

LESSON 6 - SWITCHED MODE POWER SUPPLIES 1

INTRODUCTION

The series pass regulator suffers from a number of disadvantages such as

- ♦ Poor efficiency that becomes worse as the differential between the input voltage and the regulated output voltage becomes greater. The series pass transistor carries slightly more current than the load and this causes lost energy in the form of heat.
- ♦ The heat dissipated requires a heatsink that may be expensive if designed for compact equipment or if the regulator is required to handle heavy current the size and shape may add to the cost of production.
- ♦ The input voltage is required to be larger than the output voltage to allow for both variation of input and output voltage regulation.
- ♦ Most series regulators are designed to operate from transformer/rectifier systems that need to be effectively filtered. This leads to large bulky components that increase the cost for the manufacture of modern electronic equipment.

Switched mode regulators use an active device that operates between saturation and cutoff determined by the output voltage. Both power BJT's and power MOSFET's are used as the 'CHOPPER' device and require that the switching rise and fall times to be very short so as to reduce the dissipation down to very small levels. The use of a switched mode regulator has the following advantages

- ♦ A greatly reduced power dissipation by the main pass transistor and hence improving the regulator efficiency to as high as 90%.
- ♦ The smaller dissipation requires a smaller and less costly heatsink.
- ♦ The output voltage can be stepped up, stepped down or inverted in polarity.
- ♦ It is possible to provide isolation between the load and the rectified power source and in some cases, the 'MAINS VOLTAGE' is rectified directly and the switching regulator provides various dc voltages for the operation of different sections of electronic circuits.
- ♦ The switching regulator operates at high frequencies (10's of kHz to 100's of kHz) and hence the passive filter components are much smaller in value than mains frequency supplies. Other components are likewise reduced in value and physical size..

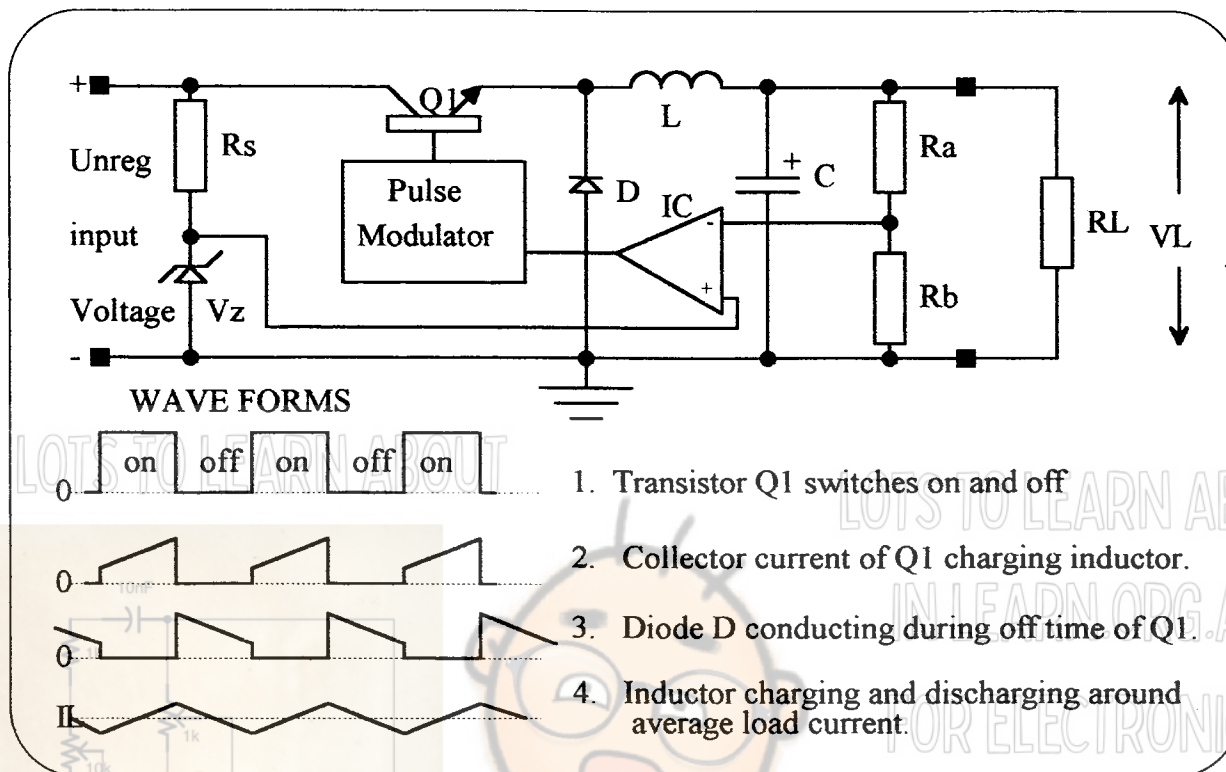
The disadvantages of switched mode power supplies are

