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Design and Development of 22W, Three Isolated Outputs Smart Converter for Missile Application

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ABSTRACT: This paper aims at the design and implementation of compact, reliable, efficient and robust three isolated outputs converter for missile application. In view of low power application of the unit, flyback converter and forward converter topologies are chosen. This makes the unit efficient with lesser component count and compact. The power module was made more compact using various switching regulator and PWM ICs. The PWM ICs were incorporated with improved switches, filters and protections. The voltage feedback technique to control duty cycle is dynamically slow and has poor line regulation. This was overcome by the use Current mode control. Snubber circuits were used to clamp the voltage across the switch and also to reset the transformer instead of the traditional reset winding. Due to all these above considerations, the efficiency is improved. The power supply unit is designed with additional protection circuit to safeguard it from any abrupt operation. This paper contains the technical specifications, design, simulation and hardware results for various operating conditions.

KEYWORDS: DC-DC converter, switched mode power supply (SMPS), flyback converter, forward converter.

I.INTRODUCTION

With the fast growing industrial, defence, space and other industries, requirement of increased power density, reduced size and weight of power supplies are the main driving forces towards the use of SMPS. For missile applications, the power density of SMPS is very critical as it determines the size and weight of the system. Reliability, robustness and low cost are other important factors. The switched mode DC-DC converters are most widely used power electronic circuit because of its high conversion efficiency. In the recent years, SMPS converters have found an increased use in the industrial, telecommunication, aerospace and military sectors.

As this paper deals with a military application which will be used under very harsh environmental conditions, the converter is designed to be reliable, efficient, robust, satisfies all the military standards and with all the inbuilt protections. Considering the above parameters, for low power levels with isolated output requirement, the most commonly used topologies are flyback converter and forward converter. The proposed converter has two flyback converter outputs, it also has a forward converter.

A high frequency DC-DC converter is necessary in miniaturizing the power supply. But these high frequency modules are subjected to electromagnetic interference (EMI). Hence design of EMI filters during the initial stages is very important. The power supplies used in missile applications should be insensitive to voltage fluctuations as they are operated in harsh environment. Hence, it is necessary to use proper control strategies for such applications. Motivated by these requirements, the project work is undertaken to design a Miniaturized, High-Reliability Multiple Isolated Output DC-DC Converter for missile application subjected to MIL-STD-461E with enhanced efficiency.

The transformer based bias voltage generation suffers from voltage fluctuations and linear regulator based suffers from dissipation losses. This is overcome by using a micro-module IC that improves the reliability and reduces size. The module is made more compact various switching regulator and PWM ICs with built in filters and protections are used. This results in lesser component count to implement the topologies. The voltage feedback technique to control duty cycle is dynamically slow and has poor line regulation. This is overcome by the use current mode control. Snubber

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circuits are used to clamp the voltage across the switch and also to reset the transformer instead of the traditional reset winding. Due to all these considerations the efficiency is improved.

II.TECHNICAL SPECIFICATIONS AND BLOCK DIAGRAM

The proposed power supply unit is designed for the following specifications.

Minimum input Voltage	:	16V
Maximum Input Voltage	:	36V
Output Voltage and Current ratings	:	• 5V,0.4A (flyback topology) • 2.5V,2A (flyback topology) • 15V,1A (forward topology)
Efficiency	:	>70%
Line/Load regulation	:	<±3%(no load to full load)
Ripple and Noise	:	< 15mVp-p at full load
Frequency	:	250kHz
Protections	:	• Input Over voltage Protection • Input Under voltage Protection • Input Over Temperature Protection • Output Short Circuit Protection • Output Overvoltage Protection
Features	:	• In-built EMI Filter • Isolation between input and every output

