

SOFTWARE DEVELOPMENT MODULE FOR SWITCHED MODE POWER SUPPLY (SMPS) USING A HIGH-SPEED PWM MICROCONTROLLER (dsPIC33FJ256GP710A)

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ABSTRACT

Most of the products and systems in use today have employed the switched mode power supply technology, therefore the need for power supply designers to produce switched mode power supply with integrated Microcontroller or Digital Signal Controller that have on-chip peripherals designed explicitly for power conversion is paramount. Introduction to the different types of power supply technologies employed and the relevance of a digital signal controller with an efficient software algorithm. The reviews on plasma, switched mode power supply technology, pulse width modulation, voltage regulation, microcontrollers, and analog to digital Converter, finally a comprehensive set of detailed design and implementation software development module using a dsPIC33FJ256GP710A microcontroller from Microchip Technology, MPLAB XIDE and MPLAB XC 16, a Microchip Explorer 16 Development Board and a MPLAB ICD3 debugger to produce Pulse Width Modulation signals suitable for driving a Switched Mode Power Supply. The dsPIC33FJ256GP710A microcontroller is programmed to generate interactive algorithm to control the pulse width modulation signals by user input parameters (Duty-Cycle and Frequency) and an interactive voltage feedback control loop in response to power input change or load change operations The system can be expanded by building the printed circuit board of the switched mode power supply and improve the user interface to enhance the system intelligence level.

Keywords: Power Supply, Switched Mode Power supply, Low Temperature Plasma, Software Development Module, Pulse Width Modulation, Analog to digital Converter and Digital Signal Controller

1 INTRODUCTION

Technology for power supply unit of modern innovations in industries, health sectors, research institutes and ongoing space exploration require more flexible control features and significant improvement to meet the increasing power density demand and efficiency requirement [1, 2]. Previous technologies used the linear power supply and it encountered numerous challenges such as high radiation of much heat which resulted in power loss, poor regulation technique at the instance of load change events and thereafter voltage/current instability, the occurrence of transient response from circuit conditions and waveform distortion due to harmonics [1, 2]. Today, the switched mode power supply (SMPS) is the most employed technique in power supply designs, comprises of few active components to make the system smaller, light weight and removes the presence of heavy-line transformers or any similar heat generation device [2]. The SMPS technique employs the pulse width modulations (PWM) generated by some ICs for switching the power transistors, the metallic oxide-semiconductor field-effect-transistors (MOSFETs) to efficiently convert electrical power required to drive the loads [1]. Progress work has been done on various switched mode power supply (SMPS)

design to produce the waveform signals to drive loads and incorporate a feedback loop for monitoring the operations. The power supply usually experiences under/over voltages at any instance to load change events, phase fault events and start-up of a large load. Likewise, circuit conditions like internal short-circuit, rise in temperature from the system components causes sudden spikes, voltage oscillation called transient and pulse width modulation (PWM)/waveform distortion because of DC offset, noise, and harmonics. The reason for such functional anomalies in the previous SMPS design is the absence of duty cycle adjustment to suit the desired output voltage and a user interface to monitor and control the feedback voltage for stable operation in order to maximizing system performance [2]. In this project, dsPIC33FJ256GP710A 16-bit microcontroller (100-pin device) from Microchip Technology with the explorer 16 development board is employed for the PWM generation using C-language [3]. The microcontroller has output compare modes configuration for high-speed PWM, high-speed ADC conversions, fast clock conversion, timer control registers, interrupt service routine (ISR), an onboard analog potentiometer and debugger development support; which are all required to achieve the duty cycle adjustment for successfully PWM waveforms needed to drive the SMPS and an interactive voltage feedback control loop [3, 4]. The task is expected to use the microcontroller to generate a PWM waveforms of frequencies of 1-20kHz and capable of controlling the duty cycle of the PWM to drive the switching devices metallic oxide semiconductor field effect transistors (MOSFETs) and produce a high voltage power supply (up to 10KV) capable of generating low temperature plasma (LTP). The switched mode power supply (SMPS) should be able to operate in a continuous mode as well as in modulated mode with adjustable duty cycle (10 to 90%) [5] as described in Figure 1.

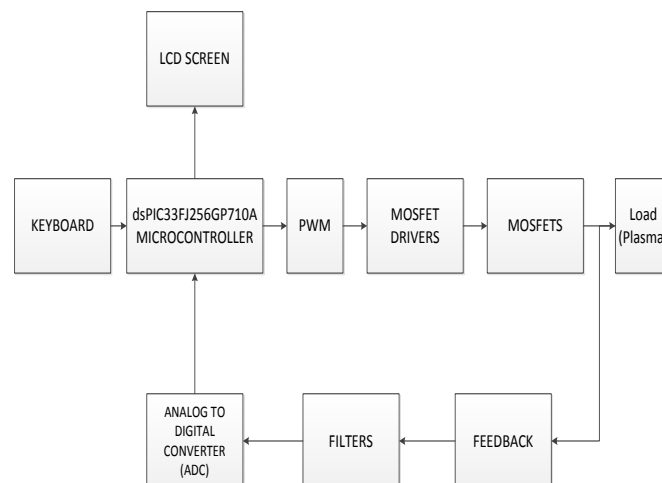


Figure 1. System Block Diagram (Hardware and software development)

The microcontroller is then used to control the duty cycle of the PWM for the switching of the MOSFETs and a discerning user interface, enabling the user to adjust the operating frequency and the duty cycle. The user interface will display the voltage applied to the load and prompt some operating and safety information.

