Electronics

Power Supplies

(Higher)

5825

September 1999

HIGHER STILL

DET: Electronics

Power Supplies

Higher

Support Materials

CONTENTS

LECTURER'S /TEACHER'S INFORMATION AND SUPPORT MATERIAL

STUDENT'S INFORMATION AND SUPPORT MATERIAL

SECTION 1: LEARNING OUTCOMES

Outcome 1

Identify a rectification circuit and interpret its operation.

Performance criteria

a. A rectification circuit is correctly identified.
b. Circuit voltage levels are accurately measured and recorded.
c. The operation of a rectification circuit is correctly interpreted.

Note on the range of the outcome

Rectification circuit: full-wave; half-wave

Evidence requirements

Written, oral and graphical evidence to show that the candidate can record input and output voltages, and draw neat, annotated input/output waveforms and from them correctly identify the operation of the rectifier circuits.

Performance evidence that the candidate can measure input and output voltages, and correctly identify and interpret the operation of the rectifier circuit.

Outcome 2

Identify power supply filter circuits and interpret their operation.

Performance criteria

a. The filter circuit is correctly identified.
b. Circuit voltage levels are accurately measured and recorded.
c. The operation of a filter circuit is correctly interpreted.

Note on the range of the outcome

Filter circuit: capacitor or capacitor and resistor.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can record input and output voltages, and draw neat, annotated input/output waveforms.

Performance evidence that the candidate can measure input and output voltages, and correctly identify and interpret the operation of the filter circuit.

Outcome 3

Identify power supply stabilisation / regulation and protection circuits and interpret their operation.

Performance criteria

a. Stabilisation / regulation and protection circuits are correctly identified.
b. Load regulation is determined for a pre-constructed circuit.
c. The operation of a stabilisation / regulation circuit is clearly described.
d. The operation of a 3 terminal integrated circuit voltage regulator is clearly described.

Note on the range of the outcome

Stabilisation / regulation: zener, series pass transistor.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can clearly describe the action of a protection circuit.

Performance evidence that the candidate can measure and record correctly the output voltage for a range of loads and identify correctly the regulation and protection circuits.

Outcome 4

Identify switched mode power supplies and interpret their operation.

Performance criteria

a. The different sections are correctly identified in a switch mode power supply.
b. The operation of a switch mode power supply is clearly explained.
c. The operation of the switch mode power supply is tested / simulated.

Note on the range of the outcome

Sections: rectifier; filter; switch mode controller; switching transistor.
Operation: output regulation; ripple voltage variations; efficiency.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can explain correctly the operation of a switch mode power supply in terms of power supply, output voltage and load.

Performance evidence that the candidate can correctly identify the different sections of a switch mode power supply and can accurately measure the output voltage with varying levels of load.

SECTION 2 TEACHING AND LEARNING ADVICE INCLUDING HOW TO USE THE RESOURCE MATERIAL

Teaching Methods

In general the teaching and learning methods used are very dependent on the content of the unit and the facilities and expertise available at the delivering centre. By their very nature, however, the units in the Higher Electronics Course suggest the following teaching methods:

- Laboratory based learning activities
- Use demonstration circuits where possible
- Use student centred circuit testing and analysis
- Relate essential theory to circuit applications
- Place components used in a commercial contexts

It is important that all the teachers/lecturers working on the Higher Electronics Course share a commitment to these methods and employ them as much as possible. In addition other methods may be identified such as Computer Based Training if the centre has such a facility. The outcome of this should be a teaching ethos which pervades the course and sets it apart from other courses which will enjoy a different background.

POWER SUPPLIES UNIT DELIVERY

MAIN TOPICS	DELIVERY SUGGESTED
OUTCOME 1	
Half-wave rectification	Explain the theory and technology, tutorial examples. Practical exercises.
Full-wave rectification	Explain the theory and technology, tutorial examples. Practical exercises.
OUTCOME 2	
Filter capacitor	Explain the theory and technology, tutorial examples.
Ripple voltage	Explain theory, practical exercise.
OUTCOME 3	
Zener shunt stabiliser, series pass regulator	Explain the theory and technology, tutorial examples. Practical exercises.
Short-circuit current protection, over voltage protection circuits	Explain the theory and technology, tutorial examples.

MAIN TOPICS	DELIVERY SUGGESTED
OUTCOME 3 CONTINUED	
Three terminal voltage regulator	Literature searches, data sheets, explain technology, benefits and use.
Load regulation	Explain theory, practical exercises.
OUTCOME 4	
Components of a switch mode power supply (SMPS)	Relate the circuit of the SMPS to the general block diagram of a power supply. Explain circuit operation.
SMPS characteristics	Practical exercise to determine regulation, ripple voltage and efficiency.

SECTION 3: STARTING POINTS

Details of starting points based on Electronic and Electrical Fundamentals (Int 2)

The units in Electronic and Electrical Fundamentals (Int. 2) have been reviewed for starting points for the teaching of topics in Power Supplies (H). Relevant outcomes are identified using the Power Supplies (H) outcomes as the basis.

Power Supplies Learning Outcome 1

Identify a rectification circuit and interpret its operation.

The main topics are half-wave rectification, full-wave rectification, measuring and recording input/output waveforms.

Starting points from Electrical Fundamentals (Int 2)	Current and voltage relationships, power and energy concepts, electromagnetic fields and their interaction, generation of an e.m.f., r.m.s. and peak values.
Starting points from Introduction to Semiconductor Applications (Int 2)	Semiconductor diodes, diode characteristics, forward voltage drop, peak inverse voltage, measurement of input/output voltages.
Starting points from Combinational Logic (Int 2)	None.

Power Supplies Learning Outcome 2

Identify power supply filter circuits and interpret their operation.

The main topics are the application of smoothing capacitors, use of low pass RC filters and ripple voltage.

Starting points from Electrical Fundamentals (Int 2)	The determination of current and voltage relationships in d.c. networks.
Starting points from Introduction to Semiconductor Applications (Int 2)	Diode forward voltage drop and measurement of circuit voltage levels.
Starting points from Combinational Logic (Int 2)	None

Power Supplies Learning Outcome **3**

Identify power supply stabilisation/regulation and protection circuits and interpret their operation.

The main topics are the interpretation of the block diagram of a power supply, over voltage crowbar protection, short circuit current protection and integrated circuit voltage regulators.

Starting points from Electrical Fundamentals (Int 2)	The determination of current and voltage relationships in d.c. networks, for example voltage division and current division.
Starting points from Introduction to Semiconductor Applications (Int 2)	Zener diode, transistor amplifier, operational amplifier comparator, measurement of circuit voltage levels and operation of SCR.
Starting points from Combinational Logic (Int 2)	None

Power Supplies Learning Outcome 4

Identify switched mode power supplies and interpret their operation.

The main topics are interpretation of the block diagram, pulse width modulation, transistor switching, LC filter, flyback diode, switching frequency and duty cycle.

Starting points from Electrical Fundamentals (Int 2)	The determination of current and voltage relationships in d.c. networks, for example voltage division and current division. Power, current and voltage relationship.
Starting points from Introduction to Semiconductor Applications (Int 2)	Zener diode, transistor operation, operational amplifier comparator and measurement of circuit voltage levels.
Starting points from Combinational Logic (Int 2)	None

SECTION 4: ASSESSMENT

Assessment procedures showing what is to be assessed, when it is to be assessed and result recording methods.

Using the instrument of assessment

The Power Supplies unit is assessed using only four instruments of assessment. All of the Performance Criteria are assessed by laboratory reports. The laboratory assignments include test questions that ensure all Performance Criteria are assessed.

The following table shows how assessment tasks are related to Learning Outcomes and Performance Criteria. It also lists the evidence that should be collected.

OUTCOME	PC	ASSESSMENT TASK	EVIDENCE TO BE COLLECTED
1	a)	Learning Outcome 1 laboratory assignment question on the identification of a rectification circuit	Graphical / written restricted response question answers.
	b)	Learning Outcome 1 laboratory assignment to measure and record rectifier input and output waveforms.	Annotated graphical response.
	c)	Learning Outcome 1 laboratory assignment question to explain the operation of the rectifier using the waveforms of PC1(b)	Written restricted response question answers. All evidence to be contained in one report for outcome 1.
2	a)	Learning Outcome 2 laboratory assignment question on the identification of a filter circuit	Graphical / written restricted response question answers.
	b)	Learning Outcome 2 laboratory assignment to measure and record filter capacitor waveforms with and without load.	Annotated graphical response.
	c)	Learning Outcome 2 laboratory assignment question to interpret the operation of the filter capacitor using the waveforms of PC2(b)	Written restricted response question answers. All evidence to be contained in one report for outcome 2.
3	a)	Learning Outcome 3 laboratory assignment questions on identification of stabilisation and protection circuits	Graphical / written restricted response question answers.
	b)	Learning Outcome 3 laboratory assignment to investigate load regulation of a given circuit.	Laboratory report for Outcome 3 covering a pre-constructed circuit
	c)	Learning Outcome 3 laboratory assignment to explain the operation of the circuit tested in PC (b)	Laboratory report for Outcome 3
	d)	Learning Outcome 3 laboratory assignment questions on the operation of a three terminal regulator	Written restricted response question answers All evidence to be contained in one report for Outcome 3.
4	a)	Learning Outcome 4 laboratory assignment to investigate sections of a SMPS	Written restricted response question answers in laboratory report
	b)	Learning Outcome 4 laboratory assignment to investigate operation of a SMPS	Written response question answers in laboratory report
	c)	Learning Outcome 4 laboratory assignment to test the SMPS analysed in PC (a), (b)	Laboratory report to contain all evidence for Outcome4

The timing and duration of assessment

This unit progresses the student from the initial stages of linear power supplies to the full circuits for linear power supplies and switch mode power supplies.

Learning Outcome 1 covers rectification, Learning Outcome 2 deals with smoothing, Learning Outcome 3 develops linear power supplies and integrated circuit regulators and Learning Outcome 4 tackles the more complex circuits of switched mode power supplies. As a consequence the Learning Outcomes should be delivered and assessed in the order presented in the unit descriptor. The assessments should follow the conclusion of the teaching for each outcome.

Learning Outcome 1 assessment, laboratory assignment on rectification, should be delivered after the teaching of this topic. As an integral part of the teaching students should be given opportunities to attempt questions on rectification similar to those likely to be encountered in the end of topic laboratory assignment. This will reinforce teaching while preparing the student for assessment. All students must test either half-wave or full-wave rectification circuits. The laboratory exercise should be allocated about 120 minutes including the completion of a pro forma report. This should be an integrated learning and assessment activity with emphasis clearly on learning while assessment evidence is generated as natural product.

Learning Outcome 2 assessment, laboratory assignment on power supply filters, should be delivered after the teaching of that topic. As an integral part of the teaching students should be given opportunities to attempt questions on capacitor smoothing similar to those likely to be encountered in the end of topic laboratory assignment. This will reinforce teaching while preparing the student for assessment. All students must test filter circuits with and without load. The laboratory exercise should be allocated about 120 minutes including the completion of a pro forma report. This should be an integrated learning and assessment activity with emphasis clearly on learning while assessment evidence is generated as a natural product.

For the more able students laboratory assignments for Learning Outcomes 1 and 2 may be cascaded and performed after the delivery of the appropriate teaching materials.

Learning Outcome 3 assessment, laboratory assignment on load regulation and the operation of power supply circuits and should be delivered after the teaching of that topic. As an integral part of the teaching students should be given opportunities to attempt questions on regulation and circuit operation, similar to those likely to be encountered in the end of topic test and laboratory assignment. This will reinforce teaching while preparing the student for assessment. All students must test a stabilisation/regulation circuit with various loads. The laboratory exercise should be allocated about 95 minutes including the completion of a pro forma report. This should be an integrated learning and assessment activity with emphasis clearly on learning while assessment evidence is generated as a natural product.

Learning Outcome 4 assessment, laboratory assignment on switched mode power supply, should be delivered after the teaching of that topic. As an integral part of the teaching students should be given opportunities to attempt questions on switched mode power supplies similar to those likely to be encountered in the end of topic laboratory assignment. This will reinforce teaching while preparing the student for assessment. All students must test/simulate a SPMS with varying load. The laboratory exercise should be allocated about 60 minutes including the completion of a pro forma report. This should be an integrated learning and assessment activity with emphasis clearly on learning while assessment evidence is generated as natural product.

In principle, there are no time limits for the completion of each instrument of assessment, but it is likely that a maximum time will be allocated for the completion of each assignment. It is expected, however, that the average student will complete the work within the maximum time allowed. The table below indicates the recommended time allocated for each instrument of assessment.

Learning Outcome	**Suggested time**
1	120 minutes
2	120 minutes
3	95 minutes
4	60 minutes

It should be noted that the assessment instruments for this unit are all investigative laboratory assignments. These assignments should be an integral part of the learning process used to develop the student's knowledge, understanding and experience of the technology. They should produce assessment evidence that the student has reached a satisfactory achievement level as a natural product of the teaching and learning process.

Reassessment

Time is allowed within units for the assessment and reassessment of outcomes. Where a student has not attained the standard necessary to pass a particular outcome or outcomes, there should be an opportunity to be reassessed. Reassessment should focus on the outcome(s) concerned and, as a general rule, should be offered on a maximum of two occasions following further work on areas of difficulty. Evidence from the original unit assessment, should assist teachers and lecturers to identify why an individual student has failed to achieve a particular outcome and to plan focused support for learning.

For all the outcomes the reassessment should be based on the original instrument of assessment.

When students have not produced a satisfactory answer to a section of an assessment they should only be asked to repeat those sections in which they have not provided suitable responses. Students should be asked to complete the reassessment under the original controlled conditions. This reassessment should take place as soon as practical after the initial assessment and after discussion and analysis of the initial assessment has taken place between the student and the assessor. Students should be informed of the sections of the assessments that they are required to repeat and given additional teaching to help them tackle the reassessment. When there is a substantial number of students requiring reassessment a revision lesson on the problem area should be presented before reassessment.

Students may produce an answer which is substantially correct but which contains minor errors such as the mislabelling of a diagram or the incorrectly reading of an instrument (100 mA instead of 10 mA). In this situation students should be reassessed by asking them to give the correct answer orally. This should take place as soon as possible after the initial assessment and before any fuller discussion or analysis of it.

In the laboratory it is important that the focus is on power supply technology and that the student's attention is not distracted by other issues such as the use of test equipment and the recording of results. To this end students attempting this unit should be familiar with any test equipment or simulation software used and be able to record and interpret the readings taken from it. The assessor should distinguish between assessment difficulties resulting from a student's weakness in the use of test equipment or simulation software and a lack of understanding of power supply technology. If the student is weak in the use of test equipment or simulation software this should be resolved by additional training followed by the repeating of the requisite tests by the student.

The conditions under which assessment takes place

Arrangements documents refer to assessment being carried out under controlled conditions to ensure reliability and credibility. For the purposes of internal assessment, this means that assessment evidence should be compiled under supervision to ensure that it is the student's own work. Supervision may be carried out by a teacher, invigilator or other responsible person, for example, a workplace provider.

The assessments should take place in a laboratory adequately equipped with the necessary test equipment or simulation software. Ideally students should work individually but they may be allowed to work in pairs provided individual answer sheets are prepared. Students should not have access to teaching notes or texts on power supply technology but should complete the assessments from their own knowledge and understanding.

It is recommended that the assessments are introduced using the following procedure:

- allow the students a few moments to read the laboratory assignment sheet
- review and summarise the tasks required by the assignment
- identify the equipment and facilities provided for the assignment
- explain the operating conditions within the laboratory
- emphasise safety practices and precautions.

Students should be encouraged to identify themselves to the assessor on completion of the assignment and before any equipment is dismantled. The assessor should, if possible, mark the assignment and provide immediate feedback to the student regarding the outcome. If necessary remedial action should be performed immediately by the student.

Using internal assessment evidence to contribute to course estimates

The assessments for this unit are designed largely for internal assessment purposes and have only limited potential to generate evidence for external assessment performance. Since the assessments are all laboratory assignments they offer limited opportunities to provide evidence of a students likely performance in an external exam based assessment. Only the parts of the assignments which require the student to test and interpret the operation of a circuit offer opportunities to provide evidence for likely performance in the external assessment.

Advice on the recording and retention of evidence.

Regular meetings and informal discussions between internal verifiers and assessors facilitate good assessment practice. By using this approach assessors should understand that internal assessors are matching the internal assessments with external standards.

Internal verifiers sample records, observe a sample of assessments, countersign recording documents, support and guide assessors and are involved where disputes and appeals arise.

All evidence in the form of laboratory results/reports should be retained in case of appeals or disputes. Below is an example of a checklist, which could also be used to record results.

Unit Number: **Student's Name**
Unit Title: Power Supplies **Class**
Date: **Assessor**

OUTCOME 1	**TUTOR COMMENTS**
satisfactory	
unsatisfactory	
OUTCOME 2	**TUTOR COMMENTS**
satisfactory	
unsatisfactory	
OUTCOME 3	**TUTOR COMMENTS**
satisfactory	
unsatisfactory	
OUTCOME 4 PC a)	**TUTOR COMMENTS**
satisfactory	
unsatisfactory	
OUTCOME 4 PC b) AND c)	**TUTOR COMMENTS**
satisfactory	
unsatisfactory	

Section 5

Resource requirements including course notes, book list, audio/visual aid list.

Course notes

Student notes on Power Supplies are provided in the Student's Support Material.

These should be either adopted by the centre or modified to suit the teaching approach taken and the equipment available.

Laboratory sheets

Much of the Performance Criteria of Power Supplies require students to operate test instruments in conjunction with power supply circuits. Laboratory sheets for each outcome covering the range statements are available in the NABs pack.

These should be either adopted by the centre or modified to suit the teaching approach taken and the equipment available. Further circuits may be added to the list provided the circuits meet with the unit's performance criteria.