- ♦ The circuitry is more complex but manufacturers have a range of IC's that improve this problem.
- ♦ The regulation and ripple amplitude of the output voltage may not be quite as good as a linear series regulator.
- ♦ Radio frequency interference (RFI) from the switching transients may be a problem that necessitates a shielding cage and extra filtering of the regulator.
- ♦ Some component values are critical to the chosen frequency and design parameters.

Many modern circuits such as TV's, computer VDU's and digital control systems rely on switched mode power supplies to reduce bulk and cost.

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THE STEP DOWN REGULATOR - (BUCK REGULATOR)



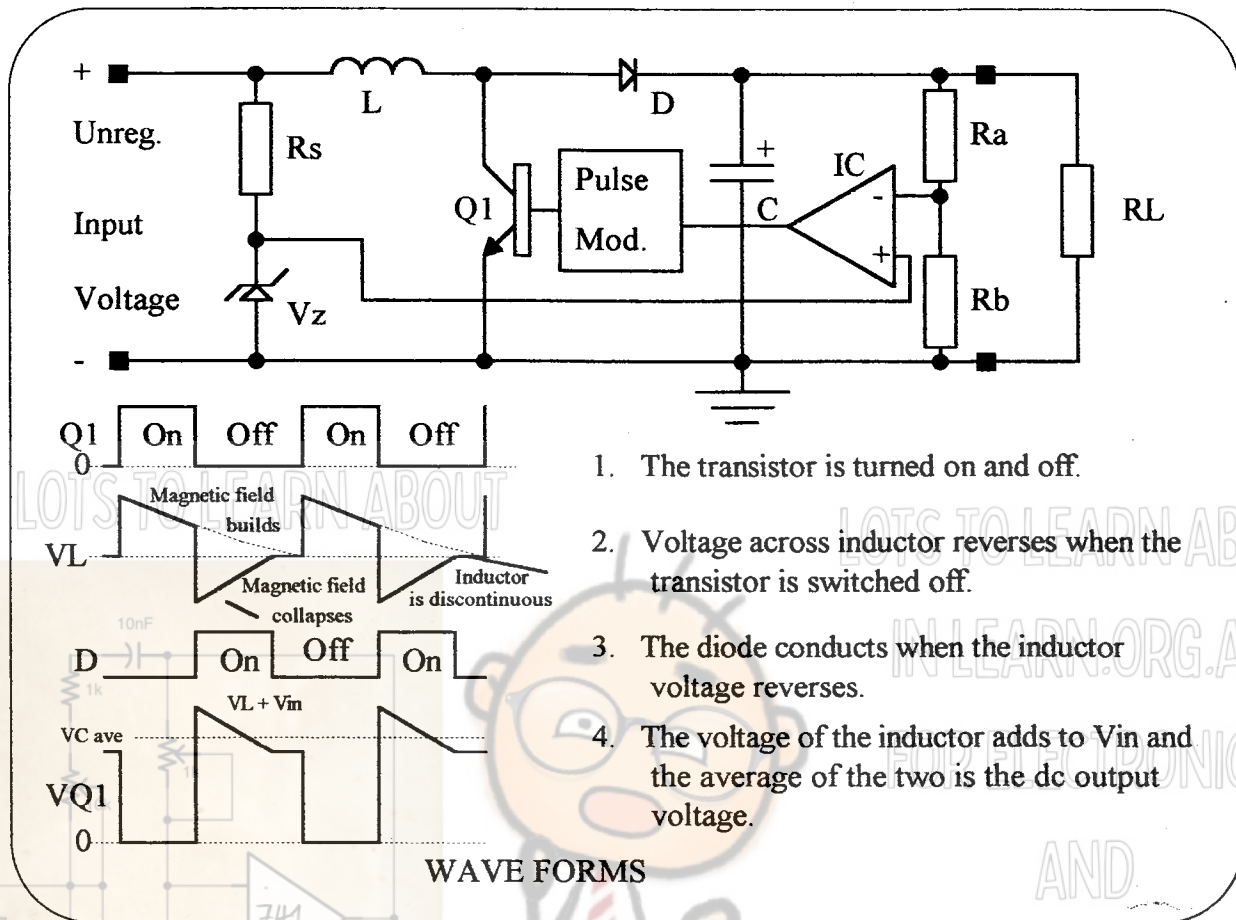
- ◆ The transistor Q1 has its 'on' and 'off' times controlled by a "PULSE MODULATOR" square wave generator. The MARK/SPACE ratio is dependent on the output of the IC.
- ◆ While Q1 is 'on', current through the transistor causes the magnetic field to build up in the inductor 'L' and charging the capacitor 'C' to some voltage.
- ◆ When Q1 is switched off, isolating the output from the input, the collapsing of the magnetic field around the inductor causes a change of polarity of the induced voltage which turns on diode 'D' and hence maintains the load current while the chopper transistor is off.
- ◆ The error amplifier IC senses the output voltage and automatically increases the 'on' time of the transistor if there is a tendency for a drop in voltage due to a greater load current demand.
- ◆ The value of 'C' and the pulse modulator operating frequency dictate the amplitude of the ripple voltage.
- ◆ The value of the inductor is critical for correct operation. The output voltage can be calculated from