2 LITERATURE REVIEW

2.1 Low temperature Plasma

A low temperature plasma, non-thermal plasma, cold plasma or non-equilibrium plasma has electron temperature much hotter than the temperature of heavy species (ions and neutrals). A common type of LTP is the mercury-vapor gas within a fluorescent lamp, where the “electron gas” reaches a temperature of 20,000K while the rest of the gas, ions and neutral atoms, stays barely above room temperature, so the bulb can even be touched with hands while operating [6]. Most recently, LTP is making remarkable contributions in emission of lights, food industry (food processing), dentistry and medicine, magneto hydrodynamic power generation and in aircraft (Plasma Propulsion Engine). The space research and security have been globally applauded. The Leading Edge Asynchronous Propeller Technology (LEAPTech) project will demonstrate distributed electric

propulsion for future aircraft. Replacing fossil-fuel and enables SPACE Aircraft to travel a large distance [7, 8]. Plasma conducts electricity because of the free positive and negative ions and there are three ways to form plasma: electric fields, thermal heating, and high energy radiation. We use electric fields as this method because it preferentially heats the electrons and results in the generation of non-thermal plasma (cold plasma or low-temperature plasma LTP) [8, 9, 10]. By means of a high voltage supply (10KV, 20KHz) suitable to generate the low temperature plasma (LTP).

2.2 Switch Mode Power Supply

A power supply is a built-in device comprises of electronic device that supplies electric energy to an electrical load [11]. These power supplies mostly function as electric power converters. Over the years, manufacturers have successfully built power supplies in discrete forms, stand-alone devices and mostly built into complete system devices to power connected loads such as initiated in personal computers and electronics devices [12, 13]. One of the general classifications of the power supply is the power conversion and is achieved by two methods. The Linear mode power supply and the switching/switched mode power supply (SMPS). The SMPS has small size and weight, cheap cost of building, high efficiency negligible power loss, good active power factor and stable output voltage despite load variation [12, 13].

2.3 Pulse Width Modulation

Machines such as sewing machine motor involve the partial or adjustable power to function. Previously, rheostat was used in controlling power as applied to the sewing machine. The use of foot pedal to control the machine was technically implemented by use of a rheostat coupled in series with the motor to regulate the amount of current flowing through the motor[14]. In the early 1960s, the emergence of pulse width modulation (PWM) technique was first implemented in the Sinclair X10 (a 10 W audio amplifier kit), applicable in variable-speed motors, constant-speed motors, a bank of variable power resistors or rotating converters. This modulation technique has been used to translate information, used for charging the battery and for maximum power point tracking in photovoltaic. PWM main application is in the control of power supplied to electrical drives and devices [15].

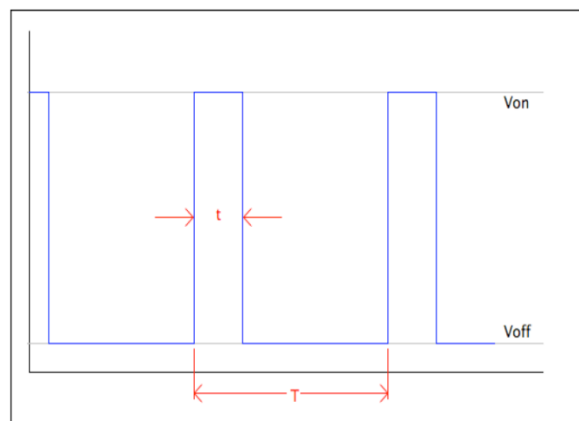


Figure 2. Pulse Width Modulation (PWM) parameters [15]

Pulse width modulation (PWM) is a simple technique that uses a rectangular digital waveform to regulate an analog variable. In power supply design, the procedure of controlling a measured quantity of power delivered to a load by simply switching ON and OFF a digital signal is known as Pulse Width Modulation (PWM). From the Figure 2, the parameters of PWM are discussed below for further references [15, 16].

$$F = \frac{1}{T} \text{ (Hertz, Hz)} \quad (1)$$

Where T: is the time duration of one PWM cycle, SI unit, second (sec), F: is the repetition frequency of the PWM output signal (Hz).

$$DC = \frac{t}{T} \times 100\% \quad (2)$$

Where DC: the duty cycle indicates when a system is active. The duty cycle can be expressed as a percentage, t: the pulse active time. The time duration when one PWM cycle is ON.

