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Design and Development of Triple Output Forward DC-DC Isolated Converter for Space Application

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Abstract: An electrical load is supplied with energy by a power source, also known as an electrical device. The primary function of a power supply is to convert the source's electrical current into the precise voltage, current, and frequency required to operate a device. In order to lower the leakage inductance through the transformer core winding, the proper transformer design has been implemented. Any power source design should aim to minimize losses while also reducing losses, increasing efficiency, and decreasing size and weight. And also compared to linear power supplies, switched mode power supplies are the more efficient and accuracy at achieving these objectives. With its simple forward design, simplicity in adding numerous outputs, and low cost, forward topology is one of the available smps topologies that is well suited for low to medium power applications. However, the forward topology has a few drawbacks, including poor cross regulation for numerous output topology and high voltage stress across the MOSFET switch. Snubber circuits must therefore be used to reduce the stress across the MOSFET switch, and coupled inductors must be used to accomplish the necessary cross regulation. This undertaking the goal of this work is to design and produce a triple output forward converter with integrated protection circuits that will increase the converter's dependability. For quicker response, the proposed converter is developed and implemented with primary side voltage mode control using UC2825 PWM IC. The converter runs at a 500 KHz switching frequency. Additionally, coupled inductors are used at the secondary to improve line, load, and cross regulations. Key factors like efficiency, ripple voltages, load, line, and cross regulation at various load circumstances are tested and analyzed for the developed board. The desired 82% efficiency, as intended, is successfully attained.

Keywords: Transformer Design, MOSFET Selection, External Synchronous Circuit, Coupled Inductors Topology, UC2825 PWM IC, UC2901 Isolated Feedback IC & Efficiency.

I. INTRODUCTION

Switched-Mode Power Supply have benefits like greater efficiency, better voltage regulation, small size, and isolated multiple outputs, linear regulated power supplies are quickly being replaced by them. By working the semiconductor transistor switch's on and off modes, the SMPS circuit system regulates the amount of power to be delivered to the load. When input supply and output voltage are isolated, the forward converter topology is much easier than any other SMPS topology. Therefore, low output power applications with output power varying from a few watts to less than 100 watts are where forward converters are most frequently used. The circuit can produce one or more isolated output voltages and work with a broad range of input voltage variations. Forward converters have an output inductance and a freewheeling diode, unlike flyback converters. Although forward power supplies are less energy-efficient than many other SMPS circuits, they are still helpful in the low output power range due to their simple forward topology and low cost. To adapt to changes in input voltage and output load, PWM control method is required. As a result, the main MOSFET's duty is varied with a constant switching frequency in order to keep a constant regulated output voltage. The UC2825 voltage mode controlled PWM IC is utilized in this endeavor. Benefits of the voltage mode control technique include a simple forward control mechanism, improved cross regulation, and a decent noise margin. This control method has poor load and cross regulation for multiple output converters. Therefore, coupled inductors are used for post regulation at each output to accomplish tight line, load, and cross regulation. The current space research organizations strive for a power source that is lighter, smaller, more efficient, affordable, and highly reliable. In addition to meeting the reduced size and weight requirements for space applications, switched mode power supplies are crucial in overcoming the drawbacks of linear supplies, such as their poor efficiency and difficulty in boosting the output voltage. The triple output forward converter is being designed and developed for use in space applications to power different control circuits.

II. SPECIFICATIONS OF THE CONVERTER

Table 1 shows the specifications of the Converter.

Table.1: Converter Specifications

Sl.no	Parameter	Specifications
1	Input Voltage Range	60V - 100V DC
2	Nominal Input Voltage	70V DC
3	Topology	Forward DC-DC Isolated Converter
4	Switching Frequency	500 KHz
5	Output Voltage & Current	5V / 4A +15V / 0.667A -15V / 0.667A
6	Efficiency	78-82%
7	Line Regulation	1%
8	Load Regulation	2%
9	Cross Regulation	3%
10	Duty Cycle	20-80%
11	Output Power	40 W
12	Output Voltage Ripple	25-50mVp-p 30-60mVp-p 30-75mVp-p
13	Operating Temperature Range	–55°C to 125°C

