Switching Power Converter Lab

Translated by ShyShenq Liou

This document is translated from the Chinese version published by Dr. Edwin Wang of the MatriTek Inc.

Preface:

There are four different modules in this manual: Buck, Flyback, Forward, and Push-Pull converters. Each experimental module should coincide with the lecture in order for students to maximize the understanding and re-enforcement of the theories of power supply converters covered in lecture. The circuit used in each module can enhance student's learning in power supply converter.

1. Buck Converter

   Learning Index:

   a) Realization of basic power converter circuit
   b) Calculation of circuit efficiency
   c) Functionality and application of PWM IC
   d) Characteristics and driving of P-MOSFET
   e) Characteristics of Schottky Diode
   f) Characteristics and making of Ferrite core inductor
   g) Parameters of feedback circuit
   h) Realization of control circuitry
   i) Estimate and measurement of circuit efficiency

2. Flyback Converter

   Learning Index

   a) Realization of power converter circuit
   b) Calculation of Circuit Efficiency
   c) Functionality and application of Current-Mode Control PWM IC
   d) Characteristics and driving of N-MOSFET
   e) Characteristics and making of coupled inductor
   f) Estimate and measurement of circuit efficiency

3. Forward Converter

   Learning Index

   a) Realization of power converter circuit
   b) Calculation of Circuit Efficiency
   c) Functionality and application of Current-Mode Control PWM IC
   d) Characteristics and driving of N-MOSFET
   e) Characteristics and making of transformer
   f) Technique to reset the transformer core
   g) Characteristics and making of Ferrite core inductor
   h) Estimate and measurement of circuit efficiency

4. Push-Pull Converter

   Learning Index

   a) Realization of power converter circuit

b) Calculation of Circuit Efficiency
c) Functionality and application of PWM IC
d) Characteristics and making of transformer
e) Technique to reset the transformer core
f) Characteristics and making of Ferrite core inductor
g) Isolation feedback circuitry
h) Estimate and measurement of circuit efficiency

Student should be able to learn practical experience by assembling these modules. For experienced students, the switching frequency and input voltage can be changed so they can explore more, assuming that some components must be redesigned and reselected. It is the hope of the author that these modules and their circuits can benefit those people interested in power electronics.

Sincerely,

Dr. Edwin Wang
MatriTek Inc.
March 19, 2004.

Module 1
Making of BUCK Switching Regulator

1. One Component Kit
2. General Specifications
3. Schematics
4. Building Diagram for Magnetic Component
5. Diagram of the printed circuit board
6. Part List
7. Assembling Procedure and Things to watch out
8. Reference
9. Estimate and Measurement