2.4 Voltage Regulation

Over time, a wide range of load conditions at the output of a power supply, sudden change of input voltage and rise in temperature of the circuit components in the internal system will cause the system efficiency and performance to reduce and may eventually fail. Regulating the line (input voltage) and load (output voltage), signal waveforms is paramount for high system efficiency. A system with the ability to deliver near constant voltage over a wide range of load conditions is described as voltage regulation. In SMPS, a sample DC output voltage is normally fed back to the control circuitry and compared with a stable reference voltage; the error produced is used to control the output voltage. Voltage regulation is achieved by adjusting the duty-cycle of the PWM before applying it to the switches [17].

2.5 Microcontrollers/digital signal controllers

A digital signal controller (DSC) is a hybrid of microcontrollers and digital signal processors (DSPs). A Digital Signal Controller (DSC) is a single-chip, embedded controller that seamlessly integrates the control attributes of a Microcontroller (MCU) with the computation and throughput capabilities of a Digital Signal Processor (DSP) in a single core. Microchip's dsPIC/DSC offers everything you would expect from a powerful 16-bit MCU: fast, sophisticated and flexible interrupt handling; a wide array of digital and analog peripheral functions; power management; flexible clocking options; power-on-reset; brown-out protection; watchdog timer; code security; full-speed real-time emulation; and full-speed in-circuit debug solutions [18]. By expertise to add DSP capability to a high-performance 16-bit MCU, Microchip's dsPIC30F and dsPIC33F families of DSCs achieve the best of both worlds and mark the beginning of a new era in embedded control [18]. In terms of integration and performance to achieve real-time control, outstanding reliability, robustness and reduced system cost, dsPIC33F is the most preferred over PIC10/12/16 8-bit MCU, PIC18 High-End 8-bit MCU, PIC24F 16-bit MCU, PIC24H 16-bit MCU. dsPIC33FJ256GP710A offers a broad selection of embedded control solutions for high-speed PWM, timers/output compare/input capture, advanced ADC modules, power conversion and monitoring, sensor control, powerful tool and libraries to ease the software development module (such as MPLAB Integrate Development Environment, MPLAB In-Circuit Debugger/Development Programme) for this particular project [18, 19].

2.6 Analog to Digital converter

The ability of a system to convert a sound picked up by a microphone, light entering a digital camera, voltage/current values detected with a probe to a digital storage oscilloscope/meter and research scientific instruments, into a digital signals/values is called Analog to Digital Conversion[20]. An Analog to Digital Converter (ADC) is a module or an electronic integrated circuit that converts the continuous form of analog signals to discrete digital numbers/signals. In practice, analog signals are always measurable quantities while the digital signals have a zero state (0) and one state (1) [21]. Signals transmitted in digital forms tend to have less noise interference and high speed. Microcontroller (MCU) or Digital Signal Controller (DSC) have on-chip ADC peripherals designed for digitizing analog signals received from the real world and fast acquisition feedback signals in power supply applications[16]. The Analog to digital conversion process involves two major steps as describes below:

- a) **Sampling and Holding:** This process samples from a continuous signal and holds the value at a steady level for some period to eliminate variations in input signals and increases the accuracy of the conversion process. The minimum sampling rate should be two times the maximum data frequency of the input signal [20].
- b) **Quantizing and Encoding:** The conversion process automatically monitors the sampled values from the analog signal in continuous time to the digital signal in discrete time and adjust for any

variations from the analog signals. The smallest change in the analog signals in continuous time that results to change in the digital signal in the discrete time interval is called resolution [20].

$$\Delta V = \frac{V_r}{2^N} \quad (3)$$

Where ΔV : resolutions, V_r : reference voltage (volts), 2^N : no of states, N : no of bits in digital output.

Quantizing: It is the process in which the reference signal voltage is subdivided into several discrete smaller values and then the input signal voltage is matched with the correct value. Real world systems are nonlinear systems. During quantization in ADC, the error is introduced by noise and it is signal-dependent. These errors are measured in a unit identified as the least significant bit (LSB). Therefore, the quantization error is evenly distributed between least significant bit (LSB), and the signal is uniformly distributed over all the quantization levels [20].

3 EXPERIMENTAL DEVICES AND REQUIREMENT SPECIFICATIONS

3.1 *dsPIC33FJ256GP710A Microcontroller*

Digital Signal Processing (DSP) microcontroller chip dsPIC33FJ256GP710A from microchip technology (plug in module, PIM) was employed for the power supply PWM generation, high-speed A/D Converter and the user interface modes [3]. During the system operation, the processor intervention was minimal on the PWM output waveforms and during the ADC operations thereby minimize control overhead.

