SWITCHING VOLTAGE REGULATOR AND VARIABLE CURRENT LIMITER

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ABSTRACT:

One of the main hazards in electrical or electronic circuits is over-current, or an excessive amount of current being delivered to the load due to a short circuit.

Circuits can be protected from over-current by simple means such as using a fuse. As the current exceeds the fuse’s limits, it blows and therefore disconnects the load from the source, preventing further current from damaging the load. This is common method for protecting house-hold mains. A similar device is the circuit breaker. While fuses are simple and secure, the drawback is that once they are blown, they need to be replaced or reset.

A much more efficient method is implementing an active current limiting circuit. Because a fuse is a passive element, it alone may not be able to protect internal devices from over-current, as it is generally too slow in operation and the time it takes for it to blow may be enough to destroy the devices. An active current limiting circuit sets a maximum load current by using sensing resistors along with transistors that act as on and off switches.

Our project explores how current can be limited independent of the input voltage by passing signals through various circuits including a transformer, rectifier, filter, and regulator.
TRF – 9-0-9 TRANSFORMER:

The power supply used in this project comes from a wall socket. These wall sockets provide a 120V, 60-cycle AC power. The difference between AC (alternating current) and DC (direct current) is that while DC power sources, such as batteries, fuel cells, and solar cells, has current flowing in the same direction between two terminals, the direction of the current in AC sources reverses, or alternates, at 60 times per second.

The big advantage of using an AC source is that it is easy to change the voltage of the power, using a device called a transformer.

This integrated circuit starts off with a step down transformer 9-0-9. It is a symmetrically balanced transformer relative to the output on the secondary side. In this case there is a 120V AC coming from the wall into the primary. This 120V is stepped down to 18V AC on the secondary. However, this 18V AC output can be tapped in the center with a ground of 0V AC and therefore splitting it into perfect halves where the result is now two 9V AC terminals that are of opposite polarity. Hence the name 9-0-9, meaning 9V AC on the output line terminal, 0V AC because of the center tapped to ground, and 9V AC on the neutral terminal as shown in the diagram below.

![9-0-9 Transformer / Full Wave - Half Bridge Rectifier with Filter Diagram](image)

RECTIFIER:

The significance of this configuration is that the two 9V AC terminals are now in opposite polarity. So, like opposing magnets, the fields cancel. This provides symmetrically balanced power which contributes to noise reduction because it cancels common mode noise, making the signal more efficient and linear across a huge bandwidth. This also allows the effective use two diodes in creating a full wave rectifier as opposed to the typical full bridge, 4 diode configurations. With this balanced output and two diodes, a full wave rectifier is created that allows the conversion of incoming AC power to DC.
The signal leaving the transformer and prior to going through the diodes is sinusoidal as shown below.

![Unrectified AC Voltage Sinusoid](image)

The signal leaving the rectifier is no longer a sinusoid, but a pulsed, or rippled, DC signal. This is shown below.

![Rectified DC Voltage](image)
TRF – FILTER:

A capacitor is used in parallel between the rectified signal and the load. This will smooth out the ripple and produce a fairly smooth horizontal signal which is the desired response for a DC signal.

When this filter is used, the RC charge time of the filter capacitor must be short and the RC discharge time must be long enough to eliminate ripple action. In other words, the capacitor must charge up fast, preferably with no discharge at all. Better filtering also results when the input frequency is high, thus leading to the choice of a full wave rectifier over a half wave rectifier. The output of a full wave rectifier is easier to filter than that of a half wave rectifier because of its higher frequency.

The smaller the impedance ($X_c$) of the filter with respect to the load resistance, the better the filtering action. The impedance is calculated with the following parameters.