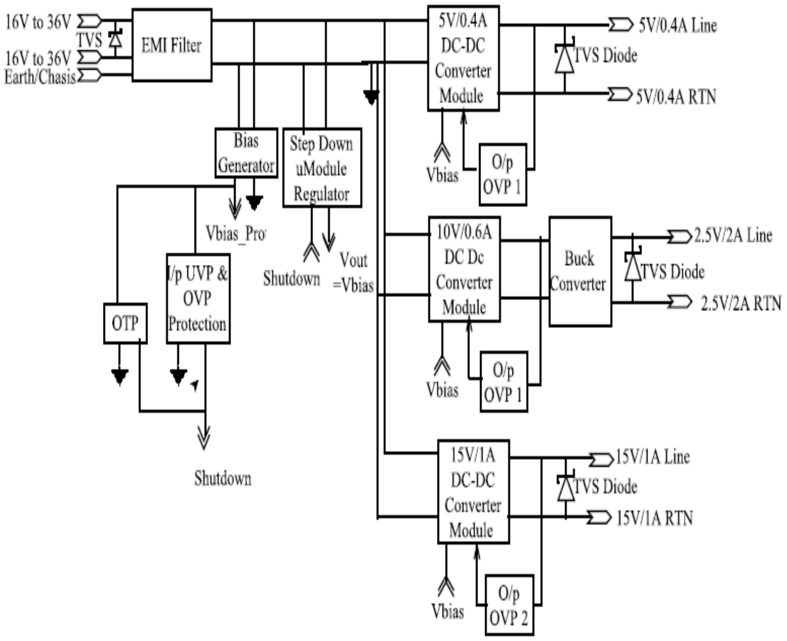

Fig 1 Functional block diagram of proposed power converter module

The Fig. 1 represents the functional block diagram of the power supply module. The power supply unit has 3 isolated outputs of the specified voltage and current ratings. An input EMI filter is used to remove the noises from the input source and also to avoid any noises emitted from the unit itself. It is designed so as to meet the military standards of EMI and EMC.

The input voltage is passed through the input EMI filter. This filtered voltage signal is applied to each converter as input voltage. The filtered input voltage is also used by the bias generator. The bias generator is a simple linear regulator. It generates bias voltage to the input protection circuits such as input under-voltage protection, input over-voltage protection and input over-temperature protection circuits. The switching regulator is also supplied with the filtered input voltage. This produces bias voltages for the converters. The switching regulator is switched off if any of the input protection is enabled. Hence removing any bias voltage to the converters and in turn turning off the entire module. Each converter module has its own output over voltage protection circuit, in addition to the loop compensation. This is provided to obtain better reliability in case of any fault in the loop compensation and the output voltage exceeds 120% of the rated value, then the converter is turned off.

III.DESIGN PROCEDURE

The power supply unit is designed to satisfy the performance parameter criteria as per specifications in section II. The selection of transformer, MOSFET, output diode and capacitors based on the ratings of proposed. In the practical design various tradeoffs and trial and error iterations are involved.

Abbreviations

$V_{in(min)}$: minimum input voltage
$V_{in(max)}$: maximum input voltage
V_{out} : output voltage
P_{out} : output power
Eff : Efficiency
F_{sw} : Switching frequency
T_s : Switching period
D_{max} : max duty cycle
D_{min} : minimum duty cycle
N_p : number of primary turns of transformer
N_s :number of secondary turns of transformer
A_p : area product of the core
A_c : cross-sectional area of the selected core
K_w : window factor:0.4
J : current density
B_m : flux density

Transformer Design

The transformer design is a very important parameter in isolated converters. In case of flyback converter as the transformer acts as a storage inductor it is particularly important for proper design. To design the proposed converters area product method is used and a suitable core is selected.

For a flyback transformer, area product is given as

$$A_p = \frac{L_p I_{pp} (A_{p_o})}{K_W J \times 10^{-6} B_m}$$

Where,

$$A_{p_o} = I_{p\,rms} + (T_{ratio\,1} \times I_{s\,rms})$$

For a forward converter the area product is given as

$$A_p = \frac{\sqrt{D_{max}} P_{out} \left(1 + \frac{1}{Eff}\right)}{K_W J \times 10^{-6} B_m F_{sw}}$$

Selection of MOSFET

The MOSFET is selected to have lower gate charge loss, lower conduction loss and lower switching loss. IPP320N20N3G, 200V, 34A, 32mOhm PG-TO220-3 was selected.