3.2 *Explorer 16 development board*

Microchip Explorer 16 development board kit with low-cost and modular development system for Microchip's 16-bits microcontroller family was employed in this project [22]. The Explorer 16 development board was powered up at the 9 to 15VDC plug-in point from the 240V mains power supply. The Explorer 16 board permitted 3V to 3.3V controllers to interface with 5V peripheral devices. The eight (8) red LEDs (D2 to D9) were configured for system functional indicators, the five (5) push buttons switches (S1, S3, S4, S5 and S6) were configured for read input switches (user define), alphanumeric LCD display with two lines of 16 characters (16x2) for display of results and adjustable potentiometer from VDD to GND also configured for analog input and adjusting the duty cycle. The board was connected via Standard 6-wire In-Circuit Debugger (ICD) connector to the MPLAB ICD 3.

3.3 *System program debugging*

MPLAB ICD3 (In-circuit Debugger) interfaced with the Explorer 16 development board was employed in this project for full emulation and debugging operations [22, 23]. With the high-speed debugger flash DSC and MSU, the MPLAB ICD3 was connected via standard 6-wire In-circuit Debugger which allowed the software component to run and it was tested first at the source-level debugging (detecting errors from the written code) then tested at single-stepping (detecting errors as the program run step-by-step) to detect any faulty code and correct the codes in its compatible integrated development environment installed on a computer system. The Explorer 16 development board hardware and software component were interconnected together to achieve system reliability.

3.4 *System Integrated Development Environment*

MPLAB X IDE (Integrated Development Environment v3.65) software program patent by microchip technology designed based on the open source NetBeans IDE from Oracle was employed in this project basically for its compatibility [23]. First the MPLAB X IDE was downloaded from the official microchip website then installed on a windows operating system and it does not occupy much space in the hard disk of the system. The WinUSB device drivers for hardware tools were all installed from the system device manager to facilitate communication with development boards and ease graphic user interface (GUI) environment operation on screen; it allowed multiple language tool selection, multiple debug session and good systematic integrated project manager format. Doubled click on the MPLAB X IDE icon to lunch the program then created a new project.

3.5 System Compiler

MPLAB XC16 v1.31 compiler was employed in this project to achieve compatible machine language applicable to computer's processor for execution [24]. First the software program was written in C-language, the compiler converts it to machine language and created a file called the source statement. The source code was used to examine variables in system frequencies and voltages, floating points, simulators, configuration bits for interrupt-controllers, timers and counters, ADC input channels for feedback voltage and output/input compare modules to generate the PWMs.

3.6 Oscilloscope and Computer System

Tektronix DPO414B 1GHz, 5GS/s and Windows Operating System (OS), 8GB RAM, USB were properly coupled and powered up then used two probes to view the PWM signals, frequency and duty-cycle. The requirement specifications outlined to achieve the technical functions towards the realization of this work are shown in table 1 with their respective experimental devices. The PWM generation, fast operating speed of the system, high analog to digital converter for system feedback and precise interrupt service routine for monitoring and sequencing of system operations were all configured using the dsPIC33FJ256GP710A microcontroller. The LEDs indicators were used as user defined (keyboards) for input of command and the LCD for display of results (output data) on the explorer 16 development board. The explorer 16 development board further enabled the adjustment of duty cycle and potentiometer for analog input.

Table 1: Requirement Specifications

S/N	Technical Functions	Requirement Specifications	Experimental Devices
1.	High oscillator output and operating speed of the device.	Fast RC internal oscillator is 7.37MHz. Programmable PLL for higher device speed. Independent Watchdog Timer (WDT). Fast wake-up and start-up of the device.	dsPIC33FJ256GP710A Microcontroller
2.	Program Memory, Data memory	256Kbyte FLASH and 30Kbyte RAM. 8-DMA	dsPIC33FJ256GP710A Microcontroller
3.	Generate PWM for half bridge and full bridge DC-AC topology	Output/input compare modules, 16/32-bit timers and counters	dsPIC33FJ256GP710A Microcontroller
4.	High-A/D Converter for feedback voltage	2 ADC modules, 32 ADC input channels, 10-bit, 4-sample/hold 1.1Msps conversion speed. ADC interrupts priority.	dsPIC33FJ256GP710A Microcontroller
5.	Interrupt Service Routine Interrupt flag, interrupt enable, and interrupt priority setting for monitoring and sequencing of system operations.	Interrupt-controllers: INTCON1, INTCON2, IFS0-IFS4, IEC0-IEC4, IPC0-IPC17	dsPIC33FJ256GP710A Microcontroller
6.	LEDs for functional indicators, read input switches for user interface and LCD for display of results.	Eight red LEDs (D2-D9). Five push button switches: S1 for MCLR and S3, S4, S5 and S6 user define. Alphanumeric LCD display with two lines of 16 characters (16x2).	Explorer 16 development board
7.	Potentiometer for analog input and adjusting the duty cycle.	Adjustable potentiometer adjusted from VDD to GND to provide an analog input to one of the controller's A/D channels.	Explorer 16 development board

8.	Full emulation and debugging functions.	High-speed debugger for flash DSC and MSU devices	MPLAB ICD3 Debugger
9.	Develop applications for microchip MCU & DSC.	The latest version MPLAB X IDE v3.65. Easy user interface	MPLAB X IDE
10.	Compile the source code C-language used.	The latest version XC 16 v1.31	MPLAB XC16
11.	View the PWM signals Frequency & duty-cycle.	Digital Phosphor Oscilloscope and two probes	Tektronix DPO4104B 1GHz, 5GS/s

Plate 1 and plate 2 below, shows the complete setup of the experimental devices and the main explorer 16 development board used to achieve the software development module for the Switched Mode Power Supply (SMPS). The setup has a computer system, the oscilloscope with probes to view the High-Speed PWM from the explorer 16 development board and the Microcontroller (dsPIC33FJ256GP710A) to drive the Switch Mode Power Supply.

