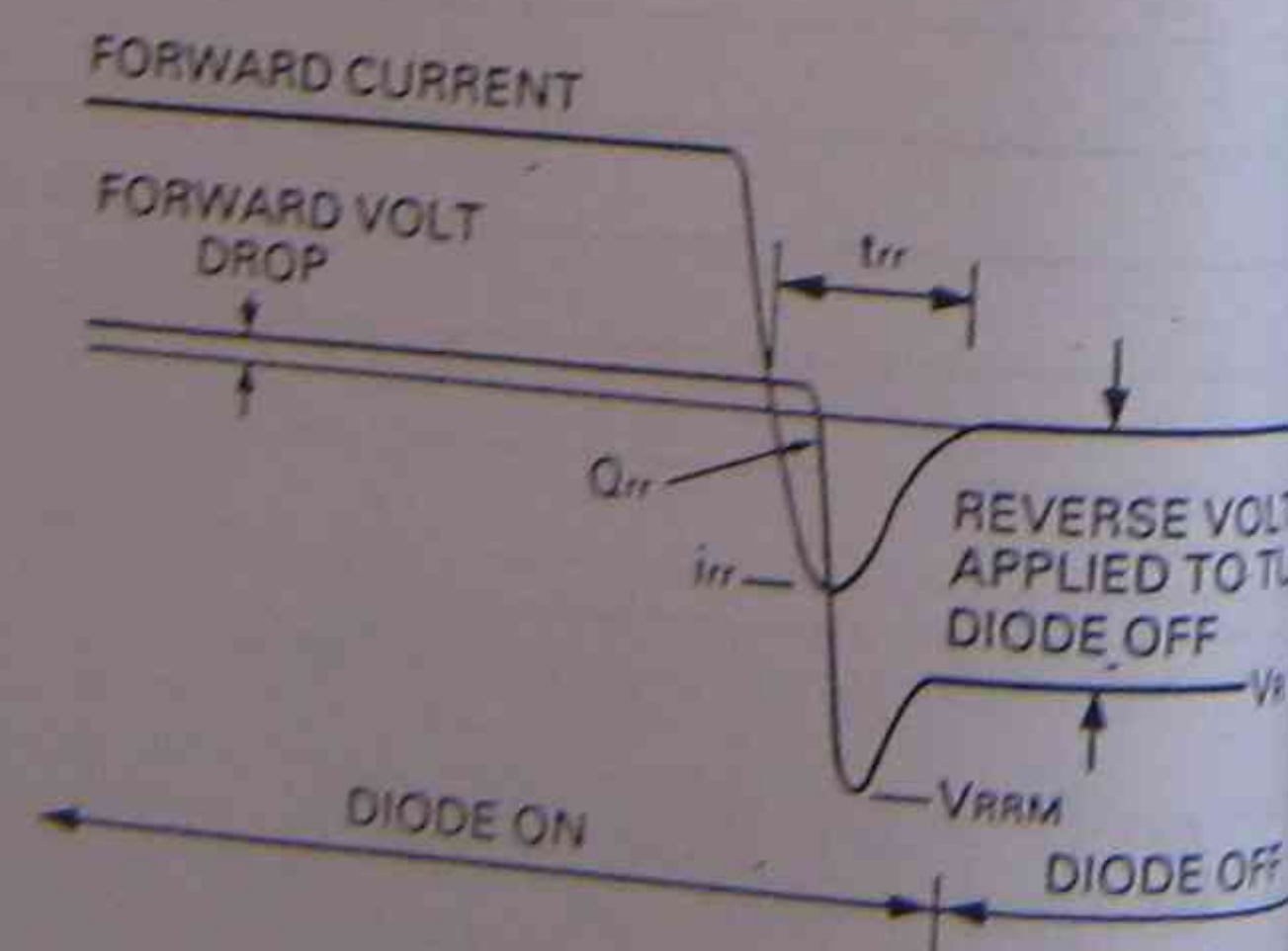

IR FAST RECOVERY RECTIFIERS
401 PDL (LEFT), 400 AMP.
251 UL (CENTER), 250 AMP.
101 KL & KLR (RIGHT), 100 AMP

(a)

(b)

Figure 20.12   Power diodes and heat sinks. (Courtesy International Rectifier Corporation.)

Left page figure

ANODE
CATHODE

P
N

a   b

FORWARD VOLT DROP

FORWARD
CONDUCTION

LEAKAGE
CURRENT

V_{RRM}

≈ 1V   V

REVERSE
BREAKDOWN

REVERSE
BLOCKING

c

1 Diode: **a** circuit symbol; **b** structure; **c** characteristic.

FORWARD CURRENT

FORWARD VOLT
DROP

t_{rr}

Q_{rr}

i_{rr}

REVERSE VOLT
APPLIED TO TURN
DIODE OFF

V_r

V_{RRM}

DIODE ON

DIODE OFF

2 Switching characteristics of a diode

2

20.4 POWER DIODES

There are a number of diodes designed specifically to handle the high-power and high-temperature demands of some applications. The most frequent use of power diodes occurs in the rectification process, in which ac signals (having zero average value) are converted to ones having an average or dc level. As noted in Chapter 2, when used in this capacity, diodes are normally referred to as *rectifiers*.

The majority of the power diodes are constructed using silicon because of its higher current, temperature, and PIV ratings. The higher current demands require that the junction area be larger, to ensure that there is a low forward diode resistance. If the forward resistance were too large, the I^2R losses would be excessive. The current capability of power diodes can be increased by placing two or more in parallel and the PIV rating can be increased by stacking the diodes in series.

Various types of power diodes and their current rating have been provided in Fig. 20.12a. The high temperatures resulting from the heavy current require, in many cases, that heat sinks be used to draw the heat away from the element. A few of the various types of heat sinks available are shown in Fig. 20.12b. If heat sinks are not employed, stud diodes are designed to be attached directly to the chassis, which in turn will act as the heat sink.
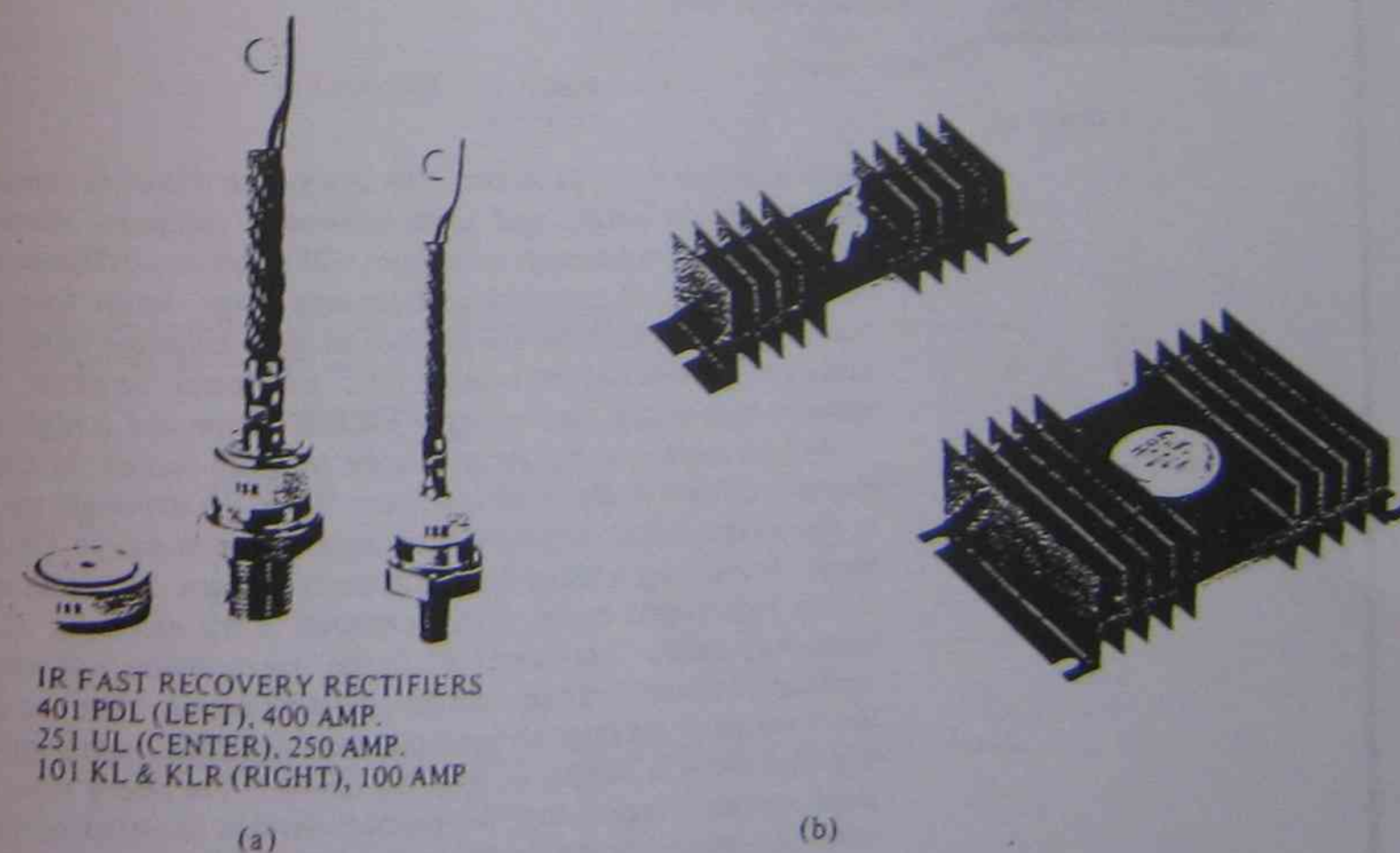

IR FAST RECOVERY RECTIFIERS
401 PDL (LEFT), 400 AMP.
251 UL (CENTER), 250 AMP.
101 KL & KLR (RIGHT), 100 AMP

(a)   (b)

Figure 20.12 Power diodes and heat sinks. (Courtesy International Rectifier Corporation.)

20.2 SCHOTTKY BARRIER (HOT-CARRIER) DIODES

In recent years there has been increasing interest in a two-terminal device referred to as a *Schottky-barrier*, *surface-barrier*, or *hot-carrier* diode. Its areas of application were first limited to the very high frequency range due to its quick response time (especially important at high frequencies) and a lower noise figure (a quantity of real importance in high-frequency applications). In recent years, however, it is appearing more and more in low-voltage/high-current power supplies and ac-to-dc converters. Other areas of application of the device include radar systems, Schottky TTL logic for computers, mixers and detectors in communication equipment, instrumentation, and analog-to-digital converters.

Its construction is quite different from the conventional *p-n* junction in that a metal-semiconductor junction is created such as shown in Fig. 20.1. The semicon-
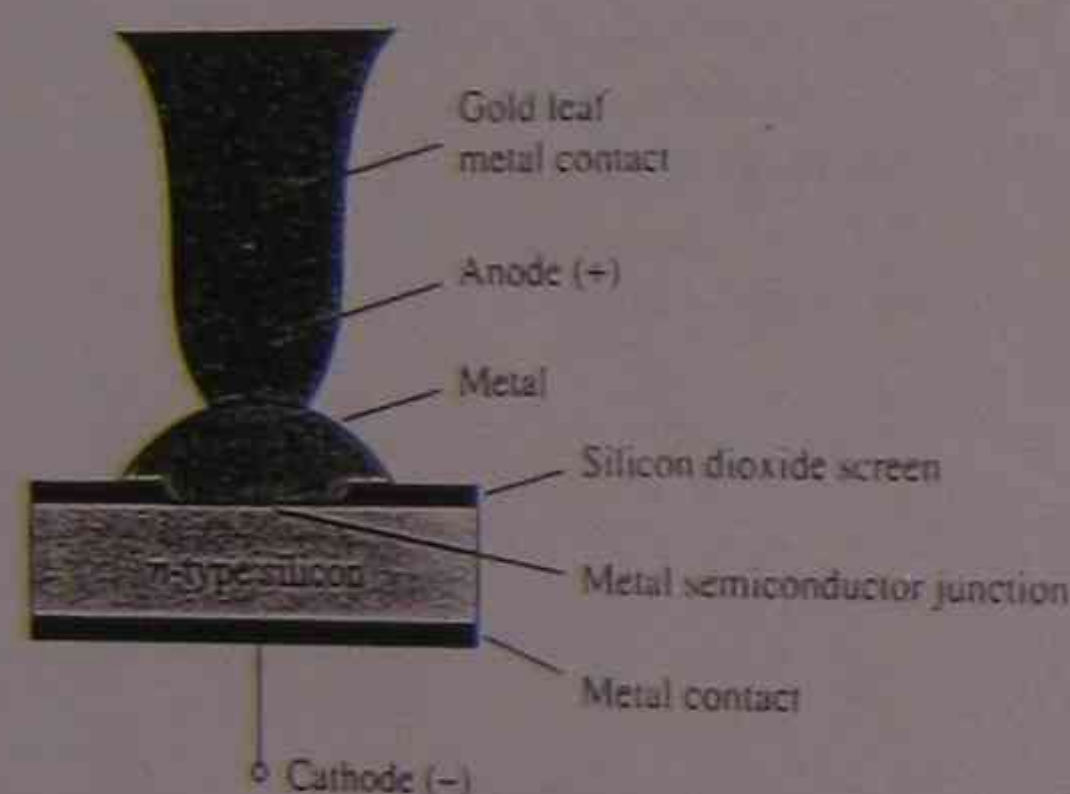
Gold leaf metal contact

Anode (+)

Metal

Silicon dioxide screen

Metal semiconductor junction

n-type silicon

Metal contact

Cathode (−)

Figure 20.1 Passivated hot-carrier diode.

ductor is normally *n*-type silicon (although *p*-type silicon is sometimes used), wh host of different metals, such as molybdenum, platinum, chrome, or tungsten, used. Different construction techniques will result in a different set of characteri for the device, such as increased frequency range, lower forward bias, and so Priorities do not permit an examination of each technique here, but information usually be provided by the manufacturer. In general, however, Schottky diode struction results in a more uniform junction region and a high level of ruggedn

In both materials, the electron is the majority carrier. In the metal, the lev minority carriers (holes) is insignificant. When the materials are joined the elec in the *n*-type silicon semiconductor material immediately flow into the adjoi metal, establishing a heavy flow of majority carriers. Since the injected carriers a very high kinetic energy level compared to the electrons of the metal, they commonly called "hot carriers." In the conventional *p-n* junction there wa injection of minority carriers into the adjoining region. Here the electrons are inje into a region of the same electron plurality. Here the electrons are inje that conduction is entirely by majority carriers. Schottky diodes are therefore uniqu metal creates a region near the junction surface depleted of carriers in the sili material—much like the depletion region in the *p-n* junction diode. The addin carriers in the metal establish a "negative wall" in the metal at the boundary betw the two materials. The net result is a "surface barrier" between the two mater preventing any further current. That is, any electrons (negatively charged) in silicon material face a carrier-free region and a "negative wall" at the surface of metal.

The application of a forward bias as shown in the first quadrant of Fig. 20.2 will reduce the strength of the negative barrier through the attraction of the applied positive potential for electrons from this region. The result is a return to the heavy flow of electrons across the boundary, the magnitude of which is controlled by the level of the applied bias potential. The barrier at the junction for a Schottky diode is less than that of the *p-n* junction device in both the forward- and reverse-bias regions. The result is therefore a higher current at the same applied bias in the forward- and reverse-bias regions. This is a desirable effect in the forward-bias region but highly undesirable in the reverse-bias region.

The exponential rise in current with forward bias is described by Eq. (1.4) but with η dependent on the construction technique (1.05 for the metal whisker type of
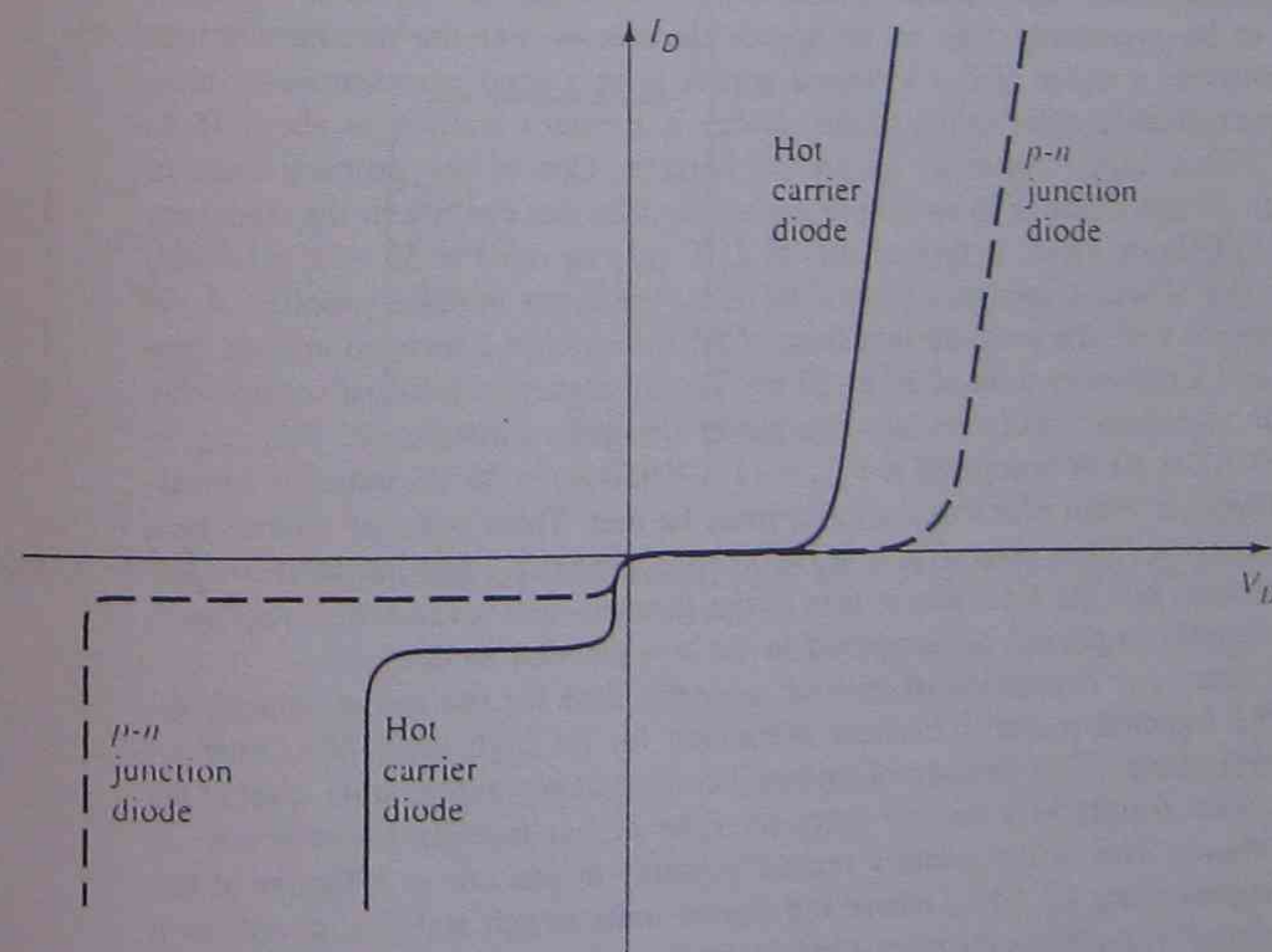
Figure 20.2 Comparison of characteristics of hot-carrier and *p-n* junction diodes.

construction, which is somewhat similar to the germanium diode). In the reverse-bias region the current I_s is due primarily to those electrons in the metal passing into the semiconductor material. One of the areas of continuing research on the Schottky diode centers on reducing the high leakage currents that result with temperatures over 100°C. Through design, improvement units are now becoming available that have a temperature range from −65 to +150°C. At room temperature, I_s is typically in the microampere range for low-power units and milliampere range for high-power devices, although it is typically larger than that encountered using conventional p-n junction devices with the same current limits. In addition, the PIV of Schottky diodes is usually significantly less than that of a comparable p-n junction unit. Typically, for a 50-A unit, the PIV of the Schottky diode would be about 50 V as compared to 150 V for the p-n junction variety. Recent advances, however, have resulted in Schottky diodes with PIVs greater than 100 V at this current level. It is obvious from the characteristics of Fig. 20.2 that the Schottky diode is closer to the ideal set of characteristics than the point contact and has levels of V_T less than the typical silicon semiconductor p-n junction. The level of V_T for the ''hot-carrier'' diode is controlled to a large measure by the metal employed. There exists a required trade-off between temperature range and level of V_T. An increase in one appears to correspond to a resulting increase in the other. In addition, the lower the range of allowable current levels, the lower the value of V_T. For some low-level units, the value of V_T can be assumed to be essentially zero on an approximate basis. For the middle and high range, however, a value of 0.2 V would appear to be a good representative value.