Output Diode Selection

The output diode of the converter is selected based on the reflected voltages and current on the secondary side.

$$I_{S\ \text{reflected}\ 1} = \left(\frac{1-D}{D}\right)\left(\frac{I_{pp}}{\left(\frac{N_{s1}}{N_p}\right)}\right)$$

$$V_{S\ \text{reflected}\ 1} = (V_{out1} + V_{TD1}) + \left(\frac{N_{s1}}{N_p}V_{in(max)}\right)$$

Output Capacitor Selection

The output capacitor is selected based on the formula

$$C_s = \frac{I_{out}(1-D_{min})T_s}{\Delta V}$$

IV.PROTECTION CIRCUITS

Input Under-Voltage Protection

The Fig 2 shows the simple circuit for the input under-voltage protection. A voltage of 2.5V is maintained at the non-inverting terminal of the op-amp AU4A. The input voltage is fed to the voltage divider circuit consisting of AR28 and AR29. Under normal operating range of the input voltage, the voltage across the resistor AR29 is higher or equal to 2.5V. Hence the output of the op amp is low and the module operates normally. The applied input voltage is less than the 16V then the divider voltage goes less than 2.5V and the output of the op amp goes high. Hence, the RUN signal is provided to the switching regulator micro-module shuts down entire module as no bias voltage is provided to any of the isolated converters.

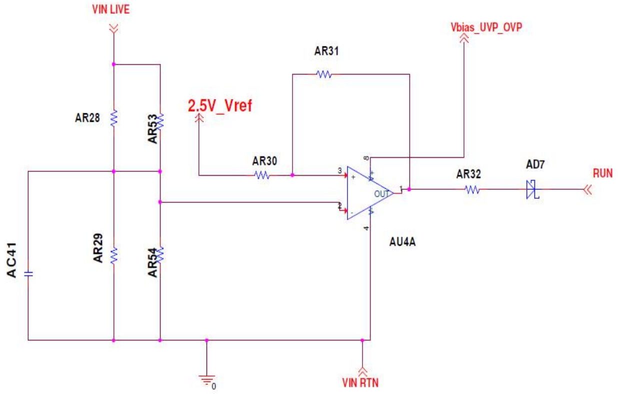

Fig 2: Schematic diagram of the input under voltage protection

Input Over-Voltage Protection

The Fig 3 shows the simple circuit for the input overvoltage protection. A voltage of 2.5V is maintained at the inverting terminal of the op-amp AU4B using a three terminal zener diode. The input voltage is fed to the voltage divider circuit consisting of AR33 and AR34. Under the normal operating range of the input voltage, the voltage across the resistor AR34 is higher or equal to 2.5V. Hence the output of the op amp is low and the module operates normally. The applied input voltage is greater than the 36V then the divider voltage is less than 2.5V and the output of the op amp is high. Hence the RUN signal is provided to the switching regulator micro-module shuts down entire module as no bias voltage will be provided to any of the isolated converters.