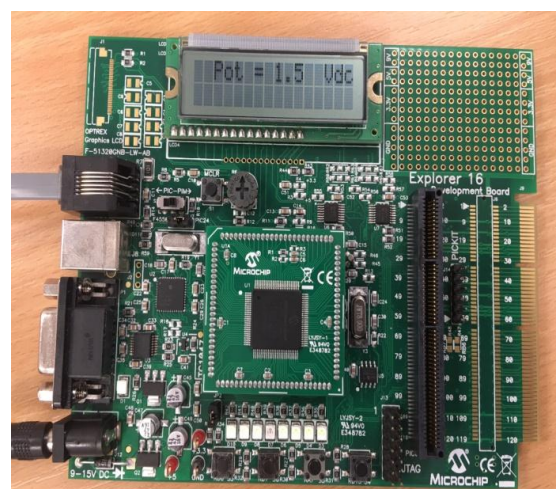
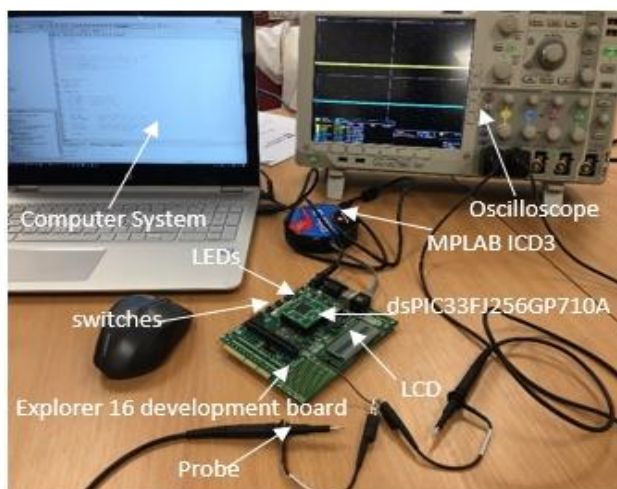


Plate 1. The Set-up of the experimental devices used Plate 2. Explorer 16 development board

4 SYSTEM DESIGN, IMPLEMENTATION AND TESTING OF THE SYSTEM

4.1 Design of the overall system

The overall system designed for this work was to program the microcontroller dsPIC33FJ256GP710A to generate the PWM signals of frequency 20KHz that enhance switching of the MOSFETs required to drive the switched mode power supply of 10KV output, with a user interactive feedback control loop using the onboard analog potentiometer and microcontroller A/D Converter peripheral to adjust the duty cycle in response to power input change or load change events. The following were the set-up of the experimental devices and the required implementation/task deployed to achieve the objectives of this work:

1. The dsPIC33FJ256GP710A microcontroller was properly placed on the explorer 16 development board and the ICD3 debugger was connected to the development board via USB.
2. The MPLAB X IDE and the MPLAB XC 16 compiler are both downloaded freely from the microchip official website and installed properly on the system PC.
3. The board was powered up by direct 9VDC power input that provides regulated +3.3V and +5V to the entire board. The MPLAB ICD3 was connected to the board through the standard 6-wire in-circuit debugger connector and connected through a USB to the PC.
4. A high-level designed (software codes) using C language was developed/written, which the MPLAB XC 16 compiler directly translate into machine for the microcontroller to function and enabled to control the required peripherals (input/output ports, output compare for the PWMs,

timers, interrupts and A/D Converter), user interface (LCD display, switches, LEDs and the onboard analog potentiometer) and pins control of the microcontroller.

5. The codes written were built and tested successfully to eliminate errors also viewed values of variables at various points in the program.
6. The microcontroller dsPIC33FJ256GP710A was then programmed.
7. The results/output displayed on the LCD and the PWM waveforms on the oscilloscope were measured and verified. The analog potentiometer as the interactive voltage feedback control loop (A/D Converter) was also used to adjust the duty cycle in response to power input change or load change events.

4.2 Design of a two PWM waveform with 20 KHz frequency and 25% duty cycle

For a half bridge DC to AC power conversion methodology, two PWM waveforms/signals are required. The two pulse width modulation (PWM) waveform with 20 KHz frequency and 25% duty cycle was designed to control an amount of power delivered to a load by switching ON and OFF a digital signal. The main settings in the output-compare mode configuration:

- i. The bits for PWM mode on OC2CON and OC3CON were selected and timer bit was set at TON.
- ii. The PWM periods were calculated and the values placed in the period registers PR1, PR2 and PR3.
- iii. The TON value was calculated and the result placed in the OC2RS or OC3RS output compares register.