III. BLOCK DIAGRAM

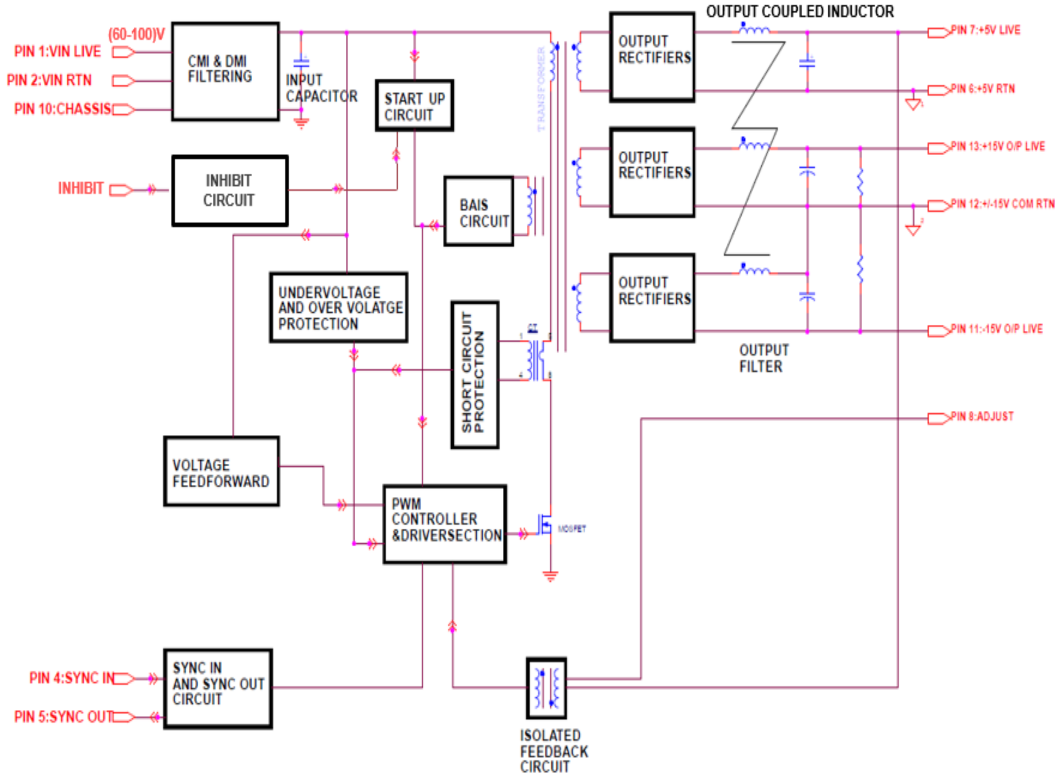


Fig.1: Block diagram of Proposed Converter

The block diagram of the triple output forward converter is as been shown in Fig.1. It consists of input section, control section, protection section and output section. Along with the bias voltage circuit that is drawn from a transformer's auxiliary winding, the input portion also includes EMI filters, a start-up circuit, and other components. PWM control IC, a MOSFET switch, and input from the bias winding make up the control section. The output short circuit safety, input under voltage protection, and output over voltage protection are all included in the protection section. In order to keep isolation among the three outputs, each output has a unique ground. The input voltage is passed through an EMI filter, which removes noise in the differential and common modes. The **UC2825 PWM IC** is initially powered by the start-up circuit, and once the converter is fully operational, bias voltage, which is higher than start-up voltage, will take over from the start-up circuit. Here, a current sense resistor measures the primary side current that is supplied to the UC2825 IC and compares it to the feedback error signal from the bias voltage feedback to produce PWM signals that operate the main MOSFET switch. By tuning the RT and CT of the PWM IC, the converter's switching frequency is subsequently changed to **500kHz**. To produce the necessary RAW voltages, the secondary side outputs are corrected and also filtered using Schottky diodes and output capacitors, respectively. These RAW voltages are passed to the appropriate coupled inductors to produce the output stage's regulated outputs of **5V/4A, +15V/0.667A, and -15V/0.667A.** The shutdown pin of the PWM IC is latched to switch off the converter in the event of any failures or abnormal conditions in all protection circuits. Additionally, the converter won't operate unless the input is reprocessed.

IV. CONVERTER DESIGN

4.1 Transformer Design

An appropriate core will be selected which must have area product greater than the calculated A_p. Area product (A_p) is given as the product of the core cross selection (A_c) and the window area (A_w). These data are available in ferrite magnetic core design catalog. The area product method is used to calculate the size of a power transformer.

The selected core is **YP-41605-TC, Material: *P*, *U*$_r$: 2500** with ***AL*: 1375mH / 1000T**.

Area product is calculated by, $$A_p = \frac{\sqrt{Dmax} * P_{out} * (1 + 1 / E_{ff})}{K_w * J * 10^{-6} * B_m * F_{sw}} \text{ in } mm^4 \tag{1}$$

Where, Window factor, K_w **= 0.4**, Current density, ***J* = 4Amp/*mm*^{2}**, Flux density, B_m **= 0.1Tesla**, P_{out} **= 41.21W**

Number of turns for the primary side of the transformer, $$N_p = \frac{V_{in\,(min)} * D_{max}}{B_m * A_C * 10^{-6} * F_{sw}} \text{ in Turns} \tag{2}$$

Number of turns ratio, $$T_{ratio} = \frac{(|V_{out1}| + V_{ld1}) + V_{d1} * D_{max}}{D_{max} * V_{in\,(min)}} \tag{3}$$

4.2 MOSFET Selection

The maximum voltage across the MOSFET in a forward converter will be twice to the maximum input voltage during the turn-off time. The MOSFET selected is therefore **IPP60R125CP, 650V, 25A, 125mOhm, PG-TO220**. The breakdown voltage of a MOSFET should be greater than three times the maximum supply voltage for safe operation.

SELECTED **IPP60R125CP / BUY65CS08J, 650V , 25A, 125mOhm, PG-TO220**.

Supply Voltage, $$V_s = V_i + \frac{N_p}{N_r} * V_i \text{ in Volts} \tag{4}$$

Rise time, $$T_r = \frac{Q_{gate} * R_{gate}}{V_{gate} - V_{th}} \text{ in Nanoseconds} \tag{5}$$

Fall time, $$T_f = \frac{Q_{gate} * R_{gate}}{V_{th}} \text{ in Nanoseconds} \tag{6}$$

Power Conduction, $$P_{conduction} = 1.25 * R_{ds} * (I_{p\_rms})^2 \text{ in Watts} \tag{7}$$

Power output capacitor loss, $$P_{coss} = \frac{C_{oss} * (V_{off})^2 * F_{sw}}{2} \text{ in Watts} \tag{8}$$

Power switching ON loss, $$P_{switching\_on} = \frac{V_{in\,(min)} * I_{pft} * (T_r) * (F_{sw})}{3} \text{ in Watts} \tag{9}$$

Power switching OFF loss, $$P_{switching\_off} = \frac{V_{off} * I_{pft} * (T_f) * (F_{sw})}{3} \text{ in Watts} \tag{10}$$

4.3 Selection of Secondary Output Diodes

Forward converters must have output secondary diodes because they regulate the system's output voltage, making them a crucial part of the device. In a forward converter, the secondary diodes are frequently schottky diodes that can sustain large reverse voltages. The ability to reduce voltage spikes and noise in the system is one benefit of using output secondary diodes in a forward converter.

The output secondary diodes in a forward converter are in a state of conducting current during the switching cycle's off-time. By eliminating reverse current flow and minimizing losses, output secondary diodes can increase the efficiency and dependability of a forward converter. In a forward converter, the selection of output secondary diodes is performed based on the load characteristics, operating conditions, and utilized system performance.

4.3a Selecting a Diodes for Output1

Freewheeling diode voltage1, $V_{fwd1} = \frac{N_{s1} * V_{in\,(max)}}{N_p} = 18.1333V$ (11)

Forward diode voltage1, $V_{fd1} = \frac{N_{s1} * V_{in\,(max)}}{N_p} = 18.9833V$ (12)

Reflected secondary diode voltage1, $V_{SreflectedD1} = \frac{1.5 * V_{fwd1}}{0.7} = 38.8571V$ (13)

The diode that was chosen based on above conditions is a **100V, 16A, 16CYQ100C** (Industrial), and a **SC105H100SCDV** (Space Grade Die).

4.3b Selecting a Diodes for Output2

Freewheeling diode voltage2, $V_{fwd2} = \frac{N_{s2} * V_{in\,(max)}}{N_p} = 49.8667V$ (14)

Forward diode voltage2, $V_{fd2} = \frac{N_{s2} * V_{in\,(max)}}{N_p} = 50.7167V$ (15)

Reflected secondary diode voltage2, $V_{SreflectedD2} = \frac{1.5 * V_{fwd2}}{0.7} = 106.8571V$ (16)

The **400V, 4A, 1N6627** (Space Grade Die) diode was chosen based on the above-mentioned specifications.

4.3c Selecting a Diodes for Output3

Freewheeling diode voltage3, $V_{fwd3} = \frac{N_{s3} * V_{in\,(max)}}{N_p} = 49.8667V$ (17)

Forward diode voltage3, $V_{fd3} = \frac{N_{s3} * V_{in\,(max)}}{N_p} = 50.7167V$ (18)

Reflected secondary diode voltage3, $V_{SreflectedD3} = \frac{1.5 * V_{fwd3}}{0.7} = 106.8571V$ (19)

The chosen diode for the above-mentioned parameters is the **16CYQ150** (Industrial), **150V, 16A, SC125H150ACDV** (Space Grade Die), / **SHD125146SSQ** (Alternate Space Grade), **200V, 7.5A**.