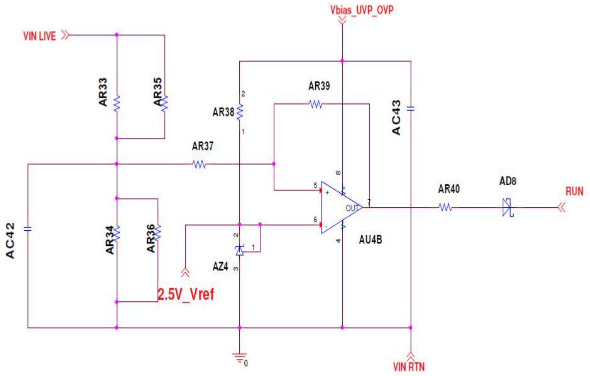

Fig 3: Schematic diagram of the input over voltage protection

Input Over-Temperature Protection

The Fig 4 shows the schematic for an over temperature circuit. It consists of a thermistor AR21 with a negative temperature coefficient. The bias voltage from the bias generator is applied as the input to the circuit. The three terminal zener is used to maintain the voltage of 2.5V at the thermistor. For the normal temperature range, the thermistor resistance is high and the output of the op amp is low. Hence, the module operates normally. For the high temperatures range, the thermistor resistance is very low and the output of the op amp is high. The module shuts down. The probability of line noise interfacing with the converter's start-up and shutdown is reduced by providing about one volt of hysteresis that is implemented by AR24 and AR25.

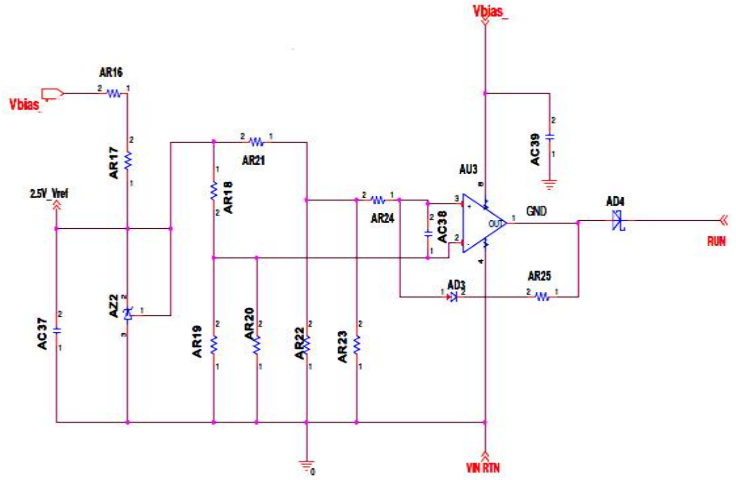

Fig 4: Schematic diagram of the input over temperature protection

Output Over-Voltage Protection

Loss of voltage control can cause excessive output voltages. In direct-off-line switched mode power supply, the transformer isolates output from the input. Therefore, most failures result in a low or zero output voltage.

The undesirable shutdown is avoided by the protection strategy that is designed for protection greater than 120% of the output voltage. As the output voltage exceeds, the zener diode BZ3 and the diode of the optocoupler BU_3 starts conducting as shown in Fig. 5. This results in the conduction of the phototransistor of the Optocoupler. This activates the shutdown circuit as the output of the OVP circuit exceeds. The converter starts working again as the output voltage reaches 5V.

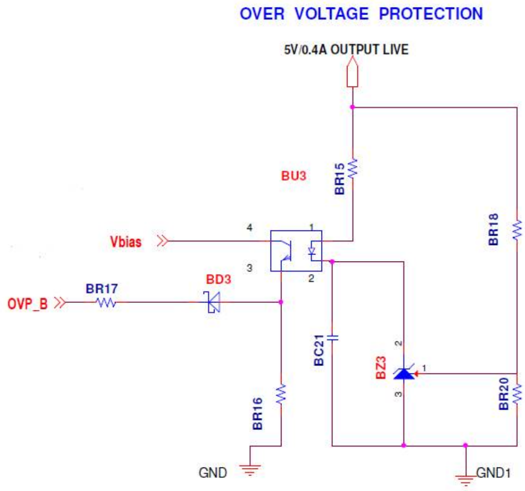

Fig 5: Schematic diagram of the output over voltage protection

Input Over-Current and Short Circuit Protection

The short circuit current protection is required to protect the converter components and load, from abnormal conditions which leads to large current. The basic principle of operation is the current is sensed by a current sensing element. The sensed current is compared with the fixed reference value, if the sensed component is larger than the reference value a turn OFF command is sent to the PWM IC. The schematic of the short circuit current protection circuit is shown in Fig6. The primary ramp current flows through a resistor to produce a ramp voltage, which is indicated by the signal I_{sense}. The signal strength is very low and hence it is amplified with an op-amp AU5A. This amplified signal is compared with 2.5V that is always maintained at the inverting terminal of AU5B. When the current exceeds 125% of the rated primary current, the output of AU5A goes beyond 2.5V. Hence, the output of AU5B goes HIGH. This HIGH signal will be sent to the shutdown pin of PWM IC. Thus the PWM IC and the converter are shut down.