The maximum current rating of the device is presently limited to about 75 A, although 100-A units appear to be on the horizon. One of the primary areas of application of this diode is in *switching power supplies* that operate in the frequency range of 20 kHz or more. A typical unit at 25°C may be rated at 50 A at a forward voltage of 0.6 V with a recovery time of 10 ns for use in one of these supplies. A p-n junction device with the same current limit of 50 A may have a forward voltage drop of 1.1 V and a recovery time of 30 to 50 ns. The difference in forward voltage may not appear significant, but consider the power dissipation difference: $P_{hot\ carrier} = (0.6\ V)(50\ A) = 30\ W$ compared to $P_{p-n} = (1.1\ V)(50\ A) = 55\ W$, which is a measurable difference when efficiency criteria must be met. There will, of course, be a higher dissipation in the reverse-bias region for the Schottky diode due to the higher leakage current, but the total power loss in the forward- and reverse-bias regions is still significantly improved as compared to the p-n junction device.

Recall from our discussion of reverse recovery time for the semiconductor diode that the injected minority carriers accounted for the high level of t_{rr} (the reverse recovery time). The absence of minority carriers at any appreciable level in the Schottky diode results in a reverse recovery time of significantly lower levels, as indicated above. This is the primary reason Schottky diodes are so effective at frequencies approaching 20 GHz, where the device must switch states at a very high rate. For higher frequencies the point-contact diode, with its very small junction area, is still employed.

The equivalent circuit for the device (with typical values) and a commonly used symbol appear in Fig. 20.3. A number of manufacturers prefer to use the standard diode symbol for the device, since its function is essentially the same. The inductance L_p and capacitance C_p are package values, and r_B is the series resistance, which includes the contact and bulk resistance. The resistance r_d and capacitance C_J are values defined by equations introduced in earlier sections. For many applications, an excellent approximate equivalent circuit simply includes an ideal diode in parallel with the junction capacitance as shown in Fig. 20.4.

A number of hot-carrier rectifiers manufactured by Motorola Semiconductor Products, Inc., appear in Fig. 20.5 with their specifications and terminal identifica-

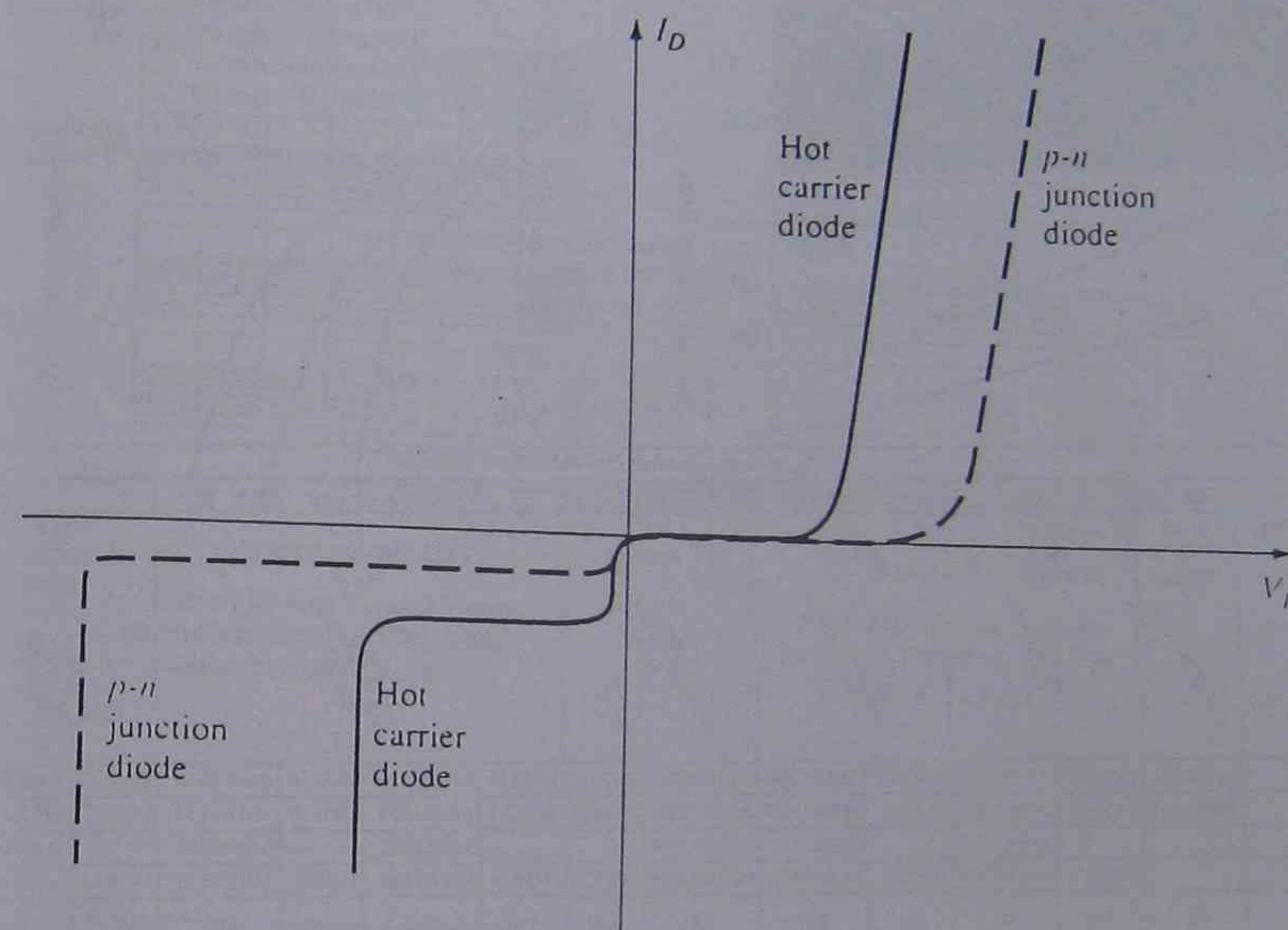**Figure 20.2** Comparison of characteristics of hot-carrier and p-n junction diodes.

26 mV

(a)
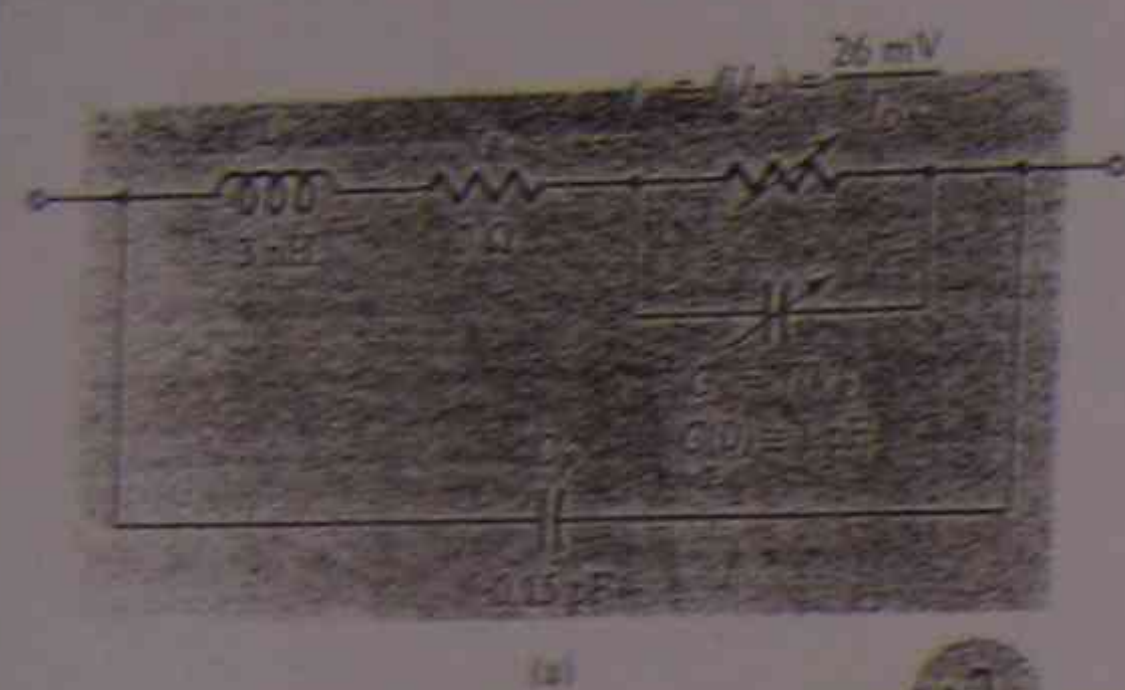
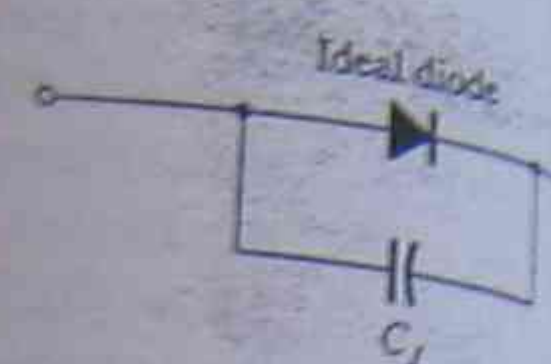**Figure 20.3** Schottky (hot-carrier) diode (a) equivalent circuit, (b) symbol

(b)

Ideal diode

C_I

Figure 20.4 Approximate equivalent circuit for the Schottky diode

Temperature	
I_F	coefficient
10 μA	−2.3 mV/°C
100 μA	−1.8 mV/°C
1.0 mA	−1.3 mV/°C
10 mA	−0.7 mV/°C
100 mA	−0.2 mV/°C

I-V Curve Showing Typical Temperature Variation for 5082-2300 Series Schottky Diodes.

(a)

5082-2300 Series Typical Reverse Current vs. Reverse Voltage at $T_A = 25°C$.

(b)

I_O, Average rectified forward current (amperes)									
	0.5 A	1.0 A		3.0 A	3.0 A	5.0 A	15 A	25 A	40 A
Case	51-02 (DO-7) Glass	59-04 Plastic	267 Plastic		60 Metal			257 (DO-4) Metal	257 (DO-5) Metal
20	MBR020	1N5817	MBR120P	1N5820	MBR320P	MBR320M	1N5823	1N5826	MBR1520	1N5829	MBR2520	1N5832	MBR40
30	MBR030	1N5818	MBR130P	1N5821	MBR330P	MBR330M	1N5824	1N5827	MBR1530	1N5830	MBR2530	1N5833	MBR40
35			MBR135P			MBR335P	MBR335M			MBR1535				MBR40
40		1N5819	MBR140P	1N5822	MBR340P	MBR340M	1N5825	1N5828	MBR1540	1N5831	MBR2540	1N5834	MBR40
									MBR2535				

Schottky barrier devices ideal for use in low-voltage, high-frequency power supplies and as free-wheeling diodes. These units feature very low forward voltage and switching times estimated at less than 10 ns. They are offered in current ranges of 0.5 to 5.0 amperes and in voltages to 40.

Figure 20.5 Motorola Schottky barrier devices (Courtesy Motorola Semiconductor Products Incorporated.) Note that the maximum forward voltage drop V_F does not exceed 0.65 V for any of the devices, while this was essentially V_F for a silicon diode.

Three sets of curves for the Hewlett-Packard 5082-2300 series of general-purpose Schottky barrier diodes are provided in Fig. 20.6. Note at $T = 100°C$ in Fig. 20.6a that V_F is only 0.1 V at a current of 0.01 mA. Note also that the reverse current has been limited to nanoamperes in Fig. 20.6b and the capacitance to 1 pF in Fig. 20.6c to ensure a high switching rate.
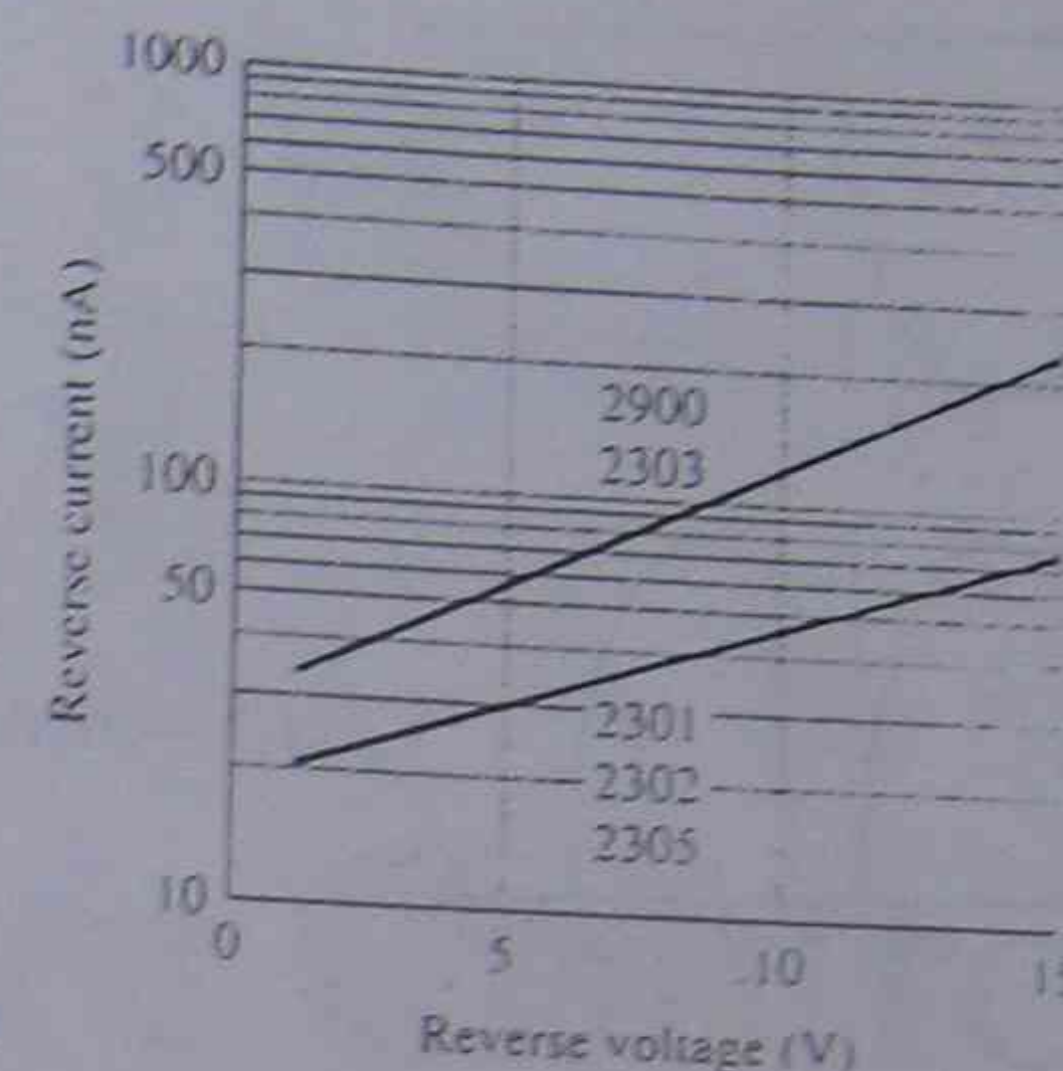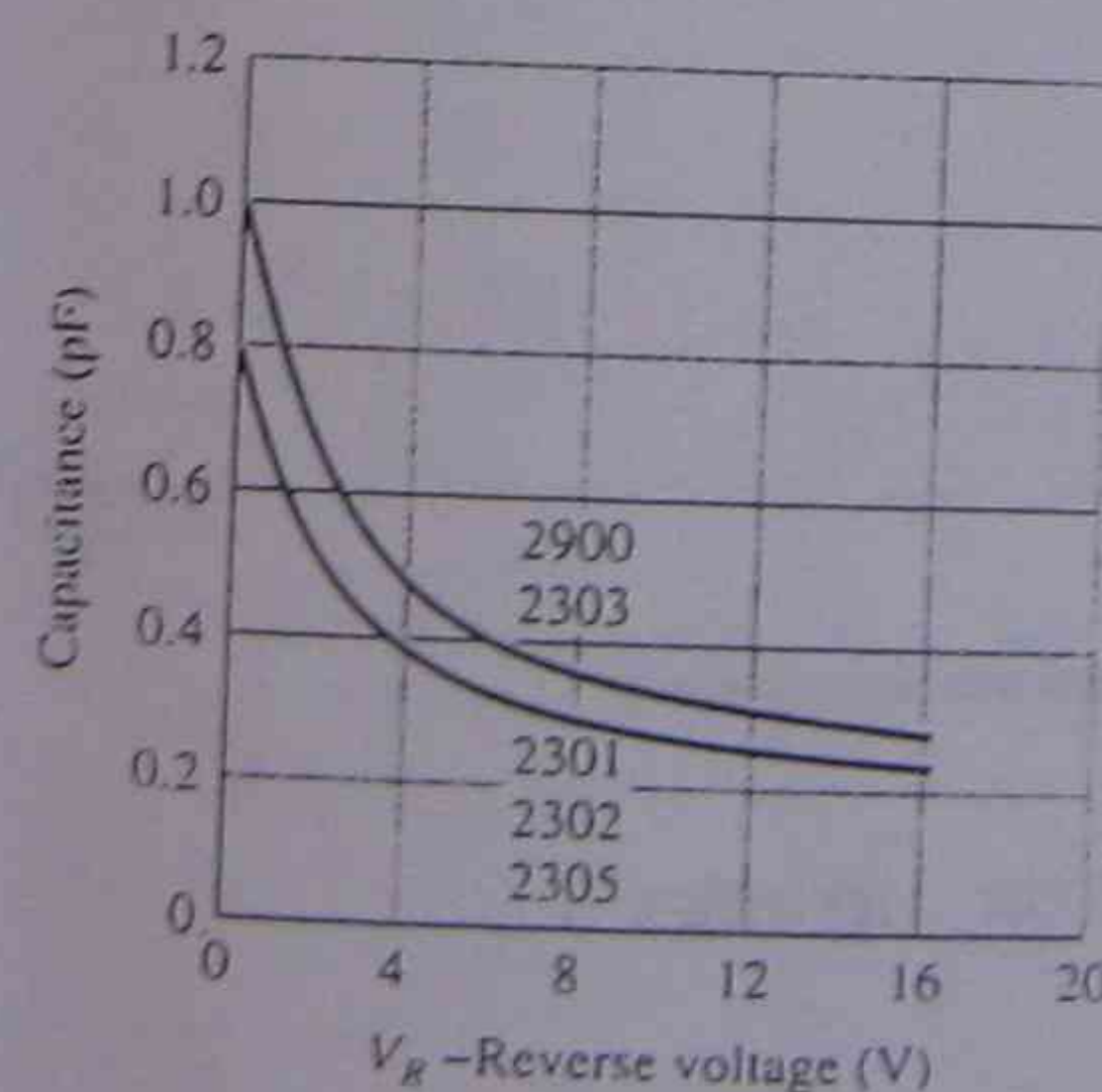

5082-2300 Series Typical Capacitance vs. Reverse Voltage at $T_A = 25°C$.