4.3d Selecting a Diode for Bias Winding (Primary Bias)

Freewheeling diode bias voltage, $V_{fwd\_bias} = \frac{N_{bias} * V_{in\,(max)}}{N_p} = 40.8V$ (20)

Forward diode bias voltage, $V_{fd\_bias} = \frac{N_{bias} * V_{in\,(max)}}{N_p} = 41.2V$ (21)

Reflected secondary diode voltage1, $V_{SreflectedD} = \frac{1.5 * V_{fwd\_bias}}{0.7} = 87.4286V$ (22)

The **1N5806, 150V, 2.5A** (Space Grade Die) diode was chosen based on the above-mentioned specifications.

4.4 Total Losses and Total converter Efficiency

When all of the input energy is lost as waste heat and none is transformed into the required output form, a converter can sustain total losses. Total efficiency, on the other hand, happens when all of the input energy is efficiently transformed into the desired output form. Advanced converter design strategies including pulse-width modulation, soft switching, and resonant circuits, among others, can be used to increase efficiency and decrease losses. In addition, careful consideration of component choice, thermal control, and circuit structure can reduce losses and increase efficiency in converter designs.

Total Loss in Converter, $Total\_Loss = P_{Xmer} + P_{mosfet\_loss} + PD_{out1} + PD_{out2} + PD_{out3} + P_{coupled\_inductor} + PD_{bias} + P_{controller1} + P_{Lbias} + P_{controller2} + P_{other\_losses}$ (23)

$Total\_Loss = 7.8897W$

Minimum input voltage, $V_{in\,(min)} = 58V$

Average current, $I_{ave} = 0.9109A$

Input power, $P_{in} = V_{in\,(min)} * I_{ave} = 52.833W$ (24)

Output power, $P_{out} = 41.21W$

Total Efficiency of Converter, $Total\_Eff = \frac{P_{out} * 100}{P_{out} + Total\_Loss} = 83.931\ \%$ (25)

4.5 Inhibit

The converter can be manually turned off using the inhibit signal, which also reduces the input current consumed by the regulator and turns off the converter without interrupting the input voltage.

4.6 External Circuit for In / Out Synchronization

Forward converters with one frequency utilize synchronization circuits to sync with devices with various frequencies. Due to the asynchronous operation of different switching frequencies, it is challenging to analyze or predict the input ripple when two or more converters operate at different switching frequencies. This also creates harmonic contents at the input DC bus that are challenging to eliminate.

4.7 Forward Converter Working with Coupled Inductors Topology

Multiple outputs filter inductors are had been tightly coupled to one another on the same core. Better coupling, less leakage, and quick response are all features of this Forward Converter topology. It is noted that coupled inductor performs the function of voltage regulation in the absence of additional regulators or LDO acting as post-regulators. An RCD snubber for reset is used with a single switch forward converter. Zener/LDOs are typically utilized as post regulators. Here, a new forward topology with coupled inductor as post regulator is employed to decrease size, cost, and improve efficiency. The fact that all of the filter inductors with multiple outputs are coupled to the same core creates a tight coupling and minimizes leakage.

4.8 UC2825 High Speed PWM Controller IC

PWM control ICs of the UC2825 family are designed for high frequency switched mode power supply applications. With the ability to feed-forward input voltage, this controller is designed for use in current-mode or voltage-mode systems. One low-side MOSFET needs to be driven by the switching frequency, which is 500 kHz, in a forward converter. Texas Instruments' UC2825 PWM Controller IC was implemented. The **RT** and **CT** pins of PWM are adjusted, with the CT value chosen from the datasheet and the RT value set, in order to set the required switching frequency. To correctly obtain a switching frequency of 500 KHz, the RT and CT values are utilized accurately. Internally, this PWM IC is provided with a ramp generator and an error amplifier.

4.9 Voltage Feedforward control Technique

The forward converter regulates the output of 5V/4A, +15V/0.667A, and -15V/0.667A with a fixed switching frequency while operating with a wide range of input voltage from 60-100V and variable loads from 10% to 100%. The PWM technique is utilized to achieve this. There are a few drawbacks to the voltage control technology, such as the variable loop gain with input voltage and the challenging scaling. Input voltage feedforward approach is thus introduced as a new method. The error amplifier is connected to the comparator's inverting point in this feedforward technique, and the oscillatory or feedforward circuit is connected to the comparator's non-inverting point. The error signal and feedforward signal are then compared, and the obtained output is a pulse that is connected to the PWM IC pin. In order to prevent the delay caused by the error amplifier, the Vin has been supplied to the feedforward circuit. Here, the ramp gets compared with the reference voltage, and we obtain an output pulse with a different duty.

4.10 UC2901 Isolated Feedback Generator IC

The high-speed MOSFET driver IC known as the UC2901 has been designed with high-frequency switching power supply in consideration. The UC2901 includes a variety of practical features, such as built-in undervoltage lockout protection, thermal shutdown protection, and an adjustable dead-time control to avoid shoot-through current. Many of the difficulties involved in closing a feedback control loop over a voltage isolation boundary are been solved by the UC2901 family of devices. The UC2901 series' programmable high-frequency oscillator enables the use of more affordable, smaller transformers that are easily built to satisfy the isolation needs of today's line-operated power systems. A square wave with an amplitude proportionate to the error amplifier input signal is the waveform at the driver outputs. The external clock input to these devices provides synchronization to a system clock or to the switching frequency of an SMPS as an alternative to RF operation.

V. SIMULATION AND HARDWARE EXPERIMENTAL RESULTS

5.1 Simulation Experimental Results

A feedback path is provided to the system to improve its transient and steady state response. As a feedback, voltage controller with type 2 Compensation Technique is employed. It is clear that simulation is essential for any system's initial design. Simulation can be used to predict system behavior and performance. The output-regulated closed loop system is designed in LTspice software is shown as illustrated in fig.2.

Table.2: Design Simulation Specifications

Sl.no	Parameter	Values
1	V_s	70V
2	V_{o1}, V_{o2}, V_{o3}	5V, +15V, -15V
3	I_{01}	4A
4	I_{02}, I_{o3}	0.667A
5	D	0.4
6	F_{sw}	500KHz
7	R_{L1}	1.25Ω
8	R_{L2}, R_{L3}	22.48Ω
9	L_1	2784µH
10	L_2	88µH
11	L_3, L_4	606µH
12	L_5	6µH
13	L_6, L_7	48.38µH
14	L_8	445µH
15	C_1	800µF
16	C_2, C_3	400µF

The output voltage (V_o) was kept constant at a level of 5V, +15V, -15V while the simulation was run for various input conditions (from 60V to 100V) and loads (for 1.25Ω & 22.48Ω). The duty cycle of the gate pulse to the MOSFET is adjusted to keep the output voltages constant even when the input voltage varies from 60V to 100V. The closed loop simulation will also improve the converter's dynamic response. As a result of the open loop system's output voltage inaccuracy, an unstable system can be observed. A feedback path is provided to stabilize the system, as shown in fig. 2. The output voltage error is determined and provided to the controller after being compared to the reference voltage.

For the simulation study, the inductance calculation is as follows.

Selected Toroid Core: **YP-41605-TC / ZP41605TC**, **AL: 1375nH/T2**.

