CHAPTER ONE

INTRODUCTION

1.1 DEFINITION

A power supply is a reference to a source of electrical power. A device or system that supplies electrical power or other types of energy to an output load or group of loads is called a power supply unit (PSU).

1.2 TYPES OF POWER SUPPLIES

Power supply for electronic devices can be broadly divided into linear and switching power supplies.

The linear supply is relatively simple and becomes increasingly bulky and heavy for high current devices; voltage regulation in a linear supply can result in low efficiency.

A switched mode power supply of the same rating as a linear supply will be smaller, usually more efficient, but will be more complex.

1.2.1 Battery Power Supply

This is a type of linear power supply that offers benefits that traditional line operated power supplies lack; mobility, portability, and reliability. A battery consists of multiple electrochemical cells connected to provide the desired voltage.

The most commonly used dry-cell is the carbon zinc dry cell battery. They are made by stacking a carbon plate, a layer of electrode paste and a zinc plate alternately until the desired total voltage is achieved. The most common dry cell batteries have one of the following voltages: 1.5, 3, 6, 9, 22.5, 45 and 90.
1.2.2 Linear Power Supply

An AC powered linear power supply usually uses a transformer to convert the voltage from the wall outlets (mains) to a different, usually a lower voltage. If it is used to produce dc, a rectifier is used. A capacitor is used to smooth the pulsating current from the rectifier. Some small periodic deviations from smooth direct current will remain, which is known as ripple.

The voltage produced by an unregulated power supply will vary depending on the load and on variations in the AC supply voltage. The simplest DC power supply circuit consists of a single diode and a resistor in series with the AC supply. This is common in rechargeable flashlights.

1.2.3 Switched Mode Power Supply

A switched mode power supply (SMPS) works on a different principle. AC mains input is directly rectified without the use of a transformer, to obtain a DC voltage. This voltage is then sliced into small pieces by a high-speed electronic switch. The size of these slices grows larger as power output requirements increase.

Switched mode power supplies have an absolute limit on their minimum current output. They are only able to output above a certain power level and cannot function below that point. In a no-load condition the frequency of the power slicing circuit increase to great speed, causing the isolation transformer to act as a tesla coil, causing damage due to the resulting very high voltage power spikes.

Switched mode power supplies with protection circuits may briefly turn on but then shut down when no load has been detected.
1.2.4 Programmable Power Supply

They are those in which the output voltage can be varied remotely. One possible option is digital control by a computer interface. Variable properties include voltage, current and frequency. This type of supply is composed of a processor, voltage/current programming circuits, current shunt, and voltage/current read-back circuits.

They can furnish DC, AC or both types of output. The AC output can either be single phase or three phase. A single phase is generally used for low voltage, while three phase is more common for high voltage power supplies.

When choosing a programmable power supply, several specifications should be considered.

For AC supplies:

- Output voltage
- Voltage accuracy
- Output frequency
- Output current

For DC supplies:

- Output voltage
- Voltage accuracy
- Current
- Power

Many special features are also available including computer interface, overcurrent protection, overvoltage protection, short circuit protection and temperature compensation.
Programmable power supplies are used in many applications e.g. automated equipment testing, crystal growth monitoring and differential thermal analysis.

1.2.5 Uninterruptible Power Supply

An Uninterruptible Power Supply takes its power from two or more sources simultaneously. It is usually powered directly from the AC mains, while simultaneously charging a storage battery. Should there be a dropout or failure of the mains, the battery instantly takes over so that the load never experiences an interruption. Such a scheme can supply power as long as the battery charge suffices; e.g. in a computer installation, giving the operator sufficient time to effect an orderly system shutdown without loss of data.

1.2.6 High Voltage Power Supply

This refers to an output on the other hundreds or thousands of volts. They use a linear setup to produce an output voltage in this range.

Several options are considered when choosing a high voltage power supply.

These are:-

- Maximum current
- Maximum power
- Maximum voltage
- Output polarity
- User interface
- Style

The first four characteristics depend upon the supply’s intended application.
1.3 APPLICATIONS OF POWER SUPPLIES

1.3.1 Computer Power supplies

A modern computer power supply is a switched–mode supply designed to convert 110-240V AC power from the mains supply, to several output both positive (and historically negative) DC voltages in the range 12V to 3.3V.

The first computer power supplies were linear devices, but as cost became a driving factor, and weight became important, switched mode supplies are almost universal. Most modern computer power supplies actually consist of several different switched mode supplies, each producing just one voltage component and each able to vary its output based on component power requirements, and all are linked together to shut down as a group in the event of a fault condition.