Model Name: BUCK 4A-12-5

GENERAL SPECIFICATION

INPUT VOLTAGE 8 VDC TO 12VDC

OUTPUT VOLATGE 5VDC

OUTPUT CURRENT 0.1 A TO 4A

OUTPUT RIPPLE VOLTAGE 50mV

LOAD REGULATION +/- 1%

LINE REGULATION +/- 1%

TRANSIENT RESPONSE @ 2A TO 4A, 0.1A/uS
- OVERSHOOT / UNDERSHOOT 200mV
- SETTLING TIME 500Us

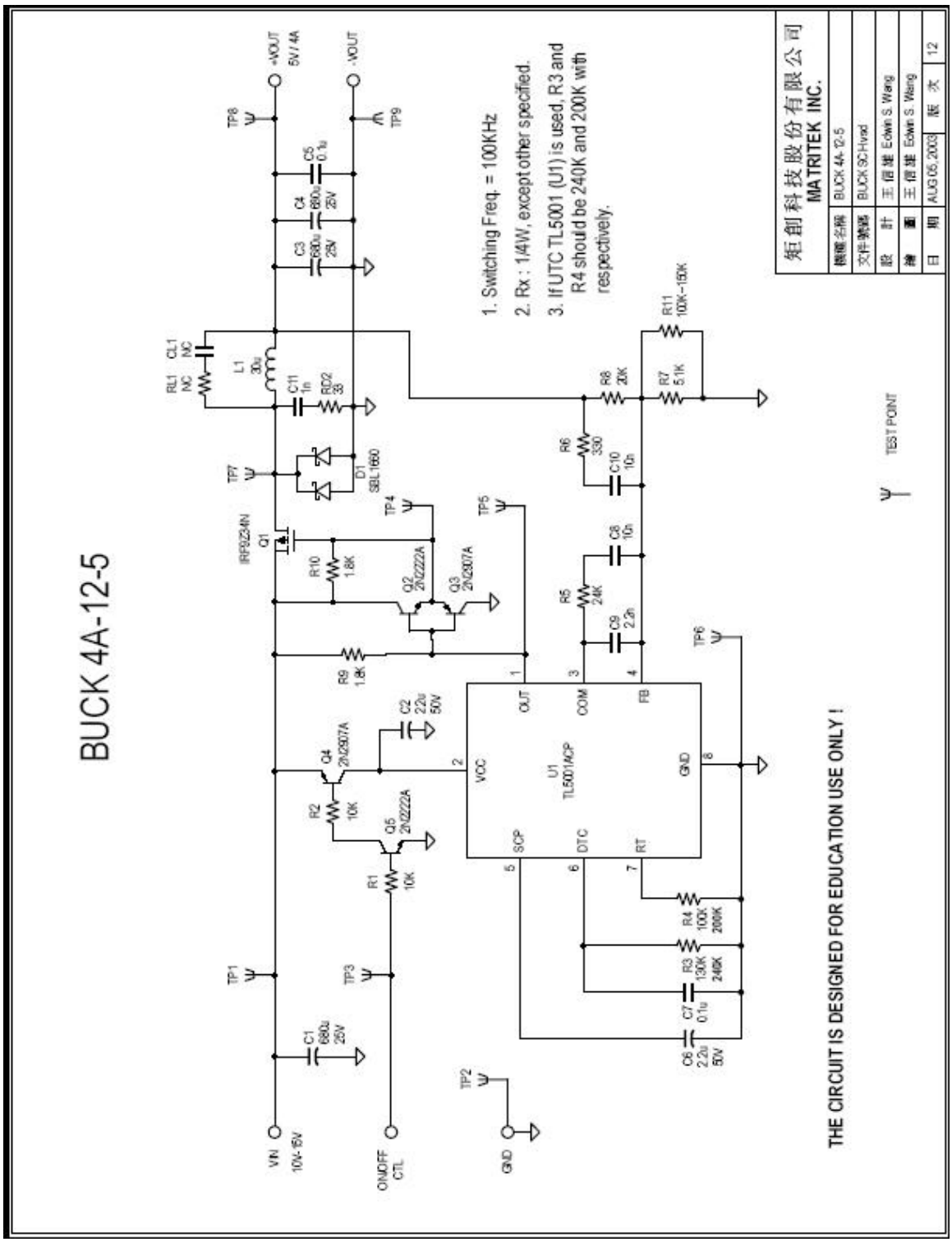
START UP
- RISE TIME 100 mS
- OVERSHORT 250 mV
- DELAY TIME 0.5 mS