Book list

Electronics for Today and Tomorrow, Tom Duncan, John Murray,
ISBN 0-7195-7413-7

Electronic Devices and Circuits, Bogart, Merrill Publishing Company,
ISBN 0675-21150-6

Applied Electronics, John C Morris, Arnold, ISBN0-340-65284-5

Electronics: Practical Applications and Design, John C Morris, Arnold,
ISBN 0-340-50427-7

Crash Course in Electronics Technology, Louis E Frenzel, Newnes,
ISBN 0-7506-9710-5

ESM Electronics Service Manual, Wimborne Publishing Ltd, Allen House, East Borough, Wimborne, Dorset BH21 1PF. Tel: 01202 881749, Fax: 01202 641692

Audio/visual aids

The electronics teaching laboratory should have prominently displayed an electrical safety notice. These are available from a variety of electrical and electronic wholesale outlets and distributors and are relatively inexpensive.

Component manufacturers and distributors offer wall charts and posters showing many aspects of electronics. These vary from resistor colour codes to product processing details and application advertisements. They are generally free and available on request. They are useful as visual aids on the walls of the electronics teaching laboratory as they create atmosphere and over a period of time act as a constant reminder to students.

Data booklets

Technological Studies Data Booklet	Robert Gibson and Sons, 17 Fitzroy Place, Glasgow G3 7SF
Electrical Formulae Booklets	These should be either constructed by the student or provided by the teaching section. Their main advantage is that they are tailored to fit the courses on offer.

SECTION 6

Electronics laboratory requirements including technical information sources, components, materials, facilities and equipment.

Technical information sources

It should be noted that developments in electronics, communications and computing continue to offer tremendous opportunities for the dissemination and retrieval of information. At the time of writing the Internet, CD ROM and on-line component distributors catalogues and web sites for manufacturers, suppliers and providers of educational material are current examples. All of these and similar potential future products originate from electronics technology. Accordingly students should be encouraged to use them and to explore and take advantage of such technological products as they emerge. A culture of using the technology to its limits should be encouraged.

There are numerous sources of technical information on electronics other than the traditional library books. These sources, however, are only helpful if they are both accessible and relevant. The following has been refined through use and experience but inevitably will be superseded by better methods as the technology advances and they become available.

Component Distributors Catalogues

MPS [Maplin]	
Web Site	http://www.maplin.co.uk
E-mail	<recipient>@maplin..co.uk
Telephone: Customer services	01702 554002
Telephone: Free technical helpline	01702 556001
Address	Maplin MPS, Freepost SMU 94, P.O. Box 777, Rayleigh, Essex SS6 8LU

RS	
Web Site	http://rswww.com
E-mail	http://rswww.com
Telephone	01536 201201
Telephone: Free technical helpline	01536 402888
Address	RS Components Ltd., P O Box 99, Corby, Northants NN17 9RS

Farnell	
Web Site	http://www.farnell.co.uk
E-mail	Enquiries@farnell.com
Telephone: Customer services	0113 2636311
Telephone: Free technical helpline	0133 2799123
Address	Farnell Electronic Components, Canal Road, Leeds, LS12 2TU

Access should be provided for students to one or more of the above Component Distributors Catalogues in either paper, CD ROM or on-line form.

Selected data books, reference books and specialist texts should also be provided from those offered by the above sources. There are so many good items on offer it is impossible to recommend a definitive list that is largely a matter of local preference. Choices should be based on staff expertise, the teaching and learning approaches used and the available budget. As many of the smaller specialised texts are low cost it should be possible to provide several reference copies for use in the electronics laboratory.

Many manufacturers of electronic components have web sites. These may be located by a net search using the manufacturer's name. Once into the web site it is often possible to locate technical data, application information and in some situations, design tutorials.

Components

The Electronics Laboratory should offer access to component stocks as a standard facility. This is for the benefit of both staff and students who will require access to components for demonstrations, experimentation and for case study and project work. The stock, however, has to be managed and controlled if the quality of the facility is to be sustained. The approach taken to this is a matter for the centre's organisational structure but experience suggests that one person needs to be clearly identified as having responsibility for the stock, for issuing it and for reordering.

Below is a typical basic selection of components.

resistors	Low cost metal film 0.25 W - standard preferred values from 1 Ω to 10 MΩ. High powered resistors 2.5 W silicon coated- standard available values.
potentiometers	150 mW carbon trimmers- standard preferred values from 100 Ω to 10 MΩ.
Capacitors	Metallised ceramic plate capacitors-standard preferred values from 1.8 pF to 120 pF Resin dipped plate ceramic capacitors -standard preferred values from 10 pF to 0.47 μF Radial polystyrene capacitors-standard preferred values from 100 pF to 8200 pF Radial lead electrolytic capacitors-standard preferred values from 1 μF to 47000 μF Axial lead electrolytic capacitors-standard preferred values from 1 μF to 47000 μF

diodes	1N4148, 1N4001,1N5401,BZX85- range of voltages from 2.7 V to 15 V
bridge rectifier	W005G
light emitting diodes	3 mm and 5 mm red, orange and green
transistors	BC184L, BC214L, 2N3053, BFY50, TIP31A, TIP32A,TIP33A, 2N3055E, 2N2955, 2N3819, 2N3820
op. amps.	µA 741, LM 324N, CA3140E
logic chips	74 LS series TTL - selected functions as appropriate 4000 series CMOS - selected functions as appropriate
other analogue integrated circuits	NE555N timer, ICM7555 timer, L7805CP, L7812 CP positive voltage regulators, L7905CT, L7812 CT negative voltage regulators
other digital integrated circuits	DACs and ADCs to suit laboratory applications
fuses	As required for instruments
switches	Push button, toggle, slide and DIL miniature as required
transformers	As required
lamps and bulbs	Low voltage and power selection to meet requirements
relays	Low voltage as required
connectors	Terminal blocks, 4 mm plugs and sockets in red, black, blue, yellow and green

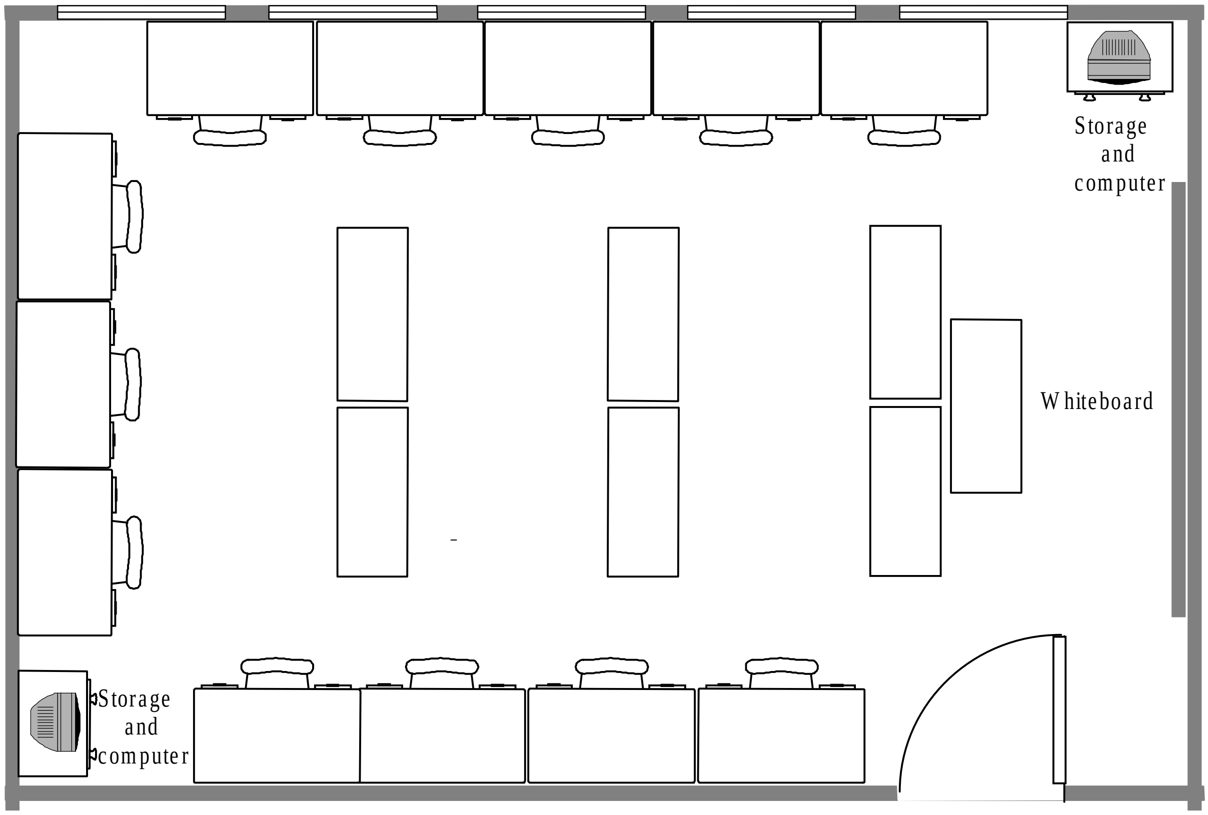
Materials

Few materials are required. It may be helpful to have reels of solid and stranded conductor wire in a variety of colours available. Some are suggested below.

WIRE TYPE	COLOUR
Solid Core Wire (1/0.6)	Black, Blue, Brown, Green, Red, White, Violet, Yellow
Hook-Up Wire (7/0.2)	Black, Blue, Brown, Green, Red, White, Violet, Yellow

Facilities

The ideal electronics teaching laboratory has office style or computer tables (wide) around the walls with matching narrow tables in the middle. A typical plan is shown below. This type of layout has found favour in a number of centres and so has clearly proved its worth for several teams of teaching engineers.



Trunking with 13 Amp socket outlets should be fitted around the walls at a convenient height above the wide tables. Each student should have available a 2 metre run of surface and at least four 13Amp socket outlets. This is necessary to allow adequate working surface for test equipment, circuits, components and papers. Eye level shelving around the walls above the power socket trunking can also be useful for test instruments and general storage.

The socket outlets should be protected by a suitable device such as an earth leakage circuit breaker and a central safety switch with key lock. The design and installation of such facilities should be undertaken by a specialist as they constitute important safety features.

The central tables are used for written work and group teaching. Suitable strong moveable chairs such as those found in hotel conference rooms should be provided in adequate numbers to allow seating around the wall tables or in the centre but not both. Excessive furniture and narrow spaces between tables in the laboratory can be a safety hazard and should be avoided.

Equipment

In the electronics laboratory each student should have access to the following equipment. Ideally there should be one set of equipment per student.

1. Multimeter
2. Dual rail power supply
3. Signal generator
4. Double beam oscilloscope
5. Logic probe
6. Computer

It is also helpful to have a limited range of tools available such as:

- Snipe nosed pliers
- Wire cutters
- Wire strippers
- Screw drivers

The types of tools and equipment on the market are constantly changing through a process of continuous improvement. It is strongly recommended that before purchasing any items for an electronics laboratory advice is sought from a current user experienced in this area. Issues such as the cost of hand tools in relation to their quality and life expectancy with inexperienced users who may damage or remove them from the laboratory have to be given due consideration. Equipment may be found which is both adequate for the teaching laboratory, student proof and inexpensive requiring little maintenance.

There are many suppliers of test equipment and tools but only those specialising in the educational market are likely to offer products at an acceptable price. Similarly these suppliers are more likely to have tools and equipment which can survive the rigours of the teaching laboratory. It is good practice to both commercially and technically survey the market to insure that the best suppliers are offered sales opportunities. Other centres which have tried and tested equipment are often the best source of information and should be consulted as part of the purchasing exercise. Suppliers may provide access to users of their products who are prepared to discuss their experiences with others. Time spent on this will pay substantial dividends in future years in terms of equipment downtime and repair costs.

Software

The electronics teaching laboratory is greatly enriched by the presence of PCs with appropriate software. Since computers are one of the main products of electronics technology they find extensive use in the application of the technology and form part of the electronics environment. While the capital outlay for this may be significant there has to be recognition of the part played by the computer with specialised software in the electronics environment.

Through access to suitable computing facilities and software students should be exposed to this environment in the teaching laboratory. Commercial software for word and data processing is widely available at reasonable cost and is generally selected by centres to conform with their local policy. These may find application in the creation of reports and the analysis of results.

In addition, however, circuit simulation and drawing software may also be used but is less widely available and more difficult to locate in a form which is cost effective for the teaching laboratory. To meet these criteria the software must be easy to use without extensive training and be available at low cost with multiple copies site licensed. While there are several products on the market those which have stood the test of time and so are favoured for use in colleges and schools are listed below.

Invent ! CROCODILE CLIPS: simple simulation of electronics and mechanics

Web address	WWW.crocodile-clips.com/education/v3.htm
E-mail	sales@crocodile-clips.com
Telephone	0131 226 1511
Fax	0131 226 1522
Address	Crocodile Clips
	11 Randolph Place
	Edinburgh
	EH3 7TA

Electronics Workbench: circuit simulation and testing

Web address	http://www.adeptscience.co.uk
E-mail	info@ adeptscience.co.uk
Telephone	01462 480055
Fax	01462 480213
Address	Adept Science plc
	6 Business Centre West
	Avenue One
	Letchworth
	Herts.
	SG6 2HB

SmartDraw: drawing of diagrams and plans with associated symbol libraries

Web address	http://www.smart draw.com
E-mail	sales@ttp.co.uk
Telephone	01889 564601
Fax	01889 563219
Address	The Thompson Partnership Lion Buildings, Market Place, Uttoxeter, Staffs. ST14 8HZ

SECTION 7: SAFETY

The safety of teaching staff and students working in the electronics laboratory must be the primary concern of everyone involved.

This has to take precedence over all other activities and be sustained against all other pressures.

There are many aspects to safety as follows:

- Statutory requirements
- Centre procedures
- Centre structure
- Staff training and behaviour
- Laboratory features
- Student training and behaviour.

It is beyond the scope of this document to provide details of all of these items which should be embraced as part of an centre's safety policy. Lecturer's /Teacher's must, however, be content that all appropriate safety measures are in place before embarking on work within the electronics laboratory.

Student training is a recurrent activity which is likely to be the direct responsibility of the lecturer/teacher. While this has to take place on a continuous basis as work in the laboratory proceeds it is helpful to perform specific safety training at course commencement. Such training might form part of the course induction as its relevance extends across all course units. This is particularly important for electronics students as they should be encouraged to develop their own safety culture which should become a lifelong asset.

Lecturers/teachers performing safety training for students may find a rich diversity of available material. Of specific relevance, however, is a teaching package prepared by the University of Southampton's Department of Electrical Engineering and Teaching Support and Media Services. The package was prepared in association with and financially supported by the Health and Safety Executive. It consists of :

- Handbook: 'Safety Handbook for Undergraduate Electrical Teaching Laboratories'
- Video Programme: 'Not to Lay Blame'
- A booklet: 'Tutor's Guide'

The package is targeted at the first year undergraduate level and works well with other students at similar levels. The handbook is very comprehensive and sufficiently inexpensive to be bought in quantity and given to students for everyday use. It is well presented using text and cartoons. The video dramatises issues associated with electrical/electronics laboratory work using a style and characters likely to appeal to the majority of students. The Tutor's Guide booklet rounds the package off by giving guidance on the use of the video and handbook. In addition it contains 'Safety Rules for Electrical Laboratories' and a comprehensive list of references to enable further reading should you wish it.

At the time of writing the distribution of the package was the subject of discussions. To find out the current situation contact:

Maggie Bond
Department of Electrical Engineering
University of Southampton
SO17 1BJ

Phone 01703 595164

Email M.A.Bond@soton.ac.uk

SECTION 8: ACKNOWLEDGEMENTS

We gratefully acknowledge the support and assistance provided by colleagues at Stow College who have contributed material and helpful advice for this pack.

We would also acknowledge with thanks lecturers and teachers in other colleges and schools who have assisted in the preparation of the pack by contributing material and by commenting on draft documents.

STUDENT'S INFORMATION
AND SUPPORT MATERIAL

SECTION 1: LEARNING OUTCOMES

Outcome 1

Identify a rectification circuit and interpret its operation.

Performance criteria

a. A rectification circuit is correctly identified.
b. Circuit voltage levels are accurately measured and recorded.
c. The operation of a rectification circuit is correctly interpreted.

Note on the range of the outcome

Rectification circuit: full-wave; half-wave

Evidence requirements

Written, oral and graphical evidence to show that the candidate can record input and output voltages, and draw neat, annotated input/output waveforms and from them correctly identify the operation of the rectifier circuits.

Performance evidence that the candidate can measure input and output voltages, and correctly identify and interpret the operation of the rectifier circuit.

Outcome 2

Identify power supply filter circuits and interpret their operation.

Performance criteria

a. The filter circuit is correctly identified.
b. Circuit voltage levels are accurately measured and recorded.
c. The operation of a filter circuit is correctly interpreted.

Note on the range of the outcome

Filter circuit: capacitor or capacitor and resistor.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can record input and output voltages, and draw neat, annotated input/output waveforms.

Performance evidence that the candidate can measure input and output voltages, and correctly identify and interpret the operation of the filter circuit.

Outcome 3

Identify power supply stabilisation / regulation and protection circuits and interpret their operation.

Performance criteria

a. Stabilisation / regulation and protection circuits are correctly identified.
b. Load regulation is determined for a pre-constructed circuit
c. .The operation of a stabilisation / regulation circuit is clearly described
d. .The operation of a 3 terminal integrated circuit voltage regulator is clearly described.

Note on the range of the outcome

Stabilisation / regulation: zener, series pass transistor.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can clearly describe the action of a protection circuit.

Performance evidence that the candidate can measure and record correctly the output voltage for a range of loads and identify correctly the regulation and protection circuits.

Outcome 4

Identify switched mode power supplies and interpret their operation.

Performance criteria

a. The different sections are correctly identified in a switch mode power supply.
b. The operation of a switch mode power supply is clearly explained.
c. The operation of the switch mode power supply is tested / simulated.

Note on the range of the outcome

Sections: rectifier; filter; switch mode controller; switching transistor.
Operation: output regulation; ripple voltage variations; efficiency.

Evidence requirements

Written, oral and graphical evidence to show that the candidate can explain correctly the operation of a switch mode power supply in terms of power supply, output voltage and load.

Performance evidence that the candidate can correctly identify the different sections of a switch mode power supply and can accurately measure the output voltage with varying levels of load.