1.3.2 Welding Power Supply

Arc welding uses electricity to melt the surfaces of the metals in order to join them together through coalescence. The electricity is provided by a welding power supply, and can either be AC or DC. Arc welding requires high current typically between 100 and 350 amps. Some types of welding can use as few as 10 amps, while some applications of spot welding employ current as high as 60000 amps for extremely short time. Older welding power supplies consisted of transformers or engines driving generators, while modern ones implement semiconductors and microprocessors.

1.3.3 AC Adapter

A linear or switched mode power supply that is built into the top of a plug is known as a wall wart. Universal adapters attempt to replace missing or damaged ones, using multiple plugs and selectors for different voltages and polarities.
DC adapter include a few diodes. Whether or not a load is connected to the power adapter, the transformer has a magnetic field continuously present and normally cannot be completely turned off unless unplugged.

AC to DC adapter has polarity. Even if the plug fits into a device, the positive and negative connections may be oriented the wrong way. It is necessary to use an adapter with the correct polarity to avoid damages.

![Figure 1.1 Mobile phone AC adapter](image_url)
CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

As programmable power supplies evolved into mainstream components of automated test systems in the last 20 to 30 years, the design of each device has been somewhat limited to one of two basic architectures, switching and linear regulation. As in any product development, tradeoffs are required when choosing each design; both switching and linear regulation offer numerous opportunities to trade off performance. The task of creating a power supply forces an innovative approach. This paper discusses the novel design characteristics of the programmable dc power supply and the unique combination of switching, linear regulation, and software-defined hardware that makes the design possible in a small package.

2.2 Linear versus Switching Regulation

The earliest programmable power supply designs all focused on linear regulation to provide a steady output voltage. They involved power transistors operating in the linear (class A) mode with feedback setting the output characteristics. Based on a fairly simple design concept, linear power supplies have the advantage of very precise regulation, low ripple and noise, and excellent response to line and load changes. However, their drawbacks make them largely undesirable for a PXI-based power supply design - large physical size, low efficiency (ranging from 5 to 60 percent), and consequently, large power dissipation. While the programmable dc power supply specification allows about 20 W of cooling per slot, this would not be enough to provide the traditional power required for ATE systems.

A more recently accepted method of delivering accurate power in test systems has come from switching regulation. Switching regulation involves transistors rapidly commutating on and off with their duty cycle determining the output voltage. Consequently, the timing regulation on the transistors will determine the precision of the output voltage. This method offers the advantage
of much greater efficiency than their linear counterparts, often in the range of 65 to 90+ percent, and therefore yields much cooler designs. The typical weight of each component is also much lower, keeping the physical package in check. However, optimum transient response tends to be more difficult to obtain, and the electromagnetic interference from the switching components must be considered. Finally, with the above factors combined, it is still difficult to compete with the low output noise and speed possible with linear designs.

Modern switching power supply technology has improved dramatically over the 30 lb power supplies of yesterday. Technically, small size in power supplies is dictated largely by switching speed. As a general rule, the higher the switching speed, the smaller the magnetic components. In the mid to late-1980s researchers at the Massachusetts Institute of Technology and elsewhere were experimenting with the concept of 1 MHz switching converters, amplifiers and regulators. Within the last five years, this technology has exceeded even those expectations. However, progress is minimized if the switching elements are so lossy that any improvement in component size is negated by the need to heat sink the switching elements due to inefficiencies. Here again, technologies have improved dramatically over even the last 10 years. Combined with new power supply controller integrated circuits, the stage is set to synthesize efficient, high power, and even quiet power supplies that do the job of their old, traditional big-iron counterparts.

So far, however, this technological evolution gets us only raw quasi-regulated power. There are still design challenges, including the ability to program to 0 V, sense currents from microamps to amps, provide rapid response to load and programmed inputs, and so on. The best way to solve these problems (and provide exceptional noise performance) is with traditional linear circuitry. So the best overall solution is a marriage of both linear and switching technologies.

As an aside, off-the-shelf Class D amplifiers are also an option for high-performance power supply designs. Unfortunately engineers determined that while these are innovative devices for audio applications such as efficiently driving speakers, they have limitations where precision DC outputs are required. These limitations outweigh the potential gains that they might offer.
2.3 Switching Regulation with Linear Output

The triple-output programmable DC power supply combines traditional linear and switching power technologies by configuring the switcher as a tracking regulator, essentially creating a rail with variable headroom above the programmed output. The end result is a module with two isolated channels, one from 0 to +20 V and the other from 0 to -20 V, and a single non-isolated channel from 0 to 6 V, all capable of putting out up to 1 A per channel. These basic power output speculations are complemented by excellent resolution and low noise for the programmable dc power supply as a voltage or current source.