Inductance, $L = A_L * N^2$ (26)

Where, $\boldsymbol{L}$ = Inductance and $\boldsymbol{N}$ = Number of turns.

Simulation circuit of **Triple output forward converter** is represented in **Fig. 2.**

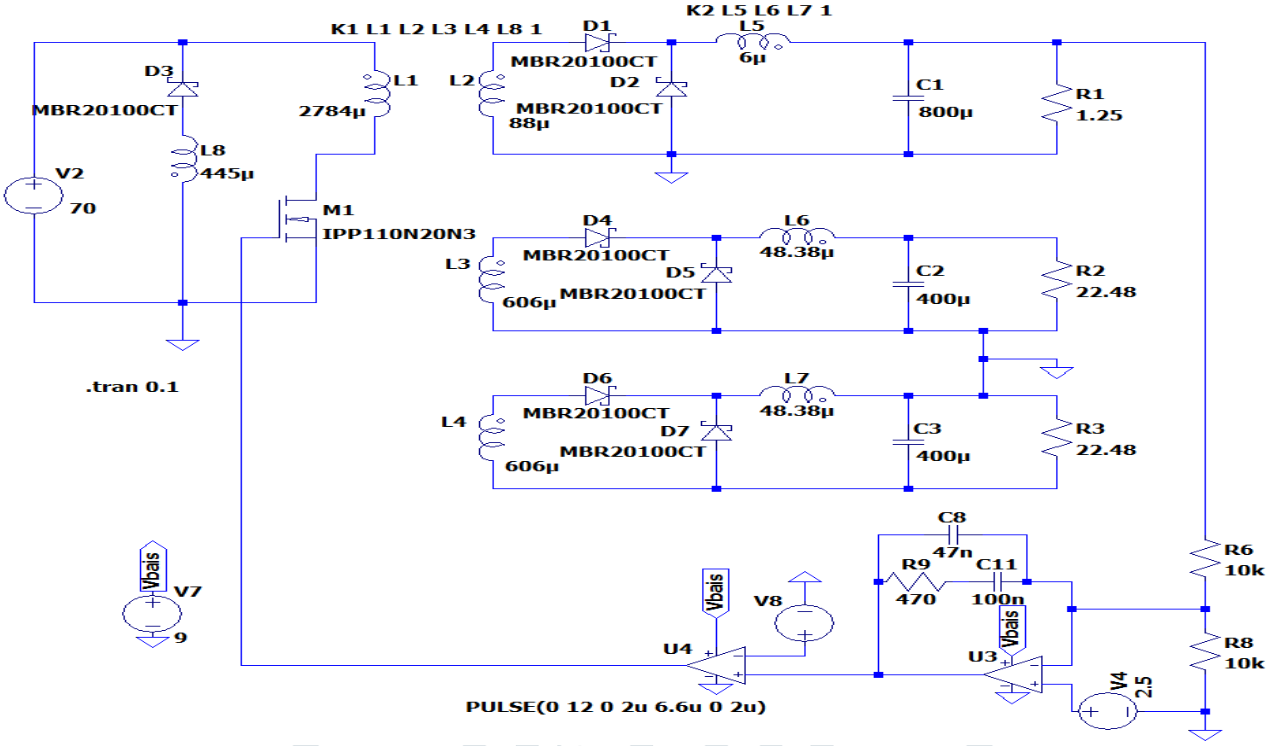


Fig.2: Circuit of Closed Loop Triple Output Forward Converter

The output is provided to the switch once the controller's signal and the ramp signal have been compared. The output is kept constant, and the dynamic response and output voltage ripple have been improved. By providing a voltage controller to provide feedback to the converter, the peak overshoot was decreased, which enhanced its transient response.

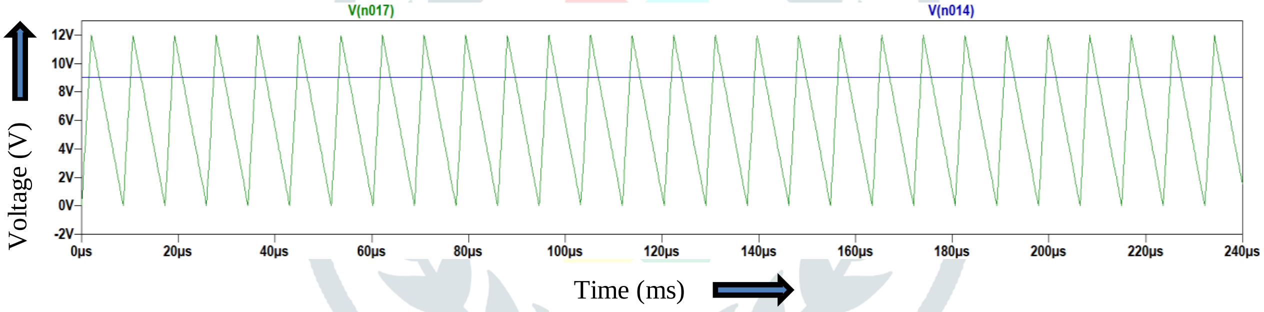


Fig.2.1: Ramp and Reference Voltage

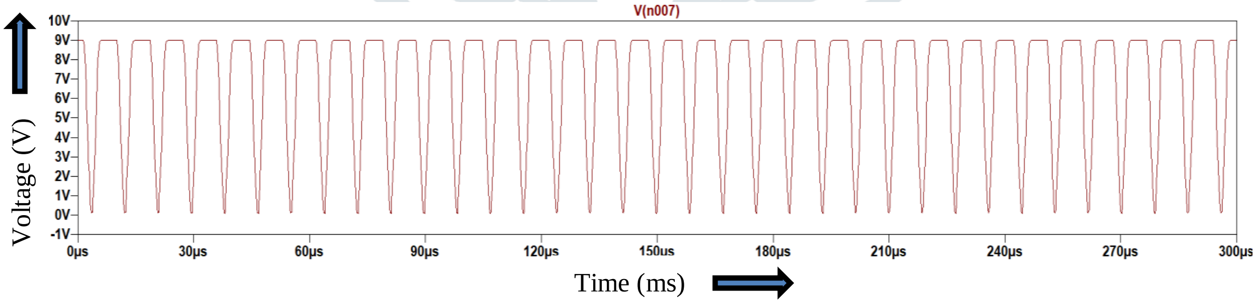
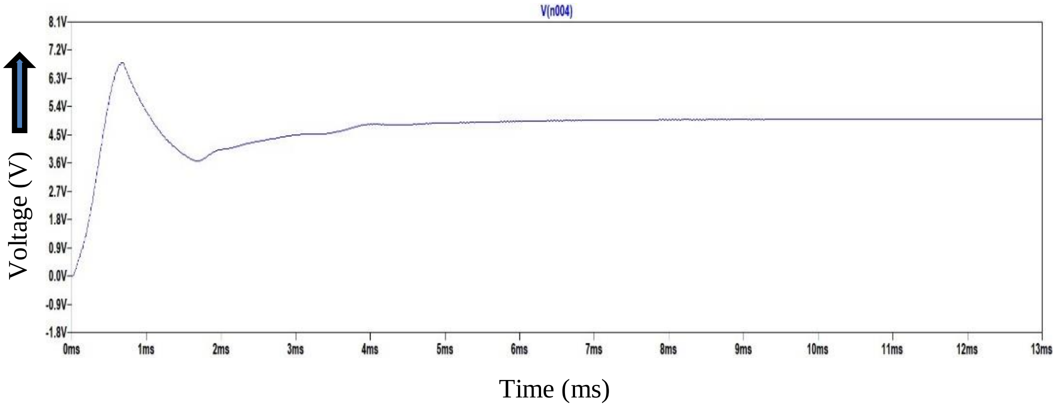
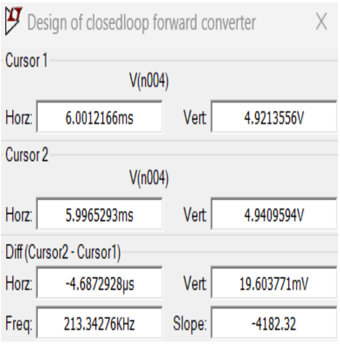