(c)

Figure 20.6 Characteristic curves for Hewlett-Packard 5082-2300 series of general-purpose Schottky barrier diodes (Courtesy Hewlett-Packard Corporation.)

SINGLE PHASE, HALF CONTROLLED,
BRIDGE RECTIFIER CIRCUIT

Line Voltage

(Vac)

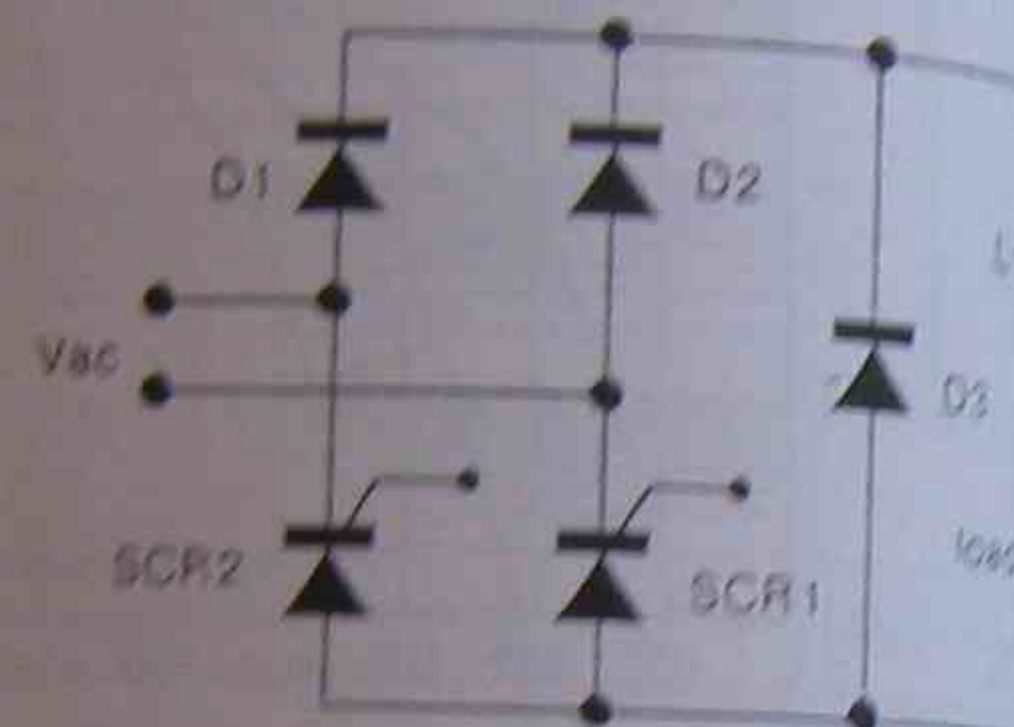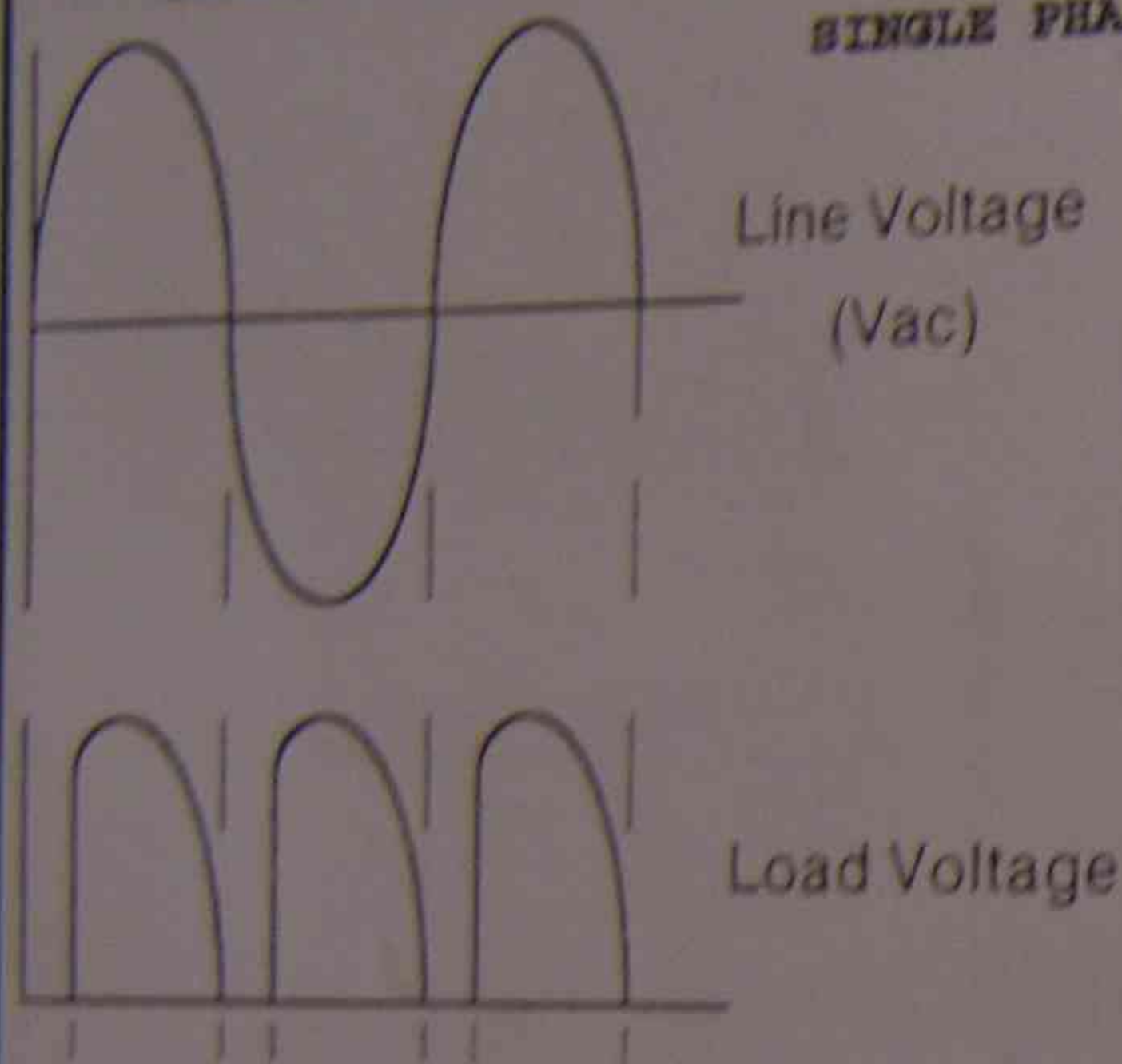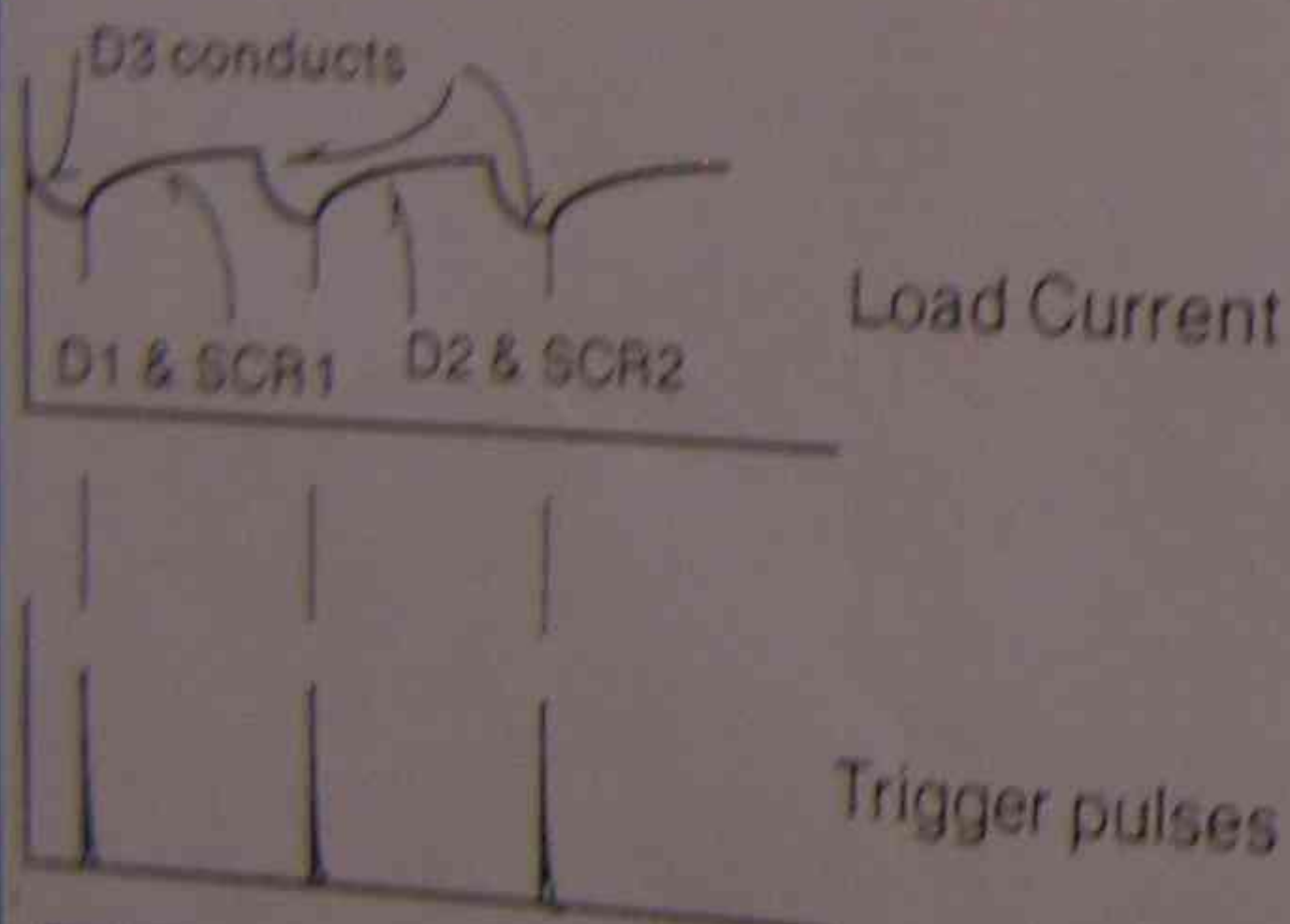Load Voltage

D1 D2

Vac D3

SCR2 SCR1 load

Fig.10 Single-phase, half controlled
bridge with flywheel diode (D3)

D3 conducts

Load Current

D1 & SCR1   D2 & SCR2

Trigger pulses

SUITABLE FOR SEVERAL kW SUPPLIES,

USE IN A 3 PHASE CONFIGURATION FOR HIGHER
POWERS.

EXHIBITS A HIGH POWER FACTOR.

FOR INDUCTIVE LOADS D3, FREE WHEELING DIODE,
MUST BE USED.

ALSO FOR INDUCTIVE LOADS TO MINIMISE di/dt THE
SATURABLE REACTOR, L1, IS INCORPORATED.

Sydney Institute of Technology

School of Electrotechnology

Learners Theory Work Book

Module NE76

A.C. Motor Control

Area

Topic

Session No. **3·4**

For further information on this module, or this subject
contact Jim Hafford, (02) 217 3620, Bld. K, Ultimo, S.I.T.

ANODE A

GATE G

CATHODE C

(a)   (b)

FORWARD ON-STATE VOLT DROP

VALUES OF V WHEN THYRISTOR GATED

HOLDING CURRENT

LATCHING CURRENT

REVERSE LEAKAGE CURRENT

FORWARD LEAKAGE CURRENT   FORWARD BREAKDOWN

REVERSE BLOCKING

REVERSE BREAKDOWN

(c)
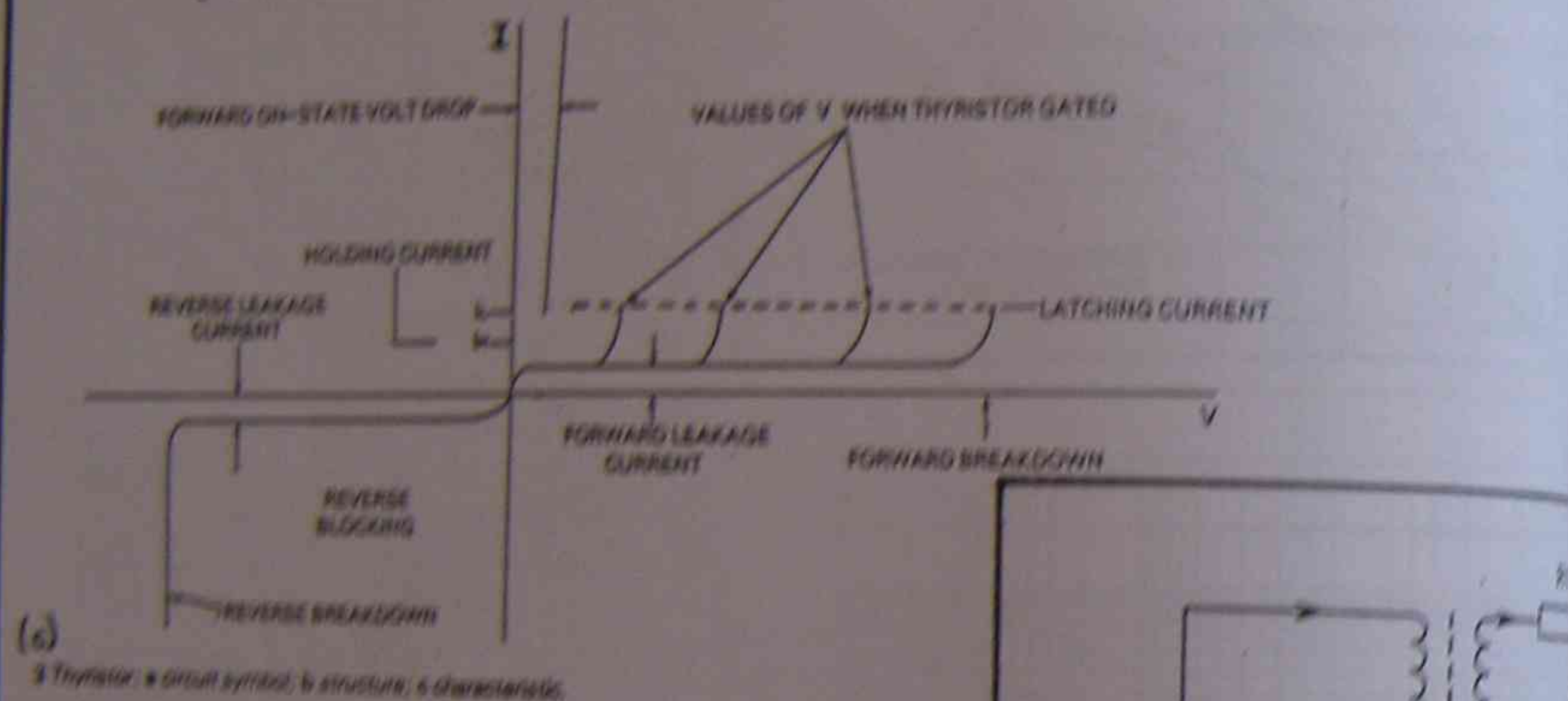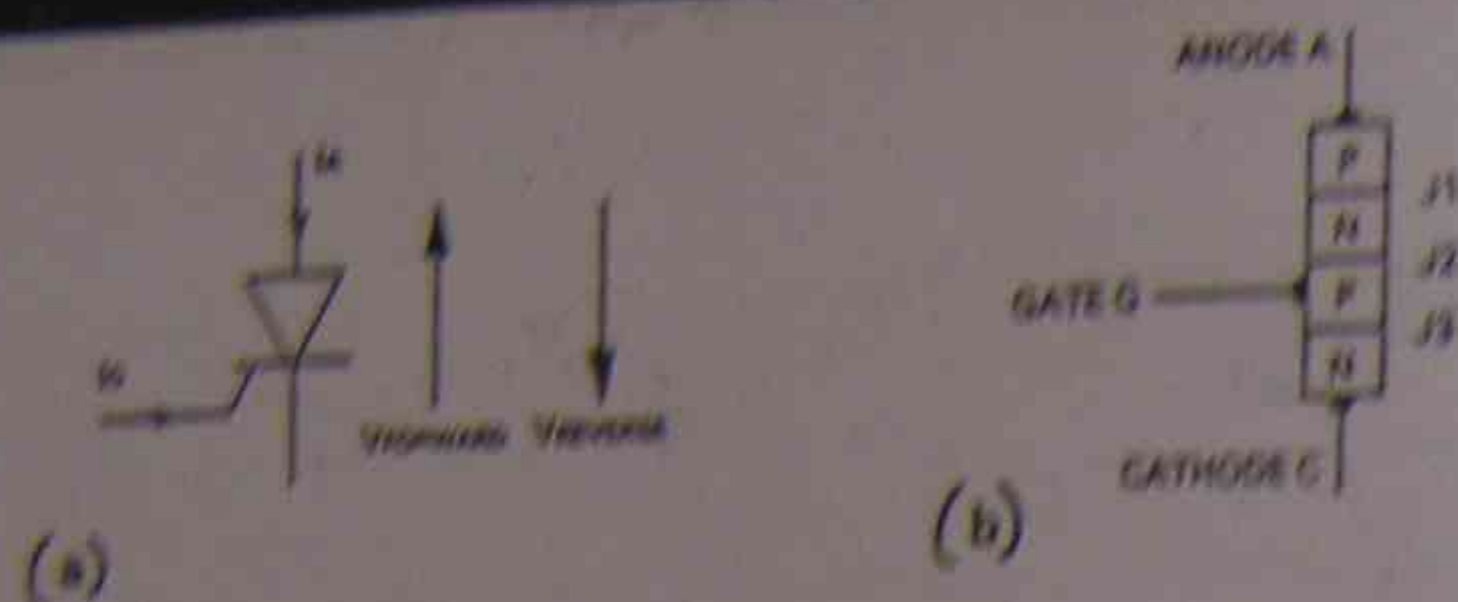
3 Thyristor: a circuit symbol; b structure; c characteristic.