The linear output control is depicted in Figure 2.1. The core technology in the linear stage is the Linear Technologies power operational amplifier with adjustable precision current limit. It has several advantages for a power supply implementation, not the least of which being its small size and "on the fly" current limit, which is specifically helpful for ATE applications. Traditionally, this was referred to as a "VI control block" because it allowed the output to be constant-voltage or constant-current controlled, depending on the input settings and output load; it was implemented with discrete op amps, diodes and resistors. This VI control block forms the heart and soul of traditional source/measure units (SMUs). Thus, using the VI control block helps give the SMU-like behavior.

![Figure 2.1: The Linear Technology is the heart of the voltage/current control block.](image-url)
Because more output voltage and current were required than it could provide, analog "translator" circuitry was designed to handle the output range. It was necessary to scale both the output control and the measurement in this fashion. Figure 2.2 shows the basic blocks that represent this dual-direction translation. In the design of this translation, it was important to keep in mind several critical details:

- It is necessary to bring the output all the way to 0 V
- It must be able to measure both voltages and currents all the way to 0 V with sub-microampere leakages
- It must sink enough current from any output load or capacitance to maintain good response time even near 0 V
- It must be able to tolerate input over-voltage conditions

![Figure 2.2: The linear regulation stage is designed to source/measure very low voltages and currents.](image)
It acts as an op amp to drive the discrete output devices providing the translation to the required output voltages. Using a discrete MOSFET output element for each channel, output current is boosted to more than 10X the capability of the power supply at more than 3X the voltage compliance of the power supply. Likewise, a high-speed op amp/FET combination is used as a current sense translator to bring the voltage appearing across the current shunts back down to within the power supply’s rails. The result is a fast control loop that delivers excellent transient response and stability over a broad range of loads. This current sense translator is also optimized for dynamic range and noise so that it is possible to sense voltages down to 0 V and currents down to sub-microampere levels.

On the non-isolated channel 0, the switching converter is a Linear Technology boost-buck converter that provides dynamic regulation of its output. The control output of channel 0 is fed back into the switching converter through signal conditioning, which results in the switching converter output "floating" over the channel 0 output by a few tenths of a volt. The result is an extremely power-efficient switching design with all the advantages of a linear regulator.

Directly combining the tracking regulator with the output amplifier described above takes care of the non-isolated channel. With isolated channels 1 and 2, the switching regulator consists of a relatively straightforward high-power DC-DC converter operating at about 200 kHz. The input drive to the converter is synthesized by an FPGA that can vary the duty cycle of the drive signal applied to the switching MOSFETs. The FPGA offers the advantage of intelligent soft-start and ramp-up, which "softens" the transient currents drawn from the power supply backplane, thereby allowing the power supply to operate within its specification.

Although with the isolated channels there is no direct analog feedback path to the switching regulator control due to the galvanic isolation (see Figure 2.3), an isolated analog-to-digital converter (ADC) and data path already existed for these channels to provide current and voltage read back. This ADC is for monitoring the output voltage and current at all times; so if it can be switched to "look at" the raw input rail supplying the linear output amplifier as well, it is possible to use this signal as isolated feedback. The FPGA can then be used to modulate the duty cycle of the FET drive to the DC-DC converters, effectively providing a digitally controlled, software-in-
the-loop PID algorithm to manage the pre-regulated input to the linear stage. All of this can be done using components that were already needed in the design for other reasons. The result is a cost-efficient, flexible design in a module that can be scaled as additional power supply requirements emerge.

There are several advantages to using this software-configurable control loop. First, it is possible to anticipate where the pre-regulator needs to be before the output amplifier attempts to get there.

Second, the response can be tailored to optimize system efficiency. Finally, we can tune the control algorithm to optimize performance depending on whether the input power is coming from the power supply’s backplane or an external source. It is important that the power being drawn from the power supply’s backplane be carefully managed to meet its power specifications for the overall product. Regulating the voltage alone is not sufficient. Instead, determining the optimal response is obtained by regulating the power being dissipated in the linear regulator.

The reason for this is shown in Figure 2.4. When lightly loaded and run at low duty cycles, DC-DC converters tend to behave more like current sources than voltage sources. When a sudden

Figure 2.3: The non isolated channels on the power supply make use of analog-to-digital converters to control the switching pre-regulation elements through the same data path as the current/voltage measurement read back.
load is applied to the output of a current source, the output rapidly falls. Thus, more voltage headroom is required to give the PID time to respond. This is accommodated by using power regulation, which automatically adjusts the output voltage headroom to be much larger under light load conditions.

Figure 2.4 Power is regulated on the power supply (as opposed to voltage) to compensate for sharp changes in the load. Sufficient headroom is maintained at all times to prevent "crashes" between the pre-regulator rail and output voltage.

Another example of this flexibility is optimizing power drawn from the input power supply - in this case the power supply’s backplane. Because the power available from a power supply’s chassis is limited, it is necessary to provide an auxiliary power source for applications above 9 W. However, many applications exist for power levels less than 9 W, and in those situations, it is not required to supplement the power supply’s backplane. Using this approach, different PID set points (resident on the FPGA) are used for powering its backplane versus an auxiliary source. If more power is needed than is available from the power supply backplane, the PID set points are
changed to provide a more optimum tradeoff between efficiency and step response.

