Single Output 40W DC-DC Forward Converter for Space Application

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Abstract - *Forward converter is preferred for designing the power supply unit in space application due to its simple structure and provides perfect isolation between input and output. Design and implementation of lesser weight, compact size, high effective single output DC-DC converter for space application. The switching frequency of 500 kHz is selected to reduce the size of the converter with PWM Controller UC2825 and Feedforward Technique is used. The inhibit is used to turn off the converter manually and LCD snubber is used to reduce the stress on MOSFET. The proposed converter drives 5V/8A from the Input voltage of 18-50 volts range. The efficiency greater than 76% with output power of 40W.*

***Key Words*: Forward Converter, Inhibit, Input voltage feed forward, LCD snubber, UC2825 PWM IC.**

1. INTRODUCTION

DC-DC Converter is designed to be backward compatible in addition of an output voltage adjustment pin for the single output models. These converters are radiation hardened, their lesser size and less weight make them ideal for applications such as geostationary earth orbit satellites and deep space probes. They demonstrate a high tolerance to the environmental changes happen in the space. The converter has a fixed frequency with the single output and forward topology is used with magnetic feedback. Forward converter opts for designing the power supply unit due to its simple structure and gives perfect isolation between input and output. The switching frequency of 500 kHz is selected to decrease the size of the converter with PWM Controller UC2825 and Feedforward Technique is used. The inhibit is used to turn off the converter manually and LCD snubber is used to reduce the stress on MOSFET, start-up circuit is used to generates initial voltage for PWM Controller circuit of forward converter. Feedforward voltage topology is being used for fast response of closed loop control with change in line voltage on primary side of forward transformer, input side has protection circuits such as Over voltage protection(OVP), Under voltage protection(UVP), Over current protection(OCP), Short circuit protection. The Secondary side voltage is rectified and filtered to give 5V/8A regulated output with power of 40W.

2. Specifications of the converter

Input voltage:	18V to 50V.
Output Voltage:	5V/8A.
Output power:	40W
Efficiency:	>75%
Switching Frequency:	500 KHz
Ripple:	<50mV
Line regulation:	5V: ±10mV
Load Regulation:	5V: ±25mV
Synchronization:	450 KHz to 550 KHz
Operating temperature:	-55ºC to +85ºC