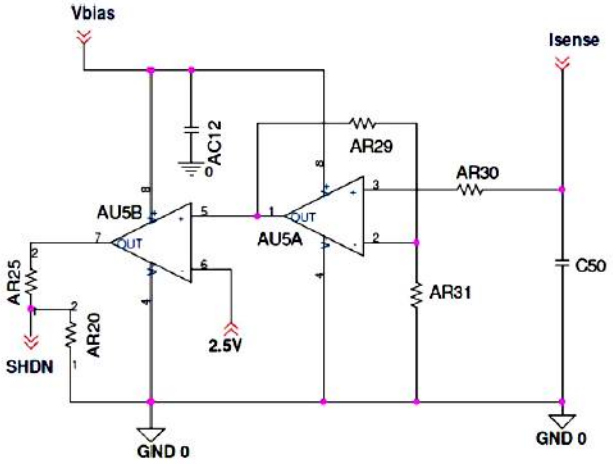

Fig 6: Schematic diagram of the input over current and short circuit protection

V. SIMULATION RESULT

For the proposed converter various simulations were carried out with valid hardware results. In the fig.7 the simulation result of the input under voltage protection using LTSPICE is shown. It shows the variation of the run pin voltage with respect to the input voltage changes.

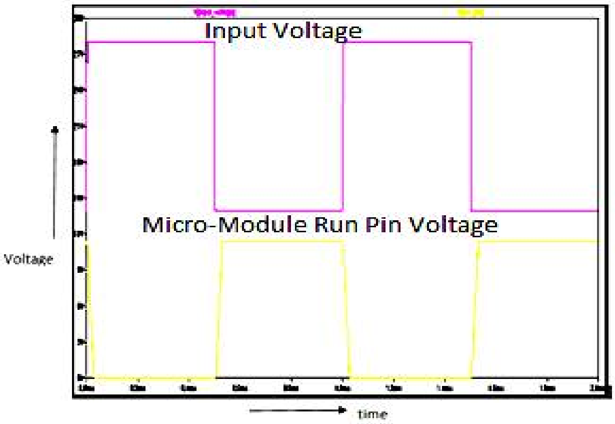

Fig 7: Simulation result for input under voltage protection

In the fig.8 the simulation result of the input over voltage protection using LTSPICE is shown. It shows the variation of the run pin voltage with respect to the input voltage changes.

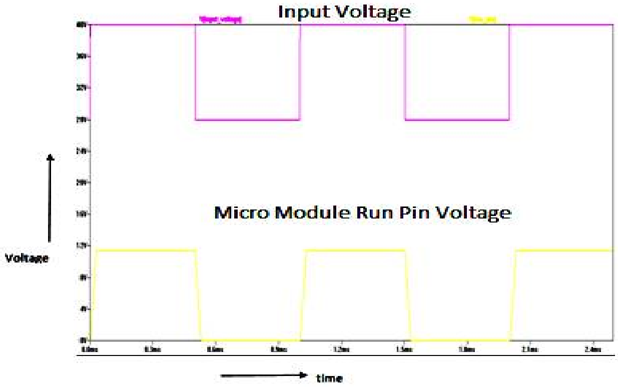

Fig 8: Simulation result of Input overvoltage Protection

In the fig.9 the simulation result of the input over temperature protection using LTSPICE is shown. It shows the variation of the run pin voltage with respect to the temperature changes.