2.4 Theory of Operation

Figure 2.5 Block diagram of a mains operated AC-DC SMPS with output voltage regulation

2.4.1 Input rectifier stage

Figure 2.6 AC, half-wave and full wave rectified signals
With the SMPS having an AC input, the first stage is to convert the input to DC. A phenomenon referred to as rectification. The rectifier circuit can be configured as a voltage doubler by the addition of a switch operated either manually or automatically. This is a feature of larger supplies to permit operation from nominally 120 volt or 240 volt supplies. The rectifier produces an unregulated DC voltage which is then sent to a large filter capacitor. The current drawn from the mains supply by this rectifier circuit occurs in short pulses around the AC voltage peaks. These pulses have significant high frequency energy which reduces the power factor. Special control techniques can be employed by the following SMPS to force the average input current to follow the sinusoidal shape of the AC input voltage thus the maintaining correcting the power factor in the design. An SMPS with a DC input does not require this stage. An SMPS designed for AC input can often be run from a DC supply (for 230V AC this would be 330V DC), as the DC passes through the rectifier stage unchanged. It's however advisable to consult the manual before trying this, though most supplies are quite capable of such operation. However, this type of use may be harmful to the rectifier stage as it will only utilize half of diodes in the rectifier for the full load. This may result in overheating of these components, and cause them to fail prematurely.

If an input range switch is used, the rectifier stage is usually configured to operate as a voltage doubler when operating on the low voltage (~120 VAC) range and as a straight rectifier when operating on the high voltage (~240 VAC) range. If an input range switch is not used, then a full-wave rectifier is usually used and the downstream inverter stage is simply designed to be flexible enough to accept the wide range of dc voltages that will be produced by the rectifier stage. In higher-power SMPS some form of automatic range switching may be used.

2.4.2 Inverter stage

The inverter stage converts DC, whether directly from the input or from the rectifier stage described above, to AC by running it through a power oscillator, whose output transformer is very small with few windings at a frequency of tens or hundreds of kilohertz (kHz). The frequency is usually chosen to be above 20 kHz, to make it inaudible to humans. The output voltage is optically coupled to the input and thus very tightly controlled. The switching is implemented as a multistage (to achieve high gain) MOSFET amplifier. MOSFETs are a type of
transistor with a low on-resistance and a high current-handling capacity. Since only the last stage has a large duty cycle, previous stages can be implemented by bipolar transistors leading to roughly the same efficiency. The second last stage needs to be of a complementary design, where one transistor charges the last MOSFET and another one discharges the MOSFET. A design using a resistor would run idle most of the time and reduce efficiency. All earlier stages do not weight into efficiency because power decreases by a factor of 10 for every stage (going backwards) and thus the earlier stages are responsible for at most 1% of the efficiency. This section refers to the block marked Chopper in the block diagram.

2.4.3 Voltage converter and output rectifier

If the output is required to be isolated from the input, as is usually the case in mains power supplies, the inverted AC is used to drive the primary winding of a high-frequency transformer. This converts the voltage up or down to the required output level on its secondary winding. The output transformer in the block diagram serves this purpose.

If a DC output is required, the AC output from the transformer is rectified. For output voltages above ten volts or so, ordinary silicon diodes are commonly used. For lower voltages, Schottky diodes are commonly used as the rectifier elements; they have the advantages of faster recovery times than silicon diodes (allowing low-loss operation at higher frequencies) and a lower voltage drop when conducting. For even lower output voltages, MOSFETs may be used as synchronous rectifiers; compared to Schottky diodes, these have even lower conducting state voltage drops.

The rectified output is then smoothed by a filter consisting of inductors and capacitors. For higher switching frequencies, components with lower capacitance and inductance are needed.

Simpler, non-isolated power supplies contain an inductor instead of a transformer. This type includes boost converters, buck converters, and the so called buck-boost converters. These belong to the simplest class of single input, single output converters which utilize one inductor and one active switch. The buck converter reduces the input voltage in direct proportion to the ratio of conductive time to the total switching period, called the duty cycle. For example an ideal buck converter with a 10 V input operating at a 50% duty cycle will produce an average output voltage of 5 V. A feedback control loop is employed to regulate the output voltage by varying
the duty cycle to compensate for variations in input voltage. The output voltage of a boost converter is always greater than the input voltage and the buck-boost output voltage is inverted but can be greater than, equal to, or less than the magnitude of its input voltage. There are many variations and extensions to this class of converters but these three form the basis of almost all isolated and non-isolated DC to DC converters. By adding a second inductor the Ćuk and SEPIC converters can be implemented, or, by adding additional active switches, various bridge converters can be realized.