3. Block Diagram

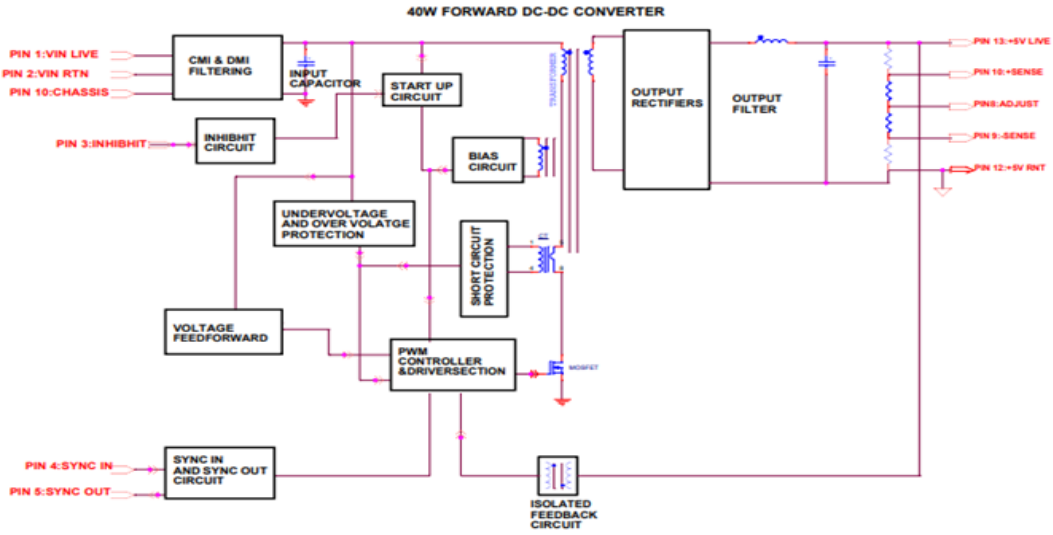

Fig - 1: Block Diagram of 40W Converter

The single output DC-DC Converter is designed and realized based on the specifications given by the Customer. The above figure shows the detailed block diagram of the power supply. The power supply has single isolated outputs(5V/8A) which is realized using Forward converter topology, Input Bus voltage 18V-50V range is supplied to EMI filler which is designed to meet the differential mode Conductance Emission and Conductance Susceptibility tests requirement. Filtered output is provided to primary side of the forward transformer. start-up circuit provide beginning voltage for PWM Controller circuit of forward converter. PWM Controller turns ON and Driver IC gets on and initiates GATE Pulses at switching frequency (500KHZ to optimize the size) to Primary side MOSFET. With this switching action of MOSFET, Input Bus voltage is applied to Forward transformer and energizes it and magnetic feedback is used [5].

Feedforward voltage topology is being used for fast response of closed loop control with change in line voltage on primary side of forward transformer, Bias winding is used to originate the bias voltage to power the controller circuits. The bias winding voltage is greater than the start-up circuit voltage so that a PWM controller circuit starts drawing the current from the bias winding instead of the start-up circuit [1]. Hence bias winding will act as the House Keeping Bus and will continue to power the PWM IC and associated ICs. Input side has protection circuits such as Over voltage protection(OVP), Under voltage protection(UVP), Over current protection(OCP), Short circuit protection. The Secondary side voltage is rectified and filtered to give 5V/8A regulated output with power of 40W.

4. Design

4.1 Transformer Design

Area product method is used to find the size of a power transformer [4].

Selected Toroid Core: YP-41605-TC, Ur:2500, AL: 1375mH/1000T.

$$\text{Area product } A_p = \frac{\sqrt{Dmax} * P_{out} * \left(1+\frac{1}{Eff}\right)}{K_w * J * 10^{-6} * B_m * f_{sw}} \quad (1)$$

Where, Window factor (K_w) should be between 0.3 to 0.5

Flux density (B_m) should be between 0.12 to 0.2 for ferrite core material.

Current density (J) should be between 3Amp/mm^2 to 6Amp/mm^2

$$Number\ of\ turns\ for\ primary\ winding, N_p = \frac{V_{in(\min)} . Dmax}{B_m . A_C . 10^{-6} . f_{sw}} \quad (2)$$

$$\textbf{Turns ratio} = \frac{V_o + (V_D * D_{max})}{D_{max} * V_{in(min)}} \quad (3)$$

4.2 MOSFET Selection

In a forward converter, during turn-off period the maximum voltage will be measured across the MOSFET will be the tice of the maximum of input voltage. So the MOSFET taken is SELECTED MPN :IPP60R125CP, 650V , 25A, 125mOhm, TO220-3 . For safe operation, MOSFET taken should has a breakdown voltage should be more than 3 times the maximum supply voltage[4].

ELECTED MPN :IPP60R125CP, 650V , 25A, 125mOhm, TO220-3

$$V_s = V_i + \frac{n_p}{n_r} * V_i \quad (4)$$

$$\text{P\_conduction} = 1.25 * R_{DS} * Ip\_rms^2 \quad (5)$$

$$\text{P\_Coss} = \frac{\text{Coss} * \text{V\_OFF}^2 * (\text{Fsw})}{2} \quad (6)$$

$$\text{P\_Switching\_ON} = \frac{\text{Vin(min)} * \text{Ipft} * (\text{Tr}) * (\text{Fsw})}{3} \quad (7)$$

$$\text{P\_Switching\_OFF} = \frac{\text{V\_OFF} * \text{Ipft} * (\text{Tf}) * (\text{Fsw})}{3} \quad (8)$$

4.3 Inhibit

The inhibit is used to turn off the converter manually, the inhibit signal turn off the converter without having interrupt to the input voltage and input current drawn by the regulator is reduced.