Fig.2.2: Gate Pulse Voltage





Cursor 1

V(n004)

Horz: 6.0012166ms Vert: 4.9213556V

Cursor 2

V(n004)

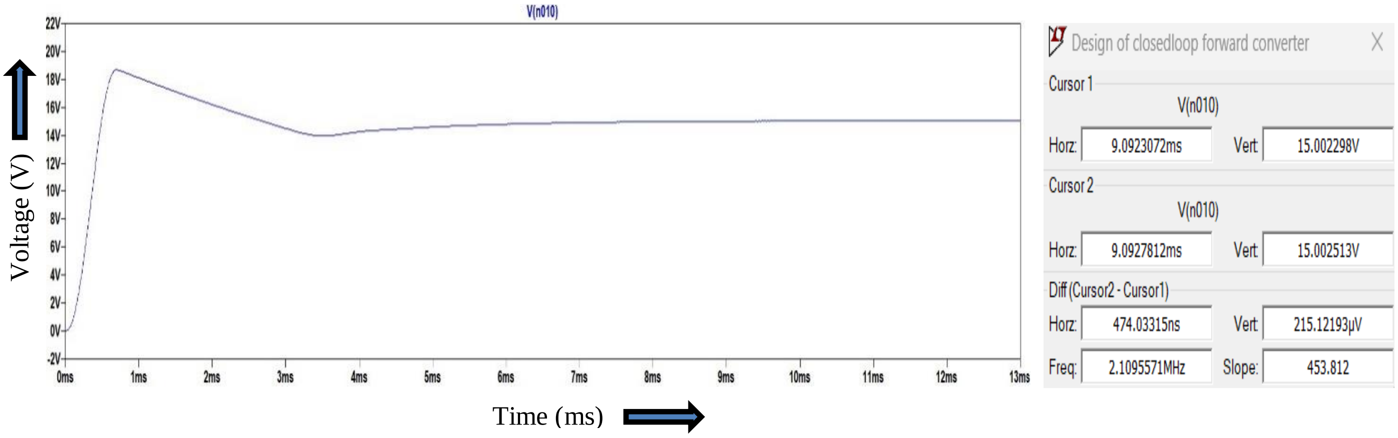
Horz: 5.9965293ms Vert: 4.9409594V

Diff (Cursor2 - Cursor1)

Horz: -4.6872928µs Vert: 19.603771mV

Freq: 213.34276KHz Slope: -4182.32

Fig.2.3: First Output Voltage

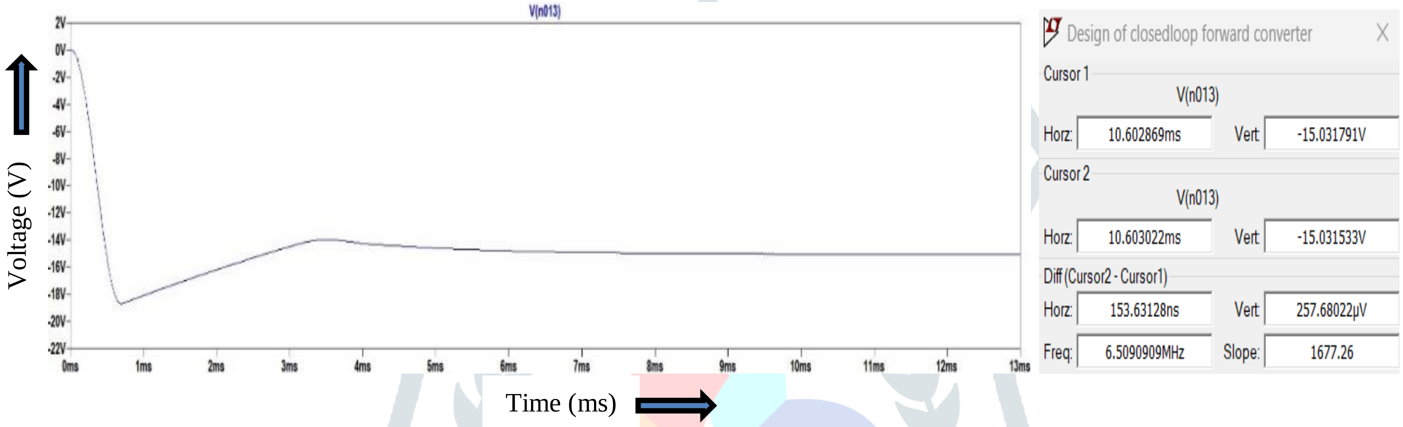


Cursor 1
V(n010)
Horz: 9.0923072ms Vert: 15.002298V

Cursor 2
V(n010)
Horz: 9.0927812ms Vert: 15.002513V

Diff (Cursor2 - Cursor1)
Horz: 474.03315ns Vert: 215.12193µV
Freq: 2.1095571MHz Slope: 453.812

