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Implementation of Multiple Output Forward Control with Voltage Feed Forward Control for Space Application

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Abstract: This paper describes the Hardware design and implementation of Forward converter with multiple outputs for remote sensing and image pay load application. The converter is designed to operate at 250kHz by PWM controller. Input Voltage Feed forward control technique is incorporated to attain ±1% line regulation. Synchronous buck converter at secondary side improves efficiency of the converter and low drop regulator is used to regulate output voltage and minimize cross regulation. Converter has Inherent features such as over voltage protection, Input undervoltage protection, short circuit protection and external disable circuit. Under ambient temperature, the electrical test is carried out to validate the design results.

***Key Words* - Forward converter, PWM controller, synchronous buck converter, Low drop out regulator, cross regulation**

I. Introduction

Switched Mode power supplies has become conventional in space grade application [1] than linear power supplies, because of higher efficiency as switching elements avoids operation in active region but operates either in saturation or cut-off region, reduces power losses. The other critical aspects are compact size, lightweight and high reliability to operate under intense temperature conditions [2]. The main applications of SMPS are battery charging, Military, biomedical equipment and electronic devices [3]. Among switch mode power supplies, DC-DC isolated converters are significant to obtain regulated outputs, provides electrical isolation with multiple outputs and are widely used in computer power supplies, uninterrupted power supplies and telecommunication [4]. Forward converter is most used for space application among DC-DC converter because of its high transformer utilization, more efficient and is often chosen for output power under 200W and voltage range of 60V-200V[5].

1.1 Forward converter

Forward converter is magnetically coupled, provides isolation between source and load also it is an isolated version of buck converter. Forward transformer does not store energy hence, ferrite core is most widely used as core material, transforms energy instantly from primary to secondary winding for high power application with high voltage conversion ratio[5]. Reset winding has to be provided on the primary side to restore flux to zero vale in every cycle to avoid saturation. The conventional Forward Converter is shown in Fig1.1

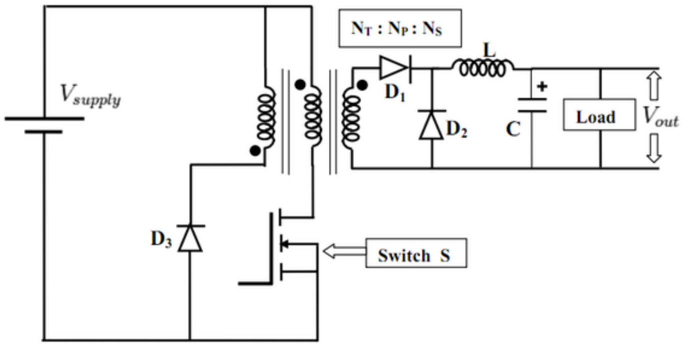

Fig1.1 Conventional Forward converter

Input voltage is applied to primary winding at the time switch S is turned ON. Secondary voltage is reflected based on turns ratio. Diode D1 rectifies voltage and energy is stored in inductance L, is delivered to load during switch S is in OFF condition. freewheeling diode D2 provides path for load current and constant voltage is maintained by output capacitance C.

1.2 Input Voltage Feed forward control Technique

The common voltage mode control technique comprises mainly error amplifier and PWM modulator, an error signal is caused due to difference between sensed output signal through voltage divider with constant reference voltage. Error signal is compared with fixed slope sawtooth signal generates larger error signal as the input voltage is varied and fed back to PWM controller to generate gate pulse for switch operation, increases the response time [7].

In order to improve transient response, input voltage feed forward control technique is incorporated [8] wherein, varying sawtooth signal corresponding to the input voltage is compared with the error signal in response to output voltage to generate gate pulse for the variation in duty cycle in accordance to changes in input voltage to achieve ±1% line regulation [9].

II. Block diagram

The design and realization of 110W with four outputs DC-DC converter is based on the detailed requirements obtained from space application center. The block diagram of converter is shown in Fig.2.1

The Input EMI filter eliminates common mode and differential mode noise generated from switching of power MOSFET and mutual inductance between wires and radiated electromagnetic interferences to meet EMI regulation. The current transformer CT1 sense the primary current. Start up circuit comprise Darlington pair amplifier generates initial voltage of 11V for PWM controller circuit of forward converter to turn ON the MOSFET during first cycle. Bias winding power up all the active components in the circuit and acts as feedback for PWM controller to generate gate pulses for MOSFET at 250kHz. with the switching action of MOSFET, the filtered input voltage is applied to primary side of transformer and transfers energy to secondary side to obtain output voltage according to turns ratio.