(a)

(b)

OFF-STATE dv/dt

RECOVERY RECOMBINATION

ON-STATE VOLT DROP

REAPPLIED dv/dt

(c)

TURN ON   ON   TURN OFF   OFF
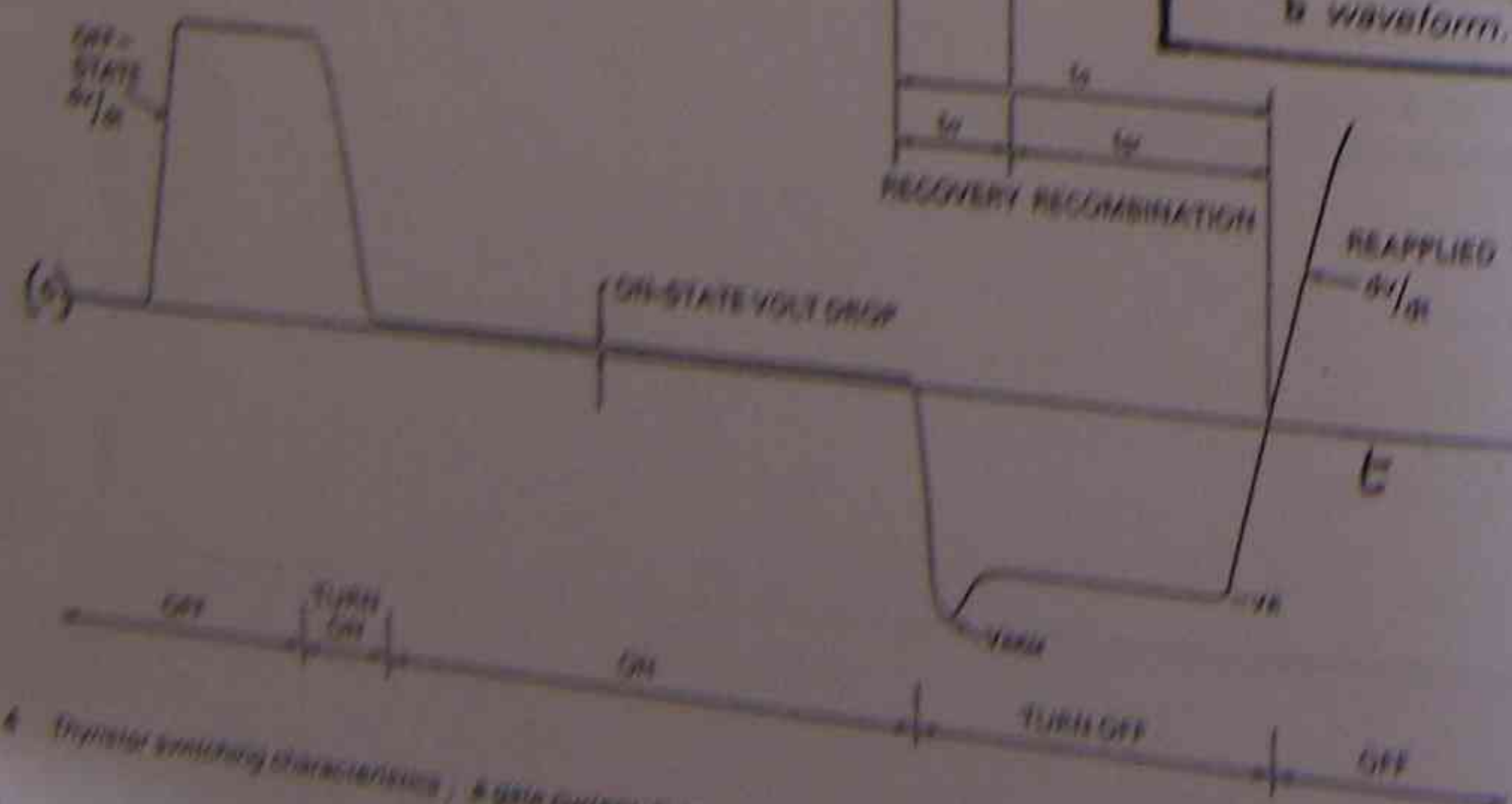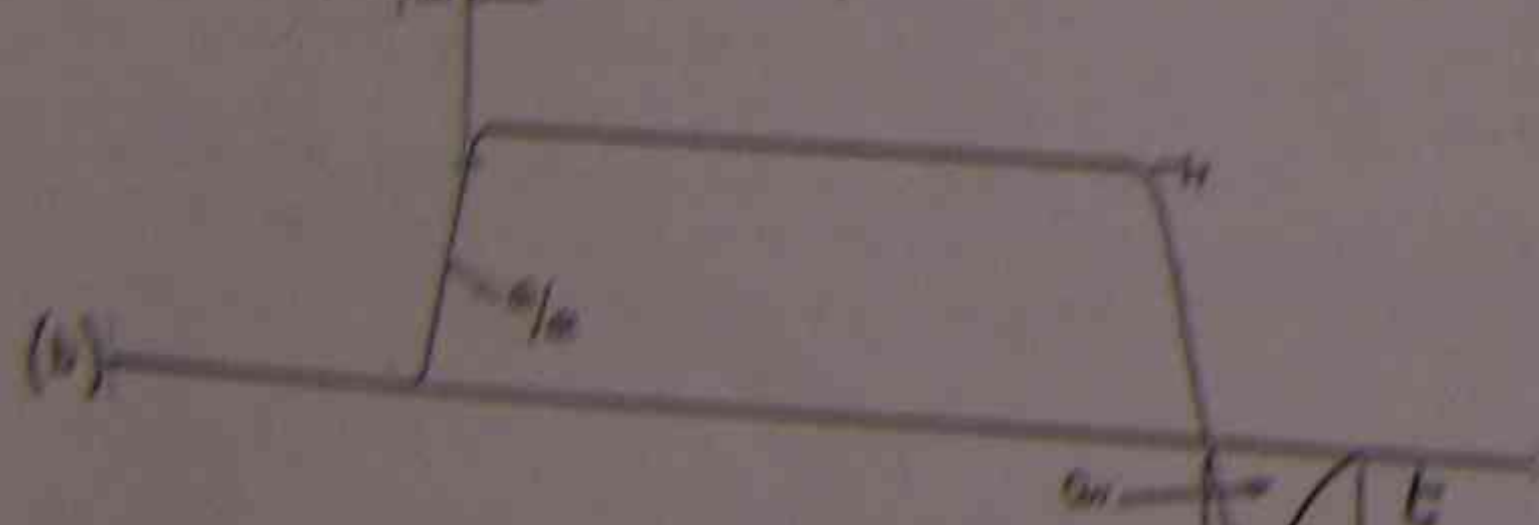
4 Thyristor switching characteristics; a gate current; b anode current; c anode voltage.

24V

1A

O   10µs

20kHz GATE CURRENT

a

b

6 Thyristor firing; a example of gate drive;
b waveform.

FIG 3(b) & (c).
VOLTAGE AND CURRENT WAVEFORMS FOR AN INDUCTIVE
LOAD WITH SMALL CONDUCTION ANGLE.

V & I

(b)

(c)
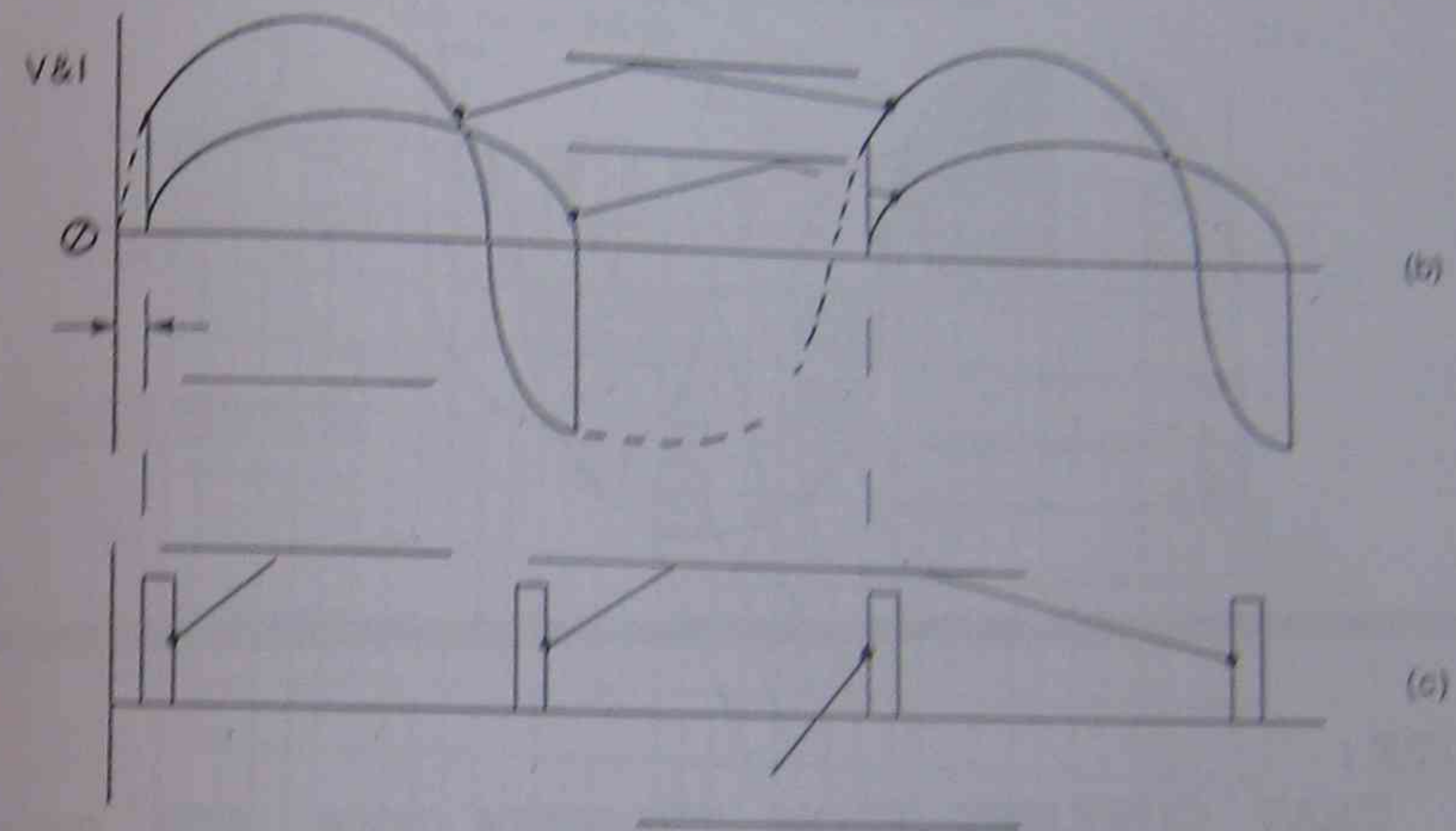
THE SITUATION SHOWN IN (a) LEADS TO PROBLEMS
WHEN THE FIRING ANGLE IS SMALL.

AFTER INITIAL FIRING OF SCR1 THE CONDUCTION OF
SCR2 IS PREVENTED BECAUSE OF SCR1 STILL
CONDUCTING AND REVERSE BIASING IT.

THIS SITUATION IS THE CASE WITH A SIMPLE
SINGLE PULSE FIRING SYSTEM.

WITH THE USE OF AN EXTENDED PULSE OR A PULSE
TRAIN OF SUITABLE DURATION, SCR WILL FIRE AS
SOON AS CONDITIONS ALLOW.

FIG 3(a),
VOLTAGE AND CURRENT WAVEFORMS FOR AN INDUC
LOAD.

V & I

0   t

|← a →|← b →|

a =

b =

Load current is discontinuous

NOTE:

• THAT CURRENT FLOW THROUGH THE SCR DOES
  STOP UNTIL THE END OF PERIOD b, THERFORE
  NATURAL COMMUTATION IS BEING USED
  WOULD NOT TURN OFF UNTIL THIS POINT.

• THERE IS TWO WAY FLOW OF ENERGY, BOTH F
  THE SUPPLY AND BEING RETURNED TO
  SUPPLY.

LOAD CURVES OF RMS SUPPLY TO RMS LOAD VOLTAGE
FOR LOAD POWER FACTORS OF 1.0 (PURE RESISTIVE)
TO 0 (PURE INDUCTIVE).

LOAD POWER FACTOR
1.0   0.8   0.5   0.2   0

$\frac{V_L}{V_{AC}}$

TRIGGER DELAY ANGLE ∝ - DEGREES
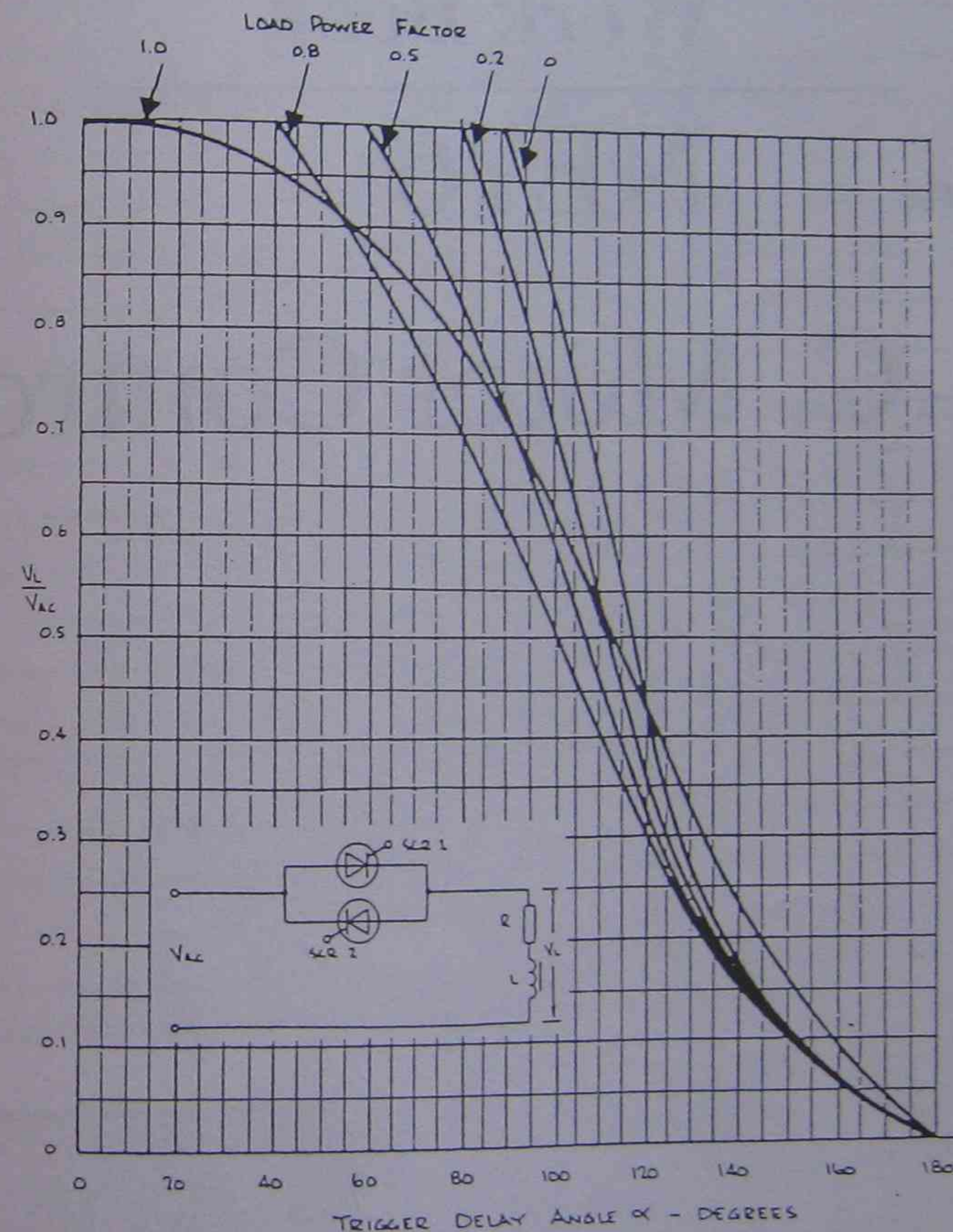
Fig 2 Curves showing the ratio of load to supply voltage for various load power factors and trigger angles