4.4 Synchronization in/out circuit

Synchronization circuit is used in forward converter, of one frequency to sync with the other device of different frequency. If the two or more converter operate in different switching frequency it is difficult to analysis or predict the input ripple and it is hard to design the input filter due to the asynchronous operation of different switching frequency, and create harmonic contents at the input DC bus which is difficult to eliminate.

4.5 Voltage Feedforward control

The forward converter operates with the wide range of input voltage from 18-50V and with the varying load from 10%-100% to regulate the output of 5V/8A with the fixed switching frequency. To achieve this the PWM technique is used. In voltage control technique there are few draw backs such as loop gain is varied with input voltage and scaling is difficult. Hence the new technique is introduced which is input voltage feedforward technique. In this feedforward technique the error amplifier is connected to the comparator inverting point and at the non-inverting point the oscillatory or feedforward circuit is connected, both the error signal and feedforward signal is compared and we get output as pulse which is connected to the PWM IC pin. To feedforward circuit the Vin has been given so that the delay from error amplifier can be avoided, here the ramp is compared with the reference and we get output as pulse with the different duty.

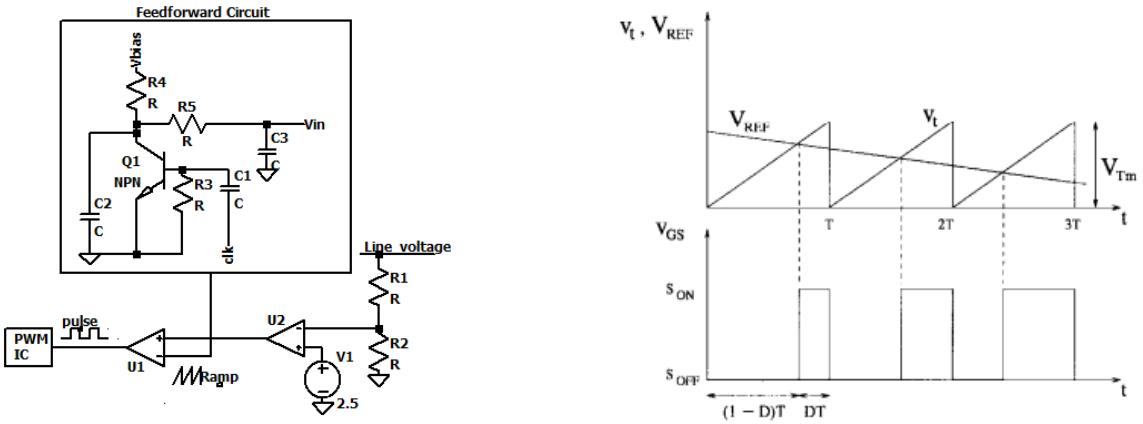

Fig - 2: circuit and Waveform of Voltage Feedforward Control

4.6 Protection Circuits

Input side has protection circuits such as Over voltage protection(OVP), Under voltage protection(UVP), Over current protection(OCP).

4.6.1 Over Voltage Protection

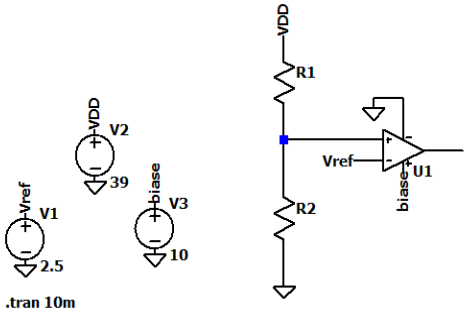

Fig - 3: circuit of Over Voltage Protection

The over voltage protection is used to avoid the damage of any device from the maximum voltage or over voltage, if the voltage exceeds more than the specification, the components may get damage to avoid those damage we use the over voltage protection circuit. The value of the resistor is designed on the bases of maximum differential voltage at the highest expected current. The voltage sensing element will be placed in the device if the voltage reaches above the maximum voltage or 125% of the rated primary voltage then the U1 pin gets high and shutdown pin of PWM IC gets high. Thus turns off the device [2].