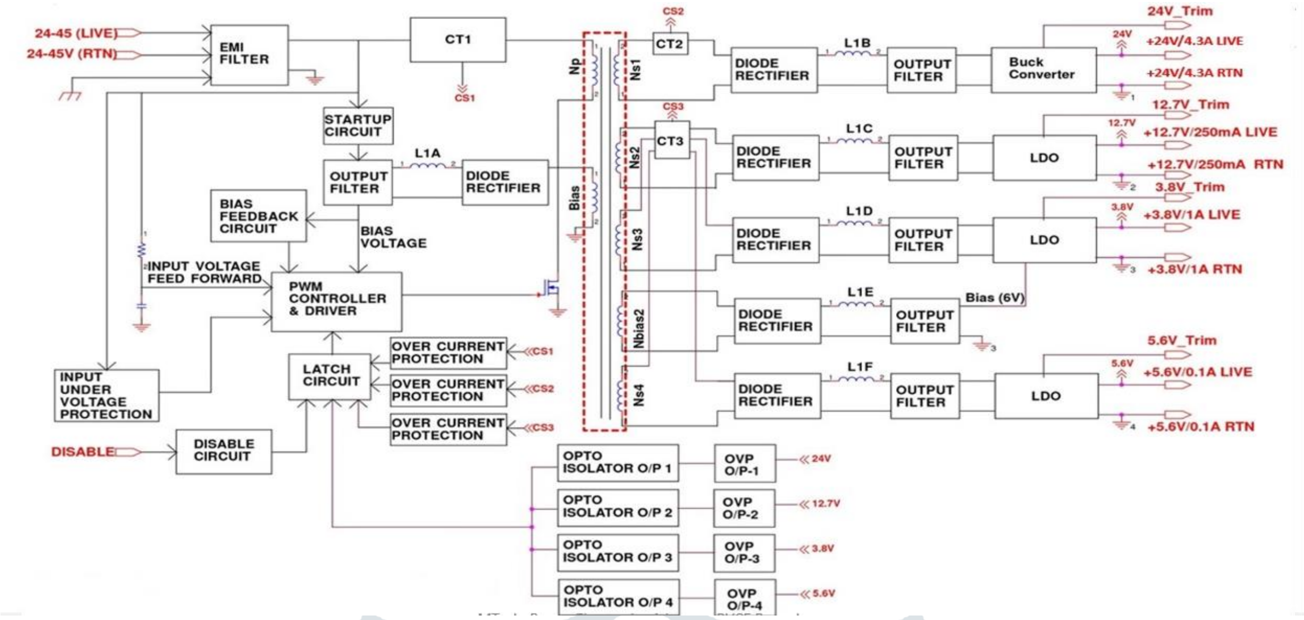

Fig2.1 Block diagram of Forward converter with multiple output

Voltage Feed forward control adjust the duty ratio with the variation in the input voltage to maintain the constant output voltage. The secondary windings generate raw voltage and are coupled using coupled inductor. Secondary raw voltages are rectified by diode rectifier also filtered out by individual output filter and connected to synchronous buck converter for improved efficiency and three LDO to maintain regulated output voltage. All the four outputs 24V,12.7V,5.6V and 3.8V are equipped with the protection circuits such as output overvoltage, Input under voltage, output short circuit, overcurrent and external disable circuit. Current Transformer CT2 sense the secondary output current of synchronous buck converter of 4.3A, one current transformer CT3 for all three LDO since load currents are of low value 0.25A,0.1 and 1A. sync circuit is used to synchronize the switching frequency of main MOSFET and synchronous buck converter MOSFET[7].

2.1Methodology

Forward converters are primarily used for protection purpose due to their isolation and to maintain a regulated output voltage (24V,12.7V,5.6V and 3.8V) over changes in the input voltage from 26V to 45V.The converter is designed to operate at switching frequency of 250kHz to optimize switching losses, mass and size of transformer and output filter. The PWM IC UC2825 is selected because of its high switching frequency, controller is designed for voltage mode with input voltage feedforward capability. It has advantages of soft start, maximum duty cycle control and requires low start up current.