Sydney Institute of Technology

School of Electrotechnology

Learners Theory

Work Book

Module NE76

A.C. Motor Control

Area

Topic

Session No. 3

Objec
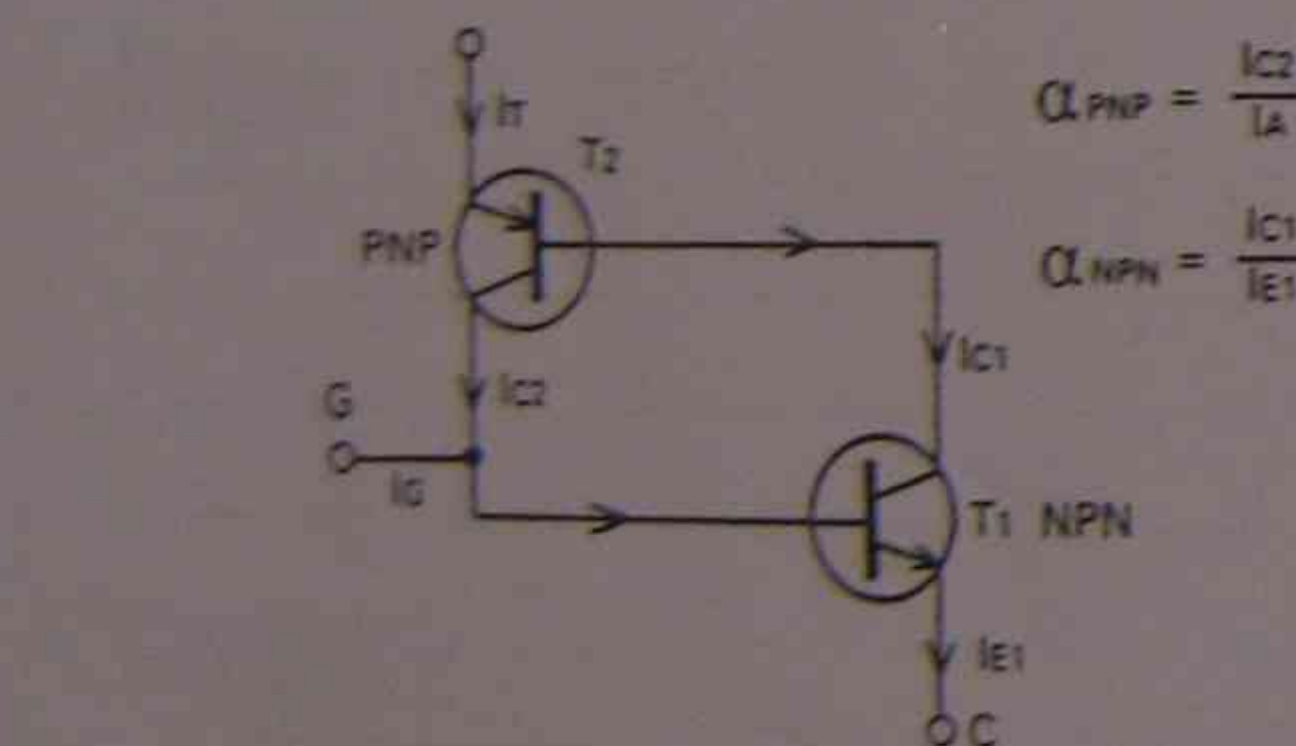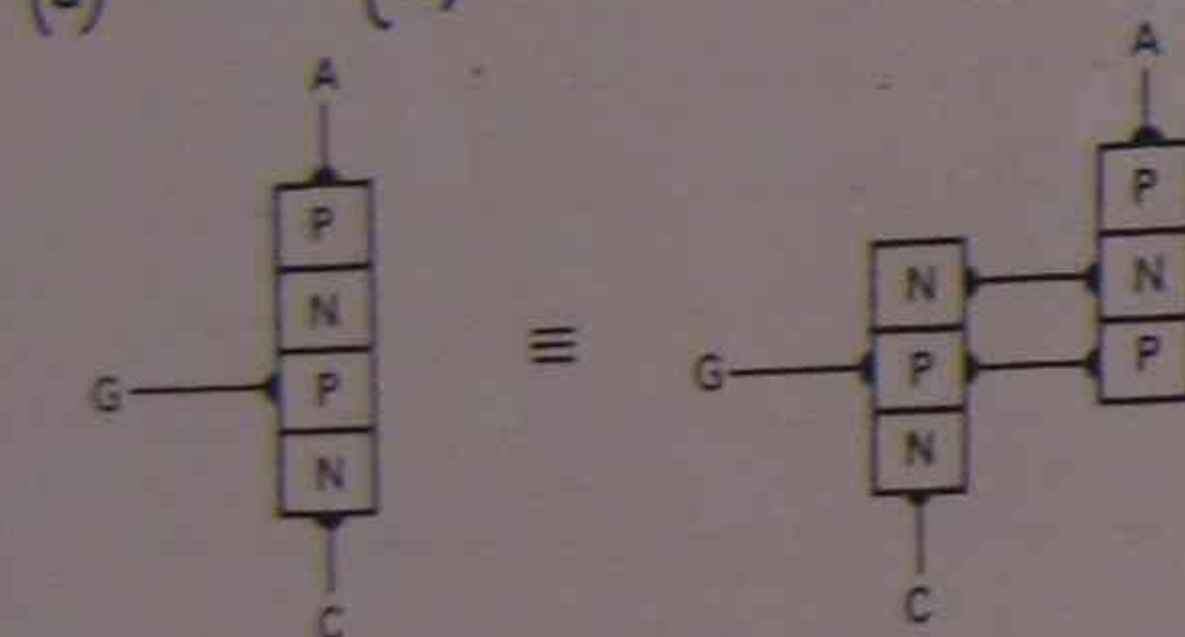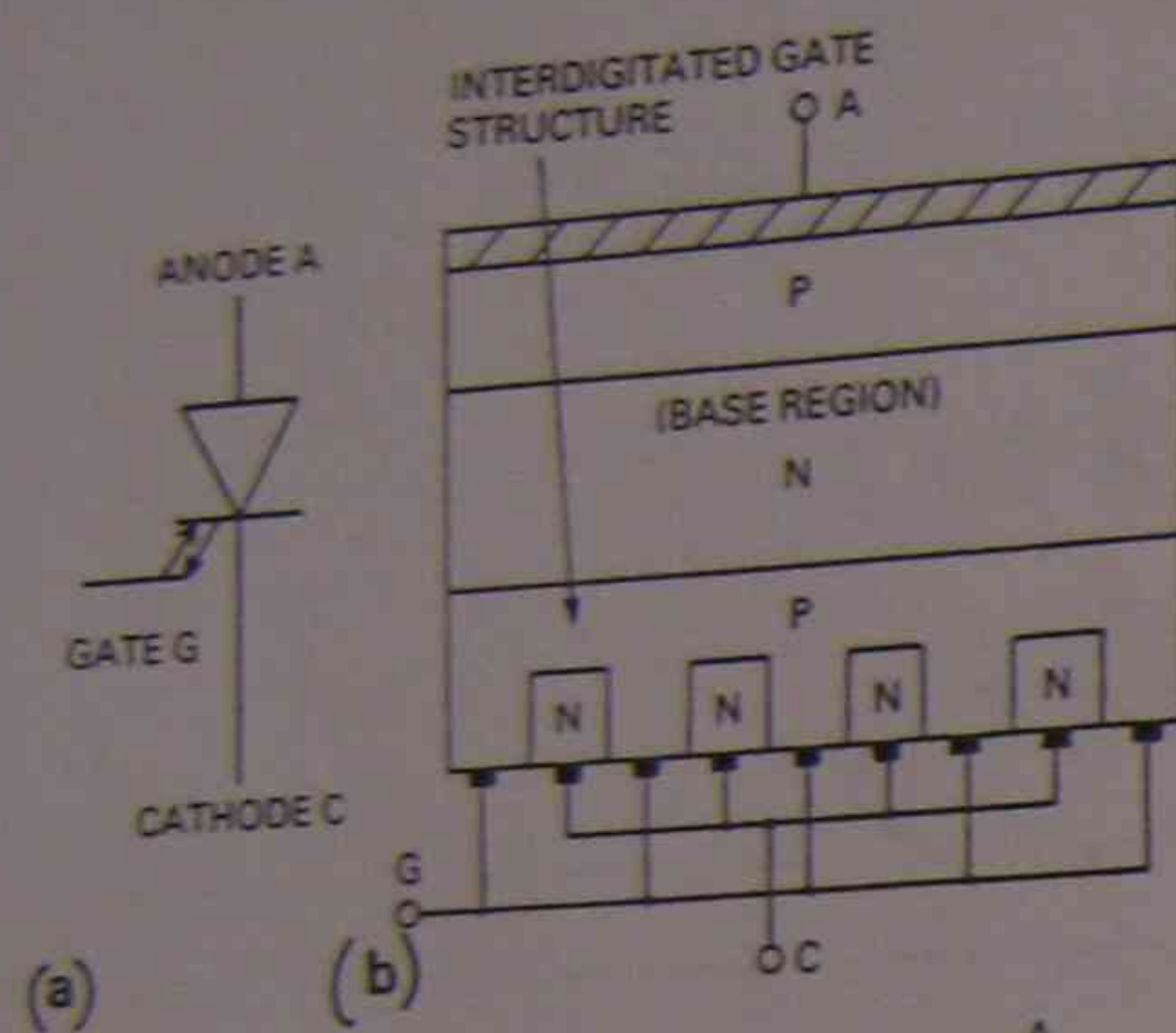
8 GTO : **a** circuit symbol; **b** structure; **c** two-transistor model of thyristor.

$$\alpha_{PNP} = \frac{I_{C2}}{I_A}$$

$$\alpha_{NPN} = \frac{I_{C1}}{I_{E1}}$$

9 GTO switching performance; **a** anode current and voltage; **b** gate current.
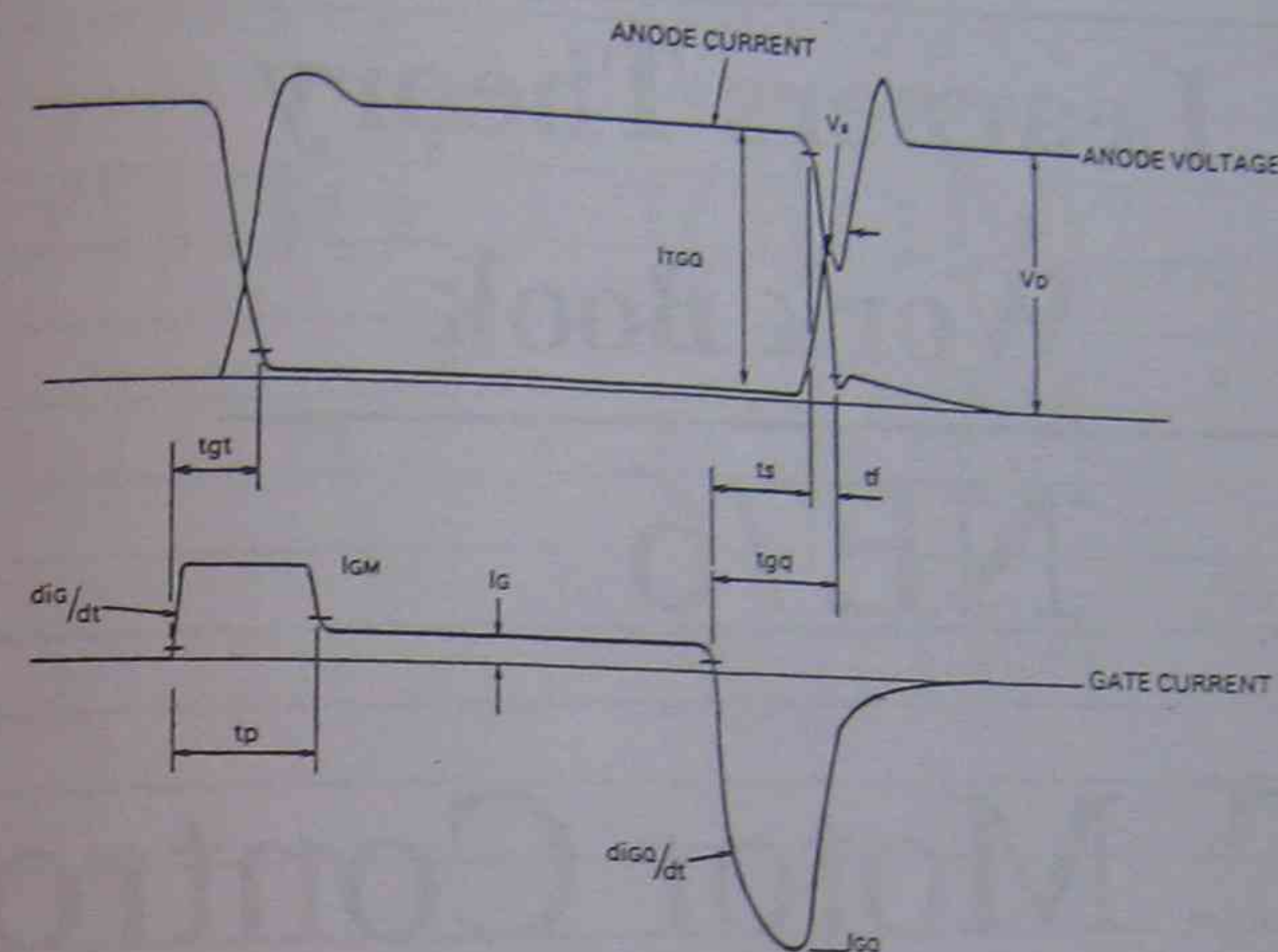
TABLE 1 Recommended Gate Drive for IR 160 PFT

I_{GM}	≥	,10A	RESISTIVE SWITCHING PERFORMANCE
I_G	≥	2A	V_D = 600V I_{TGQ} = 600A max.
I_{GQ}	≥	120A	Snubber = 2μF
tw	≥	10μs	t_{gt} = 5μs (turn-on time)
dI_G/dt	=	5A/μs	t_{gq} = 8μs (turn-off time)
			t_f = 0.8μs
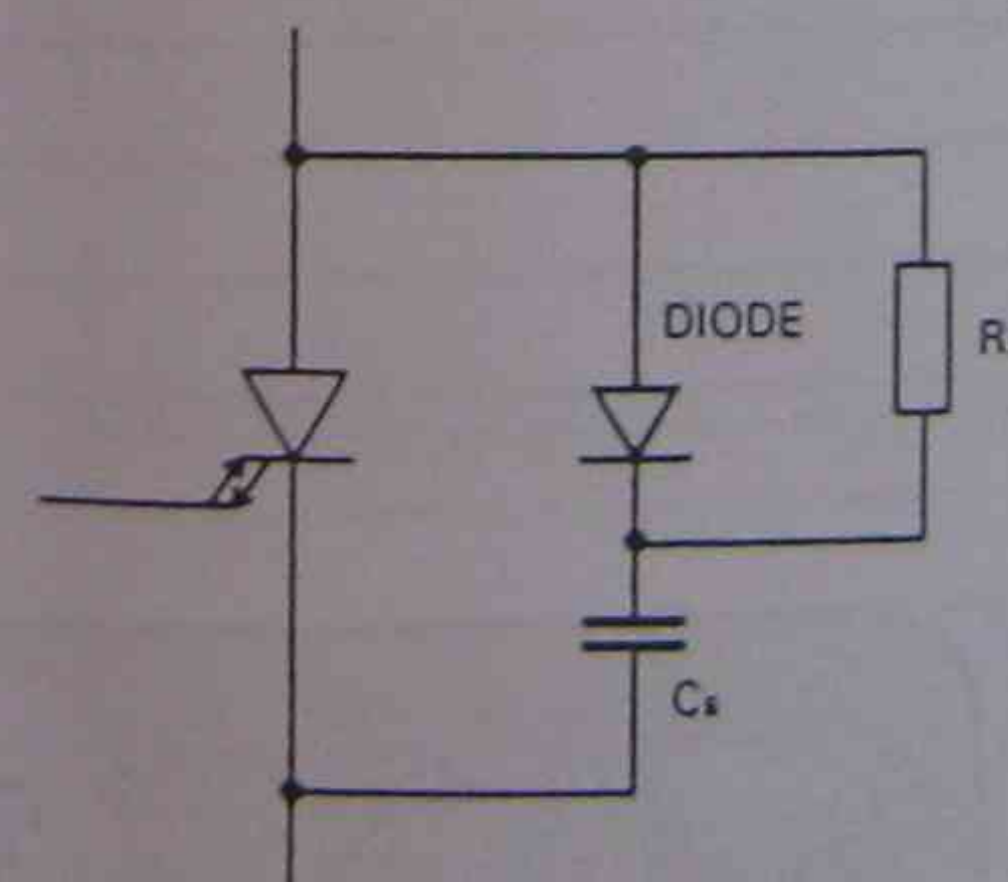
10 Typical snubber circuit required for GTO.

Learners Theory

Work Book

Module   **NE76**

A.C. Motor Control

Area _____

Topic _____

Session No. [3

Objecti

-2V

L

R

Vcc

Ic

I_{B1}

I_{B2}

Vce

(a)

PEAK CURRENT DUE TO
REVERSE RECOVERY OF
FREE WHEEL DIODE

OVERSHOOT
Vce

Ic

t_{rc} t_{cond} t_{fc}

t_f

t_s

(b)

I_{B1}

I_B

I_{B2}

t_{on} t_{off}

(c)

TURN-ON
LOSS

CONDUCTION LOSS

TURN-OFF
LOSS

t

d

15 Bipolar transistor switching an inductive load: **a** test circuit;
b collector current and voltage waveforms; **c** base drive;
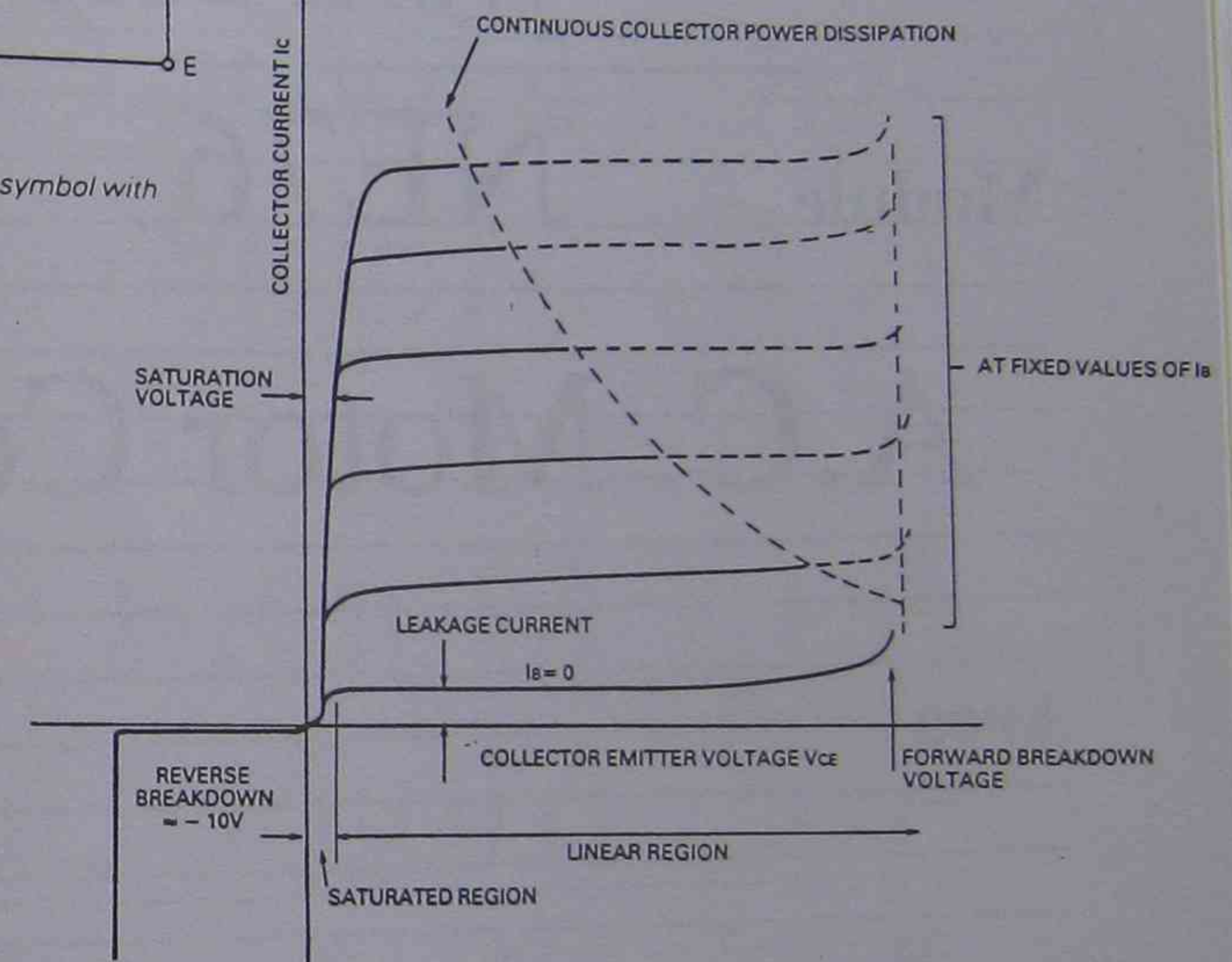**d** power loss over one switching cycle.