SECTION 2: ASSESSMENT INSTRUMENTS

The assessment instruments for the outcomes

The Power Supplies unit covers the different sections comprising a power supply. Each outcome addresses a particular section, therefore you will be involved with assessment activities for all the four outcomes.

Learning Outcome 1 deals with half-wave and full-wave rectification circuits .You will be asked to identify and test various rectification circuits and measure and record input/output waveforms. You will then be required to explain the operation of the circuit under investigation using the data acquired during testing.

If necessary you should seek clarification from your lecturer/teacher before you start any laboratory exercise, review your progress as you proceed and submit your pro forma report for comment on completion. You may prefer to work on this with a friend but you should both contribute equally as team members and submit individual reports at the end. You are unlikely to be allowed to work in teams of more than two, as there is not enough in the tests to occupy you fully.

The **laboratory exercise for Learning Outcome 1** should take about 90 minutes to complete (certainly not any more than 120 minutes).

Learning Outcome 2 covers smoothing/filtering circuits. You will be asked to identify and test various smoothing/filter circuits, measure and record input/output waveforms. You will then be required to explain the operation of the circuit under investigation using the data acquired during testing.

If necessary you should seek clarification from your lecturer/teacher before you start the laboratory exercise, review your progress as you proceed and submit your pro forma report for comment on completion. You may prefer to work on this with a friend but you should both contribute equally as team members and submit individual reports at the end. You are unlikely to be allowed to work in teams of more than two, as there is not enough in the tests to occupy you fully.

The **laboratory exercise for Learning Outcome 2** should take about 90 minutes to complete (certainly not any more than 120 minutes).
If you are well prepared and work efficiently then you may be able to perform the laboratory exercises for Learning Outcome 1 and 2 in one laboratory time slot. Consult your course lecturer/teacher.

Learning Outcome 3 examines linear integrated circuit voltage regulators, basic power supply regulation/stabilisation circuits as well as over voltage and short circuit protection circuits. The assessment instrument is a laboratory assignment in which you will be required to test a pre-constructed linear voltage stabilisation/regulation circuit. This involves measuring the output voltage for varying levels of load and using this information to explain the operation of the circuit under investigation. This laboratory assignment will also test your knowledge of over voltage protection, short circuit protection and the operation of integrated voltage regulators.

If necessary you should seek clarification from your lecturer/teacher before you start the laboratory exercise, review your progress as you proceed and submit your pro forma report for comment on completion. You may prefer to work on this with a friend but you should both contribute equally as team members and submit individual reports at the end. You are unlikely to be allowed to work in teams of more than two, as there is not enough in the tests to occupy you fully.

The **laboratory exercise for Learning Outcome 3** should take about 95 minutes to complete

Learning Outcome 4 concentrates on switched mode power supplies (SMPS) .The assessment instrument is a laboratory assignment in which you will be asked to identify the different section of a SMPS, test/simulate a SMPS and use the experimental data to explain the operation of the SMPS.
If necessary you should seek clarification from your lecturer/teacher before you start the laboratory exercise, review your progress as you proceed and submit your pro forma report for comment on completion. You may prefer to work on this with a friend but you should both contribute equally as team members and submit individual reports at the end. You are unlikely to be allowed to work in teams of more than two, as there is not enough in the tests to occupy you fully.

The **laboratory exercise for Learning Outcome 4** should take about 60 minutes to complete

SECTION 3: ASSESSMENT STANDARDS

The required achievement standard for each assessment

Learning Outcome 1 Rectification Assessment

The laboratory report test questions and the practical activities are designed to match the Performance Criteria for the Learning Outcome. Because of this you will have to reach a minimum standard in both the test questions and the practical activities to gain a pass.

Learning Outcome 2 Power Supplies Filter Circuit Assessment

The laboratory report test questions and the practical activities are designed to match the Performance Criteria for the Learning Outcome. Because of this you will have to reach a minimum standard in both the test questions and the practical activities to gain a pass.

Learning Outcome 3 Linear Power Supplies Assessment

The laboratory report test questions and the practical activities are designed to match the Performance Criteria for the Learning Outcome. Because of this you will have to reach a minimum standard in both the test questions and the practical activities to gain a pass.

Learning Outcome 4 Switched Mode Power Supplies Assessment

The laboratory report test questions and the practical activities are designed to match the Performance Criteria for the Learning Outcome. Because of this you will have to reach a minimum standard in both the test questions and the practical activities to gain a pass.

NOTE:

For each of the circuits you are testing you are expected to understand and explain its operation. This may involve performing calculations, drawing and interpreting graphs or waveforms and suggesting uses for the circuit. Your reports should have adequate information in them to convince your tutor that have correctly tested the circuit and that you understand its operation. You are required to complete this for four circuits:

- Full-wave rectifier circuit
- Filter circuit
- Power supply stabilisation circuit
- SMPS circuit

SECTION 4: STUDENT GUIDE

Power supplies are used in most electronic equipment, for example, computers, amplifiers, alarm systems and televisions. Consequently it is important that electronic technician engineers have a good grasp of the fundamentals of stabilised power supplies.

Learning Outcome 1 explores rectification, that is, converting a.c. waveforms into d.c. waveforms. In this outcome you are required to measure and record a.c. and d.c. waveforms. To prepare yourself for this outcome and the practical aspects of the remaining outcomes you should familiarise yourself with:

- test instruments, such as the oscilloscope, the signal generator, and the multi-meter
- tools such as wire strippers, wire cutters, soldering iron, bread-board
- electronic circuit simulation software.

To improve your knowledge and understanding of the subject material you should simulate given circuits and take heed of instrument readings in the simulation software.

Learning Outcome 2 investigates power supply filtering and again your are required to measure and to record waveforms. The type of filtering normally used is capacitive, however your background reading for this outcome should include capacitor charging and discharging, CR and RC networks and low pass LC filter circuits.
To improve your knowledge and understanding of the subject material you should simulate given circuits and take heed of instrument readings in the simulation software.

Learning Outcome 3 looks at the sub circuits and then at the complete circuits that make a stabilised power supply. These circuits are composed of active devices such as transistors, zener diodes, operational amplifiers and thyristors. It would be to your advantage to revise the operation of these devices. To improve your knowledge and understanding of the subject material you should simulate given circuits and take note of instrument readings in the simulation software.

Learning Outcome 4 introduces switched mode power supplies. To prepare for this outcome you should study how the transistor works as a switch, investigate how a pulse width modulated waveform is produced, identify the purpose of a flyback diode, understand the properties of an inductor and examine manufacturer's data on SMPS integrated circuits.

To improve your understanding of power supplies you should source the power supply circuits in a computer or amplifier and try to identify the various sections being studied on the course and try to describe the operation of the circuits. It is also useful to investigate power supply specifications, these give a measure of the quality of the regulation circuit. You can also obtain valuable information over the Internet and by browsing through manufacturer's catalogues. Since this unit is laboratory based and may involve you in the use of transformers directly fed from the mains, you must pay due attention to all safety procedures set down for the practical activities of this unit.

SECTION 5: INFORMATION SHEETS/REFERENCES FOR SAFETY AND LABORATORY WORK

Safety Guidelines for Electronics Laboratory Work.

You should read these guidelines and discuss them with your tutor to clarify their significance in your working environment

- Enter the Electronics Laboratory only at agreed times
- Enter the Electronics Laboratory only when you are authorised
- You should only work on equipment when a supervisor is present
- Always avoid bulky, loose or trailing clothes, long loose hair, heavy metal bracelets or watch straps
- Do not take food or drink into the Electronics Laboratory
- Avoid wet hands or clothes and clean up any liquid spillages
- Be as careful for the safety of others as yourself
- Think before you act, be tidy and systematic
- Keep passages and work areas free of obstructions
- Voltages above 120 V d.c. and 50 V rms are always dangerous, take extra precautions as voltages increase
- Never remove earth connections and make sure that all accessible conducting parts of equipment or experiments are earthed. If in doubt check for earth continuity
- Multimeters and hand-held probes should be of good fused design and are not recommended for dangerous levels of voltage or power
- Understand the correct handling procedures for batteries, capacitors, inductors and other energy-storage devices. Always handle them carefully
- Fluorescent lights can cause rotating equipment to appear stationary. You should be aware of this and take precautions if necessary
- Before equipment is made live all casings, covers or shrouds must be in place so that no live parts can be touched with fingers
- Before equipment is made live all casings, covers or shrouds must be in place so that no moving parts can be touched with fingers
- Before equipment is made live circuit connections and layouts should be checked by your supervisor
- If you are working in a group everyone in the group should give there assent before equipment is made live
- Never make changes to either circuits or mechanical layouts without isolating the circuit by switching it off and removing connections to supplies
- Experimental equipment left unattended should be isolated from the supply unless it has to be left on for some special reason, in which case a barrier and warning notice are required
- Equipment found to be faulty in any way should be reported to your supervisor immediately and not used until it is inspected and declared safe
- You should know what to do if there is an emergency in the Electronics Laboratory
- Use hand tools carefully and treat them with respect as they can be dangerous when misused or faulty
- Do not remove equipment, tools or materials from the Electronics Laboratory without authorisation from your supervisor

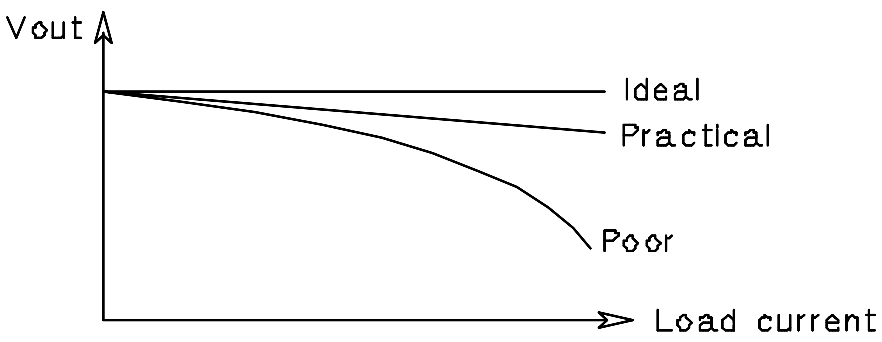
SECTION 6: STUDENT NOTES ON POWER SUPPLIES

Introduction

Stabilised electronic power supplies are circuits that give out a constant d.c. voltage irrespective of the current drawn from them and irrespective of the input voltage changes, provided they are operated within their stated specifications. A battery can be regarded as a source of constant voltage, that is, different levels of current may be drawn from it and the voltage across it will remains almost constant. The battery is very useful for portable equipment unfortunately it has a limited life span, has to be replaced regularly and therefore electronic power supplies are the preferred option.

Figure 1 compares ideal, practical and unacceptable voltage sources. An ideal voltage source gives a constant voltage out inspite of the current drawn. A practical voltage source loses some voltage across its internal resistance hence the output tends to drop as more and more current is drawn. A poor voltage source begins to drop its output voltage as soon as current is drawn.

Figure 1 comparison of ideal, practical and poor voltage sources



Most electronic equipment uses stabilised power supplies for reliable operation at reasonable cost without the need for renewal of the power source. The block diagram of a stabilised power supply is shown below, in Figure 2.The individual sections of the block diagram will be developed further in this unit.

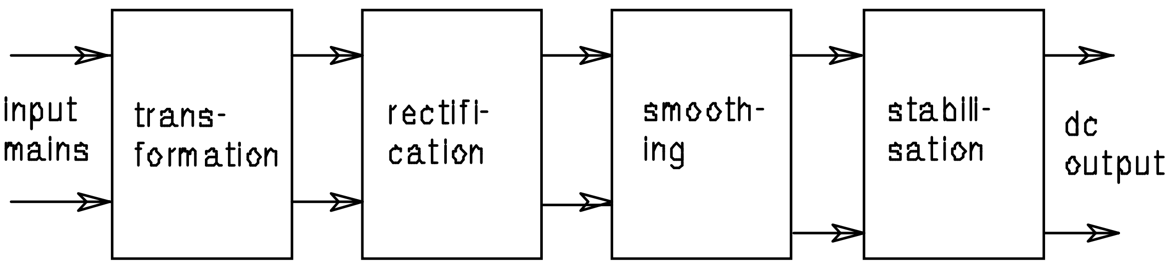


Figure 2 power supply block diagram

Rectification

Normally the d.c. voltages used in electronic systems are much lower than the 230V a.c. from the mains supply. Therefore prior to rectification the mains voltage is stepped down using a transformer as illustrated in figure 3.

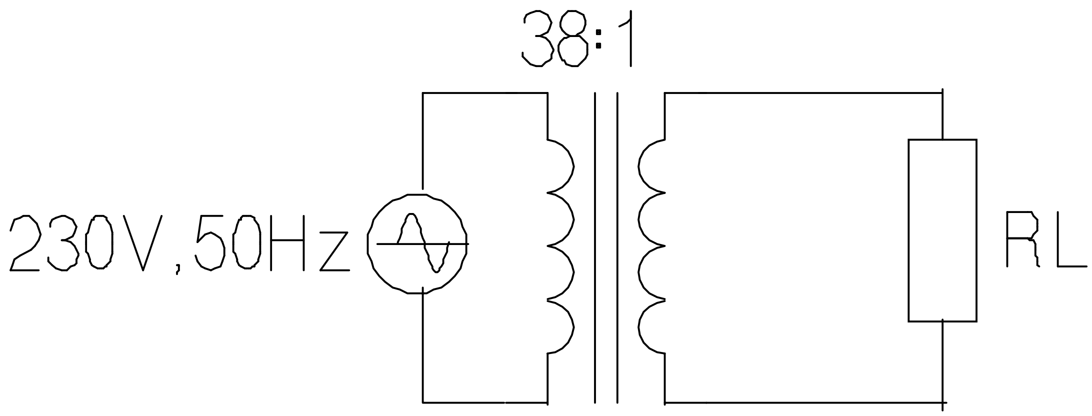


Figure 3 transformer stepping down the mains voltage

Transformer turns ratio is given by

$$V_1/V_2 = N_1/N_2 = I_2/I_1$$

The secondary transformer voltage can be found as follows. If N_1: N_2 =38:1 then V_2may be found using the above equation $V_1/V_2 = N_1/N_2$

$$V_2 = (N_2/N_1)V_1 = (1/38)230 \text{ V}$$
$$= 6 \text{ V}$$

The voltages used in the equations are root mean square (r.m.s.) values and the frequency of the mains voltage is 50Hz. The peak (pk) of the voltage can be found from the relationship

$$V_{r.m.s.} = V_{pk}/\sqrt{2} = 0.707\ V_{pk}$$

Therefore the maximum transformer output voltage value is equal to $\sqrt{2}$ x 6 V = 8.5 V, this is shown below in Figure 4.

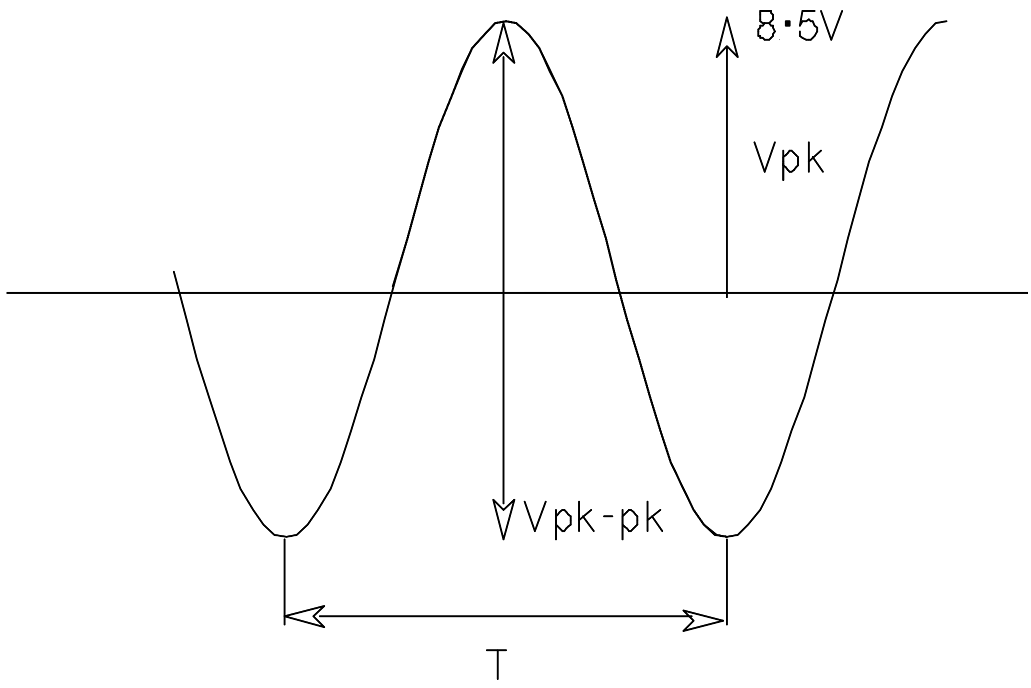
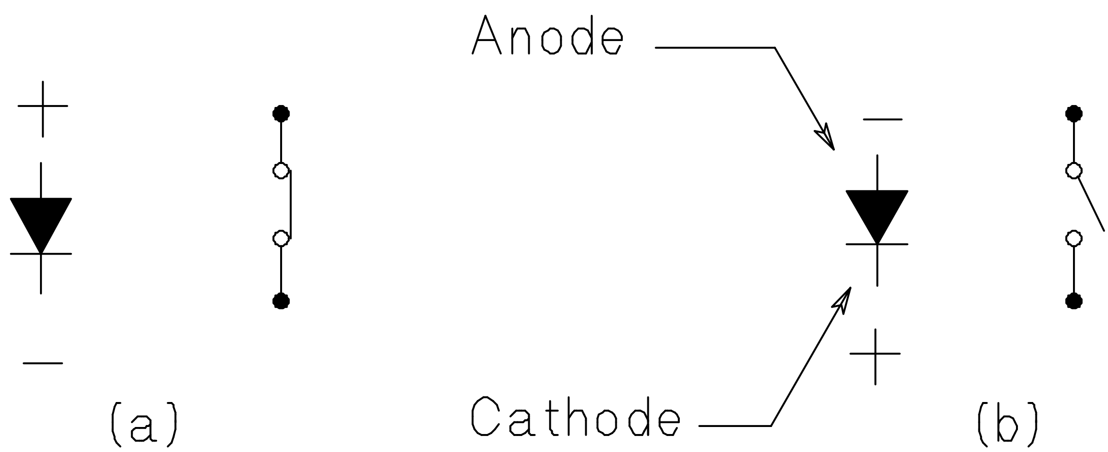


Figure 4 sinusoidal waveform

Once the mains voltage has been stepped down it can be rectified .Rectification is the process of converting a.c. voltages into d.c. voltages.