The converter includes EMI Filter, Main Transformer winding, bias winding Coupled Inductors, Diode rectifier, output filter, Snubber Resistor and Capacitor and protection circuit components. components are selected UC2825 DWTR Controller IC, SOIC 16, Diode Rectifier HF40A060ACDV 600V, 30A.The MOSFET Switch BUY25CS45B 250V, 45A, 0.05ohm Rds is selected based on the low Drain to Source on State resistance, low Conduction and Switching losses.

The selected components are embedded on the Printed circuit board using lead and a soldering gun. MOSFET switches are mounted with heat sink that absorbs the heat dissipated by the switch. The printed circuit board (PCB) is connected to a power source using wires. The converter is loaded with 10% to 100% conditions over the input voltage range 26V to 45V, and as the input voltage changes, the output voltage is adjusted by feedback from the feedforward voltage mode control that sends the signal to the PWM controller. The controller changes duty cycle to generate gate pulse to MOSFET for the operation of converter. output voltage, current, drain to source voltage are viewed in digital storage oscilloscope.

III. Converter Design

Design of the converter is carried out based on specification obtained from space application centre mainly includes transformer core selection, PWM controller IC, synchronous buck converter IC, Linear drop out regulator IC, MOSFET Switch, diode rectifier, Filter Inductor, Filter Capacitor. Filter Inductor reduces the Output Current Ripple, Filter Capacitor reduces the Output Voltage Ripple.

- Input Voltage Range: 26 V to 45 V
- Output Parameters: 24V /4.3 A: 12.7V /0.25 A: 5.6V/ 0.1A: 3.8V/1A
- Output Power: 110W
- Maximum Duty cycle: 0.6
- Efficiency: ≥80%
- Line regulation: < 1%
- Load regulation: <1%
- Cross regulation: <2%
- Ripple: < 100mV for 24V&12.7V, < 50 mV for 5.6V&3.8V

3.1Transformer Core selection:

Power handling capability and area product of transformer are the two major criteria for the selection of core transformer.

Forward converter Area product is calculated as follows

$$A_p = \frac{\sqrt{D_{max}*(P_{out}+P_{bias})*(1+\frac{1}{Eff})}}{k_w*J*10^{-6}*B_m*f_{sw}} = 4272.89mm^2 \quad (3.1)$$

P_{out} is 110W, total output power of the converter

P_{bias} is power required by bias winding.

An appropriate core is selected to have area product greater than the calculated Ap. Area product (Ap) is provided as the product of the core cross section (Ac) and the window area (Aw).

Selected Toroid Core: ZP-42207TC, Material, Ur:2500, AL: 1875nH/1000T

Turns ratio is calculated as follows

$$T_{ratio\ bias} = \frac{(V_{bias}+V_{LDB})+V_{DB}*D_{max}}{D_{max}*V_{in}} = 0.981 \quad (3.2)$$

V_{bias} is the voltage required for bias winding

$V_{LDB}$is the extra voltage required for regulator

V_{DB} is the voltage drop across diode rectifier

The primary turns of the converter is calculated as follows

$$Np = V_{in(min)} * D_{max} * B_m * A_c * 10^{-6} * f_{sw} = 10 \text{ turns} \quad (3.3)$$

The calculation of primary winding inductance

$$L_p = {N_p}^2 * A_L = 10^2 * 1875 * 10^{-9} = 188uH. \quad (3.4)$$

3.2 MOSFET selection

MOSFET selection is depending on the Drain to Source voltage (Vds), Drain current (Id), Drain to Source ON state resistance (Rds), Gate charge (Qg), conduction loss, switching loss and Output Capacitance loss (Coss)

$$\text{Conduction loss, } P_{conduction} = 1.25 * R_{ds} * {I_{prms}}^2 \quad (3.5)$$

$$\text{Gate charge loss, } P_{gate} = Q_{gate} * V_{gate} * f_{sw} \quad (3.6)$$

The selected MOSFET is BUY25CS45B, 250V, 45A, 0.05 Ohm

3.3 Low drop out regulator

Low drop out regulator are a simple inexpensive way to regulate an output voltage is powered from a higher voltage input. LDO operates with very small input-output differential voltage called drop out voltage [10]. Constant input voltage is applied to LDO to regulate output voltage for the changes in load. The feedback loop controls the drain to source resistance $R_{ds(on)}$ by varying the gate source voltage, with increased gate source voltage reduces $R_{ds(on)}$ results more drop out voltage to maintain constant output voltage as required. circuit diagram of low drop out regulator circuit is shown in Fig3.1