COLLECTOR C

N

BASE B

P

N

EMITTER E

(a)

I_B B

Vce

Ic

(b)

E
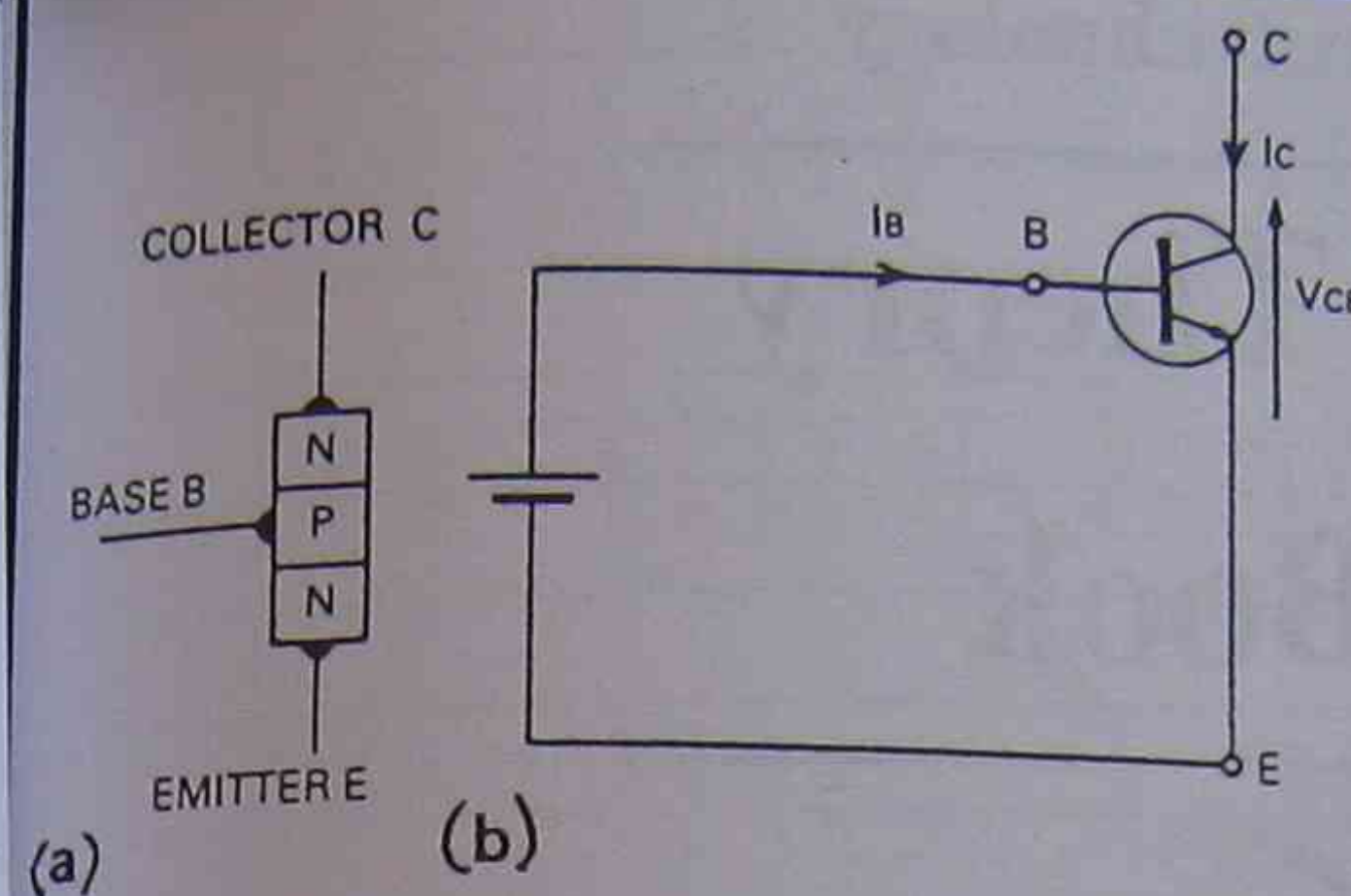
11 NPN transistor; **a** structure; **b** circuit symbol with
current directions.

C

B

E
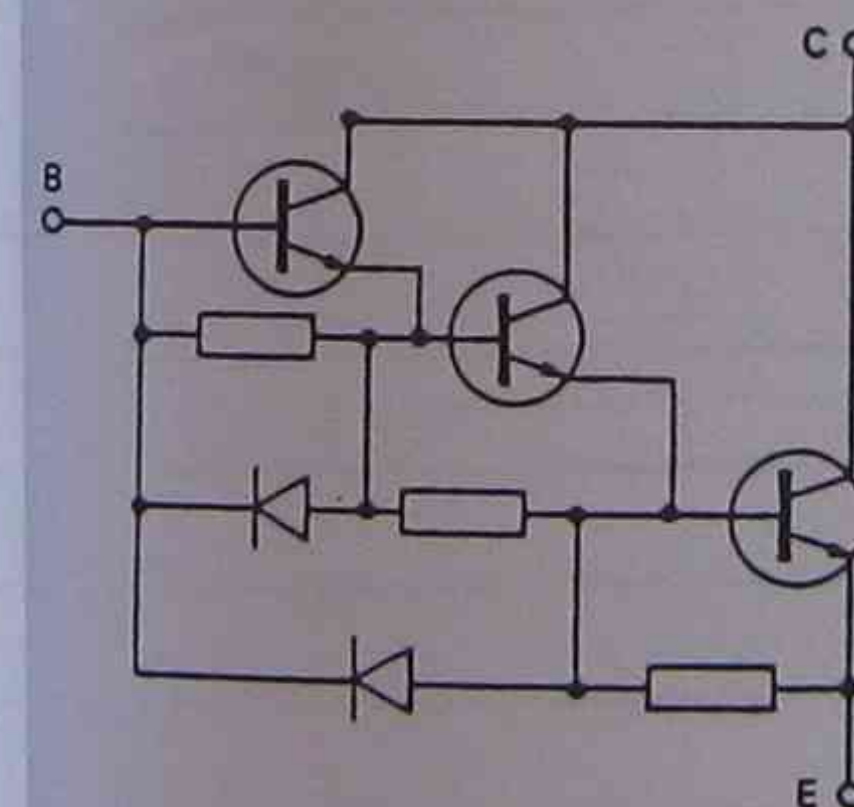
13 Three-stage Darlington arrangement of power transistor.

CONTINUOUS COLLECTOR POWER DISSIPATION

COLLECTOR CURRENT Ic

SATURATION
VOLTAGE

AT FIXED VALUES OF I_B

LEAKAGE CURRENT

$I_B = 0$

COLLECTOR EMITTER VOLTAGE Vce

FORWARD BREAKDOWN
VOLTAGE

REVERSE
BREAKDOWN
≈ −10V

LINEAR REGION

SATURATED REGION

12 Output characteristic (common emitter) for NPN transistor

TABLE 2   Calculation of Switching and Conduction
Losses for a Bipolar Transistor

Energy dissipated during turn-on	$W_{on} \approx \frac{1}{2}t_{rc} \times V_{CC} \times I_C$
Energy dissipated during turn-off	$W_{off} \approx \frac{1}{2}t_{fc} \times V_{CC} \times I_C$
Energy dissipated during conduction period	$W_{cond} \approx V_{CEsat} \times I_C \times t_{cond}$
Switching loss (watts)	$f(W_{on} + W_{off})$
Conduction loss (watts)	$f \times W_{cond}$
TOTAL AVERAGE POWER LOSS	Switching loss + Conduction loss

Sydney Institute of Technology

School of Electrotechnology

Learners Theory

Work Book

Module   NE76

A.C. Motor Control

Area

Topic

Session No. [4]
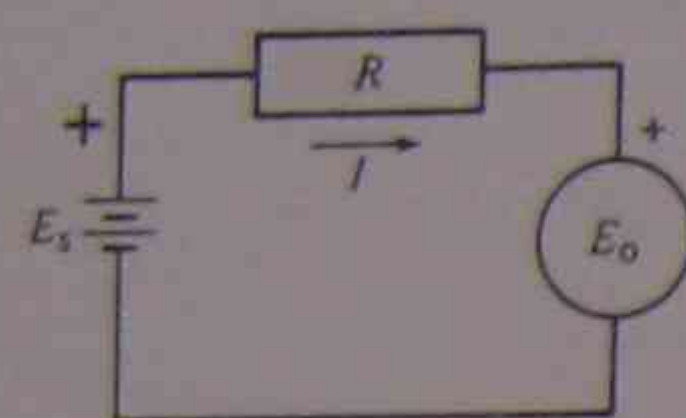
Figure 21-38
Inefficient power transfer.
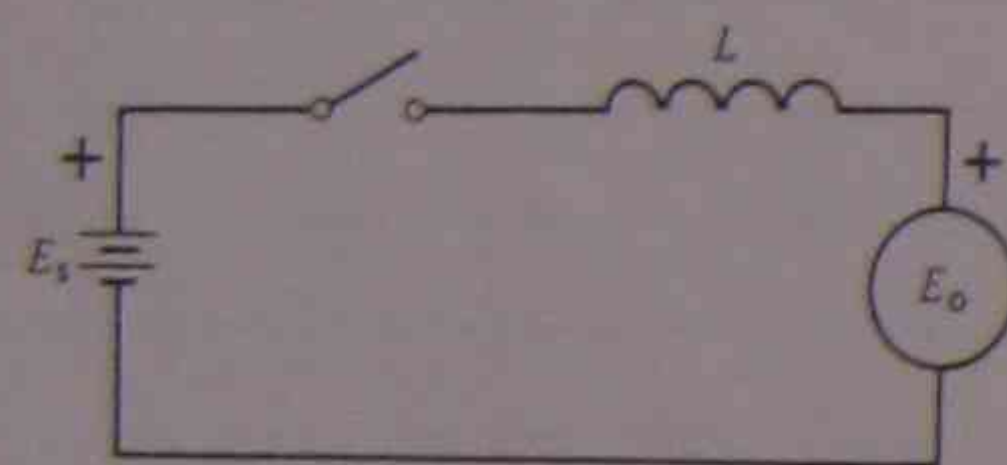
Figure 21-39
Energy transfer using an inductor.
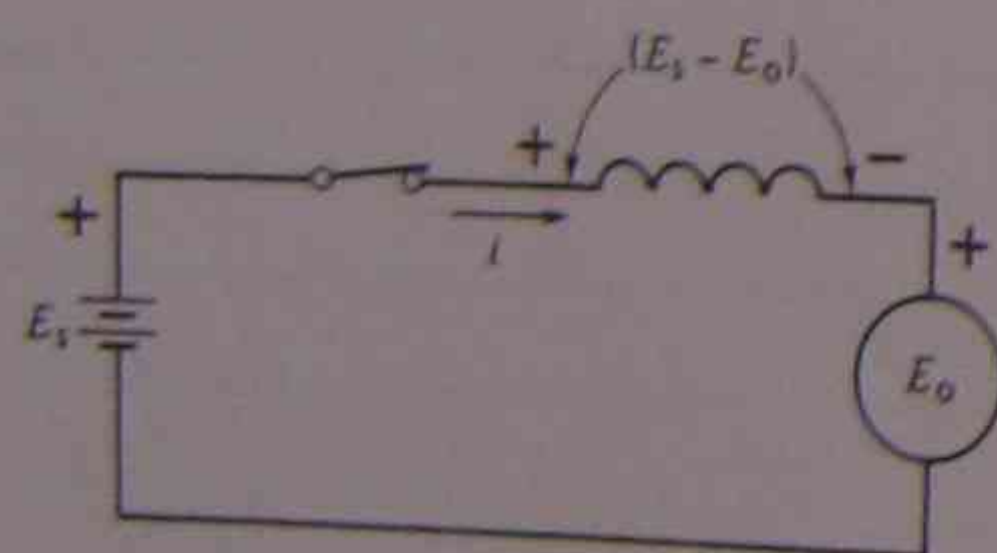
Figure 21-40
Energy is stored in the inductor.

$(A+)T_1 = (A-)T_2$

$(E_s - E_o)T_1 = E_o T_2$

Figure 21-41
Energy is dissipated in the arc. Note the polarity of e_L.

Figure 21-42
Energy transferred without loss.

$E_s - E_o$

$A+$

$A-$

E_o

T_1 T_2

repeat the cycle
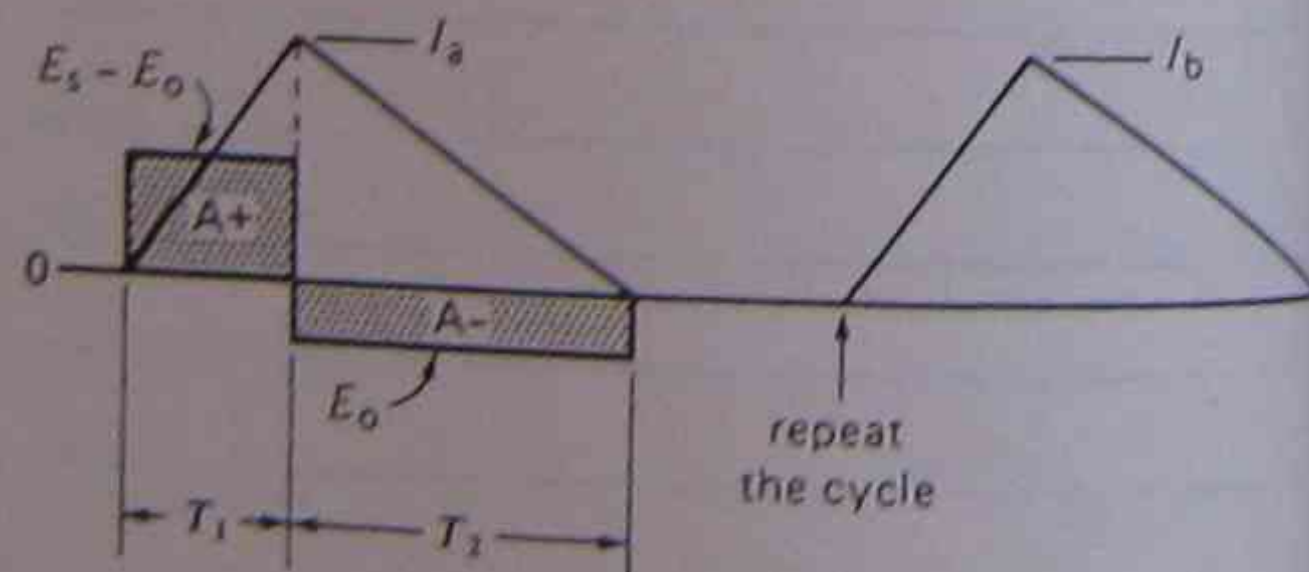
Figure 21-43
E and I in the inductor of Fig. 21-42.