Half-wave rectification

The electronic device used for rectification is called a diode. Normally a silicon rectifier diode is capable of passing a few amperes at a forward voltage drop of about 0.6V.It has a high value of peak inverse voltage (PIV), which is sometimes referred to as maximum reverse voltage (V_{rrm}).



The basic operation of the diode is shown below in Figure 5.

Figure 5 (a) forward bias diode, conducts current (b) reverse bias diode, blocks current flow

When the anode of the diode is about 0.6V more positive than the cathode the diode conducts and can be regarded as a closed switch. However when the anode voltage is less than the cathode voltage the diode can be regarded as an open switch as no current flows through it.

SAQ1

How will the diode behave if the anode voltage is made 2V greater than the cathode voltage?

Operation of half-wave rectifiers

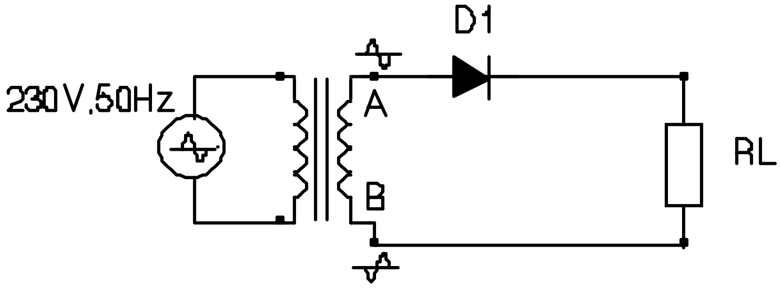


Figure 6 half-wave rectifier circuit

The half-wave rectifier is shown in figure 6. When the anode of the diode D1 is positive, it conducts and current flows from A through D1 and R_L to B. This causes a voltage, with magnitude proportional to the diode current, to be developed across the load R_L. On the negative half-cycle of the input voltage to the rectifier the diode acts as an open switch and no current flows through it and no voltage is produced across R_L, as shown below in figure 7.

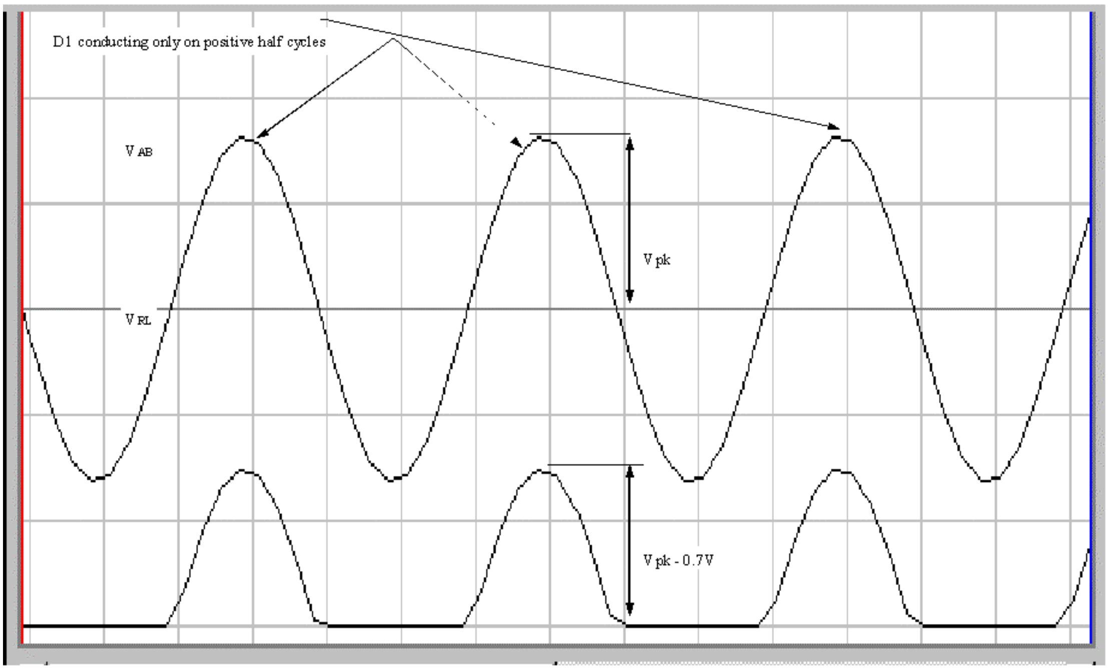


Figure 7 half-wave rectifier input/output waveforms

The output voltage of the half-wave rectifier is called pulsating d.c. or raw d.c., in other words d.c. does not mean just a horizontal straight line time graph (constant voltage), but any voltage or current that does not change polarity.

Note that to draw accurate waveforms we need to take into consideration the fact that the diode does not conduct significantly until the input voltage to the rectifier is just greater than 0.6V and that when the diode is conducting the voltage drop across it is 0.6V.

Full-wave rectification using bridge rectifier

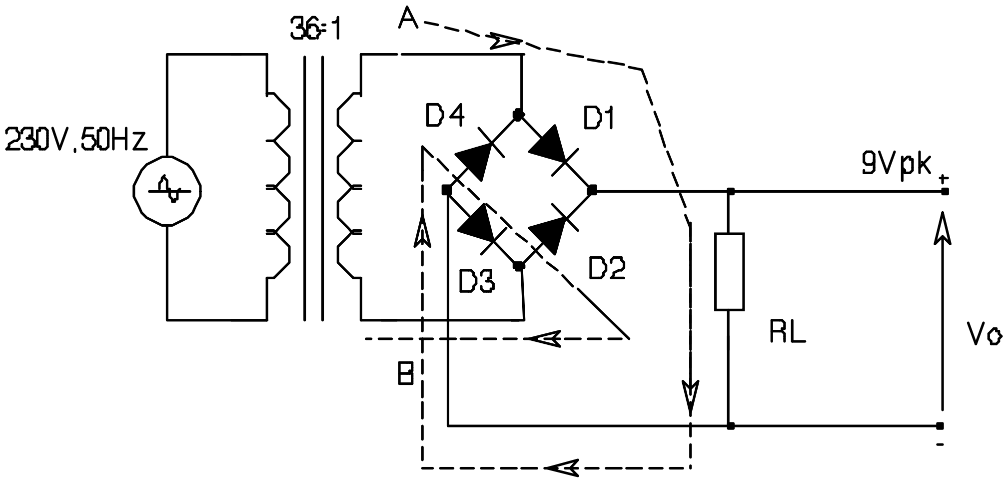


Figure 8 full-wave bridge rectifier

When A is positive with respect to B diodes D1 and D3 are forward biased and current flows as shown by the arrows. The current flow through R_L is from the top to the bottom. During the next half-cycle B is positive with respect to A and the circuit current flow is as shown in Figure 9, however the current flow through the load R_L is in the same direction. This means that the voltage developed across R_L is in the same direction irrespective of voltage polarities at A and B. Figure 10 shows the rectifier input and output waveforms.

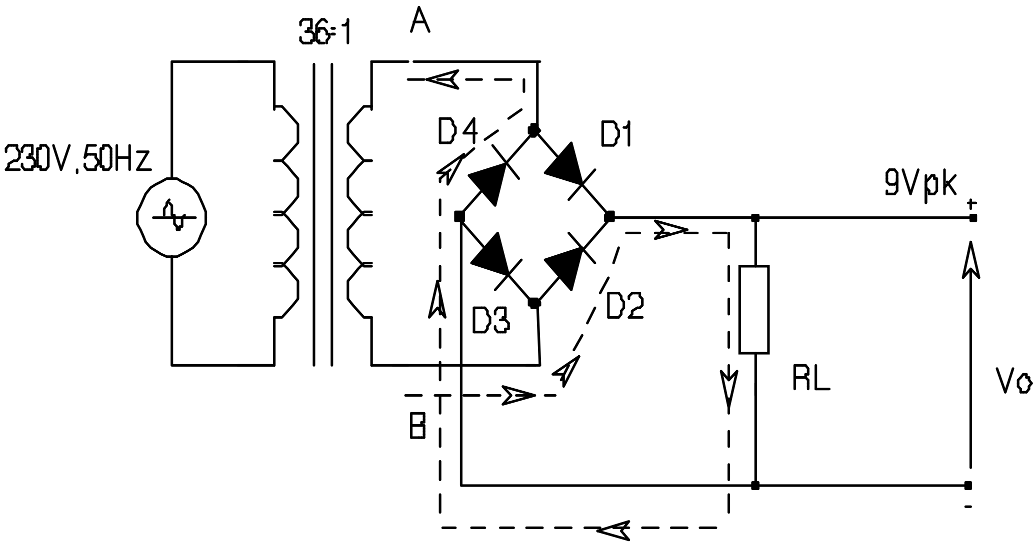


Figure 9 full-wave bridge rectifier on negative half-cycle

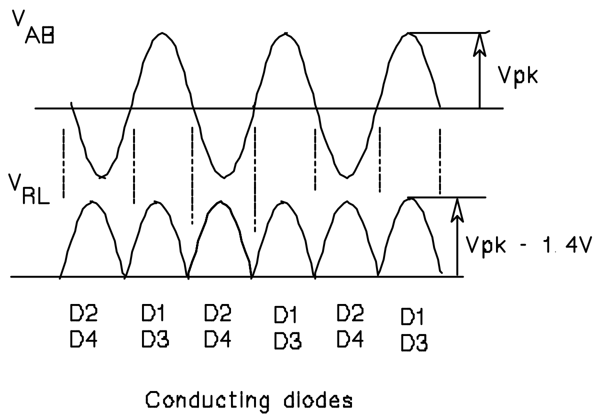


Figure 10 full-wave bridge rectifier input/output waveforms

Full-wave rectifier using centre-tapped transformer

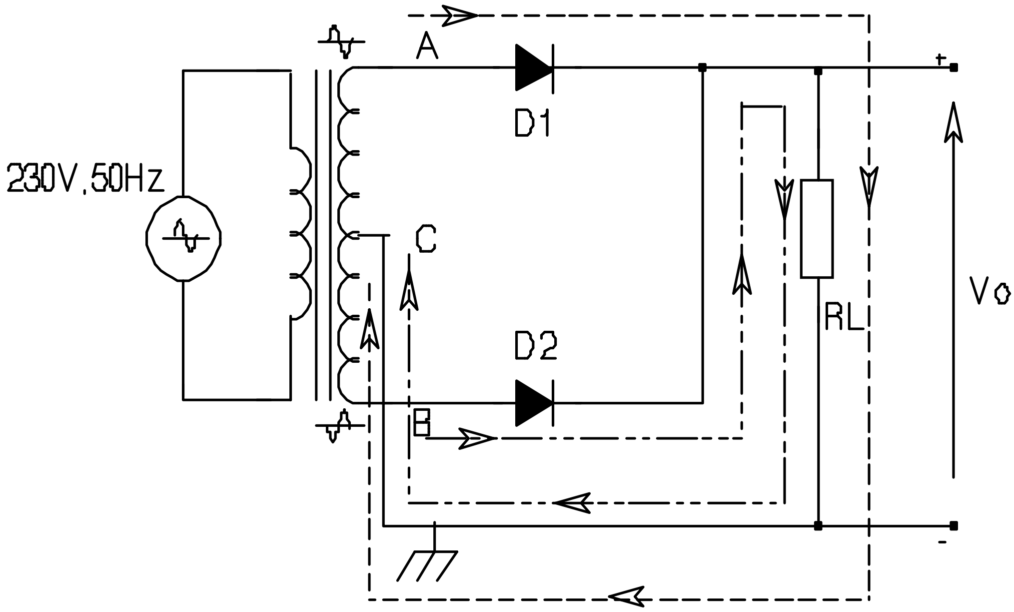


Figure 11 full-wave rectifier using centre-tapped transformer

When A is positive with respect to C. C is positive with respect to B. Then current flow is from A through D1and R_L then into C. When B is positive with respect to C. C is positive with respect to A. The current flow is now from B through D2 and R_L then into C. In both these cases the direction of the current through R_L is always the same, hence a d.c. voltage is developed across the load.

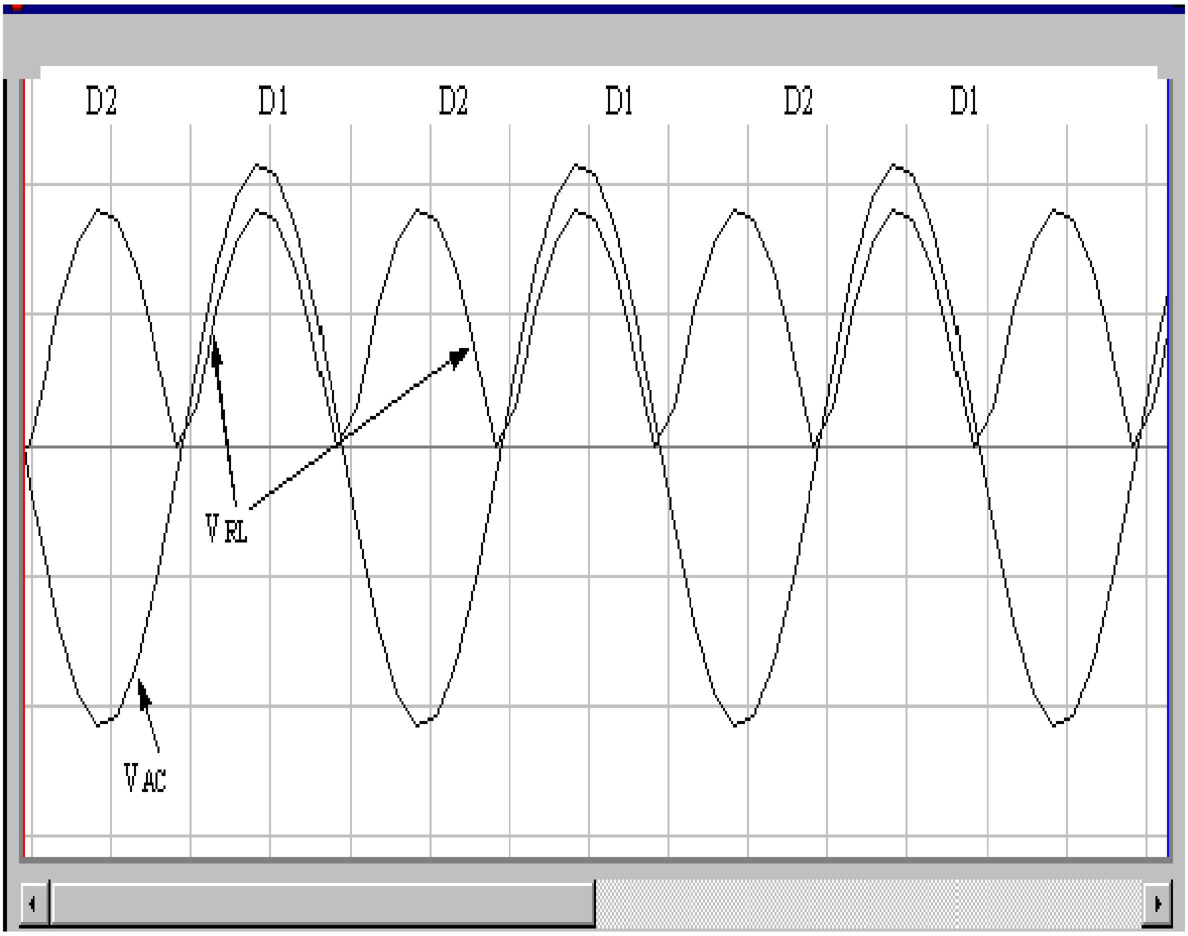


Figure 12 waveforms for full-wave rectifier using centre-tapped transformer

SAQ2

Explain the operation of a full-wave rectifier based on the centre-tapped transformer using the input/output waveforms

SECTION 7: SMOOTHING (FILTER CAPACITOR)

Capacitor charging

When a voltage is applied to a capacitor, it charges exponentially to the value of the applied voltage over a time dependent on the circuit time constant (τ). The time constant is defined as the product of R and C in the circuit. In fact τ is the time taken by the capacitor to reach 0.67 of the final voltage value. This is illustrated in the figure below:

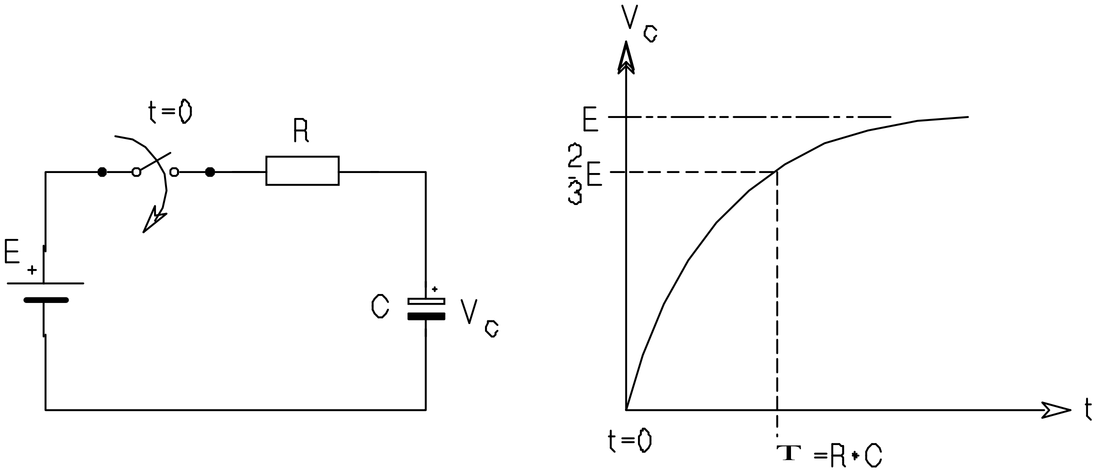


Figure13a capacitor charging

Capacitor discharging

When a load resistor is connected across a charged capacitor, the capacitor discharges exponentially to zero volts. In this situation τ is the time the capacitor takes to discharge to 0.33 of its initial voltage. This is illustrated in the figure below:

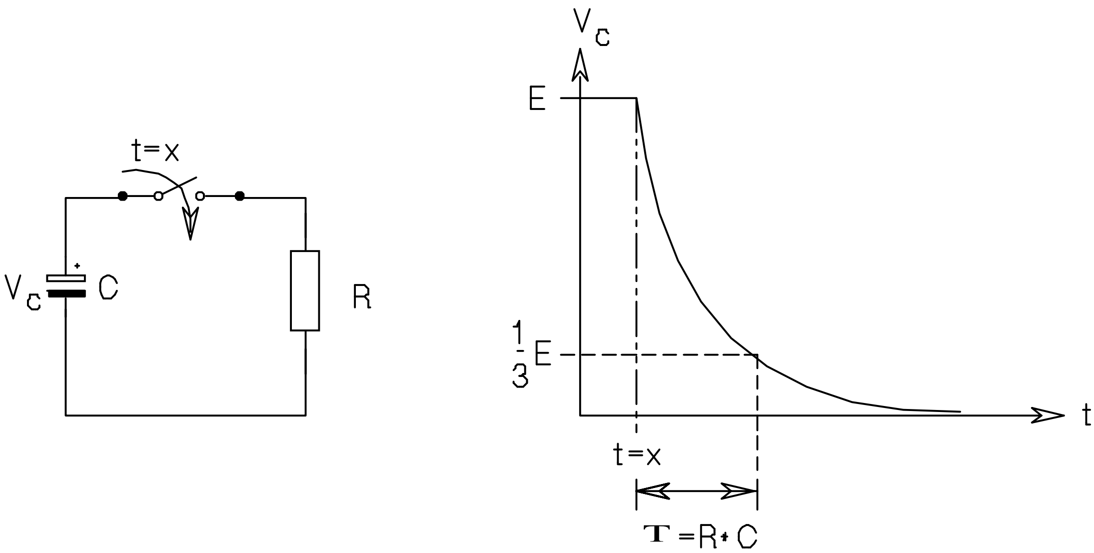


Figure13b capacitor discharging

Low-pass filter

The low-pass filter (shown below) allows signals at low frequencies to pass through but attenuates signals at and above the cut-off frequency. For example a low-pass filter with a cut-off frequency of 100Hz will only allow signals at frequencies below 100Hz to pass with a little change, all other signals will be decreased in size.