4.6.2 Under voltage Protection

The under voltage is used to avoid the damage of any device from the voltage rated below the specification, in 40W DC-DC converter the under voltage range is below 18v so the voltage reaches below 18V then current drawing will be more from the input supply this cause power loss, then the voltage sensing element gets sensed and the shutdown pin of PWM IC gets high and converter gets turn off. the voltage should be of 125% of the rated primary voltage. By this we can avoid the damage of components in the converter [2].

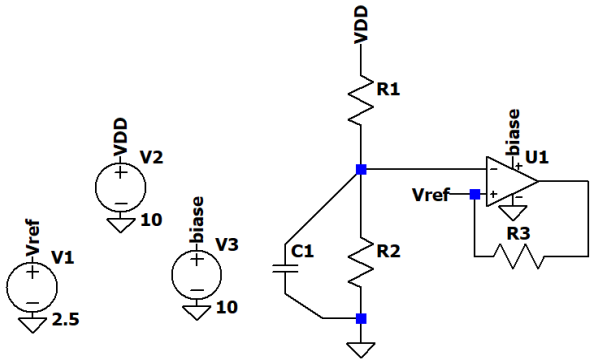

Fig - 4: circuit of Over Voltage Protection

4.6.3 Over current Protection

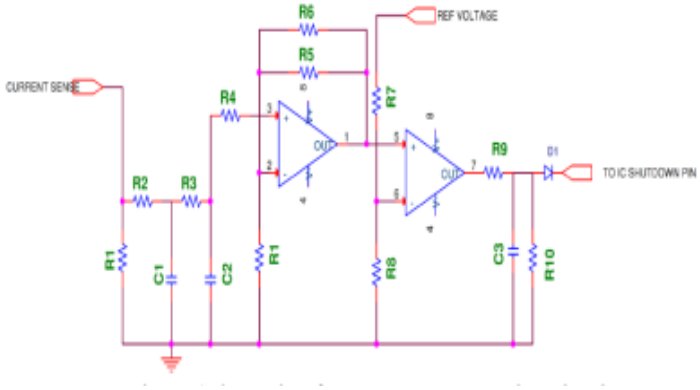

Fig - 5: circuit of Over current Protection

The over current protection is used to avoid the converter from the damage. If the current reaches above the specification, then the components in converter may get damage. So the value of the voltage divider resistor is designed according to the input voltage supply here the input voltage range if from 18-50V The current limiting resistor is designed according to the input and output current, when the current exceeds 125% of designed value. The shutdown pin of PWM IC gets high and converter gets turn off [3].

5. Experimental Results

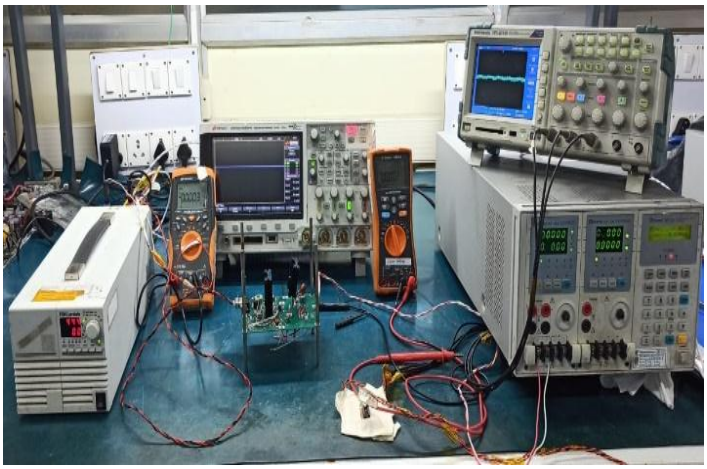

Fig - 6: Hardware experimental setup of single output 40W converter

5.1 Output voltage

The output voltage is measured at the minimum to maximum input voltage and load conditions as we observe in the below table 1.