$$V_{reg} = V_{in} \times [t(ON)/T] \quad \text{where } T = 1/f$$

Although the efficiency is high, it cannot become 100% because the switching time of the transistor produces a small loss of energy due to heat and there are voltage drops due to saturation voltages. The inductor being wound with copper wire must produce loss of energy due to its resistance as does the switching diode and the filter capacitor. The diode cannot be a standard rectifier diode that operates normally at 50Hz as these diodes exhibit a reverse conduction that occurs at the instant of 'switch off'. High speed diodes are manufactured to allow them to operate effectively at 100's of kHz.

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STEP UP REGULATOR - (BOOST REGULATOR)



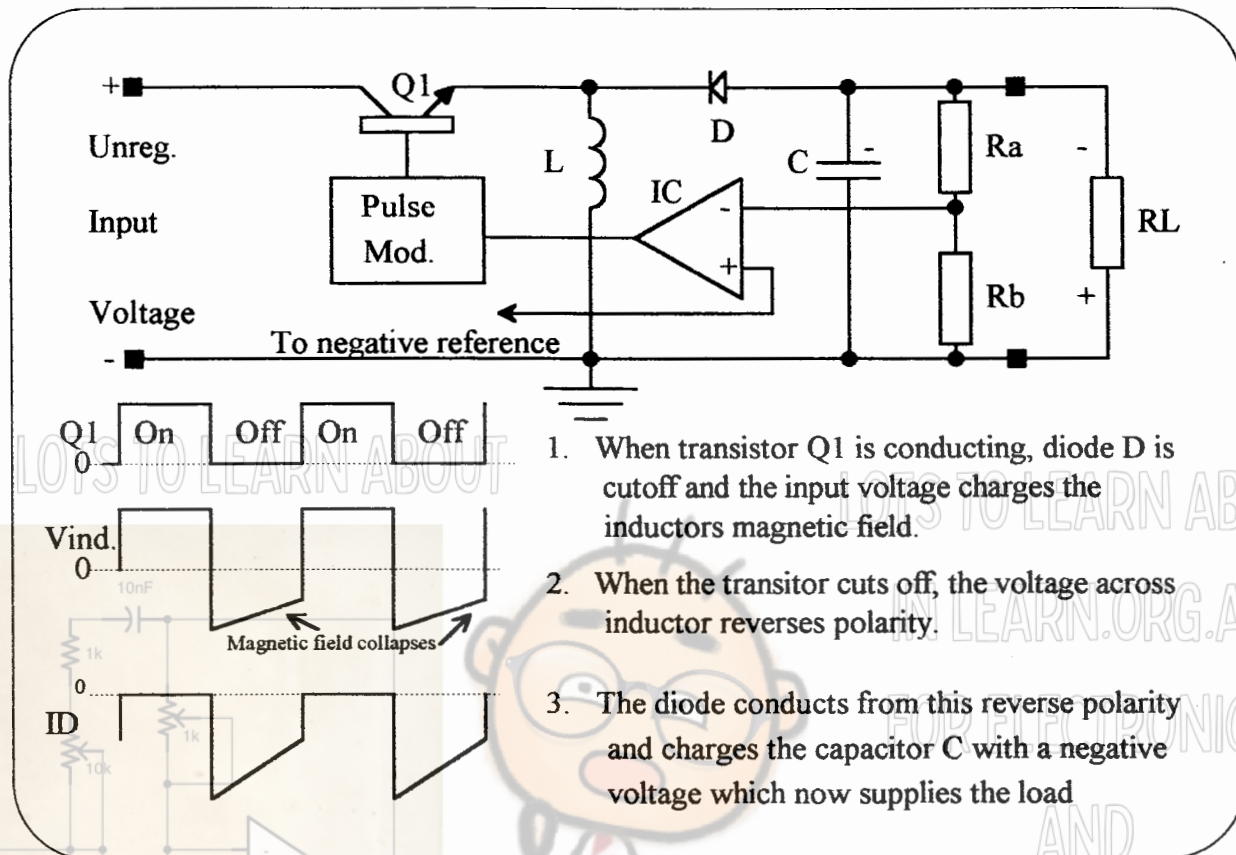
1. The transistor is turned on and off.
 2. Voltage across inductor reverses when the transistor is switched off.
 3. The diode conducts when the inductor voltage reverses.
 4. The voltage of the inductor adds to V_{in} and the average of the two is the dc output voltage.
- ◆ While the transistor Q_1 is 'on', full input voltage is applied to 'L' building up the magnetic field.
 - ◆ When Q_1 turns 'off', the collapsing field will induce a voltage across 'L' that will add to the input voltage. Diode 'D' will conduct and charge the output filter capacitance, and the average charge on the capacitor becomes the output voltage.
 - ◆ Since the output power cannot exceed the input power, the input current will be greater than the output current.
 - ◆ The error amplifier will cause the pulse modulator to increase the conduction of Q_1 if the output current demand is increased.
 - ◆ V_{out} can be calculated (approximately) from

$$V_{reg} = V_{in} \times [T/t(off)]$$

- ◆ The output ripple amplitude is set by the value of 'C' and the frequency of the pulse modulator.
- ◆ The value of the inductor is again critical for correct operation.
- ◆ If the load on the power supply is not sufficient, the inductor becomes discontinuous in operation, causing an increased ripple amplitude. All switched mode regulators can become discontinuous if the current in the load is too small and hence a minimum operating current is often specified.