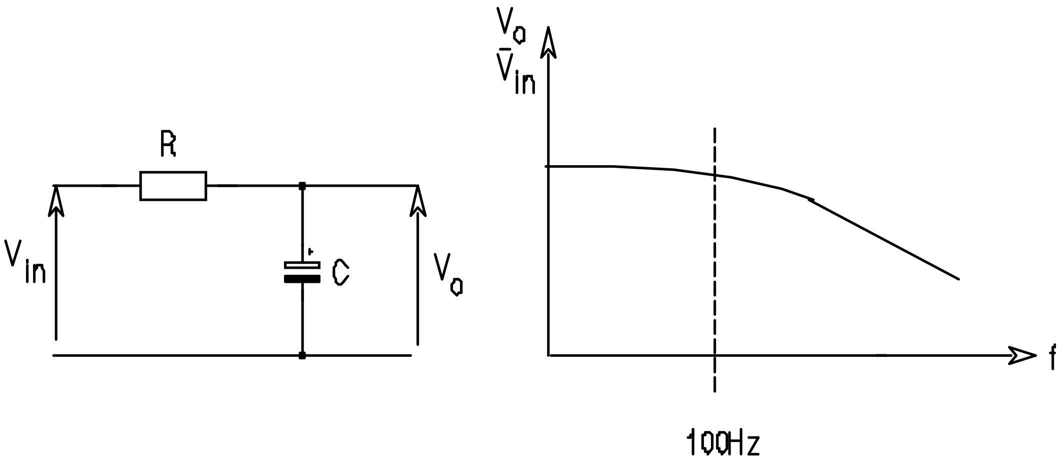


Figure14 low-pass filter and its characteristics

Smoothing Capacitor

When a large electrolytic capacitor is connected across a rectifier, it charges quickly to the peak value of the rectified voltage due to the low forward resistance of the diode. This electrolytic capacitor is known as a smoothing capacitor or filter capacitor or reservoir capacitor. The purpose of the capacitor is to convert the pulsating output of the rectifier into a steady d.c. voltage. However when a load is connected to the capacitor, the capacitor voltage falls from the peak rectifier voltage, as illustrated below.

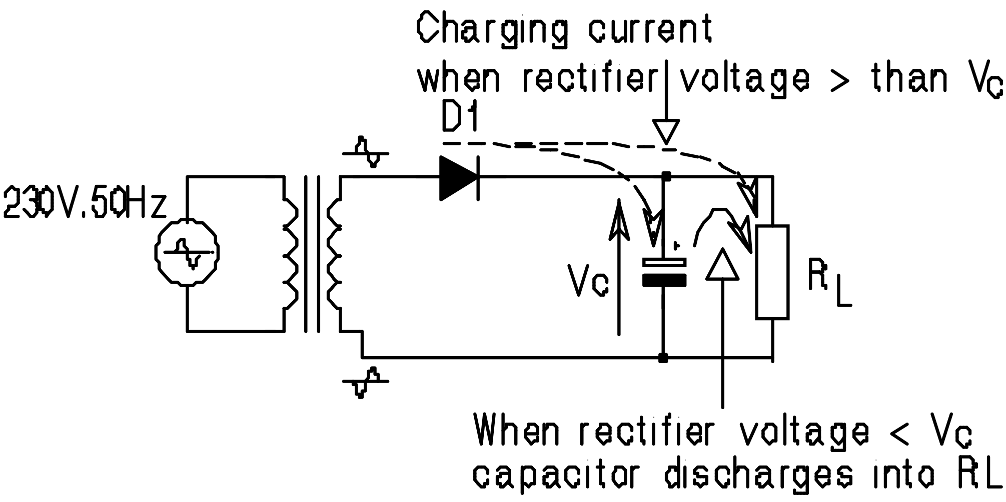


Figure15 half-wave rectifier with capacitor filter and load.

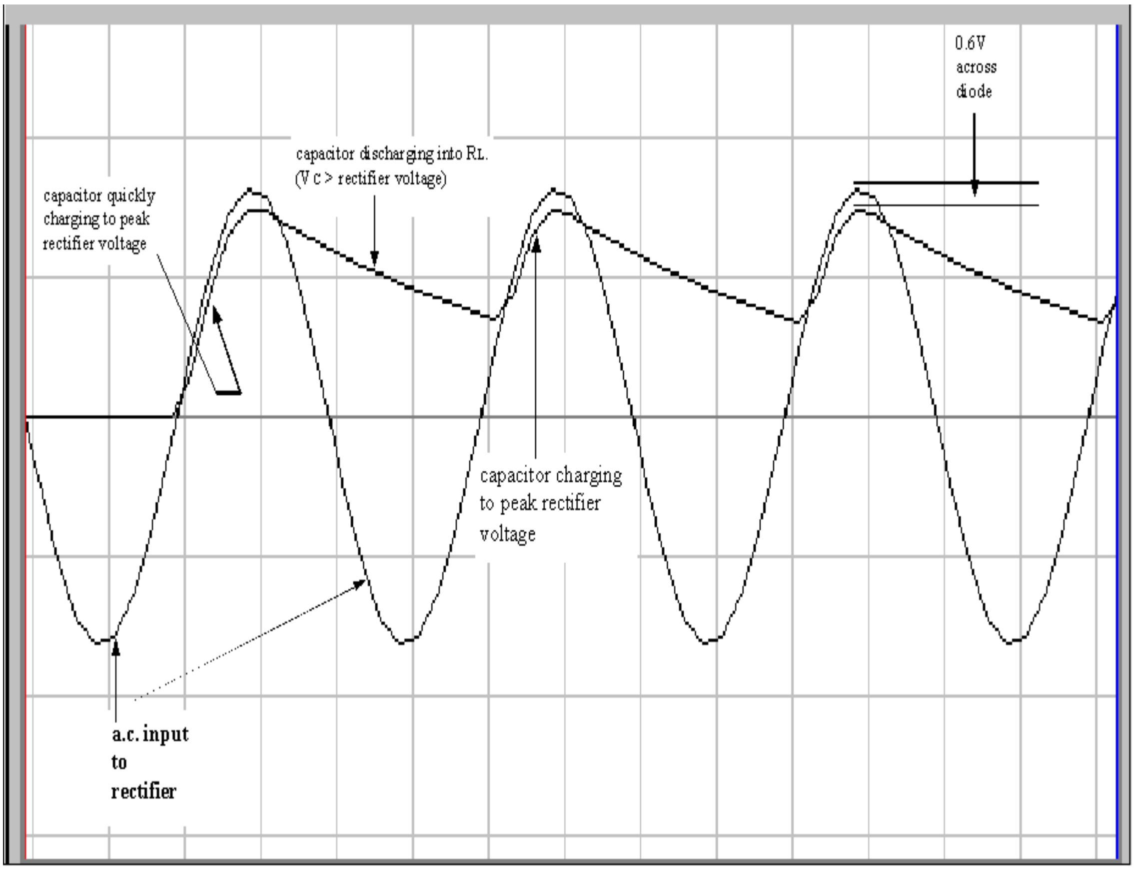


Figure 16 input/output waveforms for half-wave rectifier with smoothing and load

Assume that the capacitor has charged to the peak value of the rectified output voltage. The rectifier output voltage now drops below the capacitor voltage making the rectifier diode reverse biased. During this time the load current is supplied by the capacitor and naturally the capacitor voltage drops, as it discharges into R_L. The capacitor voltage continues to fall until the rectifier output voltage exceeds the capacitor voltage. When this occurs the capacitor charges to the peak rectifier output voltage and the rectifier supplies the capacitor charging and load currents. This cycle continues to repeat itself.

Ripple voltage

The voltage across the capacitor is no longer a constant d.c. level but a d.c. level superimposed on a varying d.c. voltage. This varying waveform is called a ripple voltage (Vr).The frequency of the ripple voltage is the same as the frequency of rectifier output wave form. The pk-to-pk value of the ripple voltage depends on the load . No load gives no ripple, as the load increases so does the magnitude of the ripple voltage. The effect of load variation on ripple voltage is shown in figure 17.

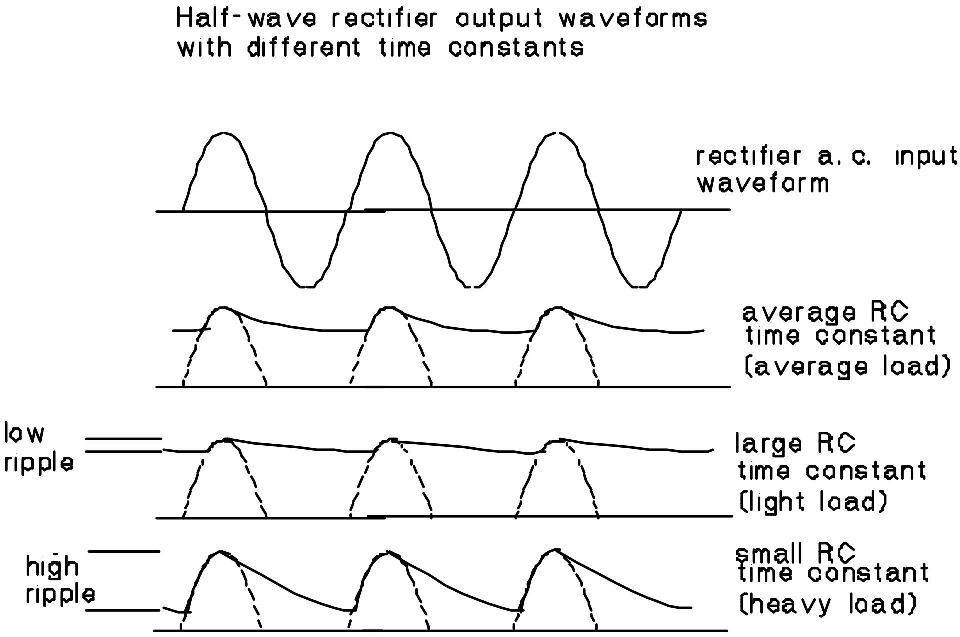


Figure 17 Ripple voltage with different loads (time constants)

FULL-WAVE BRIDGE RECTIFIER WITH SMOOTHING

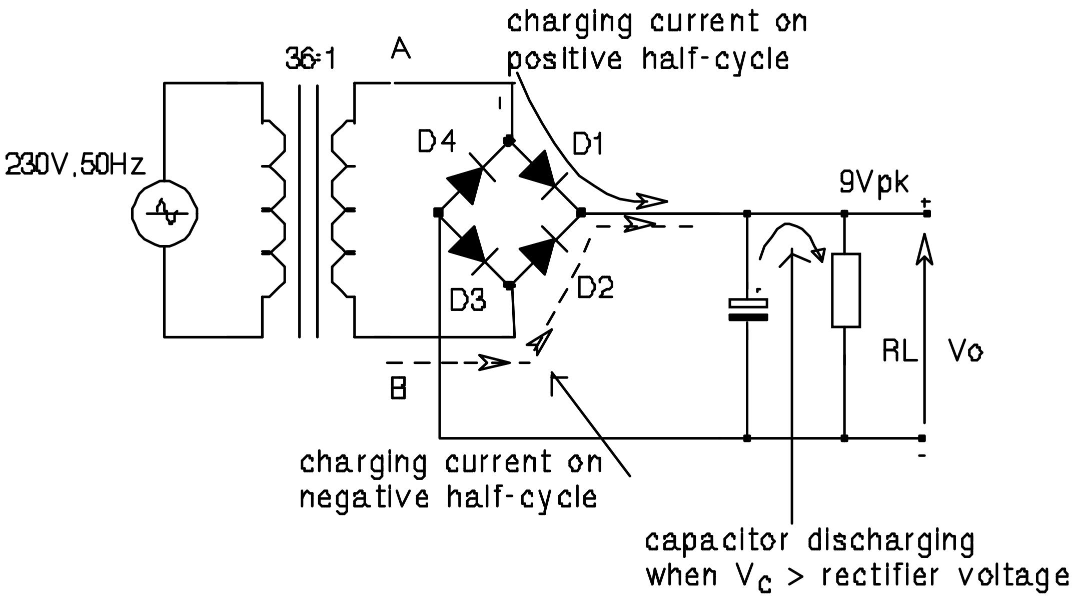


Figure18 full-wave rectifier with smoothing and load

In this circuit the capacitor is charged on both half-cycles and hence the discharge time for the capacitor is greatly reduced. The overall effect is that given the same time constant the ripple voltage is reduced for full-wave rectification compared with that for half-wave rectification. The waveforms for full-wave rectification and smoothing are given in figure 19, note the ripple frequency is now doubled to 100Hz. The last waveform is the ripple waveform enlarged.

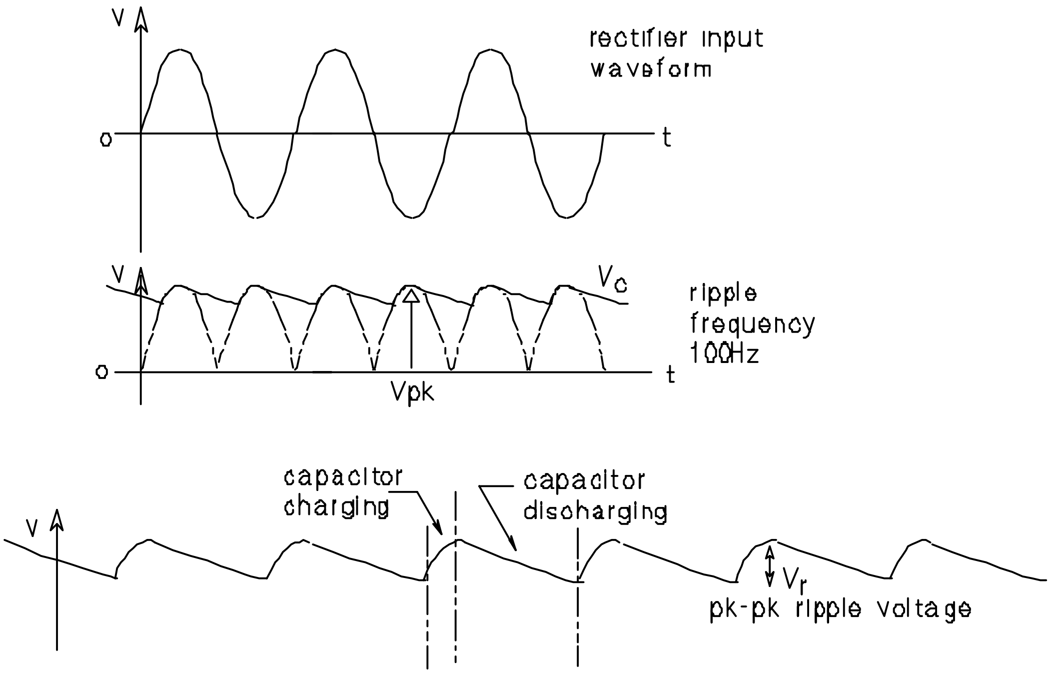


Figure 19 ripple waveform for full-wave rectifier

The d.c. (average) value of the rectified smoothed voltage waveform with ripple can be estimated to be

Vd.c. = Vpk – 0.5Vr
= Vpk – 0.5 x (Vpk / f x R x C)

where
Vd.c. is the d.c value of the smoothed waveform
Vpk is the peak rectified output voltage in volts
C is the value of the reservoir capacitor in Farads
R is the load resistance in ohms
f is the frequency of the ripple voltage in volts

π (pi) smoothing circuit

To reduce the amount of ripple a low-pass filter circuit is placed in cascade with the reservoir capacitor as shown below.