Table 1: Output voltages at load from 10%-100% at input voltage of 18-50V

VIN (V)	OUTPUT VOLTAGE(V)		
	5V O/P (4.98 - 5.02) at 100% load		
	10%	50%	100%
18	5.010	5.011	5.012
28	5.010	5.011	5.011
50	5.010	5.010	5.011

5.2 Efficiency

The input current, input power, and output power ,efficiency of 80% at minimum and maximum is observed in below table 2.

Table 2. Efficiency at load from 10%-100% at input voltage of 18-50V

VIN (V)	Input current (A)			Input power (W)			Output power (W)			Efficiency(%) Spec:Min=75%, Nom=79%		
	10%	50%	100%	10%	50%	100%	10%	50%	100%	10%	50%	100%
18	0.364	1.400	2.784	6.55	25.20	50.11	4.01	20.04	40.10	61.2	79.5	80.0
28	0.269	0.913	1.785	7.53	25.56	49.98	4.01	20.04	40.09	53.2	78.4	80.2
50	0.202	0.558	1.045	10.10	27.90	52.25	4.01	20.04	40.09	39.7	71.8	76.7

5.3 Output ripple Voltage

Table 3. Output ripple voltages at load from 10%-100% at input voltage of 18-50V

VIN (V)	OUTPUT RIPPLE VOLTAGE(mV)		
	5V O/P (V) Spec: Nom:20mV Max:50mV		
	10%	50%	100%
18	5	10.4	16.4
28	5.2	11.4	17.6
50	7.8	14.4	16.8

5.4 Line Regulation

Table 4. Line regulation at load from 10%-100%

	Line regulation (mV)		
	5V		
	Spec: ±10mV		
	10%	50%	100%
Down Reg (mV)	0	0	1
Up Reg (mV)	0	-1	0

5.5 Load Regulation

Table 5. Load regulation at input voltage from 18-50V

Vin (V)	Load regulation (mV)	
	5V	
	-0.5%(25mV)	+0.5%(25mV)
	50% to 10%	50% to 100%
18	-1	1
28	-1	0
50	0	1

5.6 Inhibit

Table 6.Inhibit at input voltage from 18-50V

Parameter	INHIBIT TEST			
	Open Circuit voltage (3 - 5)V	Voltage range (-0.5 - 50)V	Converter turn-on voltage (> 0.8) V	Drive current (sink) <(100uA)
18V (10% load)	3.98	0.5 to 50	1.36	18.4
18V (100% load)	4.11	0.5 to 50	1.39	21.23
50V (10% load)	3.99	0.5 to 50	1.26	49.97
50V (100% load)	4.34	0.5 to 50	1.25	49.97

5.7 Sync in/out

Table 7. Sync test at frequency range from 450-600kHz

Sync.Test Frequency range	Pulse high level : 4V		Pulse high level : 10V	
	Duty : 20%	Duty : 50%	Duty : 20%	Duty : 50%
	Working condition : yes/no		Working condition : yes/no	
450 kHz	YES	YES	YES	YES
600 kHz	YES	YES	YES	YES

5.8 Ripple Waveforms of 40W Single output converter for full load condition

The ripple output waveform of 40W DC-DC forward converter with full load and maximum voltage is shown in the fig-7 is having the ripple of 16.8mV and is within the specification.