Frequency = 60Hz and Capacitance = 18,000uF. This value equates to:

$$X_c = \frac{1}{2\pi fC}$$

$$X_c = \frac{1}{2 \times 3.14 \times 60 \times 18,000\text{uf}} = .147$$

With no capacitor connected the output of the rectifier circuit, the waveform would show a large pulsating component (ripple) compared with a filtered output. When a capacitor is connected across the output, the value of the voltage is increased due to the filtering action.
VOLTAGE INVERTER – BACKGROUND:

In many cases, an integrated circuit may need a negative voltage input in order to operate. A negative supply voltage can be constructed using a 555 timer and some simple passive components, such as a couple diodes, capacitors and resistors. The advantage of using this circuit is that the negative voltage together with the original positive supply can be used to simulate a dual supply. Reversal is done by routing the circuit through diodes and capacitor in such a manner that the output will always be negative with respect to ground as seen in the circuit diagram below.

The circuit above depicts how a +12V DC on the input will be ideally be inverted to a -12V DC at the output, with the NE555 timer as the heart of the circuit.
VOLTAGE INVERTER – PROJECT SPECIFICATIONS:

However, the negative voltage output will normally be 1 or 2 volts lower than the original positive supply. For example, if the original input voltage is +9V, the output will be roughly -8V to -7.5V so this must be accounted for if a specific value is desired. There is also the fact that a certain amount of voltage will be lost across several of these passive components, especially diodes that need anywhere from 0.5V to 0.7V to work. In the circuit above +12V is inserted initially and although the ideal output voltage should be -12V, the realistic output voltage will average between -10.5 and -11V.

The project includes a current limiter that requires a -5V input to drive an op amp, which requires the need for this voltage inverter circuit. In order to get the necessary output voltage, additional resistors are needed, along with a capacitor, to drop the output voltage. The calculations made to find the values of the resistors needed to drop the output voltage from an assumed -11.5V to -5V is shown below:

\[ V_i \left( \frac{R_2}{R_2 + R_1} \right) = V_o \]

\[ (-11.5V) \left( \frac{1000\Omega}{1000\Omega + R_1} \right) = -5V \]

\[ R_1 = 1300\Omega \]

The NE555 is wired as an astable multivibrator operating at around 1 KHz. The square wave output, if available, is at pin number 3 of the IC. During the positive half of the square wave, the capacitor charges through one diode and when the output of the IC is at zero, the capacitor discharges through the other.
555 TIMER – BACKGROUND:

In addition for its part in generating an inverted voltage signal, a 555 timer is also used to generate a triangular pulse wave as an input to the switching voltage regulator circuit of the project.

The 555 timer is an integrated circuit chip that can be used for generating extremely precise time delays or oscillations. It has been around since the 1970s as the first commercial timer IC available, and it continues to be popular among the industry and hobbyists due to its ease of use, low cost, and reliable stability.

Internal Circuitry of 555 Timer
555 TIMER – PINOUT:

As seen from the two diagrams of the 555 timer from the previous page, there are many resistors and transistors forming a complicated maze-like circuit inside the IC. Luckily, it has been packaged and reduced to an IC chip of only 8 pins.

1. Pin 1 is the Ground pin which connects to the 0V power supply like the name suggests.

2. Pin 2 is the Trigger pin. When its voltage becomes lower than a third of the input rail voltage, the output will be set high.

3. Pin 3 is the Output pin, which acts as the output. The output capacity is 200mA.

4. Pin 4 is the Reset pin which will reset the chip when it goes below 0.8V.

5. Pin 5 is the Control pin which directly accesses the 2/3 voltage divider point to modify the timing periods.

6. Pin 6 is the Threshold pin. When its voltage gets higher than two thirds of the input rail voltage, the output will be set low.

7. Pin 7 is the Discharge pin. Its high and low state follows Pin 3, except the fact that the high state of Pin 7 is actually open state.

8. Pin 8 is the Supply pin which is where the input rail voltage goes in. It can be any voltage from 4.5V to 15V DC.
As seen from the above basic structure of a 555 timer diagram, on the left are 3 resistors in series. They are being used as voltage divider resistors so that there can be a one third VCC and two third VCC voltages into the comparators. These three 5k resistors are where the name 555 timer comes from. After the resistors are the 2 comparators.

The top comparator compares the Threshold pin voltage with the 2/3 VCC voltage to get an output. Its output goes high when Threshold is higher than 2/3 VCC, and it goes low when Threshold is lower than 2/3 VCC.