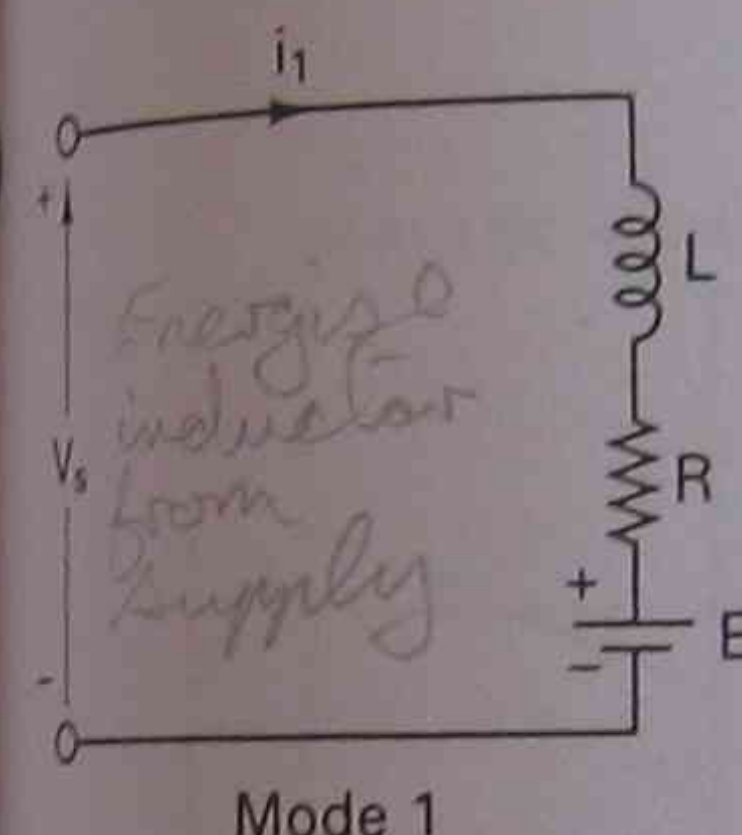at T_1 $I_a = A + /L$

$= (E_s - E_o)T_1 /L$

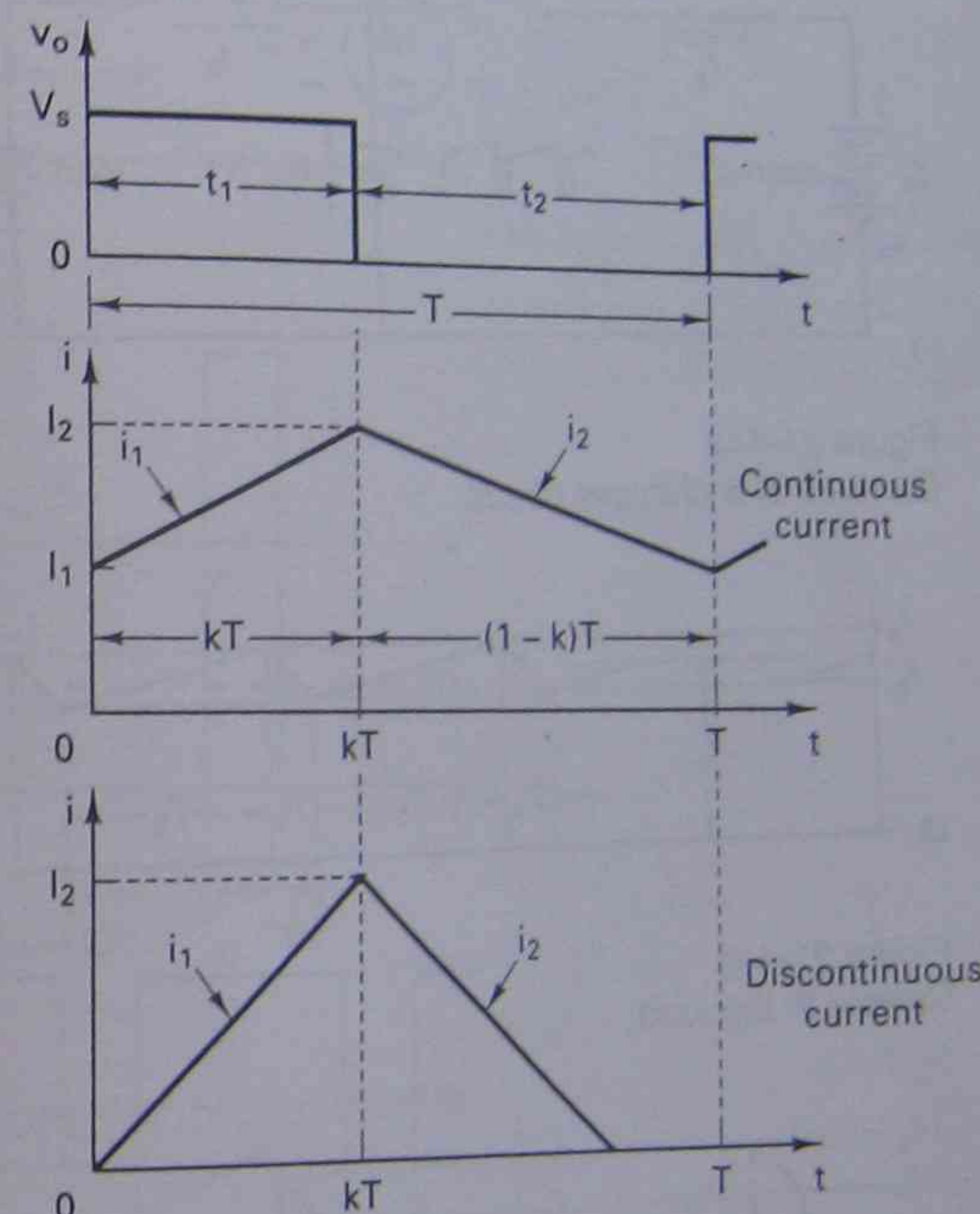Energy stored in L

$w = \frac{1}{2}L I_a^2$

$(E_s - E_o)T_1 = E_o T_2$

When the chopper is turned on, the energy is transferred from the source V_s to inductor L. If the chopper is then turned off, a magnitude of the energy stored in the inductor is forced to battery E.

Note. Without the chopping action, v_s must be greater than E for transferring power from V_s to E.

Energize inductor from Supply

Mode 1

Circulate current from inductor, when supply is removed, by Free Wheel vis diode Dm.

Mode 2

(a) Equivalent circuits

Continuous current

Discontinuous current
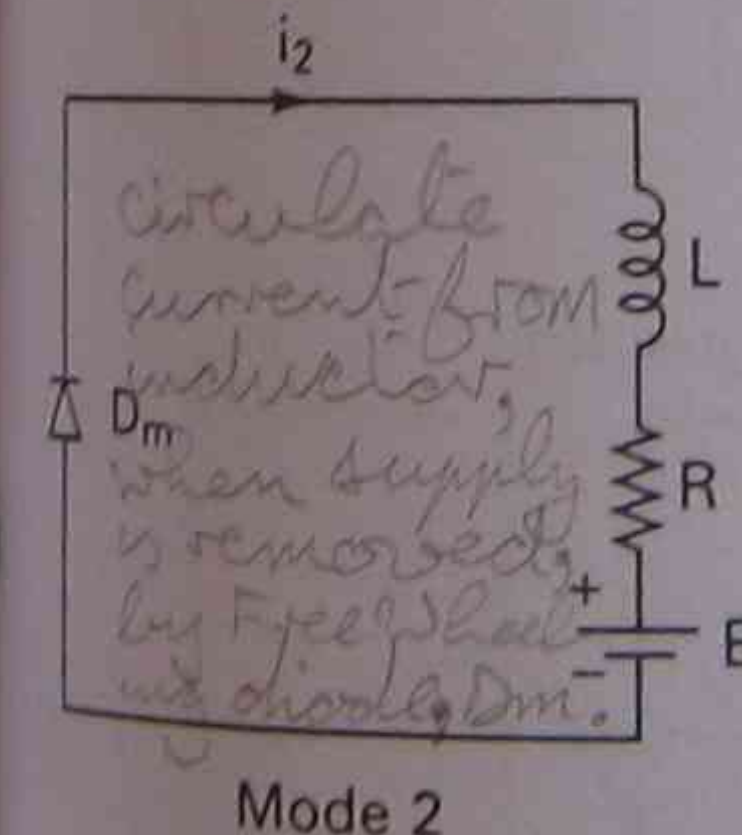
(b) Waveforms

Figure 9-3 Equivalent circuits and waveforms for RL loads.

The power semiconductor devices require a minimum time to turn on and turn off. Therefore, the duty cycle k can only be controlled between a minimum value k_{min} and a maximum value k_{max}, thereby limiting the minimum and maximum value of output voltage. The switching frequency of the chopper is also limited. It can be noticed from Eq. (9-20) that the load ripple current depends inversely on the chopping frequency f. The frequency should be as high as possible to reduce the load ripple current and to minimize the size of any additional series inductor in the load circuit.

Eq (9-20) $\Delta I_{RIPPLE} = \dfrac{V_s}{4fL}$
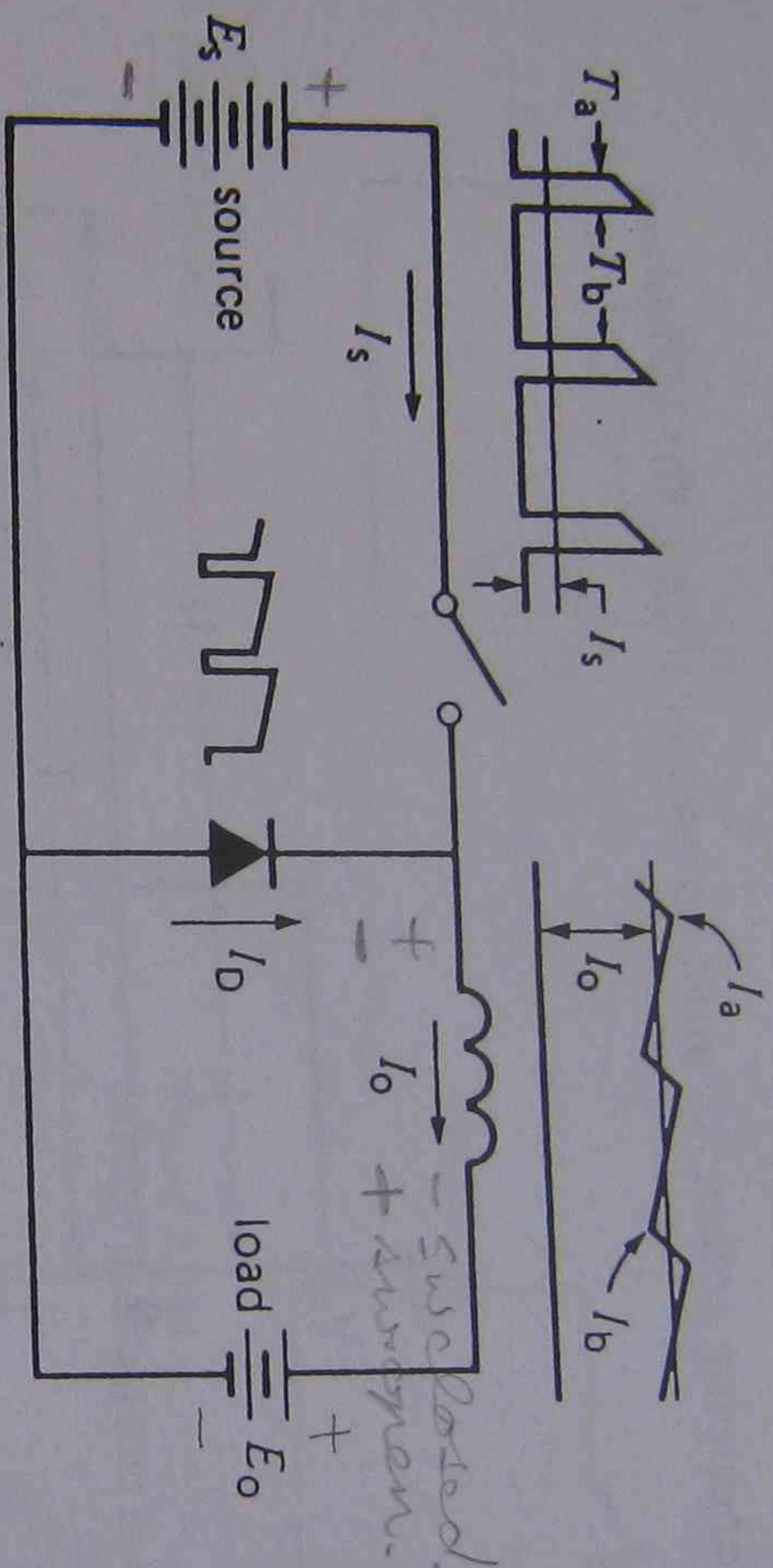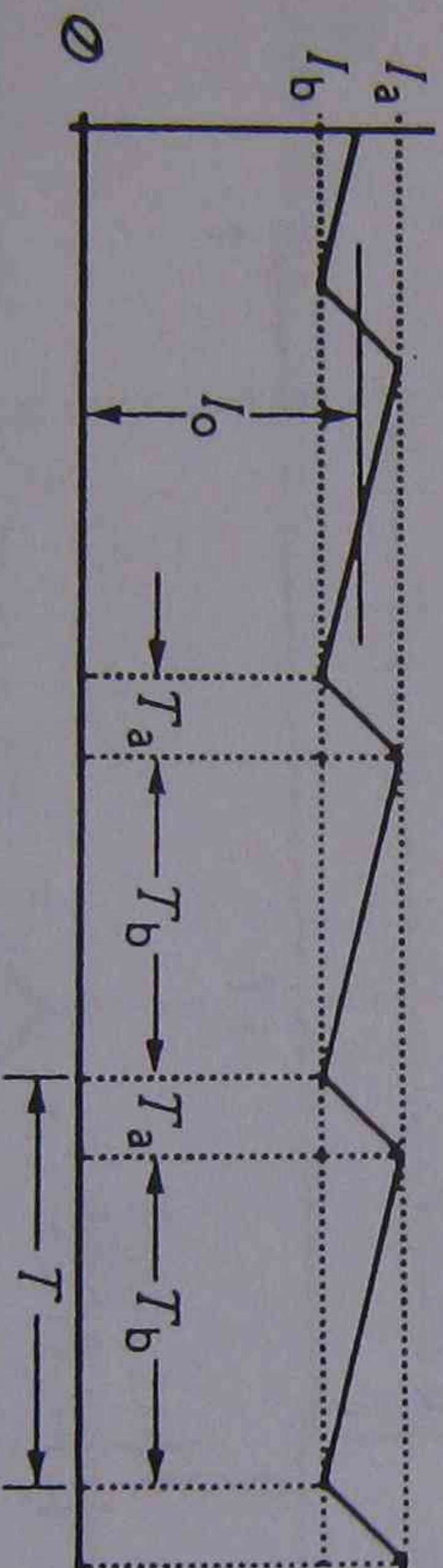
A.C. Motor Control.

Topic-

Figure 21-44a
Currents in a chopper circuit.
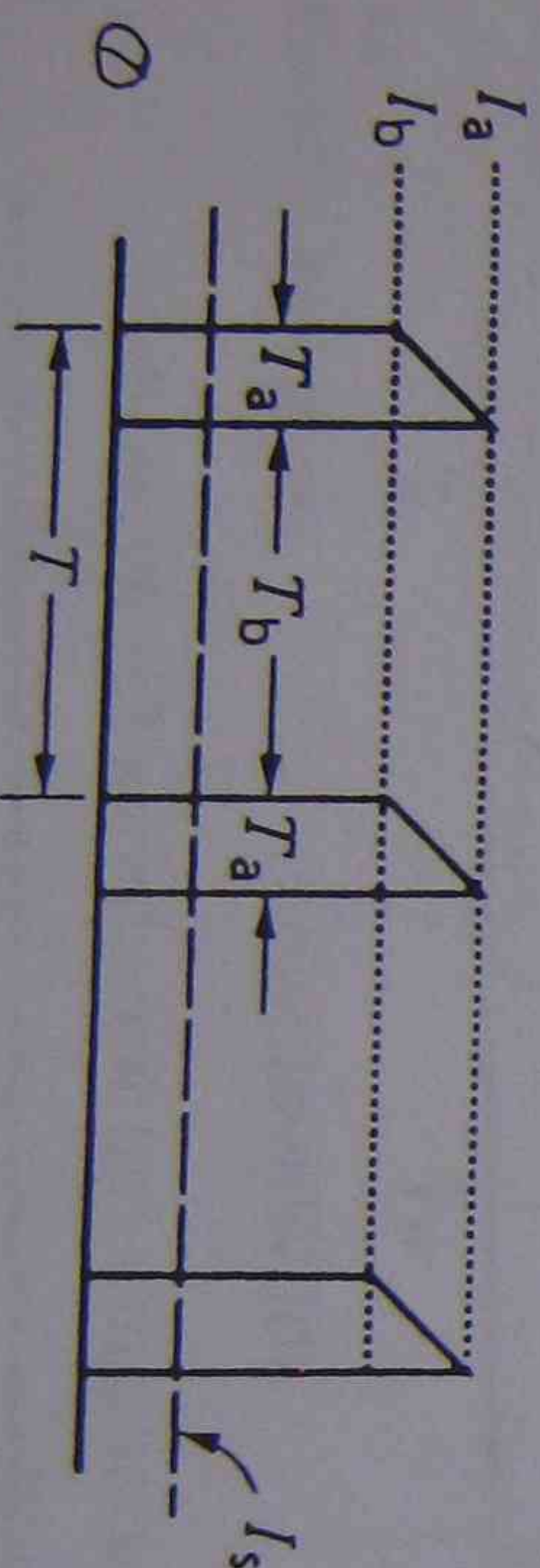

Figure 21-44b
Current in the load.
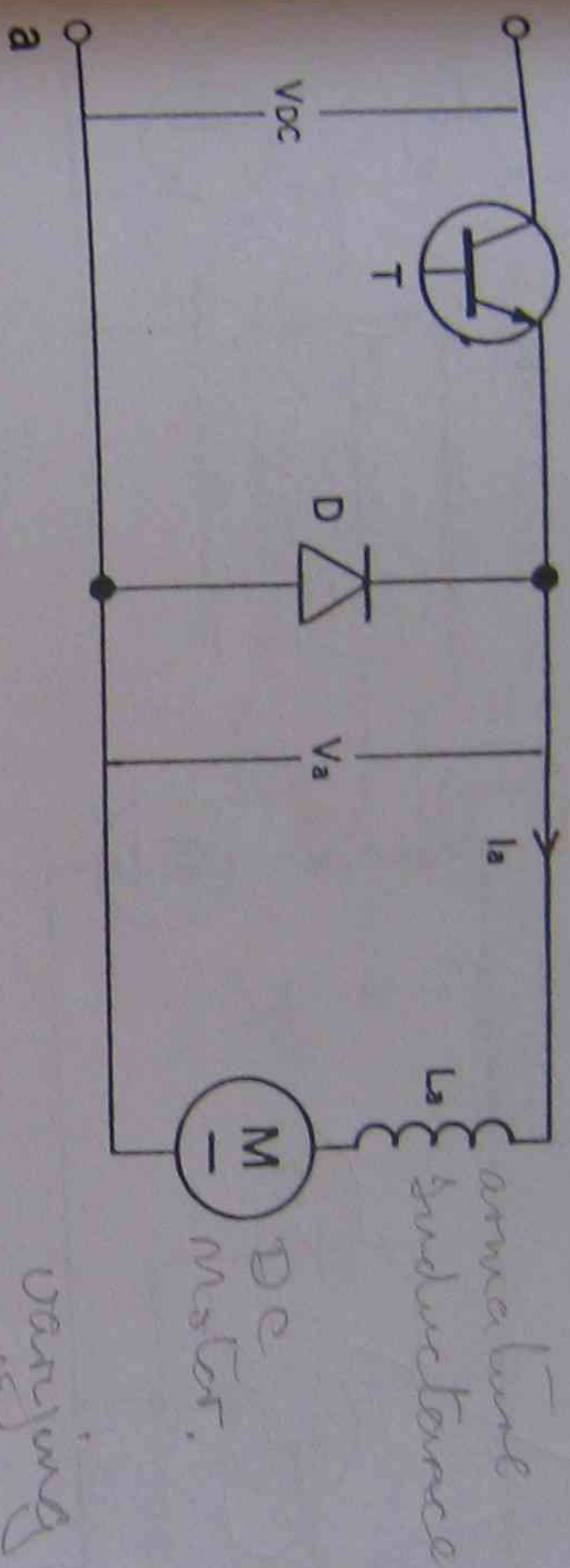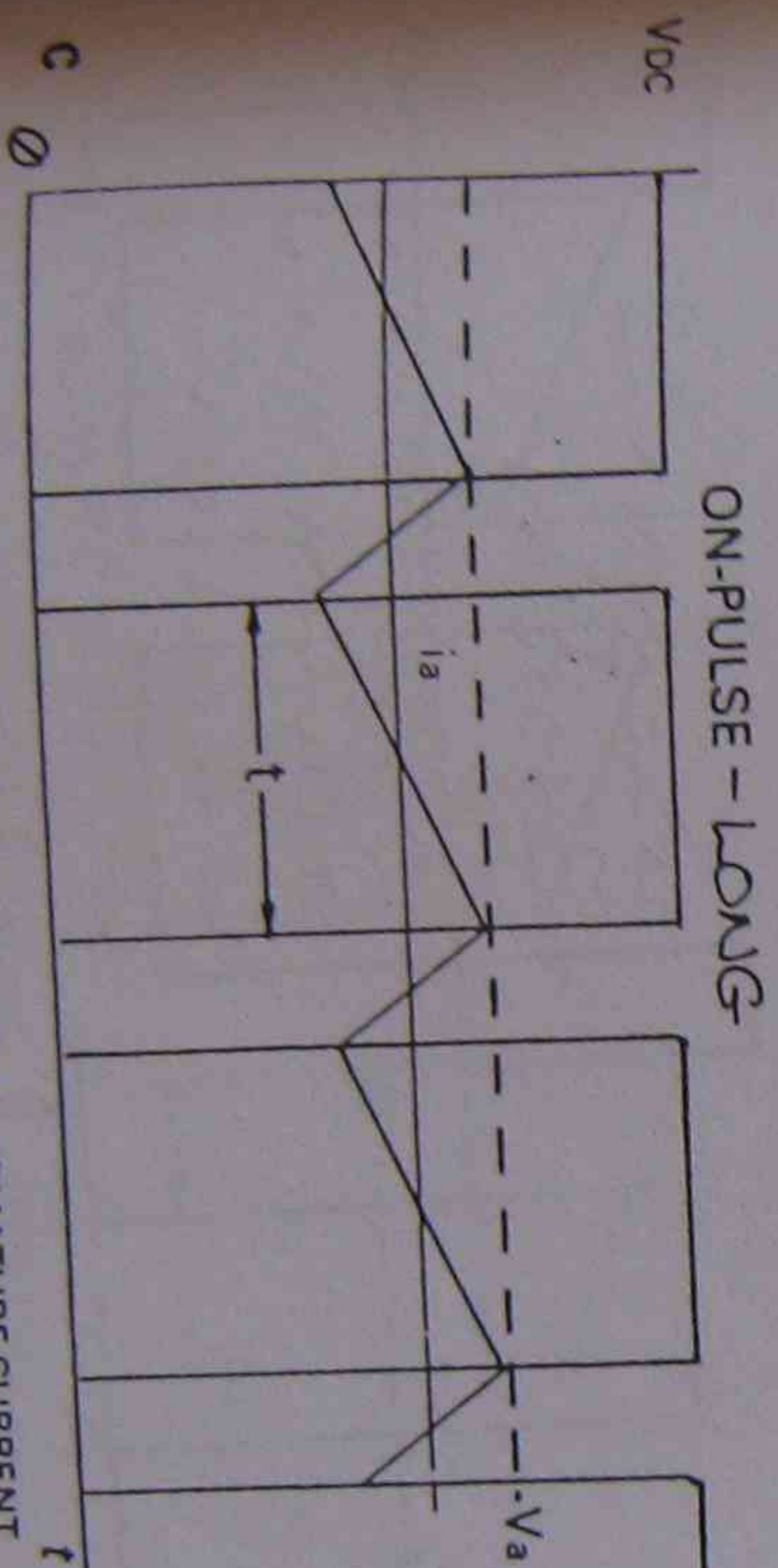

Figure 21-44c
Current drawn from the source.