4.3 Design of a dead time delay for the PWM signals

The dead time delay was created to prevent the short circuit of the power supply in PWM inverters or converters. Dead time delay ensured no two PWMs is ON at the same time, for compatible switching of the MOSFETs for system efficiency. Producing two wave signals for 50 μ s (20 KHz) using the PWM of dsPIC33FJ256GP710A (FOSC = 7.37MHz) as follows:

- i. The Fast Pulse Width Modulation Mode was set Using TMR2 and TMR3 (16bits = 65536) to avoid short circuit in the operation of the system.
- ii. The input Capture Register (ICR2/ICR3) was generated and the Period Register (PR2/PR3) was obtained from equation (7) also by setting prescaler (1:1).
- iii. The Output Capture Register (OC2RS, OC3RS) was generated using TMR2/TMR3.
- iv. The DEAD-TIME delay (T_D) was calculated using TMR1.
- v. Lastly the Output Mode (Non-Inverted) bit was set.
- vi. The 10-bit 4-sample/hold ADC module was configured and the onboard analog potentiometer was set as a user interactive feedback control loop to adjust the duty cycle.
- vii. The voltage feedback for 10KV output voltage was set at 1.6V from the 0V to +3.2V onboard supplied voltage at the analog potentiometer.
- viii. The user set up mode and the onboard switches and LCD were configured to enable/disable PWM button.

4.4 Program the dsPIC33FJ2566GP710A for user-system interface

- i. The LEDs control lines (D2 through D9) were connected to PORT A0-A7 of the plug-in module socket.
- ii. The required input/output pins were changed from analog to digital by configuring AD1PCFGL.
- iii. The LEDs were set ON/OFF by configuring TRISA.
- iv. The PORTA pins were set high to light the LEDs.

- v. The switches control lines were connected to (S3 – D6, S4 – D13, S5 – A7 and S6 – D7).
- vi. The switches were pulled high (+3.3V) when idle, therefore a debounce technique was initiated using delay function in the code.
- vii. The onboard alphanumeric LCD display was driven by three control lines linked together (RD4, RD5, and RD15) and eight data lines (RE7: RE0).
- viii. AD1CON2bits.VCFG was configured for voltage reference source to match expected range on analog inputs.
- ix. AD1CON3bits.ADCS was configured for analog conversion clock to match desired data rate MCU clock.
- x. AD1CON1bits.AD12B, AD1CON2bits.CHPS and AD1PCFGLbits.PCFG5 were set to 10-bit operation.
- xi. AD1CON1bits.SSRC and AD1CON1bits.SAMC were set to sample/conversion sequence (Sample Time).
- xii. AD1CON1bits.ASAM was set for conversion status (Sampling begins after next conversion).
- xiii. AD1CON1bits.FORM was set for how conversion results should be presented in the buffer (Only integer values).
- xiv. The TON bit was set to 1 or 0 in T1CON registers then the timer prescaler ratio set as TCKPS<1:0>
- xv. The timer period value was loaded into the period registers: PR1, PR2 and PR3.
- xvi. The interrupt was set to enable priority bit when required: T1IE, T2IE and T3IE.

4.5 Design of the Set-up and System flow chart

In the set-up mode as described in Figure 3, the user can set the desired switching frequency (1KHz to 40KHz) and set the duty cycle (1% to 49%) using the onboard switches and the LCD display to view the input duty cycle and frequency.

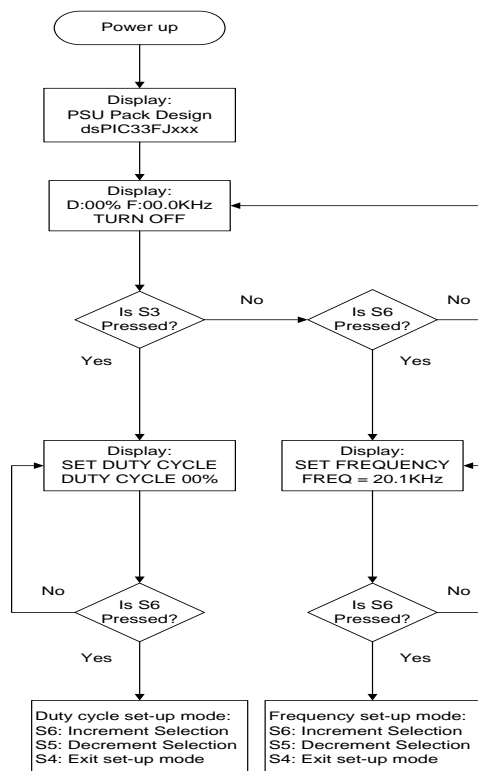


Figure 3. Set-up mode flow chart

The system function flowchart as described in figure 4, the user enable the PWM signals by using the switch (S5), immediately the A/D converter is initialized to give a feedback on the output voltage. The user can control the applied voltage to the load by adjusting the duty cycle. All these results are displayed on the onboard LCD.