SHORT-CIRCUIT PROTECTION LATCHED

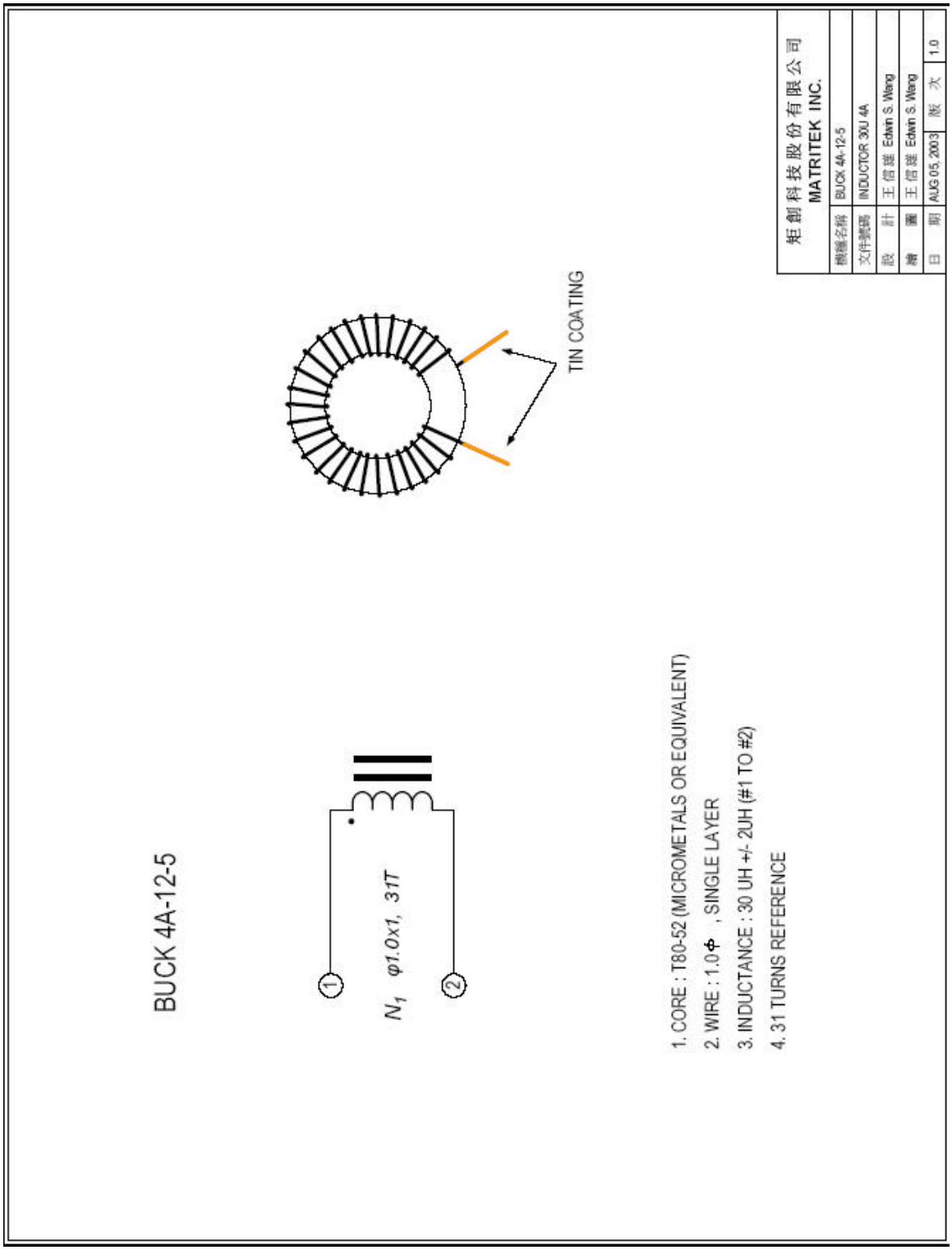
EFFICIENCY > 85% @ I/P : 10V , O/P : 4A

REMOTE CONTROL HIGH ACTIVE

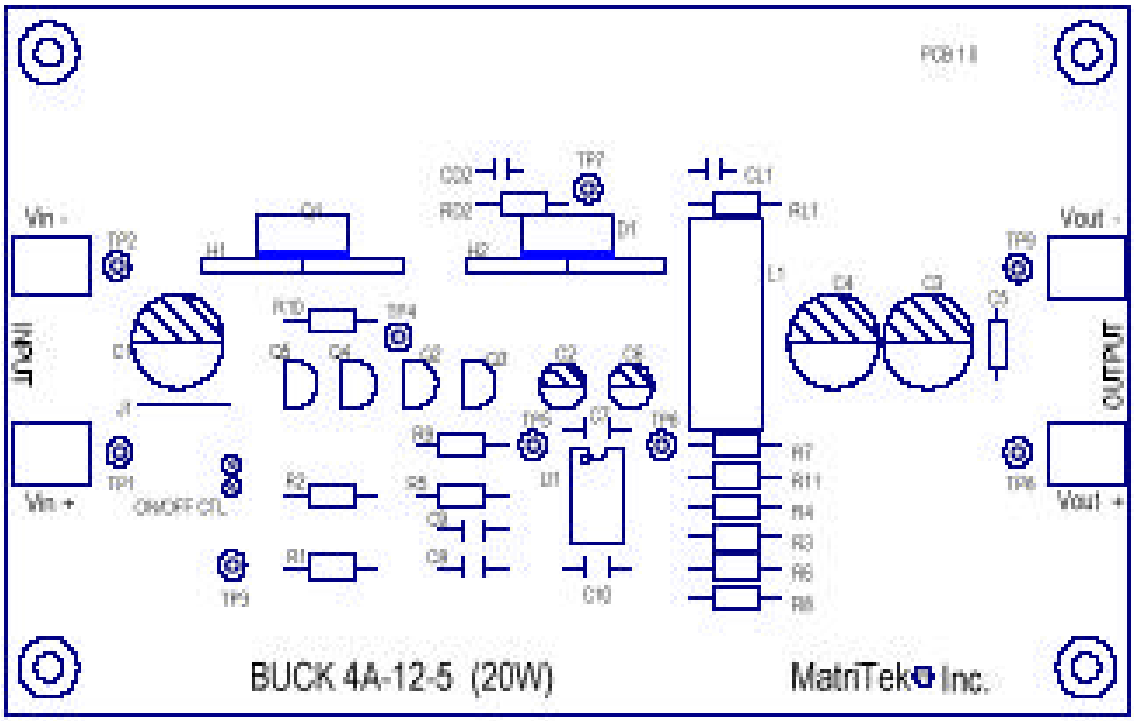
Schematics of BUCK Converter



Inductor



Printing side of the PCB


PCB 1.1
Vin -
Vin +
INPUT
TP2
TP1
H1
H2
C4
C1
J1
ON/OFF CTL
TP3
R10
TP4
C6
C5
C7
C2
C8
R9
TP5
TP7
TP8
U1
R2
R5
C11
C9
R1
C10
C12
D1
L1
RL1
R7
R11
R4
R3
R6
R8
C4
C3
C5
TP9
TP6
Vout -
Vout +
OUTPUT
BUCK 4A-12-5 (20W)
MatriTek Inc.

Part List

Item	PCB Position	Note	Quantity
1	R1	RES 10K +/-1% 1/4W	1
2	R2	RES 10K +/-1% 1/4W	1
3	R3	RES 240K +/-1% 1/4W	1
4	R4	RES 200K +/-1% 1/4W	1
5	R5	RES 24K +/-1% 1/4W	1
6	R6	RES 330 +/-1% 1/4W	1
7	R7	RES 5K1 +/-1% 1/4W	1
8	R8	RES 20K +/-1% 1/4W	1
9	R9	RES 1K8 +/-1% 1/4W	1
10	R10	RES 1K8 +/-1% 1/4W	1
11	R11	RES 150K +/-1% 1/4W	1