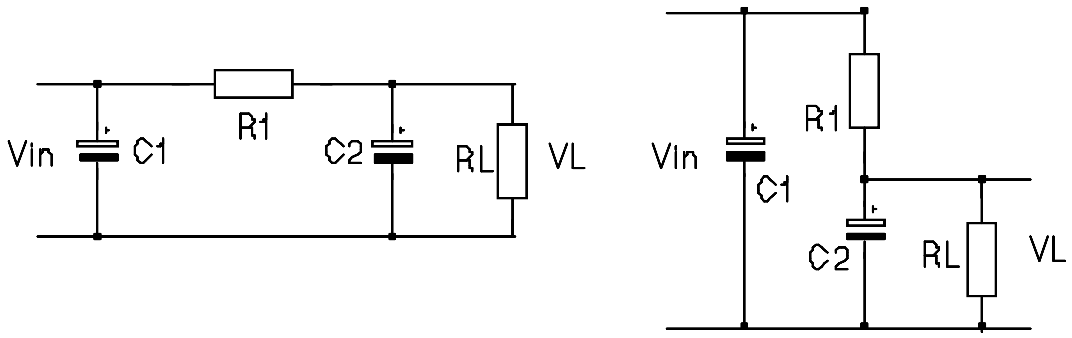


Figure 20 π smoothing circuit

Since the circuit comprising C1, R1 and C2 roughly resembles the Greek letter pi, it is known as a π smoothing circuit. The low-pass filter attenuates the ripple voltage appearing across C1, hence the ripple across the load is further reduced. In other words R1 and C2 act, as a potential divider across C1and the reactance of C2 (Xc2) is low at the ripple frequency. The large smoothing capacitor has small ripple across it and the potential divider action of R1 and C2 reduce this ripple further.

The disadvantage of the π smoothing circuit is that the load current must flow through R1. This can result in a significant voltage and power loss in the filter, and reduce the voltage available for the load. This problem can be overcome by replacing the R1 in the π smoothing circuit with an inductor L1, commonly called a choke in power supply circuits. At the ripple frequency the reactance of the inductor is high but at low frequencies (that is d.c.) it is very small.

Almost all power supplies these days use only a large electrolytic capacitor for smoothing.

SECTION 8: VOLTAGE REGULATION

The purpose of a d.c. power supply is to provide a constant d.c. output voltage irrespective of changes in a.c. input voltage or changes in d.c. load current. Most electronics circuits require this type of supply, that is an extremely constant d.c. voltage , for guaranteed and reliable operation.

The smoothing circuit is inappropriate for most applications, as a ripple voltage appears when a load current is drawn. For this reason, in a power supply, a voltage regulation/stabilisation circuit follows the smoothing capacitor.

To indicate the performance of a power supply two figures are normally used. The first one is called load regulation and it measures how well the power supply is able to maintain constant voltage between no-load and full-load conditions. Expressed as a percentage this is

$$\% \text{ load regulation} = ((V_{NL} - V_{FL})/V_{FL}) \times 100\%$$

where:
V_{NL} is the no-load output voltage in volts
V_{FL} is the full-load output voltage in volts

SAQ3

The open-circuit voltage of a d.c. power supply is 12V, When a load is applied the voltage falls to 11.5V. Calculate the % load regulation.

SAQ4

A computer power supply was tested to determine its load regulation. The no load and full-load measurements were 5V and 4.95V respectively. Calculate the % load regulation.

SAQ5

Two power supplies have the same no-load voltage. However one has a load regulation of 10% and the other 5%. Explain which is the better power supply.

The second performance figure for a power supply is line regulation. This indicates how sensitive the output is to changes in input voltage . Expressed as a % this is

% line regulation = (change in d.c. output voltage/change in a.c. input voltage) x 100%

SAQ6

Calculate the % line regulation if the d.c. output voltage of a power supply changes from 12V to 11.5v for a change in a.c. line voltage from 220V to 209V

Stabilisation/Regulation circuits

Zener diode stabiliser

The characteristics of a Zener diode is given in figure 21

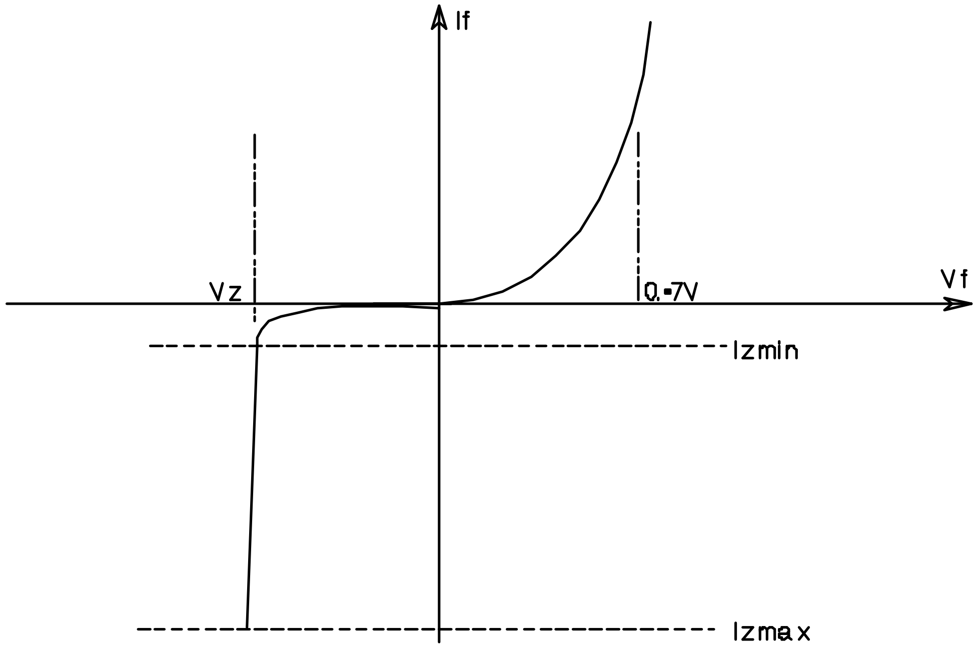


Figure21 Zener diode characteristic

The characteristics show that when the diode is forward biased it behaves as a normal silicon diode. When it is reverse biased the diode breaks down at a predetermined voltage (Zener voltage) due to the avalanche effect. Once the reverse bias is removed the diode recovers. Close examination of the reverse bias characteristic also shows that the voltage across the diode is fairly constant for varying currents through it (Izmax to Izmin). This property of the Zener diode is utilised in the Zener diode stabiliser circuit shown below

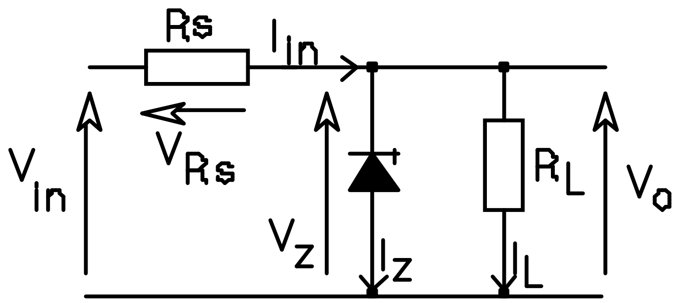


Figure 22 basic Zener diode shunt stabiliser

The Zener diode is reverse biased and operated in its break down region (at the Zener voltage). In this state the voltage across the Zener diode remains constant for changes in current through it. Since the Zener diode is across the load, it sets the output voltage value. This circuit is referred to as a basic shunt stabiliser or regulator.

Circuit operation when Vin changes

Vin is normally a few volts greater than Vz so that the Zener diode is in the breakdown region and a constant voltage Vz exists across it. If Vin now changes by a small amount, Iin and Iz change. Changes in Iz do not affect the voltage across the Zener diode. Hence changes of Vin appear across Rs as Vz remains constant (maintaining Vo at Vz).

The voltage relationship at the input terminals is given by

$$V_{IN} = V_{RS} + V_Z$$
$$\delta V_{IN} = \delta V_{RS} + V_Z$$

Circuit operation when the load changes

Assume that the Zener diode is operating in the breakdown region. In this state it may be regarded as a current reservoir.

If the load increases (that is the load takes more current because its resistance is reduced) then the Zener diode gives up some of its current to the load while maintaining Vo at Vz.

If the load decreases (that is the load takes less current because its resistance is increased) then the Zener diode absorbs the current shed by the load while maintaining Vo at Vz.

The current relationship in the circuit is given by

$$Iin = Iz + I_L$$

If Vin is fixed Iin is fixed, as Vz is a constant. However if the load changes the current distribution between Iz and I_L can vary as long as Iz does not fall below Izmin.

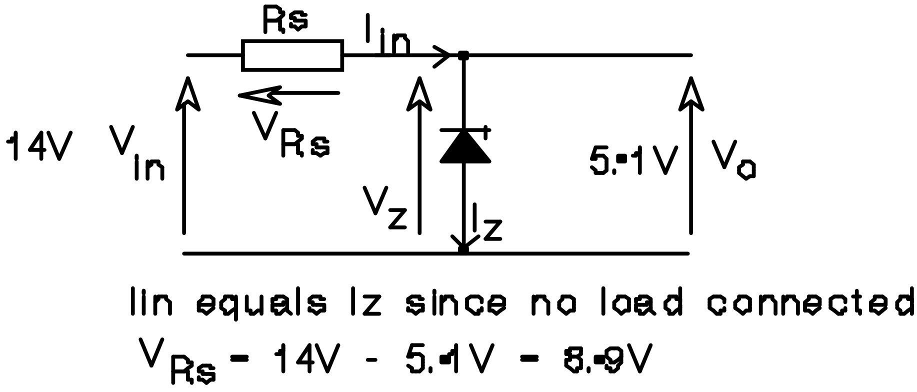
Calculation of Rs

The value of Rs is normally determined under no-load conditions with maximum current flowing through the Zener diode when Vin is at maximum. At the input terminals the voltage relationship is

$$V_{IN} = V_{RS} + V_Z$$
$$V_{RS} = V_{IN} - V_Z$$
$$I_{IN} \times R_S = V_{IN} - V_Z$$
$$R_S = (V_{IN} - V_Z)/I_{IN}$$

Example

A student wishes to operate his 5V personal Stereo from a car battery whose voltage fluctuates between 11V and 14V, Design a suitable circuit using a 5.1V, 2.5W Zener diode.



Circuit diagram for example

Worst case input voltage =14V
Maximum Zener current = (power/voltage) =2.5./5.1 = 0.49A
Value of $R_S = (V_{IN} – V_Z)/I_{IN} = (14 – 5.1)/0.49 = 18\Omega$
Power rating for Rs = I x I x R = 0.49 x 0.49 x 18 = 4.3W
Considerable power appears to be developed in the series resistor Rs

Series voltage stabiliser/regulator

In the shunt regulator discussed earlier the voltage control element (Zener diode) appeared across the load, however in a series stabilising circuit the control element (a power transistor) is placed in series with the load. This series pass transistor carries the actual load current. A functional block diagram of a series regulator is shown below.

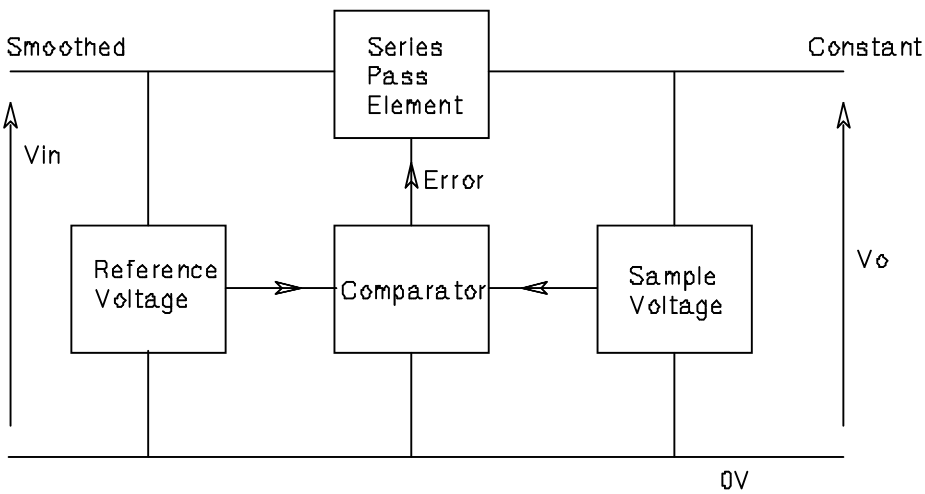


Figure 23 block diagram of series regulator

Normally the reference voltage is derived from Vin using a Zener diode. The sample voltage is obtained from Vo using a potential divider resistor chain. The sample of Vo is then compared with Vref and any difference (error) is used to drive the control element to restore Vo to the set value and to reduce the error. The comparator device may be an operational amplifier or base-emitter junction of a transistor. The control element is usually a power transistor.

At times it may be difficult to identify the above blocks of the series stabiliser circuit as some components may serve more than a one purpose.

SAQ7

Complete the table below by analysing the listed circuits to identify the components that form the sample voltage, the reference voltage, the comparator and the series pass element.

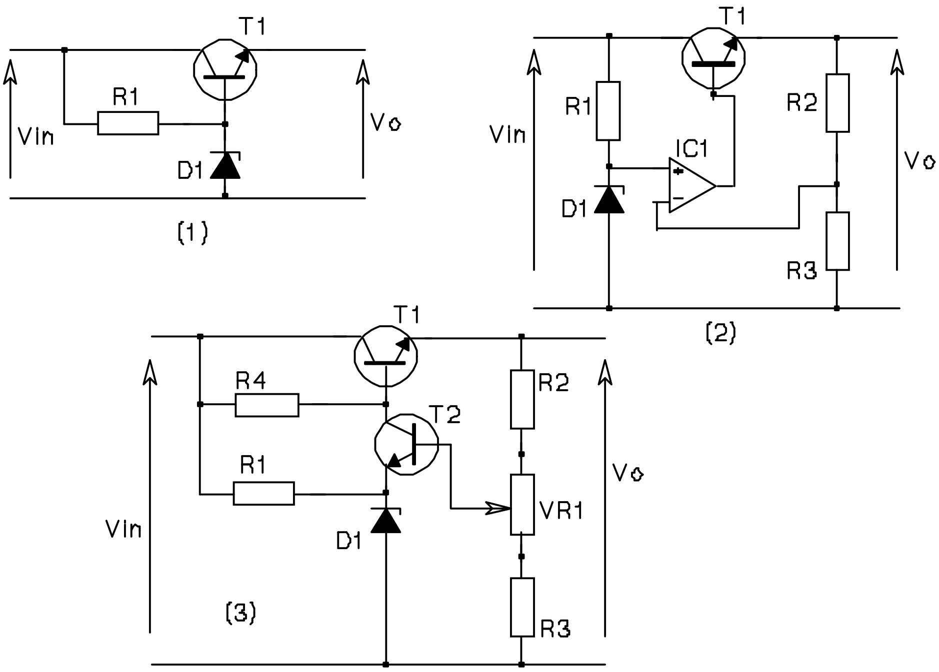


Figure 24 power supply circuits

	Circuit Components		
Circuit Block	Circuit 1	Circuit 2	Circuit 3
Reference Voltage			
Sample Voltage			
Comparator Device			
Control Element			

Operation of the basic series regulator

The circuit diagram of a basic series regulator is reproduced below

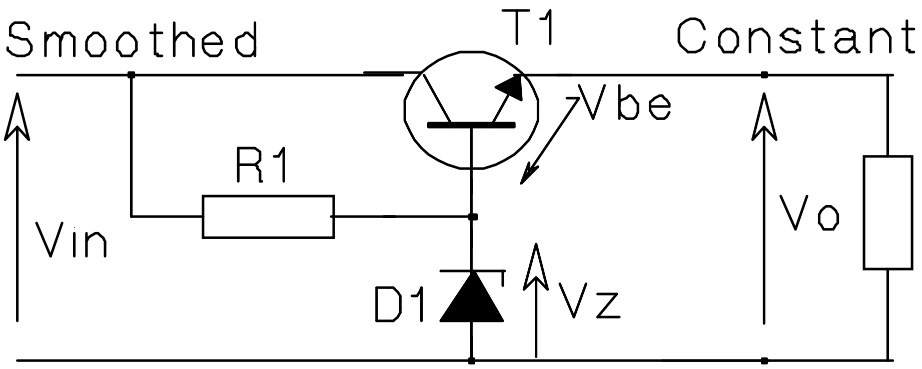


Figure 25 circuit diagram of series regulator

Using Kirchhoff's voltage law at the output terminals

$$Vo = Vz - Vbe$$

This shows that the Zener diode voltage largely determines the output voltage Vo and any differences between Vz and Vo appear across the base-emitter junction of T1 (Vz – Vo = Vbe).

In fact in this circuit (figure 25) Vz is the reference voltage, Vo is the sample voltage and the base-emitter junction of the control element is the comparator

Operation of the circuit for changes in the load current

If the load current increases due to reduced value of the load then Vo tends to drop, Vbe increases (since Vbe = Vz – Vo) and T1 conducts harder to restore Vo. If on the other hand the load decreases then Vo would tend to rise, reducing Vbe and causingT1 to conduct less and thus restoring Vo to the set value.

Operation of the circuit for changes in line voltage, that is smoothed Vin

Any changes in Vin would be transmitted to the output terminals. If a change in Vin causes Vo to increases, then Vbe would be reduced causing T1 to conduct less, to restore Vo. If a change in Vin causes Vo to drop then T1 will conduct harder to restore Vo. Note

- In the Zener shunt stabiliser the Zener diode sets the output voltage and the maximum output current
- The series pass stabiliser is a slight improvement since the output current is determined by the transistor, however the output voltage is still determined by the Zener diode.
- For improved regulation more complex control circuits are required. In these circuits the sample voltage is variable and the error amplifier more sensitive or the series pass transistor is of the Darlington type.