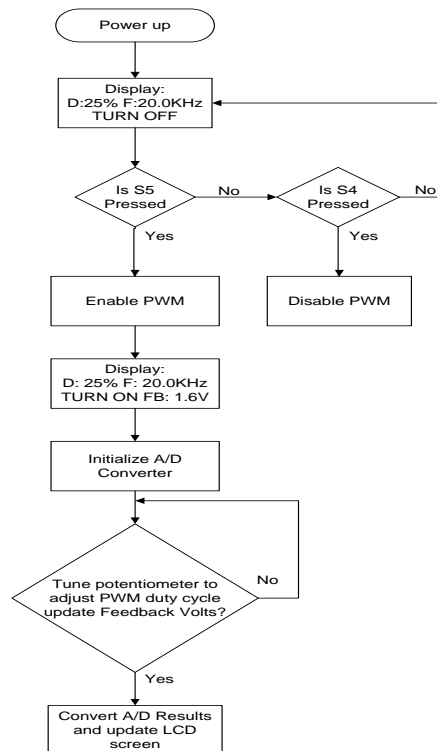


Figure 4. System function flow chart

4.6 Implementation and testing of the Software Development

The program was implemented and tested using the MPLAB X IDE v3.40 as shown in plate 3 and the MPLAB XC 16 compiler (C-code) for the PWM waveform as shown in plate 4. The MPLAB ICD3 is connected to the explorer 16 development board through the standard 6-wire in-circuit debugger connector and connected through a USB to the computer system. The software codes using C language which the MPLAB XC 16 compiler directly translate into machine for the microcontroller to function and enable to control the required peripherals for generating the required PWM and user interface (LCD display, switches, LEDs and the onboard analog potentiometer) and pins control of the microcontroller.

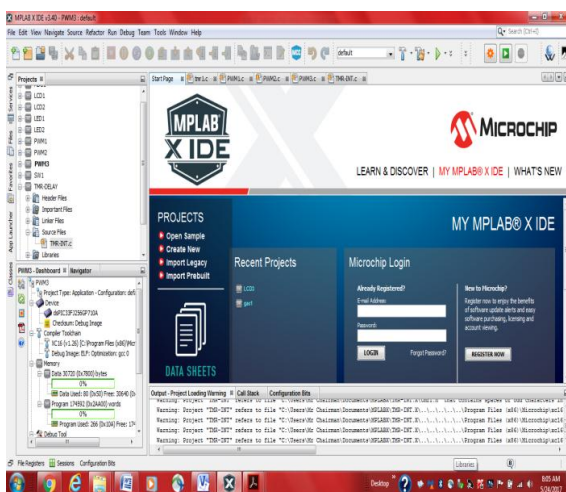


Plate 3. MPLAB X IDE v3.40 start-up window

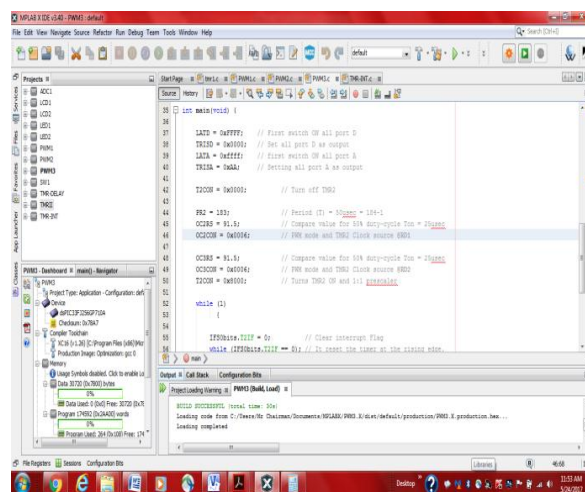


Plate 4. MPLAB X IDE v3.40 C-code for the PWM

The results/output is displayed on the LCD and the PWM waveforms on the oscilloscope, also the analog potentiometer as the interactive voltage feedback control loop (A/D Converter) to adjust the duty cycle seen in plates 5 and 6.