12	RD2	RES 33 +/-1% 1/4W	1
13	RL1	RES NC +/-1% 1/4W	0
14	C1	EC 680U 25V 10X20	1
15	C2	EC 2U2 50V 6X11	1
16	C3	EC 680U 25V 10X20	1
17	C4	EC 680U 25V 10X20	1
18	C5	MLCC 104 50V	1
19	C6	EC 2U2 50V 6X11	1
20	C7	MLCC 104 50V	1
21	C8	MLCC 103 50V	1
22	C9	MLCC 222 50V	1
23	C10	MLCC 103 50V	1
24	C11	MLCC 102 50V	1
25	CL1	MLCC NC 50V	0
26	L1	CHOKE 30U 4A T80-52	1
27	Q1	PMOS IRF9Z34N 55V/19A	1
28	Q2	XTOR NPN 2N2222A	1
29	Q3	XTOR PNP 2N2907A	1
30	Q4	XTOR PNP 2N2907A	1
31	Q5	XTOR NPN 2N2222A	1
32	D1	SBD SBL1660 60V/16A TO220	1
33	U1	IC PWM CONTROLLER TL5001ACP	1
34	H1,H2	HEATSINK 20X30X1	2
35	SCREW	SCREW PAN HEAD M3X7	2
36	NUT	NUT M3	6
37		INSULATOR TO-220	2
38		INSULATOR SILICON TO-220	2
39	TP1~9	TEST PIN 0.8D 10mm	9
40	IN/OUT	POWER CONNECTOR	4
42		COPPER STAND	4
41	PCB	PCB 3X5 BUCK 4A-12-5	1