Protection Circuits

Short-circuit/over-current protection

Most power supplies are protected against short-circuit and over current conditions. Short-circuits are caused by a number of reasons, for example, accidental connection, component failure and filter capacitor failure across the output of a power supply.
A typical current limiting circuit monitors the load current if the maximum value is exceeded then the drive current of the series pass element is reduced, resulting in a reduction of the load current.
Figure 26 shows the basic series regulator incorporating a current limiting circuit.

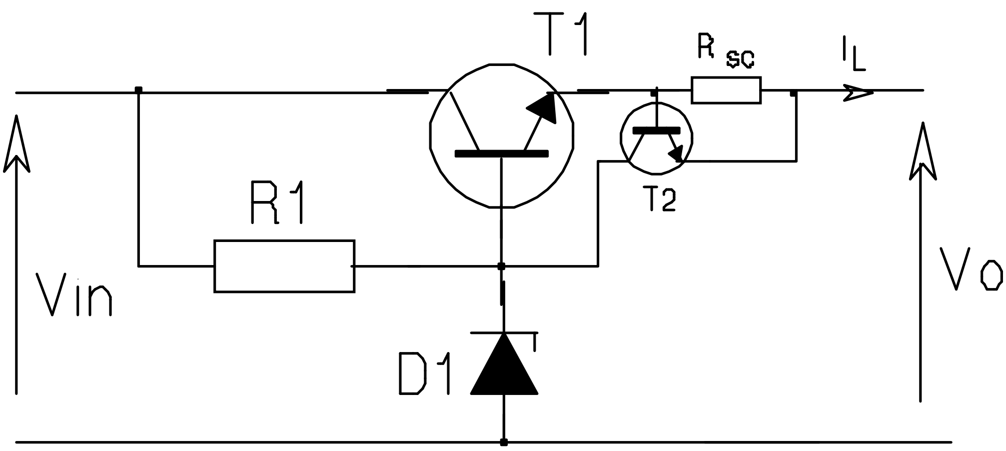


Figure 26 over-current protection circuit

Rsc is in parallel with the base-emitter junction of T2. As the load current increases the voltage across Rsc increases, as does Vbe of T2. If the load current becomes sufficiently large to cause a 0.7V drop across Rsc then T2 switches on and reduces the drive current for T1 by diverting it to the output. This protects the load and the power supply transistor T1 from too much current. The maximum load current is limited to I_L = 0.7V/Rsc.
The current-liming action is so fast that it will protect the supply without blowing any fuses and normal operation is resumed once the short-circuit is removed.

Over-voltage protection

Various factors such as failure of series pass element and inductive switching can cause the output voltage of a power supply to rise to unsafe values for the equipment being powered. A common protection circuit is the crowbar, this circuit senses the over voltage condition and then causes a short–circuit in the power supply to blow a fuse or trip a circuit breaker or turn on the current limiting circuit.
The over-voltage protection circuit uses an SCR (thyristor) as a crowbar. The SCR is like a diode rectifier that conducts when a pulse is applied between the gate and cathode. The device latches on once conduction starts and remains on until the anode current falls to zero.

The thyristor over-voltage protection circuit is used to blow a fuse at the input of a rectifier is illustrated below.

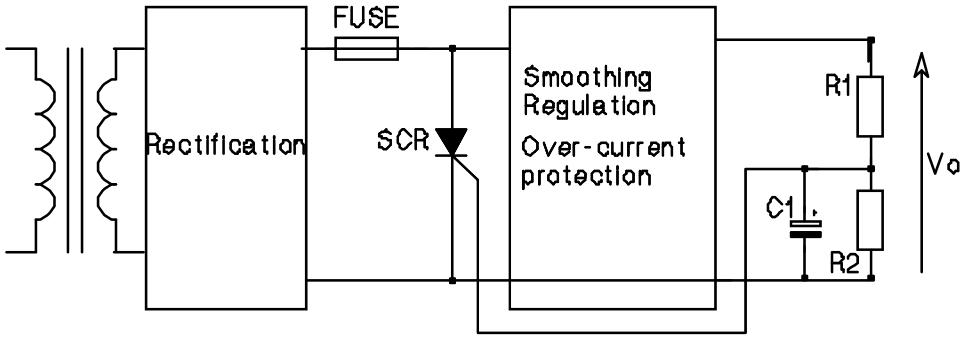


Figure 27 SCR used to blow a fuse on over voltage

Resistors R1 and R2 are chosen so that when Vo exceeds the maximum safe value the SCR is turned on and blows the fuse.

The alternative thyristor over-voltage protection circuit used to kick in the over-current limiting circuit is shown below.

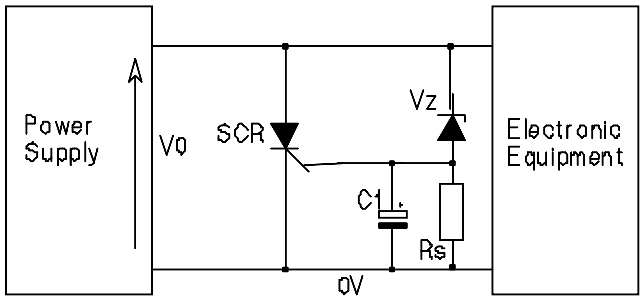


Figure 28 SCR used to short-circuit power supply on over voltage

The Zener diode is chosen so that under normal conditions it is not conducting. However if Vo exceeds the maximum safe value the Zener diode conducts and a voltage is developed across Rs which turns on the SCR causing a short-circuit across the power supply terminals, thereby protecting the equipment.

SAQ8

In the following circuit identify the current-limiting and over-voltage protection components.

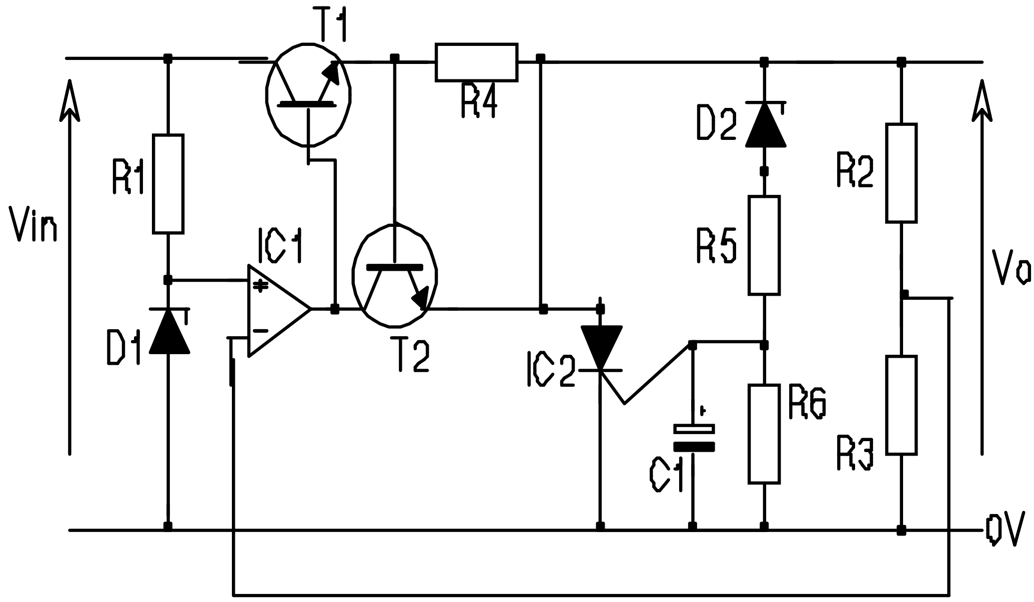


Figure 29 a power supply with protection circuits

Integrated circuit voltage regulators

The control elements of a stabiliser circuit, that is, voltage reference, voltage sample, comparator, series pass element and the rest can be combined into a single integrated circuit. This has the advantage of extremely good regulation, compact size, ease of use, and off the shelf availability. Most integrated circuit (IC) regulators are designed for a specific fixed output voltage and have internal overload, thermal and short-circuit protection.

A 3-terminal IC voltage regulator has three terminals. An input terminal which connects to the smoothed d.c. voltage (that is to the reservoir capacitor), an output terminal that connects to a small ceramic capacitor to provide a low impedance for high frequencies and a third terminal for 0V connection.

A fixed output voltage, power supply using a 3-terminal IC voltage regulator is shown in figure 30 below.

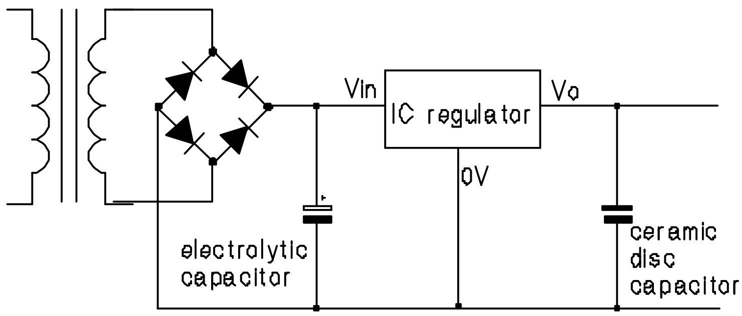


Figure 30 a 3-terminal IC regulator circuit

SAQ9

Using manufacturers data sheets for 3-terminal voltage regulators draw the circuit diagrams for

A) a fixed positive voltage regulator
B) a fixed negative voltage regulator
C) a variable positive voltage regulator

SAQ10

State the benefits of 3-terminal IC voltage regulators.

SECTION 9

Switched mode power supplies

The power supply circuits considered so far are usually referred to as linear power supply circuits. This is because the series pass element (the power transistor) acts as an amplifier, that is, if the base current is varied the collector current varies in direct proportion. In other words the transistor is operated over the linear region of its characteristics.
In this mode of operation considerable power is dissipated in the transistor. Consider the following 3-terminal linear IC voltage regulator

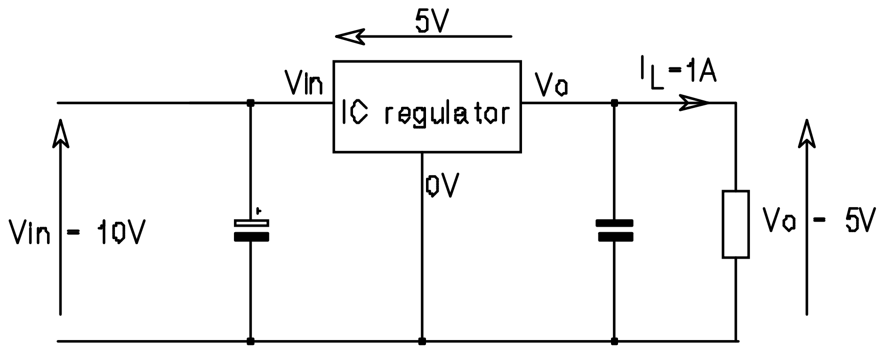
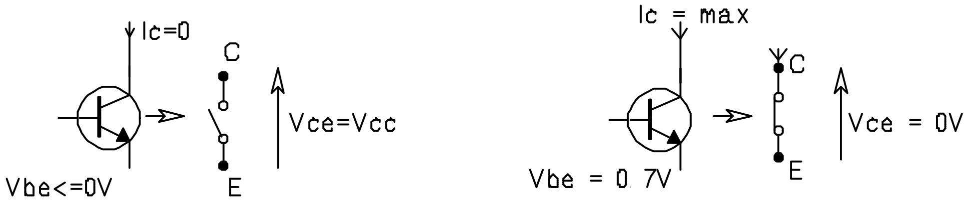


Figure31 a typical IC regulator circuit

Assume Vin = 10V, Vo = 5V, I_L = 1A
Then voltage across regulator = 5V
Load power = 1 x 5 = 5W
Power in regulator = 1 x 5 = 5W
Power from source = Vin x I_L = 10 x 1=10W
% Efficiency = (Po/Pin) x 100 % = (5/10) x 100% = 50%
This simple example shows that linear power supplies are very inefficient, in fact efficiencies are usually less than 50%.
In switched mode power supplies (SMPS) the pass transistor is used as a switch that is either fully on or completely cut-off. In these extreme modes of operation the power developed in the series pass element is very small. See below.



Power in transistor	Power in transistor
= Ic x Vce	= Ic x Vce
= 0 x Vcc	= Imax x 0
= 0W	= 0W

Figure 32 transistor as a switch

Clearly SMPS are much more efficient than their linear counterparts and this leads to added advantages.

- Less dissipation of heat
- Smaller 50Hz mains transformer
- Reduced size and weight
- Reduced cost
- A range of voltages can be made available

The SMPS have the disadvantage of producing electromagnetic interference (EMI) due to the switching operation. This may require some shielding to avoid interference. Also a square wave signal of the type illustrated below, is required to operate the transistor switch.

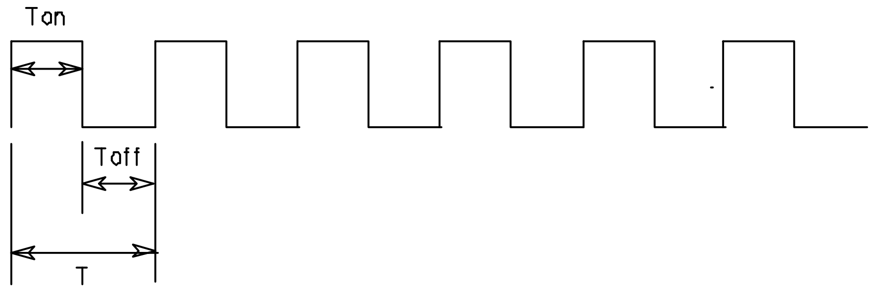


Figure33 square wave

The on time of the waveform is labelled Ton
The off time of the waveform is labelled Toff
The period of the wave form T = Ton + Toff
The frequency of the waveform f = 1/T
The duty cycle (portion of the waveform that does the work) δ = Ton/T
% Duty cycle = (Ton/T) x 100%

This square waveform is produced by one of the major components of a SMPS, called a pulse width modulator. This device is basically an astable multivibrator with a modulating input voltage .The output waveform has pulse widths that are proportional to the input voltage. A low input voltage produces a low duty cycle waveform. A high input voltage produces a high duty waveform. A varying voltage will produce a varying duty cycle waveform as shown below.

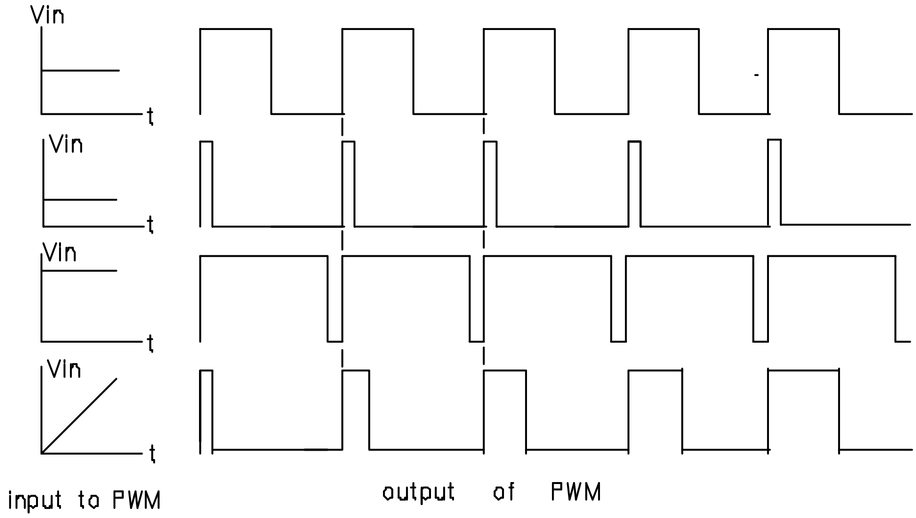


Figure34 pulse width modulator waveforms

The output of the pulse width modulator (PWM) is used to drive the series pass element. The output waveform of the series pass element has the same duty cycle as the output from the PWM. The average or d.c. value of the pulse width modulated waveform from the series pass element is recovered using a low pass LC filter circuit. Vdc = Vin x (Ton/T) = Vin x duty cycle

The d.c. voltage for various pulse width modulated waveforms is given below.

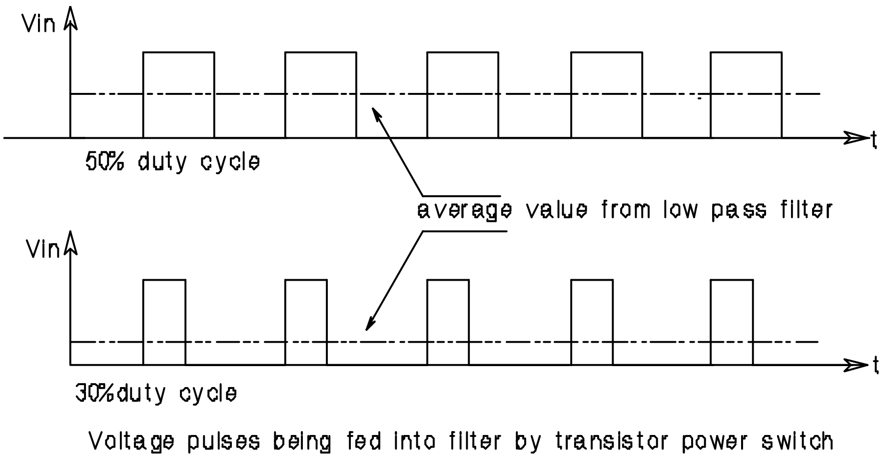


Figure35 average of PWM waveforms

Block diagram of a SMPS

The block of a SMPS is shown below and is similar to the block diagram of a conventional linear power supply.