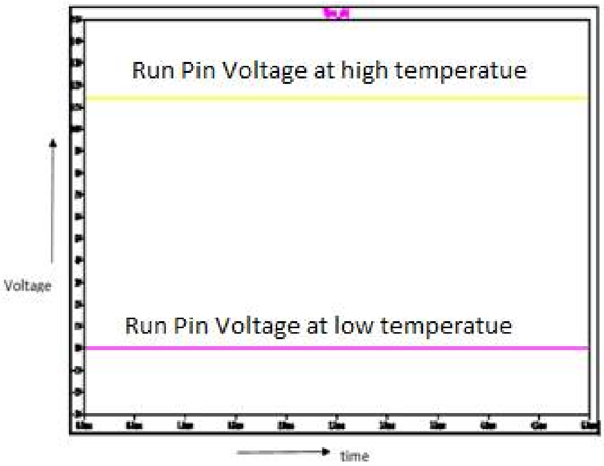

Fig 9: Simulation result of Input over temperature protection

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VI.EXPERIMENTAL RESULTS

The proposed power module is designed, analyzed and implemented. The experimental results of the protection circuits are presented in Table 1. It shows the hardware results successfully match the simulation results and the specification of the module.

Table 1: Experimental results for input protection circuits

Status	Input Under Voltage Protection		Input Over Voltage Protection		Input Over Temperature Protection	
	Practical Voltage (V)	Specified Voltage (V)	Practical Voltage (V)	Specified Voltage (V)	Practical temperature (deg)	Specified temperature (deg)
ON to OFF	15.177	Less than 15.2	38	Greater than 37.5	95	Greater than 90
OFF to ON	15.85	Greater than 15.8	36.2	Less than 36.5	75	Less than 80

Load Regulation and Line Regulation

Load regulation denotes the variation of output voltage for the changes in load from no minimum load to maximum load. The specification for load regulation is less than ±3%. Line regulation denotes the variation of output voltage with respect to variation in the input voltage with the output load held constant. The specification for line regulation is less than ±3%. The table 2 presents the load regulation in percentage is in the range 0.16-0.18 and line regulation in percentage is in the range 0.00-0.02 of 5V/0.4A DC-DC converter. These are well within the specifications.

Table 2: Output voltages of 5V/0.4A DC-DC converter at various load conditions with line and load regulation.

Input Voltage	Output voltage of 5V/0.4A		Load regulation (%)
	No Load	Full Load	
16	5	4.992	0.16
28	5	4.991	0.18
36	5	4.991	0.18
Line regulation (%)	0	0.02	

The table 3 presents the load regulation in percentage is in the range 1.04-1.08 and line regulation in percentage is in the range 0.04 of 2.5V/2A DC-DC converter. These are well within the specifications.

Table 3: Output voltages of 2.5V/2A DC-DC converter at various load conditions with line and load regulation

Input Voltage	Output voltage of 2.5V/2A		Load regulation (%)
	No Load	Full Load	
16	2.521	2.495	1.04
28	2.521	2.494	1.08
36	2.522	2.495	1.08
Line regulation (%)	0.04	0.04	

The table 4 presents the load regulation in percentage is in the range 0.2-0.21 and line regulation in percentage is in the range 0.007-0.013 of 15V/1A DC-DC converter. These are well within the specifications.

Table 4: Output voltages of 15V/1A DC-DC converter at various load conditions with line and load regulation

Input Voltage	Output voltage of 15V/1A		Load regulation (%)
	No Load	Full Load	
16	15.018	14.988	0.2
28	15.018	14.988	0.2
36	15.02	14.989	0.21
Line regulation(%)	0.013	0.007	

Ripple Voltage Measurement

Ripple is the unwanted ac component superimposed on the desired dc component. The ripple content in the output depends on the output filter part. The output voltage ripple is measured at different input voltages and load conditions and presented in Table 5. The nearly constant output ripple of less than 15mVp-p is observed at full load condition for different input voltages.