Assembly Procedure and Things to Watch Out for BUCK 4A-12-5 BUCK Converter

Tool needed:

1. Temperature controlled Soldering iron station
2. Solder
3. Philip screw driver
4. plier
5. slanted plier

Equipment:

1. DC Power Supply, 60 V DC and 3 A DC
2. Electronics Load
3. Digital Oscilloscope with 100 MHz or higher sampling frequency
4. LCR meter with 100 kHz or higher
5. Digital Multimeter
6. Current probe
7. Gain and Phase Analyzer (optional)

Things to watch out:

1. Find all the components from the component table. Use LCR meter to verify component value if necessary.
2. Assemble the circuit in steps. First assemble sub-module such as power semiconductor and heat sink. Then assemble different component using the height of the component as general guideline: assemble shorter component first and the highest component last.
3. Pay attention to and use those soldering techniques you learned in ENGR 206 and 301.

Assembly Step:

1. Assemble Q1 MOSFET, D1 SBD, and heat sink. Make sure the insulation is properly installed.
2. Find a piece of wire and use it as the jumper J1. Solder J1 to the PCB.
3. Solder those 6 ceramic capacitor (MLCC) to the PCB
4. Solder ¼ W resistors, altogether 12 of them.
5. Solder IC U1, make sure the orientation of the IC is correct.
6. Solder 9 test pins to the PCB
7. Solder Q2 to Q5
8. Solder all electrolytic capacitors and inductors
9. Assemble Q1 and heat sink sub-module and D1
10. Check whether all components are being soldered onto the PCB
11. Solder input and output pins
12. Lastly fasten brass posts

Evaluation and Measurement:

Note:

a) Set the maximum output current of the power supply to be at 3 A.
b) Make sure you know all the test pins and where they are in the PCB
c) Make sure the ON/OFF Remote Control is at "Enable" (High)
d) Make sure you know which connectors (pins) are input and which ones are output before turning on the power supply

1. Conversion Efficiency
2. Load Regulation
3. Line Regulation
4. Output Ripple and Noise (Pin 8 to Pin 9) (DSO)
5. Dynamic Response (Pin 8 to Pin 9) (DSO)
6. Duty Control Signal (Pin 4 to Pin 6) and Diode Voltage (Pin 7 and Pin 9) (DSO)
7. Remote Control (Pin 3 to Pin 2) (DSO)
8. Start-up (Pin 8 to Pin 9) (DSO)
9. Inductor Current (Optional) (DSO + Current Probe)
10. Gain Phase Margin (Optional) (Gain Phase Analyzer)

Static Measurement Records

Input Voltage is 8 V DC

Output Current	0.5 A	1 A	1.5 A	2 A	2.5 A	3 A	3.5 A	5 A
Vo								
Iin								

Input Voltage is 10 V DC

Output Current	0.5 A	1 A	1.5 A	2 A	2.5 A	3 A	3.5 A	5 A
Vo								
Iin								

Input Voltage is 12 V DC

Output Current	0.5 A	1 A	1.5 A	2 A	2.5 A	3 A	3.5 A	5 A
Vo								
Iin								

Note:
Use Multimeter to measure voltage between Pin 1 and Pin 2 to find out input voltage. Input current can be read from the DC power supply. Output voltage can be read using Multimeter to measure voltage between Pin 8 and Pin 9. Output current can be recorded by reading it directly from the electronics load or using a multimeter as current meter or using current probe.