Other types of SMPSs use a capacitor-diode voltage multiplier instead of inductors and transformers. These are mostly used for generating high voltages at low currents (Cockcroft-Walton generator). The low voltage variant is called charge pump.

2.5 Regulation

A feedback circuit monitors the output voltage and compares it with a reference voltage, which is set manually or electronically to the desired output. If there is an error in the output voltage, the feedback circuit compensates by adjusting the timing with which the MOSFETs are switched on and off. This part of the power supply is called the switching regulator. The Chopper controller shown in the block diagram serves this purpose. Depending on design/safety requirements, the controller may or may not contain an isolation mechanism (such as opto-couplers) to isolate it from the DC output. Switching supplies in computers, TVs and VCRs have these opto-couplers to tightly control the output voltage.

Open-loop regulators do not have a feedback circuit. Instead, they rely on feeding a constant voltage to the input of the transformer or inductor, and assume that the output will be correct. Regulated designs compensate for the parasitic capacitance of the transformer or coil. Monopolar designs also compensate for the magnetic hysteresis of the core.

The feedback circuit needs power to run before it can generate power, so an additional non-switching power-supply for stand-by is added.
2.6 Protecting the Inputs and Outputs

In DC power supply systems and lab settings (including academic environments), the robustness of programmable power supplies is crucial. During system debug, power supply outputs can be inadvertently connected to the wrong places. In lab settings, nodes are often accidentally shorted or connected inappropriately. Thus, the programmable dc power supply was designed to accommodate a myriad of overload conditions. The following is a summary of the key protection elements on the programmable power supply:

- **Channel Output Protection** - Each channel is, of course, current and voltage limited programmatically. In addition, each output is protected against a reverse-polarity voltage application. An output fuse provides additional protection to prevent catastrophic failures as a last line of defense. A spare fuse is available on the board to minimize downtime if it is needed.

Each output is also protected against application of excessive voltages from the outside, up to 15 V from the maximum channel voltage. So as an example, the 20 V channels can tolerate application of up to 35 V applied from outside the module. The 6 V channel has an added degree of protection. Because its output is limited to 6 V, excessive voltages applied to Channel 0 shut down all outputs and issue a warning to the user.

- **Auxiliary Power Input Protection** - An auxiliary power input allows channels 1 and 2 (+20 and -20 V) to supply up to 20 W each. Because the programmable power supply allows the use of an external power device, appropriate steps must be taken to protect the module.

The operating voltage range for the auxiliary power input is 11 to 15.5V. If voltages outside these limits are detected, the module will shut down until an input voltage within range is applied. If an input in excess of 20 V is applied, the input crowbar protection will turn on, most likely resulting in a blown input fuse. This protects the input solid-state switching devices (and pre-regulator power supply) from over-voltage damage.
• **Over-temperature Protection** - The programmable power supply is designed conservatively and operates at nominal temperature rise internally due to the intelligent PID control of the output devices. However, if a fault occurs, such as an excessively dirty chassis fan filter, blocked intake, or chassis fan failure, the output channels shut down and a warning is issued. An over-temperature condition requires user software intervention to reset, thus preventing the module from "cooking" at excessive temperatures should such a system fault develop.

2.7 **Maximized Programming Speed**

In automated test systems one of the most important performance attributes of any instrument is speed. For power supplies, the programming and measurement speed as well as the communication bus form the main areas of differentiation for this programmable power supply.

The fact this dc power supply is built around its bus significantly helps optimize programming and measurement speeds. Sending program parameters and retrieving data is greatly facilitated by the 132 MB/s PXI bus speeds. With three channels that each require voltage/current programming and measurement parameters plus status information (compliance limit, warnings, errors, temperature, and so on), the amount of data that needs to be moved in both directions can challenge traditional bus solutions. PXI can move this data in microsecond timeframes compared to several milliseconds or 10s of milliseconds required with traditional instrument bus architectures (GPIB or RS232). Thus, the software and data path overheads are practically negligible for this programmable power supply.

The power supply measurement architecture is also notable for its speed advantage over traditional measurement approaches. Integrating ADC architectures are traditionally used in power supply measurements. These ADCs have advantages for noise but don't give the user much flexibility to optimize speed, especially "under the hood" in dynamic stimulus-response devices such as precision power supplies or SMUs. With multi channel power supplies, the slower ADC creates significant overhead for acquiring the multiple parameters required to represent the status of the output.
Figure 2.7 shows the architecture used in this power supply. It is based on similar measurement engines used in National Instruments high-speed data acquisition systems. The ADCs are 200 kS/s, 16-bit high-bandwidth converters - one for the non-isolated channel and another for the two isolated channels. As previously mentioned, the ADCs are used for both measurement read back as well as PID control. The net loop speed of the measurement is in the 3 kS/s range. In other words, every 300 µs, the measurement engine returns six measurements - voltage and current output for each of the three channels (as well as the PID loop data). This is fast enough to watch the settling time of all the channels simultaneously (rise times in the millisecond range) and is faster than required for any stimulus-response step waveforms required by the user.