The bottom comparator compares the Trigger pin voltage with the 1/3 VCC voltage to get another output. Its output goes high when Trigger is lower than 1/3 VCC, and it goes low when Trigger is higher than 1/3 VCC.

Now these two outputs are put into the flip flop. The top threshold comparator output will go into the Reset pin of the flip flop. The bottom trigger comparator output will go into the Set pin of the flip flop. When set is high, the output will be high, when reset is high, the output will be low. If both are low, then output does not change. If both are high, then it is undefined.

There is a transistor on the bottom after the flip flop. The output of the flip flop is called Q Not. When Q Not goes high, the transistor turns on, and the discharge voltage of Pin 7 will be pulled down to low state. When Q Not goes low, the transistor turns off, and Pin 7 is high, or open, to be more precise.
Finally, the output Q. Not is passed through an inverter to produce the final output of the 555 timer, Q. Its high low state follows that of the Discharge pin except the fact that its high state is the actual high state, not just open.

The most important thing to remember from this is when Threshold goes higher than 2/3 VCC, output goes low and vice versa. When Trigger goes higher than 1/3 VCC, output goes low and vice versa.

**555 TIMER – DIFFERENT CONFIGURATIONS:**

**MONOSTABLE MODE (ONE SHOT):**

The 555 timer has different uses depend on how its pins are connected. One configuration of the IC is in monostable mode, also known as one shot configuration. This is shown below

![Monostable Mode (One Shot) and 555 Timer Output (Monostable Configuration)](image)

In the beginning, the Output pin will be at 0V. So that means the Discharge pin will also be low and will be pulled to 0V since it follows the output. Now, if we make the Trigger pin low, the output will become high and this will make the Discharge pin high and open. Next, the capacitor C below Pin 7 will start charging through the resistor. Eventually this will make the voltage at Pin 6 reach and surpass the threshold voltage, making the output low again. The Discharge pin will also be low again, which closes the open circuit and discharges the capacitor through Pin 7. The width of the pulse T generated can be calculated using the equation:

\[ T = 1.1 \times RC \]

It can be seen that this monostable configuration can be used as a pulse width modulator. The desired pulse can be generated using the above equation.
**BISTABLE MODE (SCHMITT TRIGGER):**

The bistable mode, also known as Schmitt trigger is similar to the monostable mode. It acts as a flip flop with two stable states, high and low. To get a high state output, the Trigger input is simply set low. To get a low state output, the Reset pin is simply set low.

![Bistable Mode (Schmitt Trigger)](image)

**ASTABLE MODE:**

The astable mode generates an output that, like the name suggests, is unstable. It will change high low states constantly.

![Astable Mode](image)

![555 Timer Output (Astable Configuration)](image)
In the beginning, there is no voltage across the capacitor C. As time passes by, it will charge up through R1 and R2 and continuously increase the voltage at Pin 6 (Threshold) and Pin 2 (Trigger), which are tied together.

At a certain time, the voltage at Pin 2 will go above 1/3 VCC due to the charging capacitor. This will keep the output low. After a while, the voltage at Pin 6 will go above 2/3 VCC due to the charging capacitor, making the output low. This results in Pin 7 being low, so that the capacitor can discharge through R2 and into Pin 7.

The frequency of the output pulse can be calculated using the following formula:

\[
f = \frac{1}{\ln(2) \cdot C \cdot (R_1 + 2R_2)}
\]

To calculate the time for high state \(T_{\text{high}}\), use the formula:

\[
T_{\text{high}} = \ln(2) \times (R_1 + R_2) \times C
\]

To calculate the time for low state \(T_{\text{low}}\), use the formula:

\[
T_{\text{low}} = \ln(2) \times R_2 \times C
\]

This astable mode can be used to generate a pulse wave which is used in this project. This circuit takes the generated pulse from the capacitor instead of the output because a triangular wave, not square wave, is needed.
Calculations:

Total period $T = 0.693 \times (R1 + 2R2) \times C = 0.693 \times (1k + 2 \times 50k) \times (500pf) = 35\, ns$

$T_{on} = 0.693 \times (R1 + R2) \times C = 0.693 \times (1k + 50k) \times 500pf = 17.7\, ns$

$T_{off} = 0.693 \times R2 \times C = 0.693 \times 50k \times 500pf = 17.3\, ns$

555 TIMER – CONCLUSION:

555 Timer is a very useful IC chip throughout the field. It can be used in LED light blinker, lamp dimmer, police siren, traffic lights, intruder alarm, motion detector, mobile incoming call indicator, this capstone project’s switching regulator, and many more applications. There have been billions of 555 timers in existence to this day, and since it is so easy to use for even beginners, it is known as the gateway to electronic circuits.
SWITCHING REGULATOR – LINEAR vs. SWITCHING:

Once rectified from AC to DC, the current is ready to pass through the regulation component of the circuit. The purpose of the switching regulator is to regulate and step down the voltage it receives as an input, much like a buck converter, while providing a highly efficient output as well. In the initial design stages, two options were available to be incorporated, which were the linear and switching regulators.

The linear regulator is popular in modern day electronics, but lacks in efficiency and power delivery. While the switching regulator has typical efficiency rates of 85%-97%, its linear counterpart has lower efficiencies between 14%-40%. Power wasted in the circuit can be calculated with the formula below.

$$P_{wasted} = (V_{in} - V_{out}) \times I_{load}$$

This lower efficiency rate also results in a higher heat dissipation, which requires additional peripheral components on the circuit, such as heat sinks, cooling fans, and isolation transformers that are bulky and invasive.

The larger heat dissipation is also a product of the difference between the input and output voltages being too great, which can be seen in the linear regulators lower efficiency rates. Linear regulators function by transferring power continuously from the input to an output. A switching regulator, on the other hand, keeps its efficiency high by breaking up small chunks of energy, bit by bit, and moving them between the input and output. The inductor and fast-switching diode are responsible for the “switch” aspect of the switching regulator, hence its coined name.

While linear regulators can power very low powered devices and are cheap to purchase, they are very inefficient by design. They take the difference between the input and the output, burning it up as heat. The larger this difference is, the more heat is produced and the more power is wasted in the circuit. These regulators can waste more power just stepping down the voltage than actually gets delivered to the output itself. The switching regulator, which delivers energies in bursts, alleviates this fault. These bursts of energy are controlled by the switching component (inductor/diode) and a controller (555) in the circuit. The controller regulates the rate at which energy is transferred to the output.
SWITCHING REGULATOR – SWITCHING OPERATION:

Because it was known the circuit would be driving an at least 1 Ampere load and a loss of power was not advantageous, the switching regulator became the preferred choice. Pictured below is a diagram of the regulation circuit used.

With regards to the controller in this circuit, the 555 timer is responsible for sending pulses to the comparator (U4 and U5). The regulator relies on a pulse width modulated output that can be controlled via voltage feedback. Using pulse width modulation controls the average power to the load by controlling the average voltage it receives.

In the above schematic, D8 is the fast-switching diode and L1 is the inductor component of the buck converter. When the switch is closed, L1 opposes rising current and generates an electromagnetic field in its core. The fast-switching diode thus becomes reverse biased. Once current has been established in the inductor, the switch opens. This current in the inductor causes the current charging in the adjacent capacitors to rise smoothly. The switch opening is caused by the fast-switching diode that closes the loop which permits the inductor’s current to keep flowing.
Because the current through the inductor resists change, it must flow through the diode and to the output. This change in the current causes a step voltage to appear across the inductor. The current then flows to the higher voltage at Vout. When the switch is open, the inductor’s electromagnetic field discharges and generates a current in the reverse polarity. The fast-switching diode then conducts until the electromagnetic field in the inductor has been depleted.

While there are many and varied ways to step down a voltage between an input and output, a switching regulator was the optimal choice because it doesn’t incur as many losses in power. Whenever a voltage source is connected to a capacitor whose initial voltage is not the same as the voltage source, you waste energy and losses occur.