A.C. Motor Control.

Topic -

solid state
switch

armature
inductance

Dc
Motor.

varying of applied
voltage by varying
the pulse width

a

ON-PULSE – SHORT

Voc

ia

ia

-Va

b

Ø

t

c

ON-PULSE – LONG

Voc

ia

t

ia

Va

Ø

t
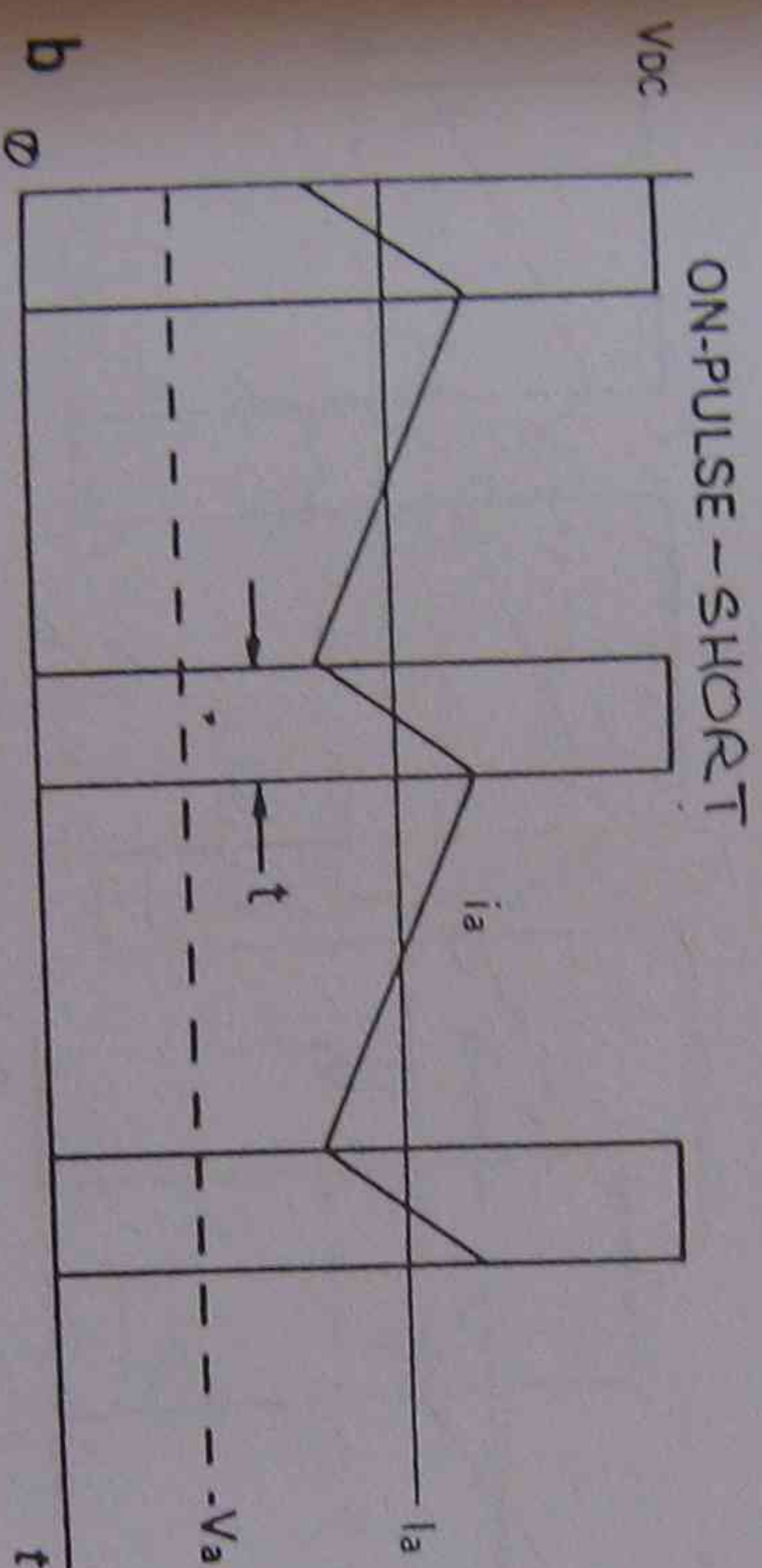
Voc = DC SUPPLY VOLTAGE   Ia = MEAN ARMATURE CURRENT
Va = DC ARMATURE VOLTAGE   ia = INSTANTANUOUS ARMATURE
La = ARMATURE INDUCTANCE   CURRENT

2   Basic dc converter, or chopper: **a**   circuit;
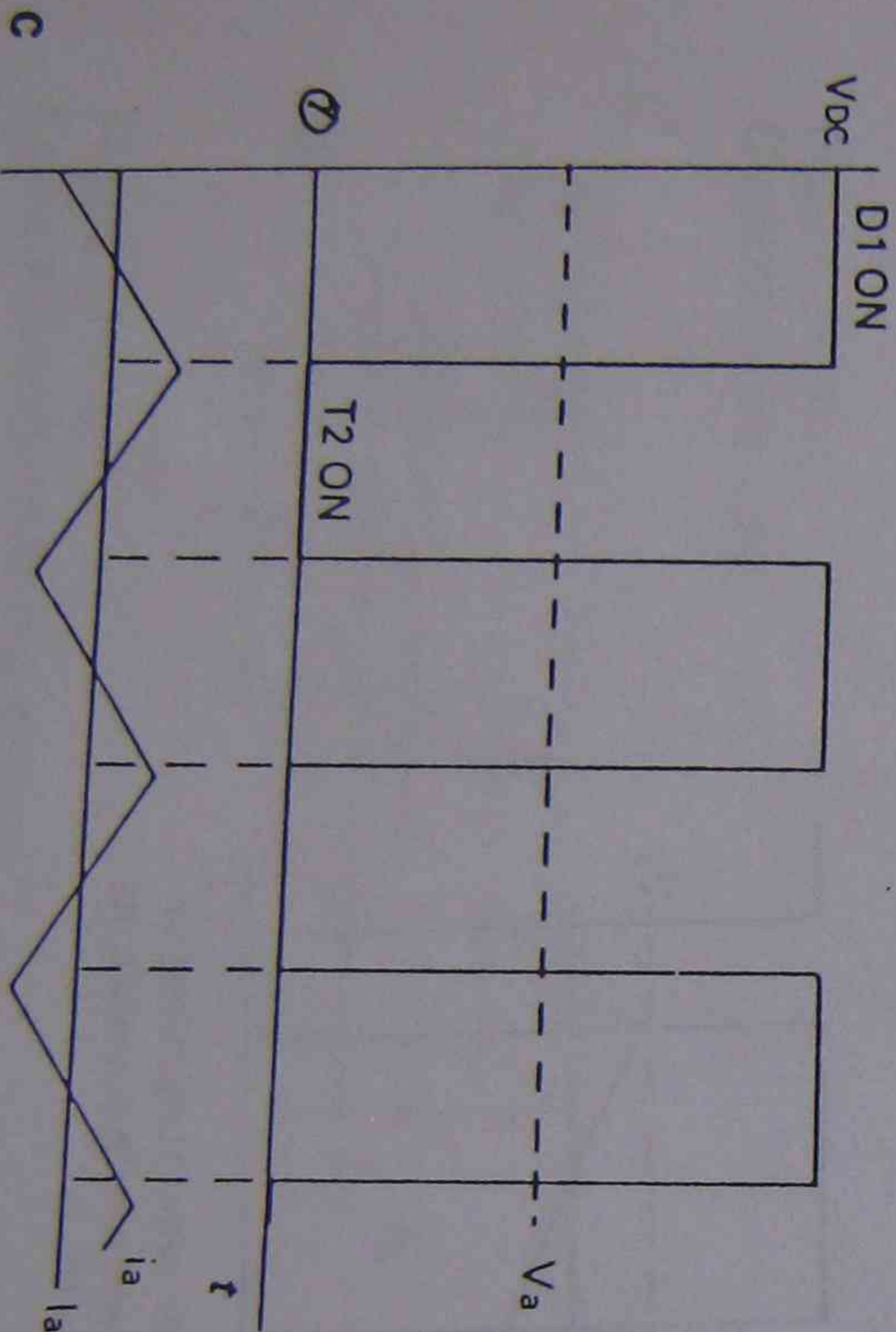**b**   low output voltage;   **c**   high output voltage.

A.C. Motor Control.

Topic-

a

VDC · T1 · D1 · T2 · D2 · M · ia
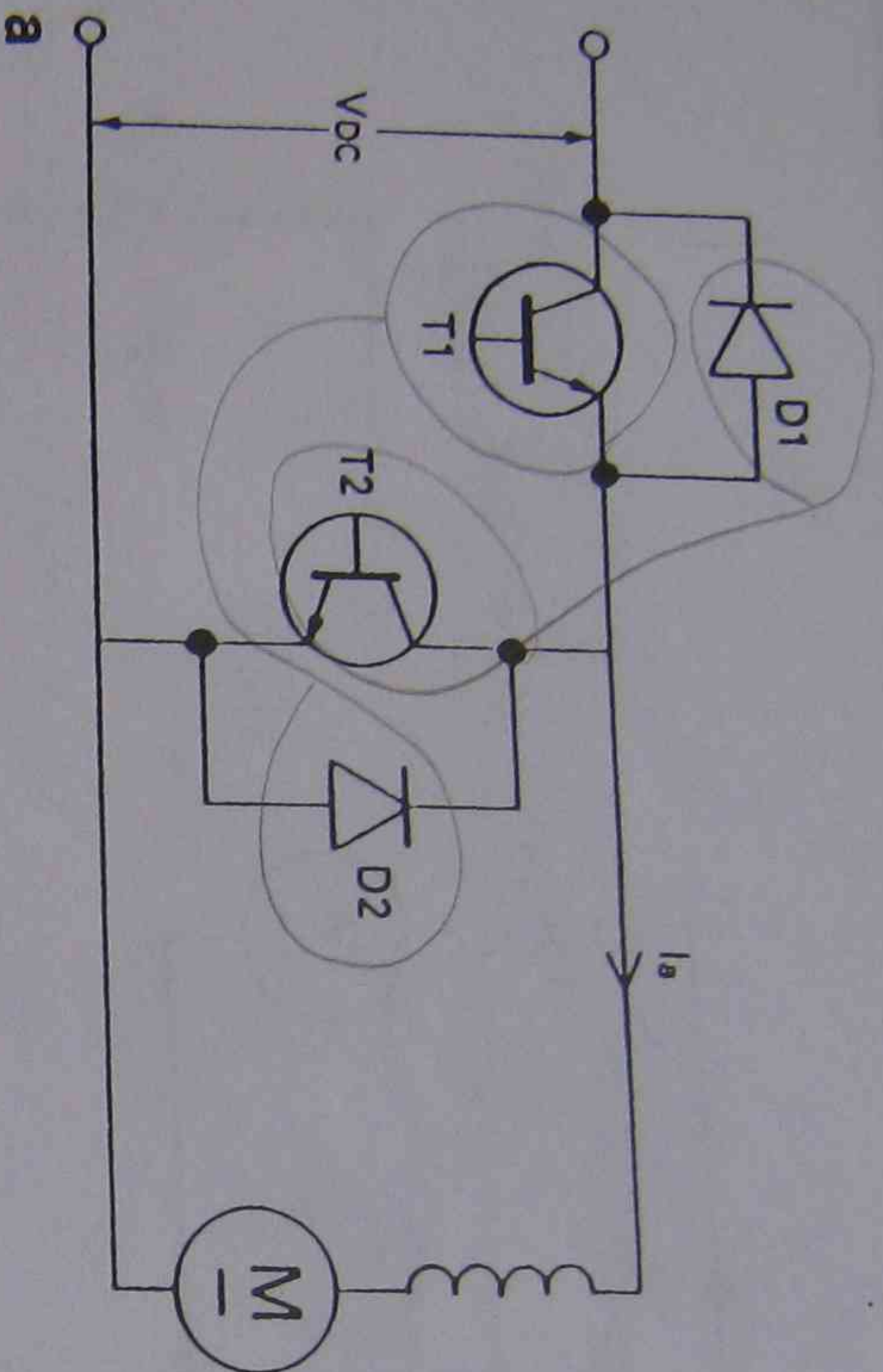
2 quadrant operation
Forward
- Motoring &
- Braking

b

T1 ON | D2 ON
Va
ia
t
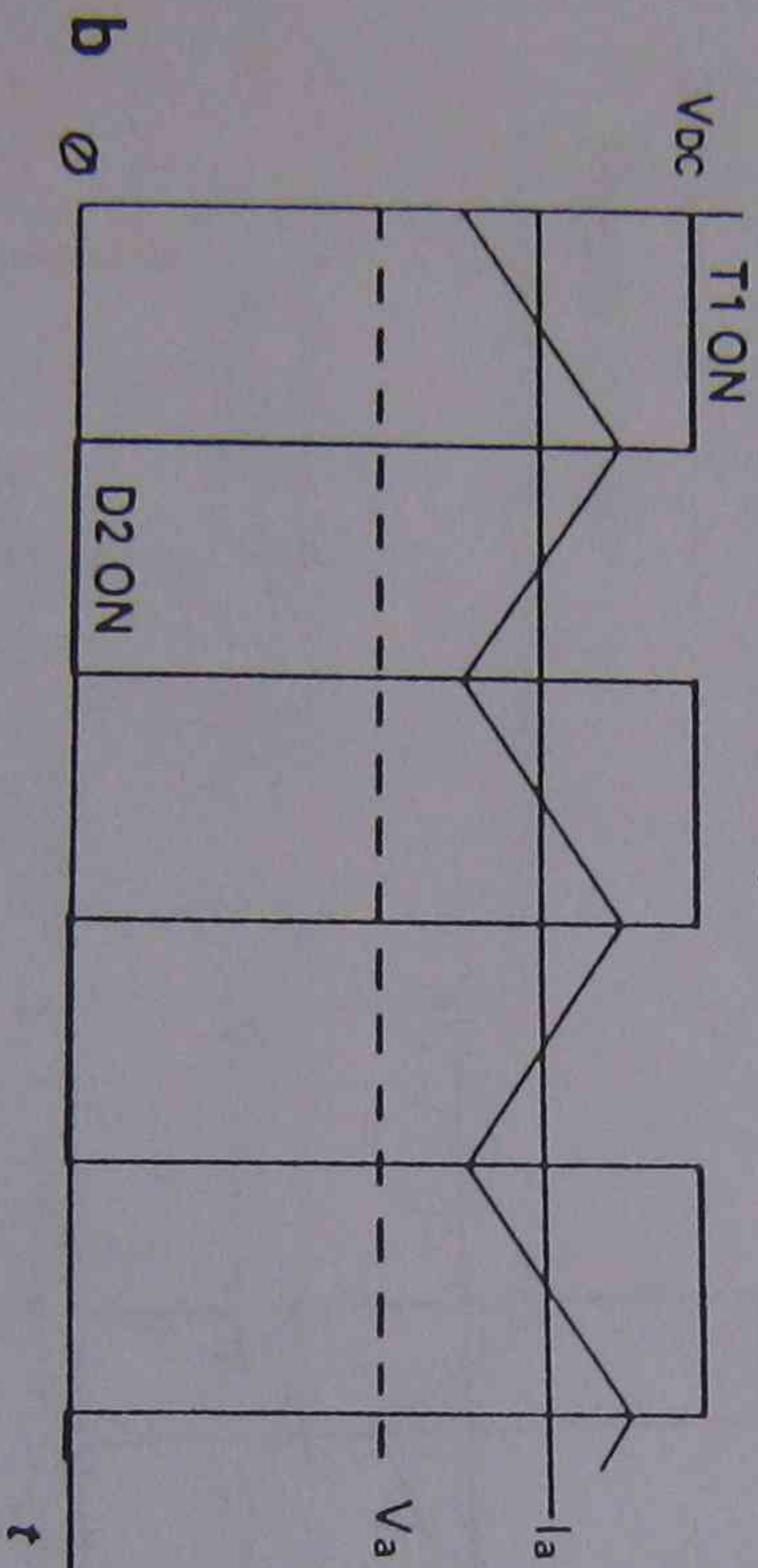
- Quadrant 1
- Motoring
- Energy transferd from supply to motor

T1 & D2 control

c

D1 ON | T2 ON
Va
ia
t

- Quadrant 2
- Braking
- Energy transfered back from motor to the supply
i.e. The motor is a generator with the supply as the load.

3 Two-quadrant dc converter; **a** circuit; **b** forward motoring; **c** forward braking.