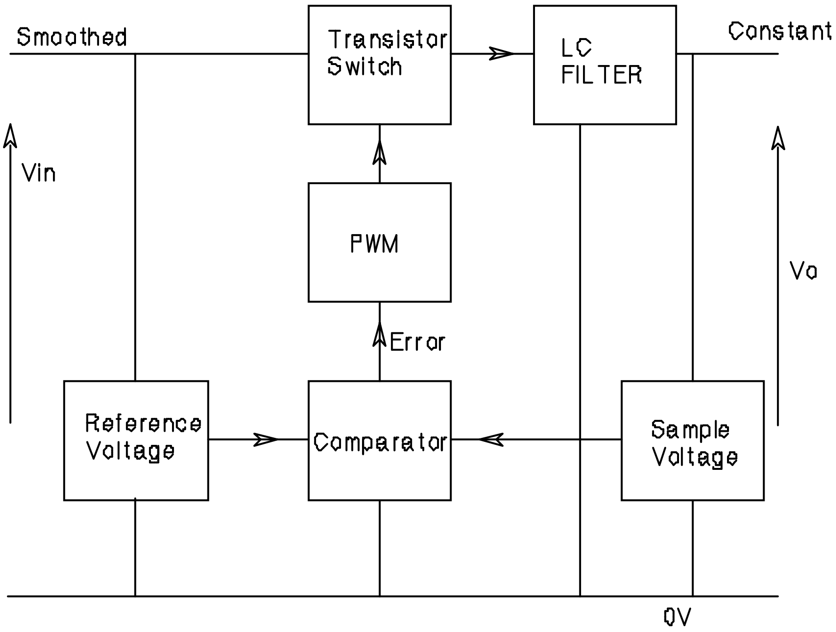


Figure 36 block diagram of a SMPS

The difference is that the error is used to modify the output of a PWM, which is then used to drive the series pass transistor switch. Also a low pass filter is used to average out the rectangular output from the transistor switch. The circuit diagram of a basic switched regulator is shown below.

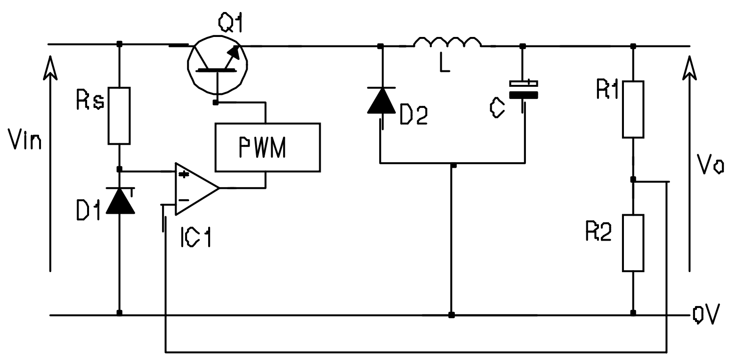


Figure 37 a basic switched regulator

Rs, D1 produce the reference voltage
R1, R2 provide a sample of Vo
OP-AMP is the comparator that compares the reference with the sample and produces the error
PWM produces a pulse train with a duty cycle proportional to the error input
Q1 is the series pass element acting as an electronic switch
L, C act as a low pass filter to recover the d.c. from Q1 output

D2 is a free wheeling (fly-back or commutating) diode and helps the inductor charge the capacitor when Q1 is switched off as explained below.
When the output of the PWM is high Q1 is switched to apply the voltage to the low pass filter and load. D2 has no effect since it is reverse biased. Under these conditions the inductor L is a ‘load’and stores energy in its magnetic field.

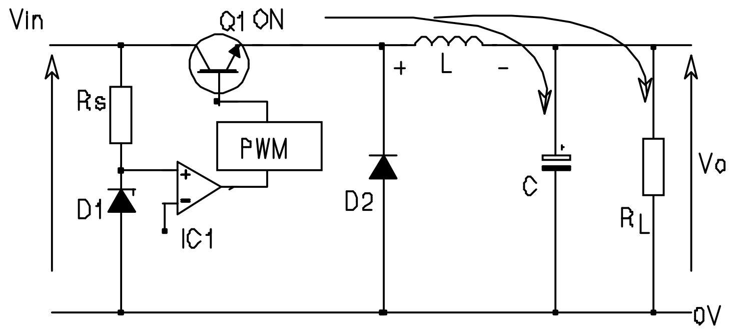


Figure 38 Q1on state, L acting as a load

When the output of the PWM goes low Q1 is switched off and an e.m.f. is developed across the inductor to maintain the current flow through itself. This time the inductor acts as a source and in conjunction with C supplies the current to the load. D2 is used to complete the circuit to allow current flow since Q1 is cut off, see diagram below,

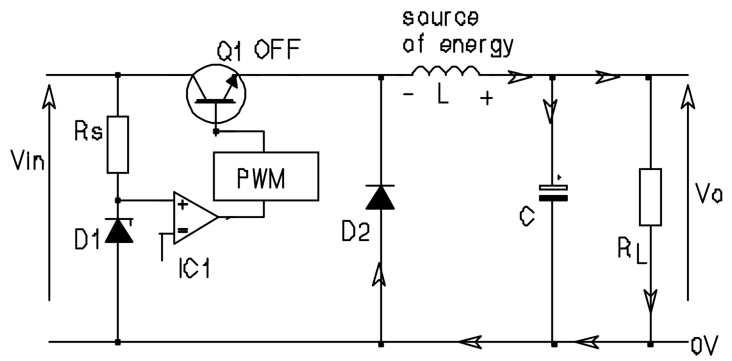


Figure 39 Q1off state, L acting as source of voltage

Output Regulation

If the output voltage increases, the operational amplifier produces a low error voltage so that the duty cycle of the PWM waveform is reduced. This turns Q1 on for a shorter time each cycle to reduce the d.c. voltage at the load.
If Vo decreases then a bigger error is produced to increase the duty cycle of the PWM output to keep Q1 on longer to restore Vo to the desired value.

Since Q1 acts as an electronic switch rather than an amplifier very little power is wasted within the regulator. Switching regulators thus have efficiencies approaching 80% to 95% compared with 30% to 50% efficiencies of conventional linear regulated power supplies

Ripple Voltage

Switching regulators are normally operated in the kilohertz range, to keep the LC filter components small and low cost. Since the capacitor goes through a charge/discharge cycle, there will be some ripple at the output but the ripple frequency will not be 100Hz. It will be the same as the switching frequency of the electronic switch.

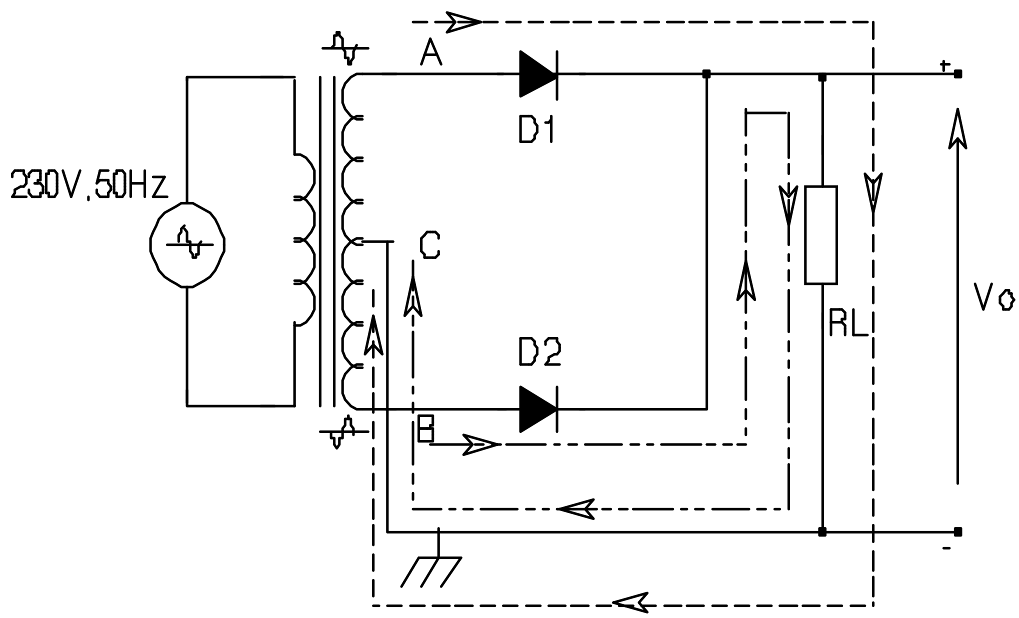
SECTION 10: SOLUTIONS TO SAQ QUESTIONS

SAQ1

The diode will conduct and break down, that is it will be permanently damaged, due to excessive current flow.

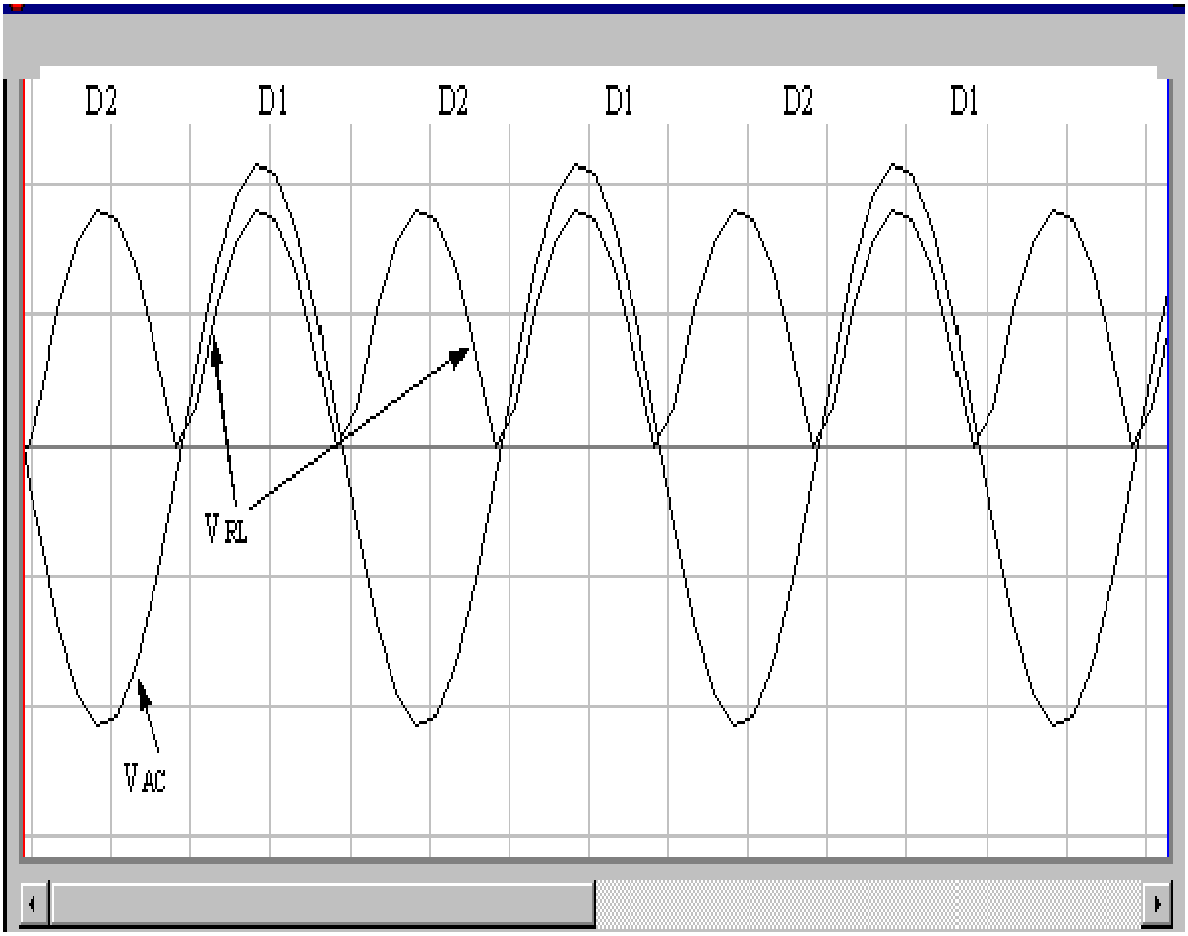
SAQ2

Full-wave rectifier using centre-tapped transformer



A full-wave rectifier using centre-tapped transformer

When A is positive with respect to C. C is positive with respect to B. Then current flow is from A through D1and R_L then into C. When B is positive with respect to C. C is positive with respect to A. The current flow is now from B through D2 and R_L then into C. In both these cases the direction of the current through R_L is always the same, hence a d.c. voltage is developed across the load.



Waveforms for full-wave rectifier using centre-tapped transformer

SQA3

% load regulation $= ((V_{NL} - V_{FL})/V_{FL}) \times 100\%$
$= ((12 - 11.5)/11.5) \times 100\%$
$= 4.3\%$

SAQ4

% load regulation $= ((V_{NL} - V_{FL})/V_{FL}) \times 100\%$
$= ((5 - 4.95)/4.95) \times 100\%$
$= 1\%$

SAQ5

The better power supply has lower % regulation i.e. 5% is better than 10% regulation. An ideal power supply has 0% regulation.

SAQ6

% Line regulation = (change in d.c. output voltage/change in a.c. input voltage) x 100%

$= ((12 - 11.5)/(220 - 209)) \times 100\ \%$
$= 4.5\ \%$

SAQ7

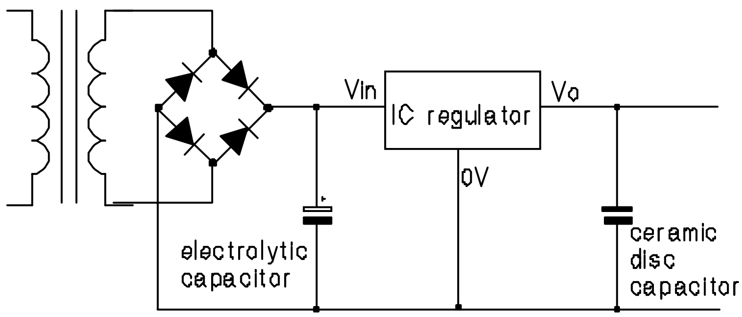
	Circuit	Components	
Circuit Block	Circuit 1	Circuit 2	Circuit 3
Reference Voltage	D1	D1	D1
Sample Voltage	Vo	R2, R3	R2, VR1, R3
Comparator Device	T1, B-E junction	IC1 op-amp	T2
Control Element	T1	T1	T1

SAQ8

Current limiting components R4,T1 and T2
Over-voltage protection components D2, R5, R6, C1, and IC2.

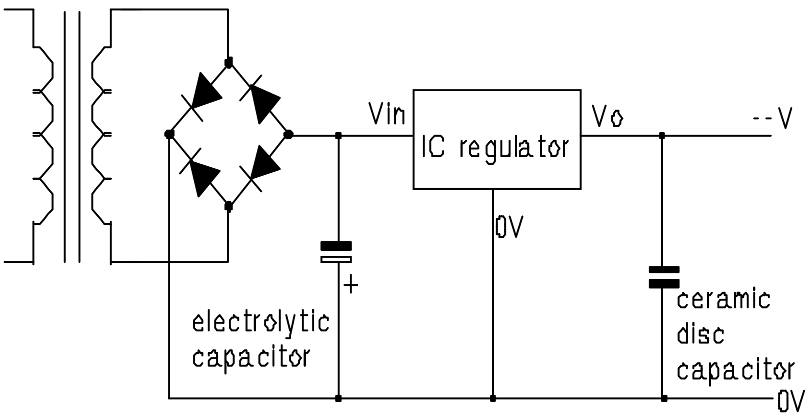
SAQ9

(A)



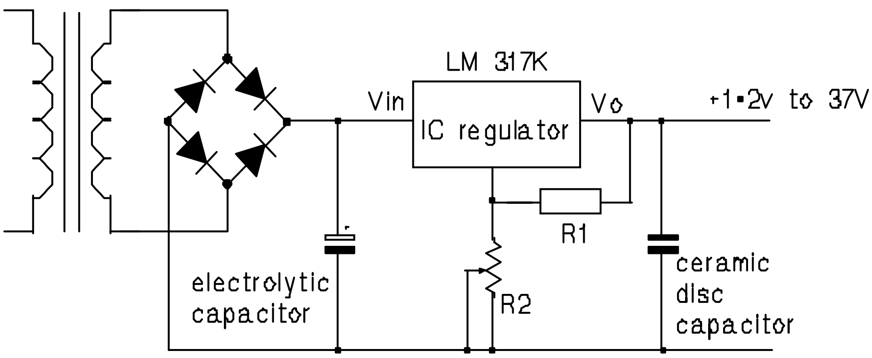
A 3-terminal IC regulator circuit

(B)



A three terminal NEGATIVE voltage regulator

(C)



A three terminal variable voltage regulator

SAQ10

Excellent regulation
Small size
Ease of use
Off the shelf availability
Built-in over current protection
Built-in over voltage protection
Built-in thermal protection
Smaller PCBs

SECTION 11: FURTHER TUTORIALS

Outcome 1

1. Draw the circuit diagram of a full-wave bridge rectifier and explain its operation using input/output waveforms.

2. Draw the circuit diagram of a full-wave rectifier using a centre-tapped transformer and explain its operation using input/output waveforms.

3. Draw the circuit of a full-wave bridge rectifier, which produces a negative output voltage.

4. Explain the need for stabilised power supplies.

5. Explain the term PIV (V r r m) with regard to a diode.

Outcome 2

1. Explain the operation of a full-wave rectifier with a capacitor load only

2. Explain the operation of a full-wave rectifier with smoothing and
   (a) Light load connected.
   (b) Heavy load connected.

3. State the formula for the approximate value of the d.c. voltage for a smoothed voltage with ripple.

4. State the advantages and disadvantages of the π smoothing circuit.

5. Explain the term low pass filter.

Outcome 3

1. State the blocks that constitute a basic power supply.

2 Why do power supplies incorporate
   (a) Over-voltage protection?
   (b) Short-circuit protection?

3. What are the advantages and disadvantages of a 3-terminal linear integrated circuit voltage regulator? Source 3 such devices and list their specifications.

4. Draw the circuit diagram of a basic shunt regulator and explain its operation. The answer should include stabilisation against varying load and changes in input voltage.

5. Draw the circuit diagram of a basic series voltage regulator and explain its operation. What advantages does it have over the Zener diode stabiliser?

Outcome 4

1. What are the advantages of SMPS over conventional power supplies?

2. Explain
   (a) PWM
   (b) The operation of a transistor as switch.
   (c) Role of the LC filter in a SMPS.
   (d) The purpose of a free-wheeling diode.

3. Draw the circuit diagram of a SMPS and explain its operation.

4. Explain why the ripple frequency is not 100 Hz.

5. List some commercial integrated circuits SMPS chips.