Alternatively, this loss can be avoided by connecting a voltage source to a current source. An inductor is the physical element most similar to a current source, which is why it is an important aspect of the switching regulator. It provides a steady current while stepping down the voltage. Because the current is reactive and out of phase for the 555 timer’s clock switch as a step down device, it becomes more efficient.
SWITCHING REGULATOR – BUCK CONVERTER CONFIGURATION:

Pictured below is the physical representation of the switching regulator circuit.

![Image of the physical representation of the switching regulator circuit](image)

This circuit incorporated a 250 uH inductor, F15UP20 fast-switching diode, 2N3904 BJT’s, and a 2N7000 power MOSFET for its regulatory aspect.

As can be observed from above, the circuit utilizes a buck converter configuration to step down the voltage from 12 V to 8 V. The 555 timer is located on the left section of the board and connects from its pin 6 to the base of the regulator’s comparator. The buck converter has the inductor connected to the output of the circuit.

Buck converters use a power MOSFET(2N7000) as a switch that connects and disconnects the input voltage to the inductor. The inductor acts as a reservoir for every segment of current it receives. Once the voltage reaches the required level, only the energy necessary for the load is transferred from the input to the output. Pictured on the next page are the closed and opened states of the buck converter.
Once the switch is on, the input voltage connects to the inductor. The difference between the input and output voltages is then transferred across the inductor, causing its own current to increase.

The current flows into both the load of the circuit and the output capacitor (C2), which begins to charge the capacitor as well. When the switch is turned off, the input voltage first applied disappears. Because inductors by nature discharge current steadily over time, the voltage across the inductor will hold the current constant.

The current through the inductor steps up when the switch is on and steps down when the switch is off. Usually, the current in the inductor does not drop to zero during operation. Performance is genuinely better in the continuous mode and it allows maximum output power to be acquired.

Mathematically, \( V_{LOn}D + V_{LOff}(1 - D) = 0 \), where \( D \) is the duty cycle.

A fast-switching diode (F15UP20) has a high reverse recovery time and continues to conduct in the reverse direction because of the stored charges. These diodes become non-conductive much sooner than their non-fast switching counterparts. The pathway between the anode and the cathode is somewhat conductive after the current that placed them in that state has disappeared.

The reverse polarity in the diode causes a conductive path in the reverse direction. These diodes act like capacitors that have been charged, and once a reverse voltage is applied, exerts a current.
SWITCHING REGULATOR – MOSFETs & BJTs:

The power MOSFET is fundamental to the switching regulator for a number of reasons. It is unipolar in nature, which allows it to switch at very high speeds. The only limitation upon the speed is decided by the transistor’s own internal capacitances. The capacitances must be charged or discharged when the transistor switches. This can sometimes be a slow affair, as the current that goes through the gate capacitances is limited by the external circuit. Pictured below is a diagram of the typical power MOSFET.

The CGD capacitance is the connection in series of two capacitances. The first is COXD, which is created by the gate electrode, silicon dioxide, and top of the N epitaxial layer. The other capacitance is CGDJ, caused by the space-charge zone when the MOSFET is in an off-state.

Controlling the circuit itself can be explained by examining the diagram below.

The switching regulating circuit uses the second pair of BJTs as a pulse width modulation comparator from the 555 timer. The first pair are responsible for being the error amplifier. It receives a reference voltage from the initial 12 V, while the comparator compares the amplified error signal with a waveform generated across the timing capacitor, C2. The error amplifier output is compared to the voltage from the 12 V input and energy is then transferred to the buck converter and output of the circuit.
CURRENT LIMITER – LINEAR REGULATORS:

As stated in the abstract, the function of current limiting circuitry is to prevent damage to the IC when an overload is placed on the output of the regulator. In other words, if the load impedance is too low, such as a short circuit, the regulator would source excessive load current and destroy the pass transistor.