Figure 2.7: The measurement architecture of the power supply allows fast read back of voltage/current on each channel before transmitting the data back to the user across the its backplane.
Optimum noise performance of the measurement is achieved by averaging multiple measurements. The default is an average of 10, but the user can select and modify that default as needed for the application. The isolated data is rapidly moved over a 10 Mb/s serial data path using high-speed MEMS-based digital isolators.
CHAPTER THREE

METHODOLOGY

3.0 Overview

A package power supply system can be divided into two parts based on the function such system carries on: to provide a high quality power supply to the device that mounted on the top of the package. The two parts are DC IR drop and high frequency power ground input impedance.

The programmable dc power supply is a triple-output precision DC power supply in a single-slot. The power supply has two isolated channels, one from 0 to +20 V and the other from 0 to -20 V, and a single non-isolated 0 to 6 V supply, all capable of sourcing up to 1 A per channel. The power supply has 16-bit resolution for programming the voltage set point and current limit and for using the voltage and current read back measurement functionality. The versatile supply rails and high accuracy make the power supply an excellent general-purpose, single-quadrant power supply for design validation and manufacturing test applications.

3.1 Power Supply with Precision Source Capability

The power supply has the ability to source both voltage and current from each of its three outputs. As a voltage source, it can be programmed in 120 μV steps on the +6 V channel and 400 μV steps on each of the 20 V channels. As a current source, it can be programmed in 20 μA steps on each channel in the 1 A current range. Additionally, you can set each of the 20 V channels to a 20 mA current range for 400 nA programming resolution. You can use this impressive level of current resolution in traditional power supply applications or in many applications that typically require a separate precision source measure unit.

3.2 Internal/External Supply Options

The power supply can be either internally from its backplane or externally through a front-panel-connected auxiliary DC supply. Using internal power reduces the number of connections required on the front panel but also limits the available output power because of per-slot PXI power restrictions. When internally powered, the non-isolated, 0 to 6 V channel can be operated at its full 1 A current range, but the isolated channels are limited to 100 mA. When externally
powered, all channels can be operated at full power of 1 A per channel for a total maximum output power of 46 W.

3.3 Linear Supply with Switching Pre-regulation

The programmable dc power supply uses a combination of switching and linear regulation to provide excellent output power and accuracy in its module. On each channel, input power is regulated to within a certain percentage of the desired output power. This pre-regulation stage is governed by an intelligent PID algorithm implemented on board the module, ensuring the amount of power passed to the second (linear) stage is at the most efficient level, given the desired output.

After additional filtering, you can use traditional linear regulation techniques and amplification to further regulate the signal and source the final voltage or current. Because the output is linearly regulated, it has very quick load response and high precision – even at levels as low as 0 V.

Also, because the linear regulation occurs on the pre-regulated signal, the power dissipation is relatively small and easily cooled in a power supply slot.

3.4 Extensive Protection Features

In addition to the standard voltage and current limiting functionality of the programmable power supply, several other features are included to protect the supply and the load. Each output is protected against a reverse-polarity voltage application as well as excessive voltages – up to 15 V above the maximum channel voltage. Output fuses provide additional protection to prevent catastrophic failure as a last line of defense.

The operating voltage range for the auxiliary power input is 11 to 15.5 V. If voltages outside these limits are detected, the module shuts down until an input voltage within range is applied. If an input in excess of 20 V is applied, the input crowbar protection turns on, protecting the input solid-state switching devices (and pre regulator power supply) from over-voltage damage.

The programmable power supply operates with only nominal temperature increases internally due to the intelligent PID control of the output devices. If an over-temperature condition occurs in its chassis due to fan failure or intake blockage, the output channels are shut down and a
warning is issued. This type of condition requires user software intervention to reset, thus preventing the module from damage at excessive temperatures.

### 3.5 Transformer design

Power supply transformers run at high frequency. Most of the cost savings (and space savings) in off-line power supplies come from the fact that a high frequency transformer is much smaller than the 50/60 Hz transformers formerly used.

There are several differences in the design of transformers for 50 Hz vs. 500 kHz. Firstly a low frequency transformer usually transfers energy through its core (soft iron), while the (usually ferrite) core of a high frequency transformer limits leakage. Since the waveforms in a power supply are generally high speed (PWM square waves), the wiring must be capable of supporting high harmonics of the base frequency due to the skin effect, which is a major source of power loss.