Table 5: Ripple voltages at various load conditions

Input Voltage (V)	Ripple voltage of 5V, 0.4A (mV)		Ripple voltage of 2.5V, 2A (mV)		Ripple voltage of 15V, 1A (mV)	
	No Load	Full Load	No Load	Full Load	No Load	Full Load
16	6.3	5.66	8.2	6	7.5	7
28	7.6	5.52	10.4	6.8	10.4	8
36	8.2	5.76	12.2	8	12.8	10

Efficiency

Efficiency of the power supply module at different input voltages is calculated by calculating the input power and output power. The efficiency plot is show in figure 10. The average efficiency of the module is found to be greater than 70%.

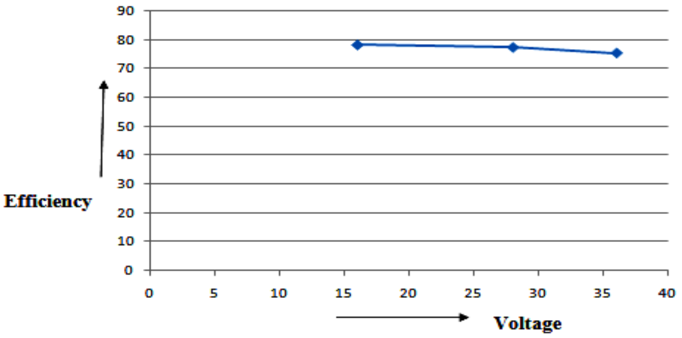
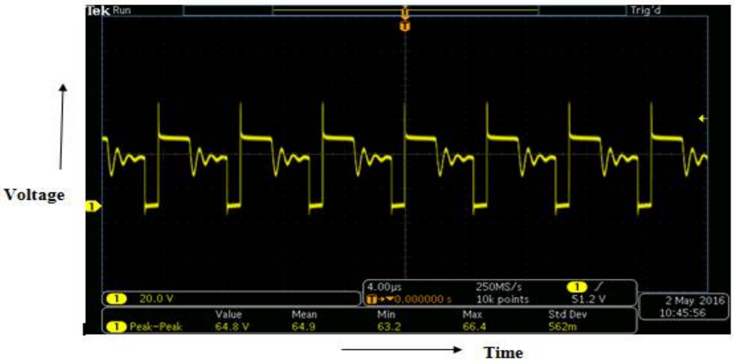


Fig 10: Efficiency plot of converter

Observed Waveforms

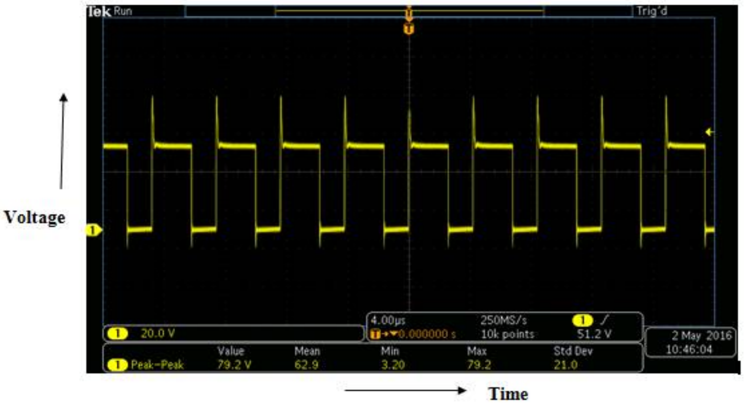
The fig 11 shows the drain voltage waveform of 5V/0.4A converter at 28V input and full load condition observed at the PWM IC LM5001 using an oscilloscope.



	Value	Mean	Min	Max	Std Dev
1 Peak–Peak	64.8 V	64.9	63.2	66.4	562m

Fig 11: Drain waveform of 5V/0.4A converter at 28V input and full load condition.

The fig 12 shows the drain voltage waveform of 2.5V/2A converter at 28V input and full load condition observed at the PWM IC LM5001 using an oscilloscope.



	Value	Mean	Min	Max	Std Dev
1 Peak–Peak	79.2 V	62.9	3.20	79.2	21.0

Fig12: Drain waveform of 2.5V/2A converter at 28V input voltage and full load condition.