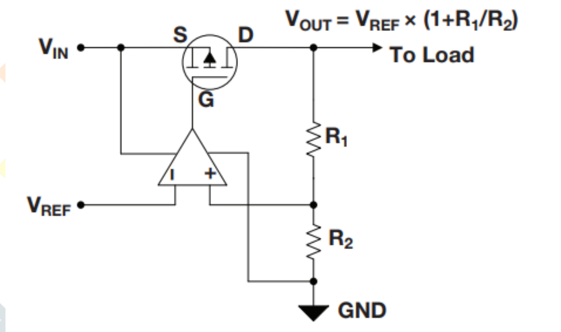

Fig3.1 LDO circuit

IV. Hardware Implementation

Hardware layout of Forward Converter is shown in the Fig4.1. It consists Input connector, EMI filter includes differential mode and common mode filter, Primary side MOSFET, Forward transformer, three LDO, Output Inductor Coupled inductor, Current transformer and output connector.

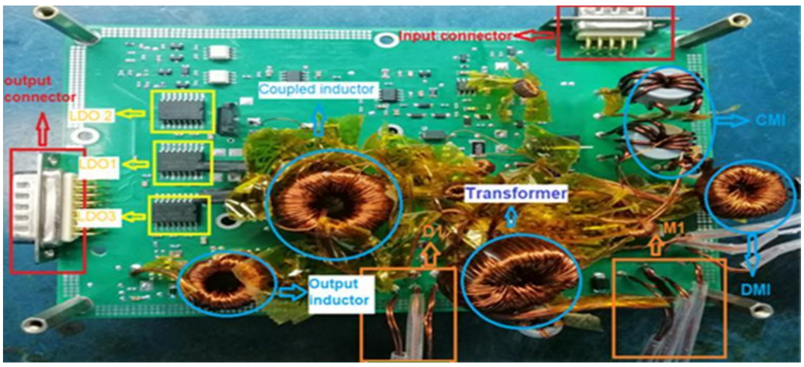

Fig4.1 PCB layout

4.1Tested waveforms of converter

The converter topology performance is evaluated by observing waveforms of all four output voltages, Mosfet gate pulse to adjust duty ratio for input voltage variation from 26V to 45V, Transformer primary current, output current, ripple voltage is measured for different load conditions from 10% to 100%. The waveform of the ramp signal generated from PWM controller is of 250kHz is shown in Fig4.2

Fig4.2 Ramp voltage waveform

The duty cycle of gate pulse varies according to the input voltage. As input voltage increases, the width of the duty pulse decreases**.** waveform of gate pulse for 37V with the duty cycle of 30% is shown in Fig4.3

Fig4.3 Gate pulse waveform for 37V

The waveform of drain to source voltage waveform of MOSFET is shown in the Fig4.4. stress on the switch is high without snubber circuit.

Fig4.4 Mosfet drain to source voltage Vds

The secondary side of the forward transformer are designed to get output voltage of 24V from synchronous buck converter with input raw voltage of 36V and other raw voltages of 14V,6V and 4V further connected to LDO regulators to regulate these voltages to 12.7 V, 5.6V and 3.8V respectively is shown in Fig4.5

Fig4.5 Multiple outputs of forward converter

24V 12.7V 5.6V 3.8V

V. Hardware Experimental Results

The practical values for Output Voltage, Output Current, Output Voltage ripple are shown in the Table 5.1 for 100% Loading Conditions for 37V Input Voltage

Table5.1:100 % Loading conditions for Nominal input voltage 37V

Parameter	Output1 (+24V)	Output2 (+12.7V)	Output3 (+3.8V)	Output4 (+5.6V)
Input Current (A)	3.641			
Output Voltage (V)	23.909	12.693	3.802	5.616
Load Current (A)	4.30	0.25	1.00	0.10
Output Power (W)	102.8	3.2	3.8	0.6
Total Output Power(W)	110.3			
Input Power (W)	134.7			
Total Loss (W)	24.4			
Efficiency (%)	81.9			
Ripple(mV)	75.0	82.0	33.6	42.0

VI. Conclusion

Multiple Output Forward Converter with Feed-Forward Control has been designed and implemented for space application. The main components include PWM Controller IC, Driver Circuit, MOSFET Switch, Transformer, LT3845 IC synchronous buck converter to obtain 24V output and Three UC2834 IC LDO's to regulate output voltage to 12.7V,5.6V and 3.8V. Hardware implementation results ±1% line and load regulation also 80% efficiency was found to be within specified norms

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