Fig.2.4: Second Output Voltage

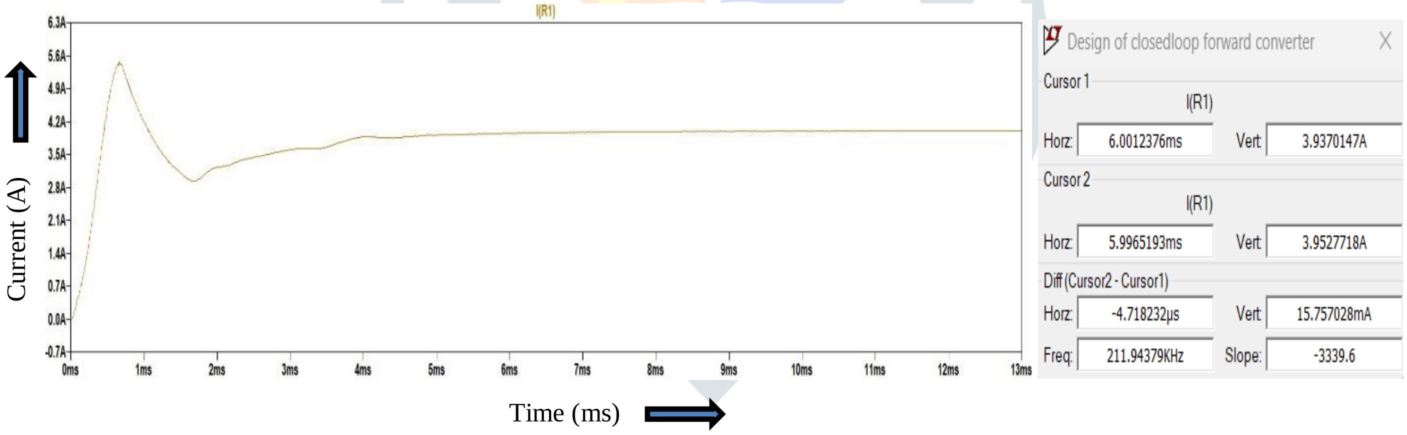


Cursor 1
V(n013)
Horz: 10.602869ms Vert: -15.031791V

Cursor 2
V(n013)
Horz: 10.603022ms Vert: -15.031533V

Diff (Cursor2 - Cursor1)
Horz: 153.63128ns Vert: 257.68022µV
Freq: 6.5090909MHz Slope: 1677.26

Fig.2.5: Third Output Voltage

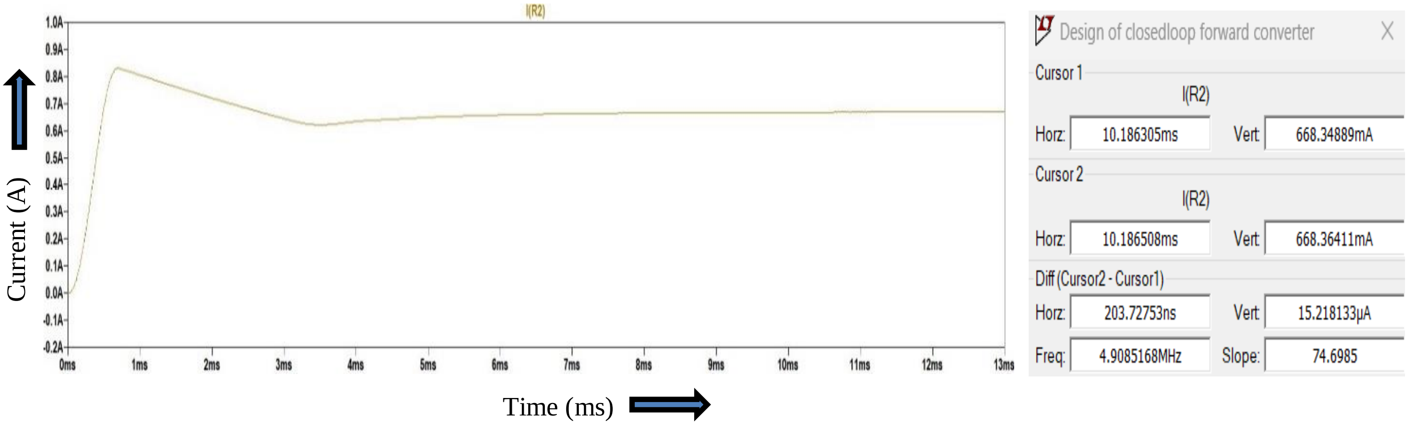


Cursor 1
I(R1)
Horz: 6.0012376ms Vert: 3.9370147A

Cursor 2
I(R1)
Horz: 5.9965193ms Vert: 3.9527718A

Diff (Cursor2 - Cursor1)
Horz: -4.718232µs Vert: 15.757028mA
Freq: 211.94379KHz Slope: -3339.6

Fig.2.6: First Output Current

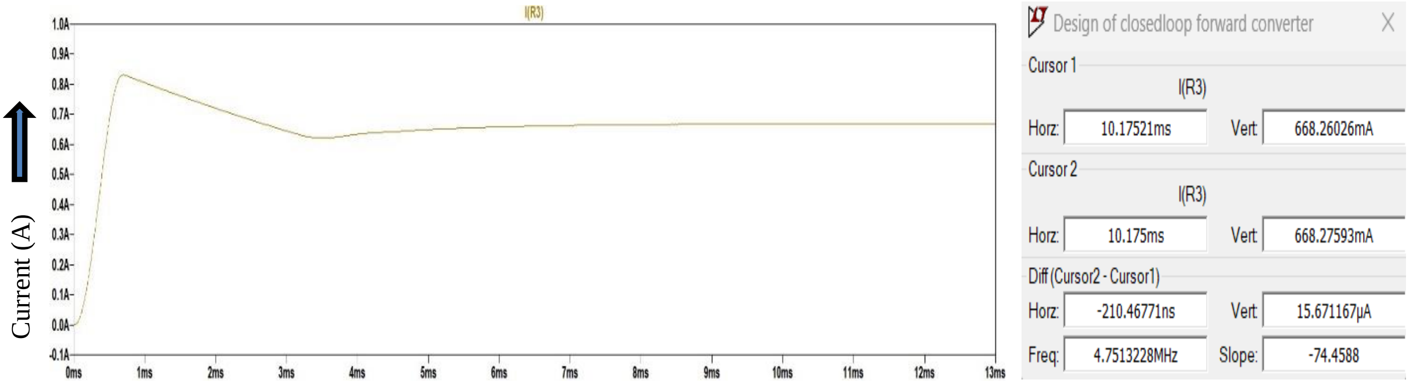


Cursor 1
I(R2)
Horz: 10.186305ms Vert: 668.34889mA

Cursor 2
I(R2)
Horz: 10.186508ms Vert: 668.36411mA

Diff (Cursor2 - Cursor1)
Horz: 203.72753ns Vert: 15.218133µA
Freq: 4.9085168MHz Slope: 74.6985

Fig.2.7: Second Output Current



Design of closedloop forward converter

Cursor 1
I(R3)
Horz: 10.17521ms Vert: 668.26026mA

Cursor 2
I(R3)
Horz: 10.175ms Vert: 668.27593mA

Diff (Cursor2 - Cursor1)
Horz: -210.46771ns Vert: 15.671167µA
Freq: 4.7513228MHz Slope: -74.4588

Fig. urrent

5.2 Hardware Experimental Results

The triple output forward converter experimental setup is shown in Fig. 3. Digital storage oscilloscope (DSO), converter, electronic load, pulse generator, multimeter, and input power supply are various components of the experimental setup. The input voltage can be regulated between 60 and 100 volts at the minimum, nominal, and maximum load levels. The table above shows the efficiency, line regulation, load regulation, cross regulation and ripple voltages. The test results under full load are shown in tabular format.