### 3.6 Power Factor

Simple off-line switched mode power supplies incorporate a simple full wave rectifier connected to a large energy storing capacitor. Such power supplies draw current from the AC line in short pulses when the mains instantaneous voltage exceeds the voltage across this capacitor. During the remaining portion of the AC cycle the capacitor provides energy to the power supply.

As a result, the input current of such basic switched mode power supplies has high harmonic content and relatively low power factor. This creates extra load on utility lines, increases heating of the utility transformers and standard AC electric motors, and may cause stability problems in some applications such as in emergency generator systems or aircraft generators. Harmonics can be removed through the use of filter banks but the filtering is expensive, and the power utility may require a business with a very low power factor to purchase and install the filtering onsite.

In 2001 the European Union put into effect the standard set limits on the harmonics of the AC input current up to the 40th harmonic for equipment above 75 W. The standard defines four classes of equipment depending on its type and current waveform. The most rigorous limits
(class D) are established for personal computers, computer monitors, and TV receivers. In order to comply with these requirements modern switched-mode power supplies normally include an additional power factor correction (PFC) stage.

Putting a current regulated boost chopper stage after the off-line rectifier (to charge the storage capacitor) can help correct the power factor, but increases the complexity (and cost).

With the shrinking available space and the high premium placed on performance in the modern automated test system, an innovative power supply design is required to keep pace. The triple-output, programmable DC power supply uses the best elements of both switching and linear power supply designs to offer a compact, high-resolution source that fits into a single-slot. When this product is used in combination with other world-class modular instruments available as modules, it further enhances the user's ability to develop flexible, efficient test systems to meet any challenge in any industry.
CHAPTER FOUR

DESIGN IMPLEMENTATION AND RESULTS

4.0 Introduction
Traditional power supply designs use analog ICs with fixed functionality to provide regulated power. The intelligent power supply integrates a microcontroller (MCU) or digital signal controller (DSC) for a fully programmable and flexible solution. Below are some examples of Intelligent Power Supply functions:

- Digital On/Off control for low standby power
- Power supply sequencing and hot-swap control
- Programmable soft-start profile
- Power supply history logging and fault management
- Output voltage margining
- Current fold back control
- Load sharing and balancing
- Regulation reference adjustment
- Compensation network control and adjustment
- Full digital control of power control loop
- Communications
- AC RMS voltage measurement
- Power factor correction

Example Intelligent Power Supply applications include the following:

- AC-to-DC Converters
- DC-to-DC Converters
- Uninterruptible Power Supply (UPS)
- Renewable Power/Pure Sine Wave Inverters
- Battery Chargers
- Digital Lighting
4.1 The 8051 Instruction Set

The microchip used in implementing this project was the 80C51 microcontroller. The 80C51 instruction set is optimized for 8-bit control applications. It provides a variety of fast addressing modes for accessing the internal RAM to facilitate byte operations on small data structures. The instruction set provides extensive support for one-bit variables as a separate data type, allowing direct bit manipulation in control and logic systems that require Boolean processing.

4.1.1 Program Status Word

The Program Status Word (PSW) contains several status bits that reflect the current state of the CPU. The PSW, shown in Figure 10, resides in the SFR space. It contains the Carry bit, the Auxiliary Carry (for BCD operations), the two register bank select bits, the Overflow flag, a Parity bit, and two user-definable status flags. The Carry bit, other than serving the function of a Carry bit in arithmetic operations, also serves as the “Accumulator” for a number of Boolean operations.

The bits RS0 and RS1 are used to select one of the four register banks shown in Figure 7. A number of instructions refer to these RAM locations as R0 through R7. The selection of which of the four is being referred to is made on the basis of the RS0 and RS1 at execution time.

The Parity bit reflects the number of 1s in the Accumulator: \( P = 1 \) if the Accumulator contains an odd number of 1s, and \( P = 0 \) if the Accumulator contains an even number of 1s. Thus the number of 1s in the Accumulator plus \( P \) is always even. Two bits in the PSW are uncommitted and may be used as general purpose status flags.

4.1.2 Addressing Modes

The addressing modes in the 80C51 instruction set are as follows:

a) Direct Addressing

In direct addressing the operand is specified by an 8-bit address field in the instruction. Only internal Data RAM and SFRs can be directly addressed.

b) Indirect Addressing

In indirect addressing the instruction specifies a register which contains the address of the operand. Both internal and external RAM can be indirectly addressed. The address register
for 8-bit addresses can be R0 or R1 of the selected bank, or the Stack Pointer. The address register for 16-bit addresses can only be the 16-bit “data pointer” register, DPTR.

c) Register Instructions

The register banks, containing registers R0 through R7, can be accessed by certain instructions which carry a 3-bit register specification within the opcode of the instruction. Instructions that access the registers this way are code efficient, since this mode eliminates an address byte. When the instruction is executed, one of the eight registers in the selected bank is accessed. One of four banks is selected at execution time by the two bank select bits in the PSW.