Every electronic circuit is designed to operate off of some voltage supply, which is assumed to be constant. A voltage regulator provides this constant DC voltage and with external components, continuously holds the output voltage at a designed value regardless of changes in load current or input voltage (as long as the load current and input voltage are within the specified operating range for the regulator).

The basic linear regulator operates by forcing a fixed voltage to appear at the regulator output terminal. The control circuitry senses the output voltage, and adjusts the current source according to the load in order to hold the output voltage at the desired value. A basic linear regulator diagram is shown below.

There are three basic types of linear regulator designs that can maintain a designed output voltage: Standard (NPN) Regulator, Low Dropout (LDO) Regulator, and Quasi LDO Regulator. The most important difference between these types as the dropout voltage, which is the minimum voltage drop required across the regulator to maintain output voltage regulation. A critical point in determining selection of regulator is that the linear regulator that operates with the smallest voltage across it dissipates the least internal power, and therefore has the highest efficiency.

![Regulator Diagram](image)

- **LDO**
  - $V_D = \text{PNP SAT} \approx 0.1V$ to $0.7V$
  - $I_G \leq 20 - 40 \text{ mA}$
  - $I_{L(\text{MAX})} = 1A$
  - $V_D = V\text{BE} + \text{PNP SAT} \approx 0.9V$ to $1.5V$
  - $I_G \leq 10 \text{ mA}$
  - $I_{L(\text{MAX})} = 7.5A$
  - $V_D = 2 \text{ VBE} + \text{PNP SAT} \approx 1.7V$ to $2.5V$
  - $I_G \leq 10 \text{ mA}$
  - $I_{L(\text{MAX})} = 10A$
CURRENT LIMITER – SELECTION OF REGULATOR:

In selecting the best choice for this project, several specifications are evaluated. The major ones include maximum load current, type of input voltage source, and output voltage precision. The load current that is needed for this project is a single value, and the regulator selected must be able to provide sufficient current to the load even under worst-case scenarios.

By the time the input signal reaches the current limiting circuit, it will be a DC voltage. In this case, an LDO regulator is the best choice because it will utilize the available input voltage more fully. In addition, LDO regulators allow for greater design flexibility because they offer special features such as load-dump protection, reverse input voltage protection, error flag, and others. These other features will not be explored in depth in this project.

The reason for choosing a linear regulator over a switching regulator is because of two protection circuits found in nearly all ICs: thermal shutdown and current limiting. While the first is not necessarily needed, as adding a heat sink can be a suitable substitution, the second provides the fundamental core of this entire current limiter.

The specific IC linear regulator used in this project is the LM317T. This IC is very easy to use, and requires minimal external circuitry to set regulation. The device itself also includes on-chip current limiting, thermal overload protection, and safe-operating-are protection.

In terms of meeting specifications, the LM317T can operate with an input voltage of anywhere from 3V to 37V, and can supply a constant load current of 10mA to 1.5A.
CURRENT LIMITER – CONSTANT vs. FOLDBACK:

There are two basic types of current limiting circuits that are most commonly used in linear regulators, Constant Current Limiting and Voltage-Dependent Current Limiting (sometimes referred to as Foldback Limiting).

CONSTANT CURRENT LIMITING:

With constant current limiting, the maximum current that the regulator can supply to a load is specified on its data sheet. Most LDO regulators specify only a single value of maximum current. This value is guaranteed for any input or output voltage within the operating range for the regulator.

For the simple diagram shown on the previous page, the load current is sensed by the “I SENSE” resistor, which generates a voltage that is directly related to the current. This voltage is shifted and amplified by the differential amplifier. The voltage at the output of the differential amplifier is a ground-referenced signal that is proportional to the load current. This signal is then applied to the inverting input of the current error amplifier, while a reference voltage is applied to the non-inverting input. The maximum current limit point occurs when the reference voltage is equal to the voltage at the output of the differential amplifier.

When load current reaches the limit, the regulator operates in constant current mode. At this point, the regulator limits the load current to the maximum value, and the output voltage can vary from any value down to zero volts.