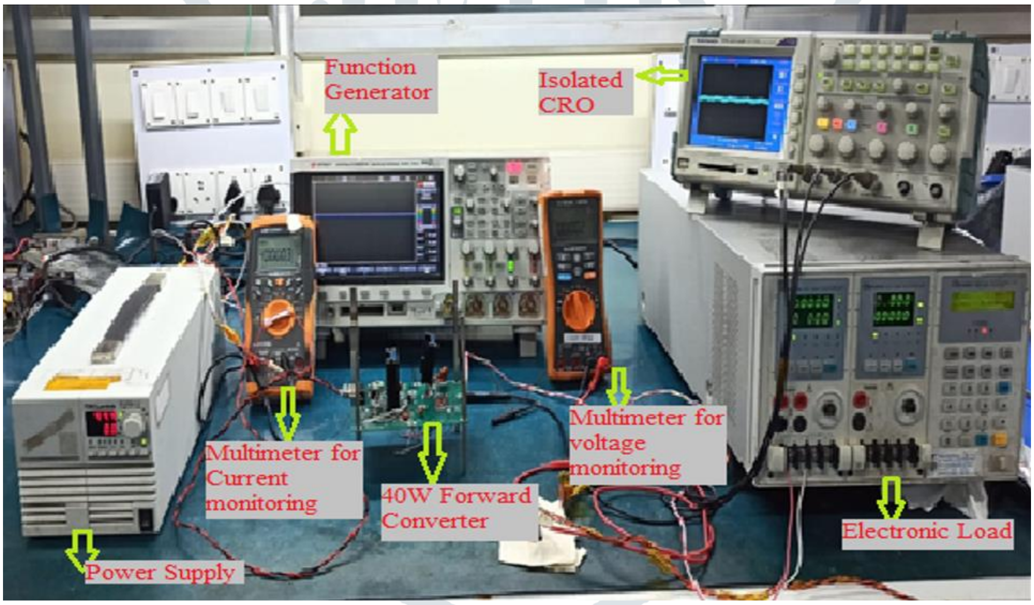


Fig.3: Shows the Hardware Setup for a Triple Output 40W Converter

5.2.1 Output Voltage & Efficiency

As shown in table 3 below, the output voltage is determined at varying input voltages and load condition. At the minimum and the maximum values, input current, input power, and output power, efficiency are observed to be 82%.

Table.3: Output voltages at full load from 60V - 100V input voltages & efficiency

Vin (V)	5V O/P Vout1	+15V O/P Vout2	-15V O/P Vout3	Iin (A)	Ip (W)	Op (W)	Efficiency (%)
60	4.927	14.930	15.050	0.8000	48.00	39.70	82.7
70	4.927	14.936	15.050	0.7000	49.00	39.70	81.0
100	4.947	14.900	15.040	0.4800	48.00	39.75	82.8

5.2.2 Output Voltage Ripple

Table.4: Output ripple voltages at 100% load from 60 - 100V input voltage

Vin (V)	Output Ripple Voltage (mV) Spec: Nom: 20mV Max: 50mV		
	5V O/P	+15V O/P	-15V O/P
	Vout1	Vout2	Vout3
60	16	18	28
70	30.4	22	22
100	16	24	22

5.2.3 Line Regulation

Table.5: Line regulation at full load

Vin (V)	Load Condition	Line Regulation (%)		
		5V O/P	+15V O/P	-15V O/P
		Vout1	Vout2	Vout3
60	10%	0.00	0.6265	0.6266
	100%	0.0072	0.033	0.006
100	10%	0.00	0.54	0.56
	100%	0.023	0.039	0.039

5.2.4 Load Regulation

Table.6: Load regulation from 60V - 100V input voltages

Vin (V)	Load Regulation (%)		
	5V O/P	+15V O/P	-15V O/P
	Vout1	Vout2	Vout3
60	0.18	2.01	1.99
70	0.189	2.00	1.98
100	0.213	1.54	1.59

5.2.5 Cross Regulation

Table.7: Cross regulation from 60V - 100V input voltages

Vin (V)	Cross Regulation (%)		
	5V O/P	+15V O/P	-15V O/P
	Vout1	Vout2	Vout3
60	0.03	0.03	0.02
70	0.02	0.03	0.02
100	0.02	0.03	-0.02

5.2.6 Inhibit

Table.8: Inhibit at input voltage from 60 - 100V

Parameter	INHIBIT TEST			
	Open Circuit voltage (3 - 5) V	Voltage range (-0.5 – 100) V	Converter turn-on voltage (> 0.8) V	Drive current(sink) <(100uA)
60V (10% load)	3.98	0.5 to 100	1.36	18.4
60V (100% load)	4.11	0.5 to 100	1.39	21.23
100V (10% load)	3.99	0.5 to 100	1.26	49.97
100V (100% load)	4.34	0.5 to 100	1.25	49.97

5.2.7 Synchronization In / Out

Table.9: Synchronization test at 450-550 kHz range in frequency

Synchronization 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
550 kHz	YES	YES	YES	YES

5.2.8 40W Triple Output Converter Ripple Waveforms of 70V at Full Load

The 40W DC-DC triple output forward converter has ripples that all are within specification like 30.4mV, 22mV, and 22mV at maximum load and nominal voltage is shown in fig.4.

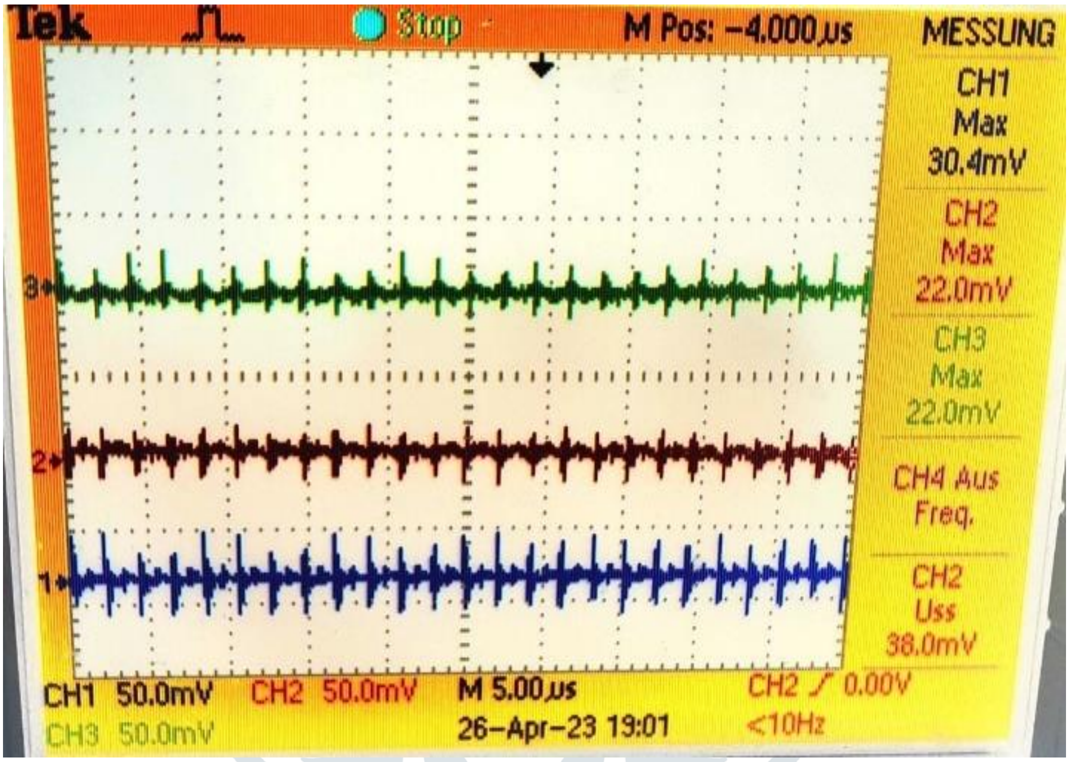


Fig.4: Input Voltage: 70V, CH1: 5V/4A, CH2: +15V/0.667A, CH3: -15V/0.667A

5.2.9 MOSFET Gate Voltage (Vgs) of 70V waveform at full load condition

As shown in Fig.5, the MOSFET gate voltage output waveform of the 40W DC-DC triple output forward converter has a gate voltage of 10.2V, which is within the specified range.