d) Register-Specific Instructions

Some instructions are specific to a certain register. For example, some instructions always operate on the Accumulator, or Data Pointer, etc., so no address byte is needed to point to it. The opcode itself does that. Instructions that refer to the Accumulator as A assemble as accumulator specific opcodes.

e) Immediate Constants

The value of a constant can follow the opcode in Program Memory. For example, MOV A, #100 loads the Accumulator with the decimal number 100. The same number could be specified in hex digits as 64H.

f) Indexed Addressing

Only program Memory can be accessed with indexed addressing, and it can only be read. This addressing mode is intended for reading look-up tables in Program Memory A 16-bit base register (either DPTR or the Program Counter) points to the base of the table, and the Accumulator is set up with the table entry number. The address of the table entry in Program Memory is formed by adding the Accumulator data to the base pointer. Another type of indexed addressing is used in the “case jump” instruction. In this case the destination address of a jump instruction is computed as the sum of the base pointer and the Accumulator data.
In the 8051 there are a total of four ports for I/O operations. Examining figure 4.1, note that of the 40 pins, a total of 32 pins are set aside for the four ports P0, P1, P2 and P3, where each port takes 8 pins.
4.1.3 Arithmetic Instructions

All of the arithmetic instructions execute in 1ms except the INC DPTR instruction, which takes 2ms, and the multiply and divide instructions, which take 4ms.

Note that any byte in the internal Data Memory space can be incremented without going through the Accumulator. One of the INC instructions operates on the 16-bit Data Pointer. The Data Pointer is used to generate 16-bit addresses for external memory, so being able to increment it in one 16-bit operation is a useful feature.

The MUL AB instruction multiplies the Accumulator by the data in the B register and puts the 16-bit product into the concatenated B and Accumulator registers. The DIV AB instruction divides the Accumulator by the data in the B register and leaves the 8-bit quotient in the Accumulator, and the 8-bit remainder in the B register. Oddly enough, DIV AB finds less use in arithmetic “divide” routines than in radix conversions and programmable shift operations. An example of the use of DIV AB in a radix conversion will be given later. In shift operations, dividing a number by \(2^n\) shifts its \(n\) bits to the right. Using DIV AB to perform the division completes the shift in 4ms and leaves the B register holding the bits that were shifted out. The DA A instruction is for BCD arithmetic operations. In BCD arithmetic, ADD and ADDC instructions should always be followed by a DA A operation, to ensure that the result is also in BCD. Note that DA A will not convert a binary number to BCD. The DA A operation produces a meaningful result only as the second step in the addition of two BCD bytes.

4.2 Power supply specifications

The power supply provides low regulated, variable DC output at 40 watts of output power. The output voltage for this case is a staircase waveform with a maximum current of 1ampere.

The relation in equation (i) was used to design and realize the circuit.

\[
V_o = V_{dc} \times D \quad \text{(i)}
\]
\[
D = T_{on}/T \quad \text{(ii)}
\]
\[
D_i = (V_{dc} - V_o)T_{on}/L \quad \text{(iii)}
\]
Where:
Vo-is the output voltage
Vdc-is the input dc voltage after rectification
T-is the period of the generated pulse.
Ton-is the duration during which the pulse is on.
L-is the inductance of the inductor in the circuit.

The 8051 microcontroller was programmed to switch the transistors in cascade on and off at varying duty cycles and thereby realise different output voltages with the same input voltage.
The circuit diagram used to achieve the results is shown in figure 4.2.

Figure 4.2 Circuit diagram

The pulse generator was used in place of the 8051 in the MULTISIM simulation that gave the given results.
4.3 RESULTS

The following results were obtained with simulation MULTISIM electronic software. The waveforms obtained were as follows. The period was 1ms and with alternations we got the following.

Figure 4.3 Display 20% duty cycle.
Figure 4.4 Display for 80% duty cycle
Figure 4.5 Display for 40% duty cycle
Figure 4.6 laboratory results displayed on the oscilloscope.
CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

A methodology for modeling, analysis, and design package for a power delivery system has been demonstrated. Furthering of this work can be done starting from the results obtained here and employing more research.

A fully programmable power supply would include the generation of different waveforms from the same device. This however requires time and dedication.

5.2 RECOMMENDATIONS

Due to time and lack of resources the results were not fully obtained and hence with availability of resources and enough time the following can be achieved.

- A state-of-the-art programmable dc power supply
- A power delivery modeling and design methodology for package power supply system design can be introduced.
- Improvement of the power supply performance of the package can be realized.
- Careful design of the power supply system inside a package and optimization of the ratio of I/O pins to power ground pins can be achieved for both DC and high frequency band so that the simultaneous switching noise can be minimized.
REFERENCES