VOLTAGE DEPENDENT (FOLDBACK) CURRENT LIMITING:

This type of current limiting is used by regulators that are high current, greater than 1A. The maximum load current is dependent on the input-output voltage differential across the IC. This is due to the safe operating area of transistors, which limits the amount of current a transistor can safely handle as the voltage increases.
In this project, the designed maximum load current is 1A. This means that the load current should never exceed this value. Due to this specification, constant current limiting is more desirable.

**CURRENT LIMITER – OPERATIONAL AMPLIFIER LM741:**

In general, the LM741 operational amplifier can be used in many different circuits. They can function as inverting or non-inverting amplifiers, differentiators or integrators, filters, regulators, peak detectors, etc. For this project’s purpose, the LM741 will serve as a comparator.

Below is a diagram of the internal circuitry of the LM741.
CURRENT LIMITER – LM741 PINOUT:

1. **Pin 1 (Offset Null):** Since the operational amplifier is the differential type, input offset voltage must be controlled so as to minimize offset.

2. **Pin 2 (Inverting Input):** All input signals at this pin will be inverted at the output pin.

3. **Pin 3 (Non-Inverting Input):** All input signals at this pin will be processed normally without inversion.

4. **Pin 4 (V-):** Negative supply voltage terminal. Operating range for the 741 is -4.5V (minimum) to -18V (maximum), while specified operating range is between -5V and -15V DC.

5. **Pin 5 (Offset Null):** Same as Pin 1.

6. **Pin 6 (Output):** Output signal’s polarity will be the opposite of the input’s polarity when this signal is applied to the inverting input.

7. **Pin 7 (V+):** Positive supply voltage terminal. Operating range for the 741 is +4.5V (minimum) to +18V (maximum), while specified operating range is between +5V and +15V DC.

8. **Pin 8 (NC):** Stands for “Not Connected”. Nothing connects to this pin.
CURRENT LIMITER – VARIABLE CURRENT LIMITING CIRCUIT:

This circuit is used to impose a max load current, protecting it from over-current in the case of a short circuit load. It takes two inputs, a positive 8V DC from the switching voltage regulator, and another -5V DC from the voltage inverter to power the operational amplifier.

The TIP42 TO-220 package PNP BJT transistor is the only transistor used in this project’s current limiter. This transistor acts as an on/off switch for determining how much voltage and current to allow at the load terminals. It takes a small current leaving the base junction and amplifies it at the collector output. In the event of a short circuit load, the entire input voltage will be dumped across this transistor. This evaluates to about 64W using the formula below. The TIP42’s power dissipation max rating is 60W, this transistor must be mounted on a heat sink.

\[ P_D = \frac{V^2}{R} \]

Adjustable current limiting is provided by the operational amplifier LM741, which is used as a comparator. This IC monitors the voltage across R_SENSE. If this voltage exceeds a certain level, set by the potentiometer R_LIMIT, the output goes low, dragging down the ADJ pin of the LM317 and thus the output voltage.

The LED lights up when the load current has reached the limit. Also the potentiometer R21 has one side connected to -5V instead of 0V so that the output voltage can be varied down to zero volts instead of the 1.2V limit of the LM317.
CURRENT LIMITER – TESTING:

The current limit is tested by using a load resistance of 10 ohms and lowering it to 1 ohm by 1 ohm increments. As resistance is decreased, the current should gradually increase until it hits a certain max limit. Once it hits the maximum load current, the LED lights up, indicating the limit has been reached. From this point on, any further reduction in load resistance will continue to produce a constant max load current.

The short-circuit test is performed by replacing the load resistance with a wire. Without a current limiter, this would result in over-current and the load circuit would be damaged. However, as shown below, even with a short-circuit the output load current is still under the set maximum limit of 1 A.
DIVISION OF LABOR:

ARENDEL RICHARDS
- Transformer-Rectifier-Filter
- Voltage Inverter

YUN TANG
- 555 Timer

PETER TU
- Current Limiter

JEFFREY WHITE
- Switching Regulator
REFERENCES:


"Doctronics." 555 timer. 05 May 2013 <http://www.doctronics.co.uk/555.htm>.