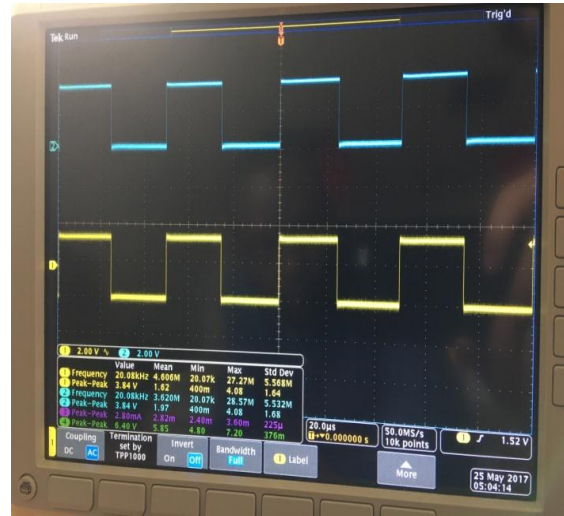
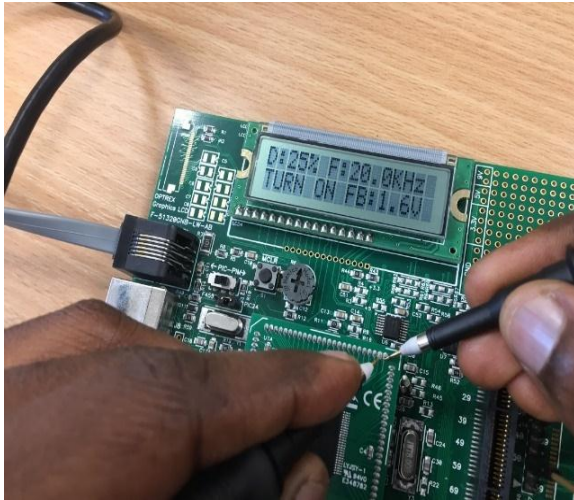


Plate 5. System implementation and testing with dead time delay Plate 6. Oscilloscope display of the two PWM waveforms

5 RESULTS AND DISCUSSION

Table 2 shows the test results for the pulse width modulation (PWM) waveform parameters with the repetition frequency of the PWM output signal of 20 KHz to obtain the period of the PWM cycle and to evaluate the various duty cycles in percentage equivalent to the time the signal is ON to drive the load and also to ascertain best operational status. The values of the pulse width modulation (PWM) period at ON signal are placed in the period registers (PRx). The 25% of the period register (PR) configured in the software module of this project work essentially generated a high voltage power supply capable of generating efficient low temperature plasma (LTP).

Table 2. Test results for the PWM waveform parameters with 20 KHz Frequency

Duty Cycle (%)	T_{period} (μsec)	T_{ON} (μsec)	T_{OFF} (μsec)	Period Register (PR)
25	50	12.5	37.5	45
50	50	25	25	92
75	50	37.5	12.5	138

$$T_{period} = \frac{1}{F_{pwm}} \quad (4)$$

$$DutyCycle = \frac{T_{ON}}{T_{period}} \times 100 \quad (5)$$

$$T_{OFF} = T_{period} - T_{ON} \quad (6)$$

Where FOOSC: Output of the oscillator used. Prescaler of 1.

$$Period\ Register\ [PR] = \frac{FOOSC \times T_{period}}{2^{\frac{cycles}{inst}} \times prescaler} \quad (7)$$

Using the output compare modes configuration and timer configuration. Table 3 shows the results of the corresponding duty cycle, frequency and the voltage values for the PWM waveforms. The 25% duty cycle produced the best operational status with precise operating frequency of 20 KHz and the +1.60V equivalent feedback voltage presumed equivalent of the real system voltage of 10KV. A confirmation of measured values obtained from the displayed on the LCD development board and the oscilloscope.

Table 3. Test results of Duty Cycle, Frequency and Voltage for the PWM waveforms from the oscilloscope

Duty Cycle (%)	Frequency (KHz)	Voltage (V)
25	20.00	1.60
50	20.07	3.10
75	20.09	3.20

6 CONCLUSIONS

This report has detailed the design and implementation of a software module for switched mode power supply using the dsPIC33FJ256GP710A necessary for the formation of low temperature plasma (LTP). The software module developed has successfully achieved the objectives:

- i. Successfully created a user interface (onboard switches, LEDs, LCD display and the analog potentiometer) to set the required switching frequency of the PWM signals and the duty cycle for the desired voltage output.
- ii. Successfully generated two PWM waveforms both at a frequency of 20 KHz, with 25µsec dead time-delay to ensure the MOSFETs are switch ON/OFF separately.
- iii. Successfully used the fast A/D Converter and an onboard analog potentiometer to form a feedback closed loop, where the output voltage is closely monitored and controlled by adjusting the PWM duty cycle.
- iv. The oscilloscope displayed the PWM waveforms and the exact results as displayed on the LCD screen of the development board to verify the exact frequency 20KHz, the duty cycle of 25% and the +1.6V feedback voltage presumed equivalent of the real system voltage of 10KV.

Related with previous designs, this project has used output compare mode, timers, interrupts and fast A/D conversion process to generate PWM signals with accurate dead time-delay. The user interfaces implemented can enable set the desired switching frequency, monitor the output voltage by a feedback voltage loop and adjust the duty cycle to maintain the required output voltage. The set-up mode in the design has reduced the stress of designing and the cost of building a new system for another switching frequency within (1KHz-40KHz) range for further applications. The system function design can display the voltage applied to the load and prompt some operating and safety information.

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