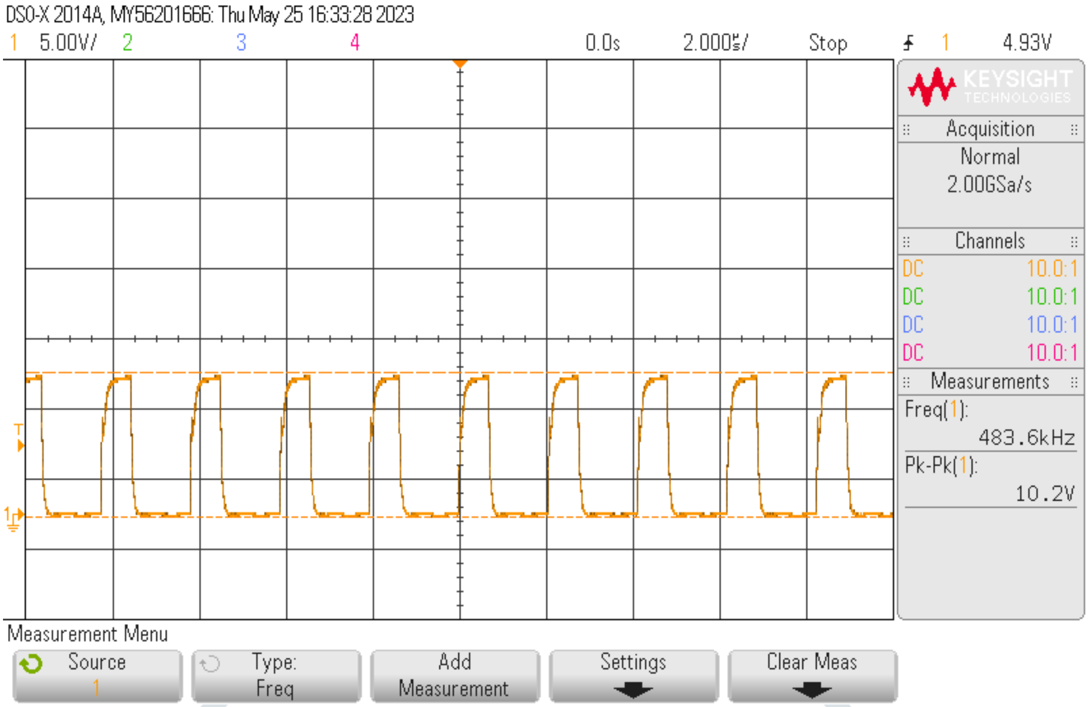


Fig.5: Input Voltage: 70V, Nom. Gate Voltage: 10.2V

5.2.10 MOSFET Drain Voltage (Vds) of 70V waveform at full load condition

The 40W DC-DC triple output forward converter's MOSFET drain voltage output waveform is illustrated in Fig.6 with a full load and the nominal voltage, and it is within specifications with a 129V drain voltage.

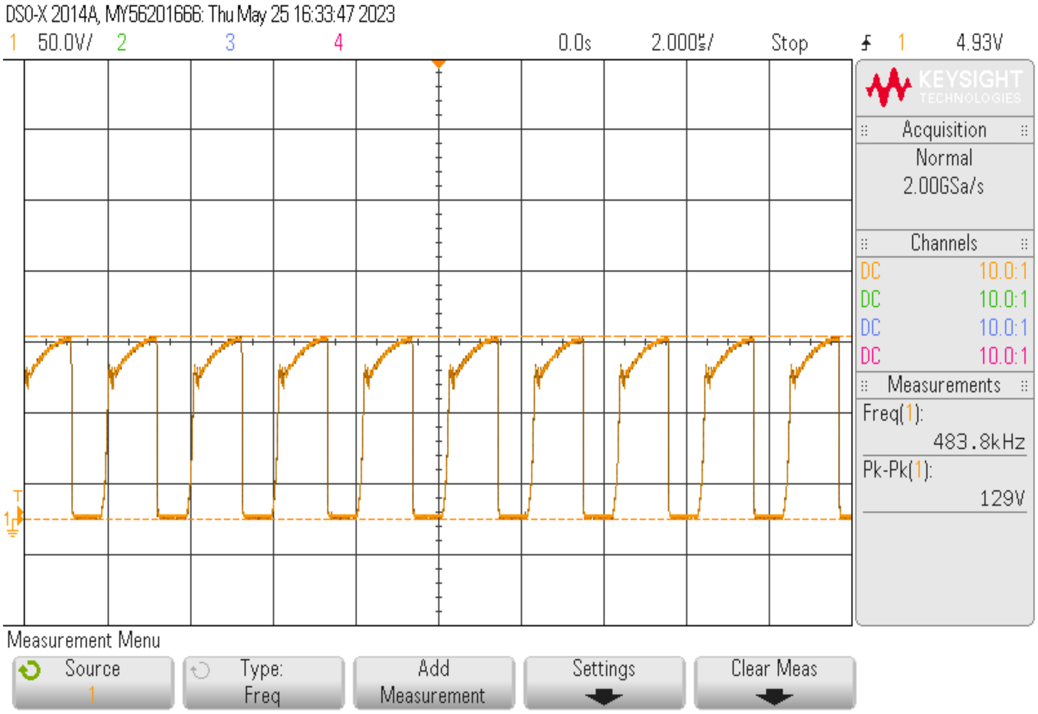


Fig.6: Input Voltage: 70V, Nom. Drain Voltage: 129V

VI. CONCLUSION

Triple output isolated forward converter has been implemented using voltage mode control technique and coupled inductor as post regulators. Post regulators that are properly designed to regulate output voltages to well within the desired range. As seen in the practically validated experimental results at the full load 100% with the varied input voltages, the output ripple, MOSFET stress, Diode stress, Line regulation, cross regulation and Load regulation are all within specification. The use of a snubber circuit increases converter efficiency by 4-5% overall. Future research can focus on improving the digitally controlled MOSFET, feedforward technology's and the efficiency. The analysis is particular to space application. The design follow-up has been verified in hardware for all three outputs, and all simulation and hardware experimental results and waveforms are shown sequentially.

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