The fig 13 shows the gate and drain voltage waveform of 15V/1A converter at 28V input and full load condition observed at the MOSFET of the forward converter using an oscilloscope.

	Value	Mean	Min	Max	Std Dev
1 Peak–Peak	96.0 V	47.9	6.00	98.0	44.2
2 Peak–Peak	14.8 V	15.4	14.8	16.0	308m

Fig 13: Gate and drain waveform of 15V/1A converter at 28V input voltage and full load condition.

VII.CONCLUSION

The software simulation and also the hardware implementation are carried out successfully and test results of the converter are presented. A detailed analysis of the results obtained is presented. This analysis shows that the converter is operating at efficiency greater than 70% according to the specification. At maximum load conditions an efficiency of 76.92% is achieved. The module is made compact and efficient using PWM IC LM5001. For the 5V, 0.4A converter module the load regulation in percentage is in the range 0.16-0.18. The line regulation in percentage is in the range 0.00-0.02, thus meeting the specifications. For the 2.5V, 2A converter module the load regulation in percentage is in the range 1.04-1.08. The line regulation in percentage is 0.04, thus meeting the specifications. This is achieved using the switching regulator IC LTM 4624.For the 15V, 1A converter module the load regulation in percentage is in the range 0.2-0.21. The line regulation in percentage is in the range of 0.007-0.013, thus meeting the specifications. The switch voltages are presented and analyzed. The experimental results obtained under input and load conditions validate and justify the design of the proposed topology. From the test results, it is concluded that the output voltage ripple are within limits of ±15mVp-p. The necessary protection circuits such as voltage and current protection are implemented and tested.

VIII.ACKNOWLEDGEMENT

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REFERENCES

[1] Harish Kuqshal, “Power Supply Considerations for Missile Applications”, A Workshop on Futuristic Aerospace Vehicles Integration and Testing (FAVIT 2014), Research Centre Imarat, Hyderabad, 20-21 Feb 2014

[2] Jun Lee, Kyung-Hwan Lee, Jung-Ik Ha, “Design Considerations for High Frequency DCM Flyback Converter” 6th International Conference on Power Electronics Systems and Applications (PESA),pp.1-6, 15-17 Dec 2015

[3] Subrahmanya Bhat , Rajkiran Ballal, “Design, Simulation And Analysis Of 100 Watt Forward Converter For Photovoltaic Power Conditioning System”, National Conference on Challenges in Research & Technology in the Coming Decades, Ujire, pp.1-4, 27-28 Sept. 2013.

[4] Emelogu G. C. and Raji A. G., “Single Switch Forward Converter”, IEEE International Conference on Emerging and Sustainable Technologies for Power & ICT in a Developing Society,Owerri, pp. 348-356, Nov 2013.

[5] J. B.V.Reddy, G. Bhuvaneswari and Bhim Singh, “A Single DC-DC Converter Based Multiple Output SMPS with Fully Regulated and Isolated Outputs”, IEEE Indicon 2005 Conference, Chennai, India, I I - 1 3 Dec. 2005.

[6] Sean C., Smithson and Sheldon S. Williamson, “A Unified State-Space Model of Constant-Frequency Current-Mode Controlled Power Converters in Continuous Conduction Mode”, *IEEE Transactions on Industrial Electronics*, vol. 62, no. 7, pp. 4514-4524, 2015.

[7] Kai-Hui Chen,” Design of Quasi-Resonant Flyback Converter Control IC with DCM and CCM Operation”, 2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA), Hiroshima, pp. 2750 – 2753, 18-21 May 2014

[8] V. Ramanarayanan, “Course Material on Switched Mode Power Conversion”, Department of Electrical Engineering Indian Institute of Science Bangalore 560012, Jan 15, 2008.

[9] Christophe P. Basso, “Switch- Mode Power Supplies”, The McGraw-Hill Company, 1st Indian edition, 2008.

[10] Microchip, ”Switched Mode Power Supply(SMPS) Topologies(Part I)”, Microchip Technology Inc,2007.