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POLARITY INVERTING REGULATOR



- ◆ The circuit provides a negative voltage from a positive input voltage.
- ◆ The output voltage may be larger or smaller in magnitude compared to the input voltage.
- ◆ When the transistor conducts, energy from the input is transferred to the inductor's magnetic field.
- ◆ When the transistor is cutoff, the collapsing magnetic field of inductor L reverses the voltage and causes the capacitor C to charge through D to a negative voltage.
- ◆ The error amplifier controls the on/off times of the pulse modulator. Because of the negative voltage, the pulse modulator would require some form of polarity inversion to allow control to take place.
- ◆ The approximate output voltage can be calculated from

$$V_{reg} = -V_{in} \times [t(on)/t(off)].$$

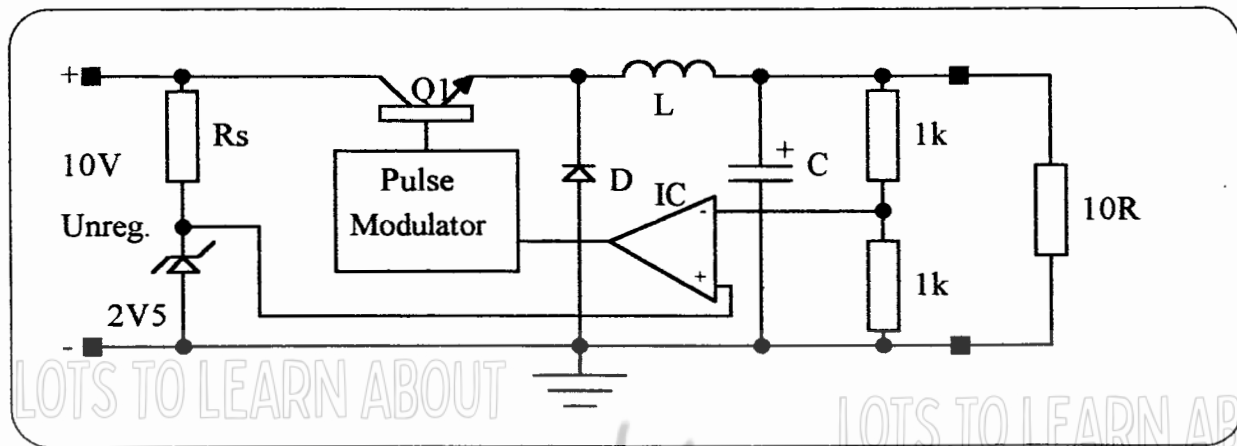
Both the step up and the inverting mode regulators operate on the FLYBACK principle in which energy is placed in the inductor while the output circuit is isolated from the input circuit and then using the collapsing magnetic field to charge the output capacitor to the appropriate voltage. There are three possible methods of altering the on/off times of a switching regulator

1. Constant frequency, variable MARK/SPACE control.
2. Constant ON time, variable frequency control.
3. Constant OFF time, variable frequency control.

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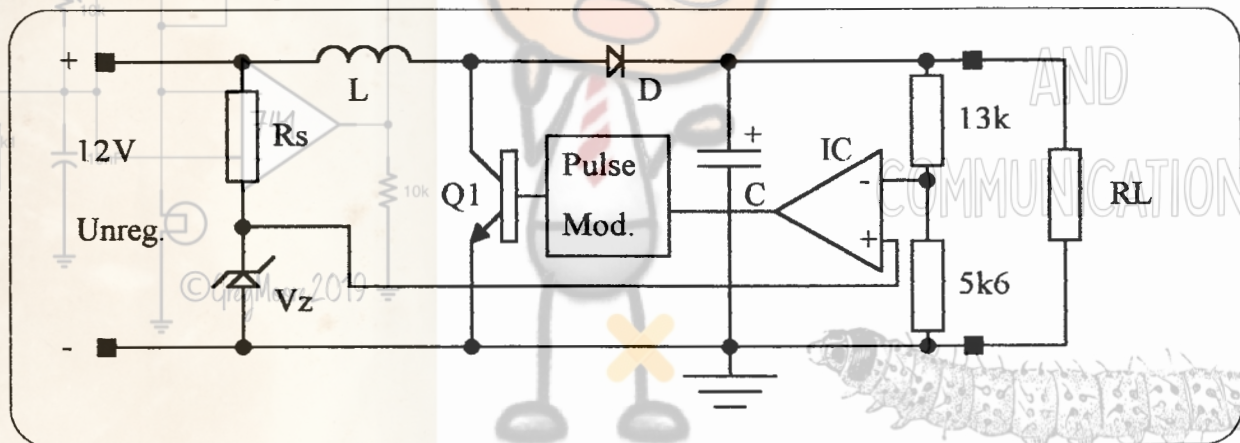
PRACTICE PROBLEMS

Q.1 Refer to the following circuit. If the pulse modulator operates at a frequency of 20kHz and has an equal mark/space ratio, determine



- i) The current in the load ii) The period of the conduction of diode D.