Fig - 7: Input Voltage = 50V, CH4: 5V/8A ,Ripple:16.8mV

5.9 MOSFET Drain Voltage waveforms at full load conditions.

The MOSFET drain voltage output waveform of 40W DC-DC forward converter with full load and maximum voltage is shown in the fig-8 is having the drain voltage of 159V and is within the specification.

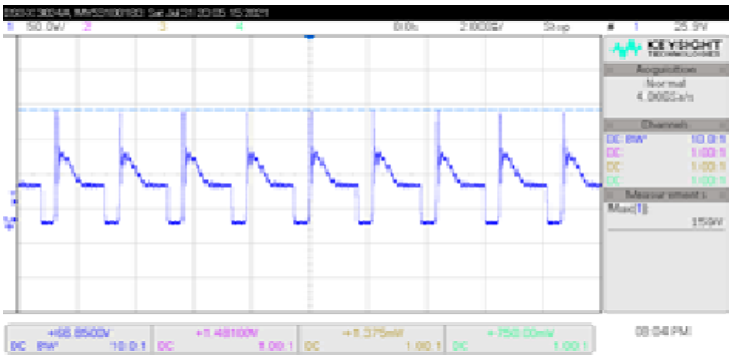

Fig - 8: Vin=50V, Max. Drain Voltage: 159V

5.10 MOSFET Drain current Waveforms at Full-load condition.

The MOSFET drain current output waveform of 40W DC-DC forward converter with full load and maximum voltage is shown in the fig-9 is having the drain current of 7.247A and is within the specification.

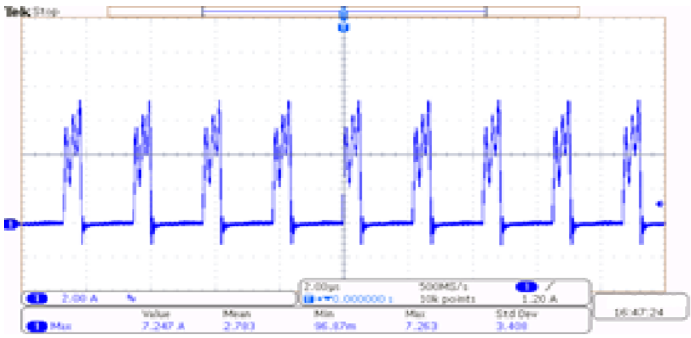

Fig - 9: Vin=50V, Max. Drain current:7.247A

5.11 Diode stress waveforms at full load condition.

The Diode stress output waveform of 40W DC-DC forward converter with full load and maximum voltage is shown in the fig-10 is having the diode stress of maximum stress voltage is between 45V & 37V and is within the specification.

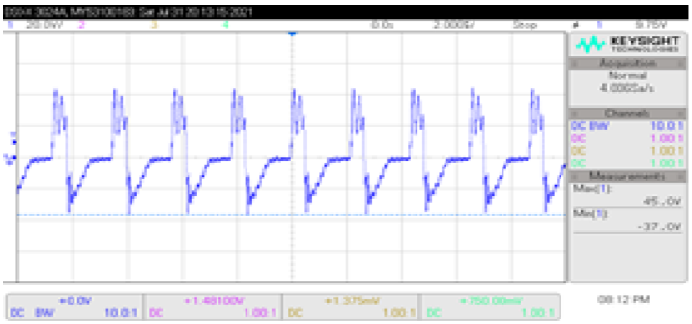

Fig - 10: Vin=50V, Max. Stress Voltage: 45V & 37V

6. Conclusion

The Forward converter with single output of 5V/8A has been successfully implemented with feedforward technique, sync in/out ,and inhibit circuits. The output ripple, MOSFET stress, Diode stress, Line regulation , and Load regulation is within the specification as observed in the practically proved experimental results at the full load 100% and 50%,10% with the variable input voltage. The 4-5% of over all converter efficiency is improved by using snubber circuit. Future work can be carried out on improving the efficiency and digitally controlled MOSFET, feedforward technology.

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