Q.2 Refer to the following circuit. The circuit operates on a frequency of 30kHz and for this particular load of RL has an 'on time' of 13.3 usec.

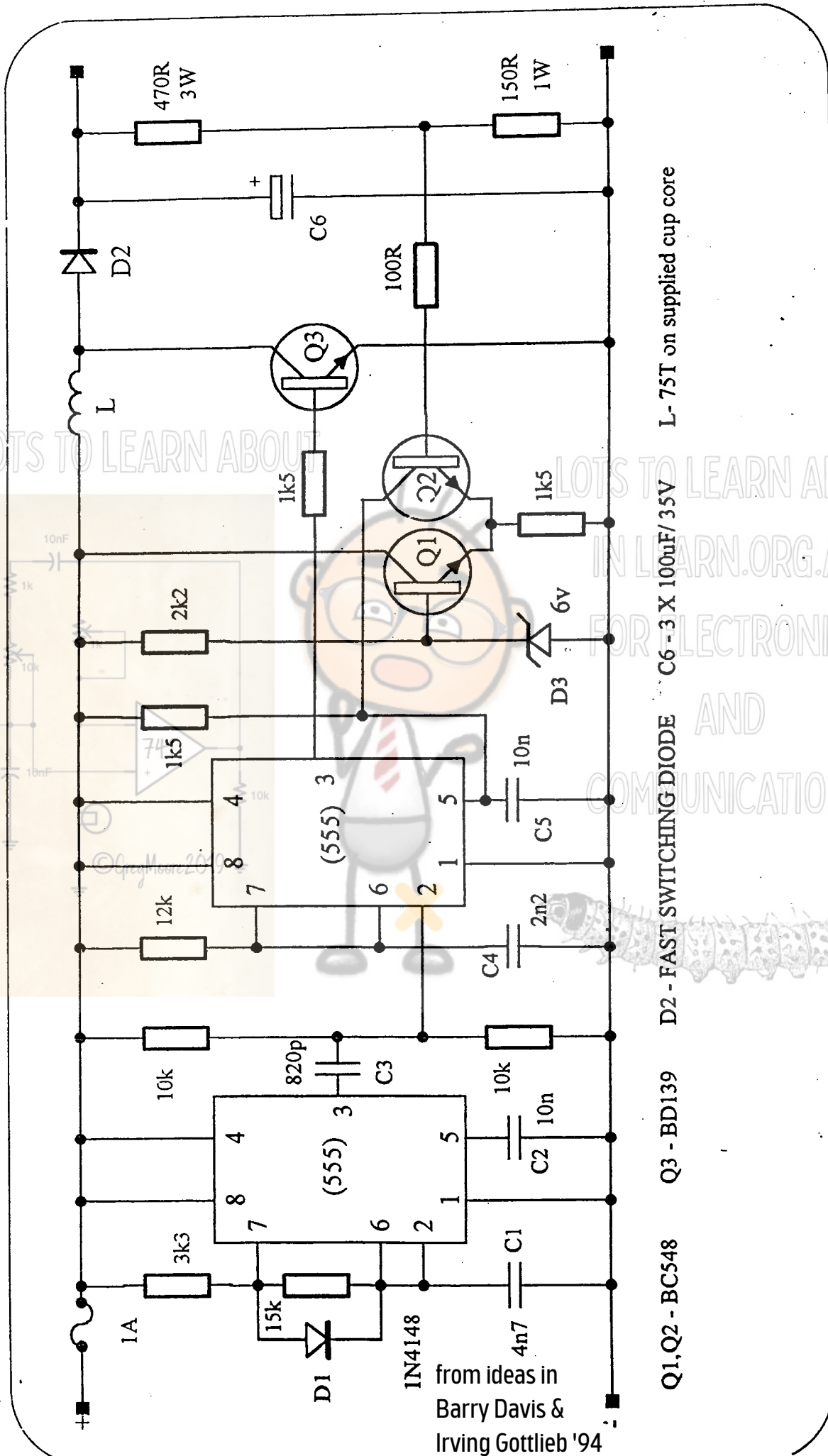


- i) Determine the voltage across the load.
ii) What would be the nominal voltage of the reference source Vz ?

Q.3 Briefly describe what is meant by the term "flyback mode" when referring to switched mode voltage regulators.

Q.4 What important feature is required by the diodes marked D in the above switched mode voltage regulators ?

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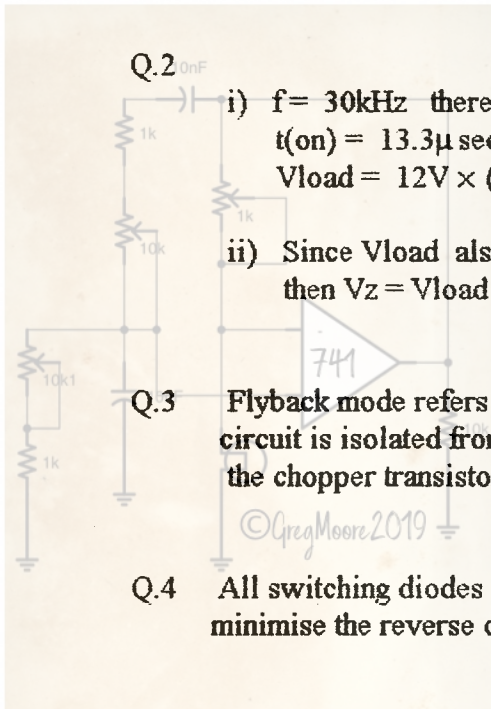
ANSWERS TO PRACTICE PROBLEMS

Q.1

- i) $f = 20\text{kHz}$ therefore $T = 1/20\text{kHz} = \underline{50\mu\text{secs}}$
 equal mark/space ratio therefore $t(\text{on}) = t(\text{off}) = \underline{25\mu\text{secs}}$
 $V_{\text{Load}} = 10\text{V} \times [25\mu\text{sec}/50\mu\text{sec}] = \underline{5\text{V}}$
 $I_{\text{load}} = 5\text{V}/10\text{R} = \underline{0.5\text{A}}$

check: $V_{\text{Load}} = 2.5\text{V} \times (1\text{k} + 1\text{k})/1\text{k} = 5\text{V}$

- ii) The diode conducts during the transistor 'off' time = $25\mu\text{sec}$



- i) $f = 30\text{kHz}$ therefore $T = 1/30\text{kHz} = \underline{33.34\mu\text{sec}}$
 $t(\text{on}) = 13.3\mu\text{sec}$ therefore $t(\text{off}) = \underline{20\mu\text{sec}}$
 $V_{\text{load}} = 12\text{V} \times (1 + 20\mu\text{sec}/13.3\mu\text{sec}) = \underline{30\text{V}}$

- ii) Since V_{load} also equals $V_z \times (R_a + R_b)/R_b$
 then $V_z = V_{\text{load}} \times R_b/(R_a + R_b) = 30\text{V} \times 5\text{k}/(13\text{k} = 5\text{k}6) = \underline{9\text{V}}$

Q.3

Flyback mode refers to the storage of energy in the inductor when the output circuit is isolated from the input circuit and the transferring of that energy when the chopper transistor is turned off to the output filter capacitor.

Q.4

All switching diodes used in switched mode regulators have been designed to minimise the reverse conduction at switch off that can plague normal rectifiers.

Notes originally circa 1999 for course 6030

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