1. Conversion Efficiency

Calculate efficiency using measured data. Use Excel to make plot.

2. Load Regulation

Calculate the load regulation for three input voltage values.

$$\text{Load Regulation} = \left| \frac{V_{O,\text{min load}} - V_{O,\text{full load}}}{V_{O,\text{min load}}} \right| \times 100\% \quad @ \text{ specified input voltage}$$

3. Line Regulation

Calculate the line regulation

$$\text{Line Regulation} = \left| \frac{V_{O,\text{min input}} - V_{O,\text{max input}}}{V_{O,\text{min input}}} \right| \times 100\% \quad @ \text{ specified load}$$

Use measured data, calculate the line regulation when output current is 0.5 A, 2 A, and 4 A.

4. Output Ripple and Noise

Test conditions: Output current: 4A
Input Voltage: 8 V, 10 V, and 12 V

Use digital oscilloscope to monitor and record the output voltage using AC coupling setting for the oscilloscope. Save the waveforms and include them in your report.

5. Dynamic Response

Test condition:

Set the load as the following:

Input voltage is 8 V, 10 V, and 12 V DC

Use digital oscilloscope to monitor and record the output voltage using AC coupling setting for the oscilloscope. Save the waveforms and include them in your report.

6. Duty Cycle Control Signal and Diode Voltage

Test Condition:

Load is set at 0.1 A DC, Boundary Current 2 A and 4 A
Input Voltage is 10 VDC

Use oscilloscope to monitor and record voltage between pin 4 and pin 7. Gradually increase the electronics load until it reaches the boundary between CCM/DCM (Continuous current mode and discontinuous current mode). Monitor the relationship between Duty Cycle and load variation.

7. Remote Control

The provided circuit has a remote control function designed and built in. When the voltage at pin 3 (with respect to that of pin 6) is "HIGH", the control IC can then function. When the voltage at pin 3 (with respect to that of pin 6) is "LOW", then the control IC is OFF so there will be NO output.

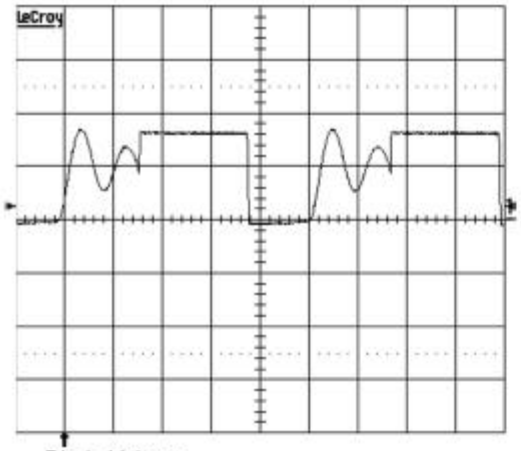
You can build a small switch to connect the ON/OFF control to the power supply to monitor the effect of this ON/OFF control with respect to the output including delay time.

8. Start up

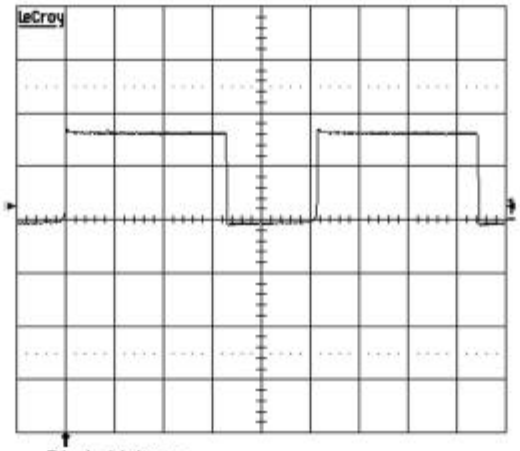
Monitor the output voltage when the input voltage is applied using two channels of the oscilloscope, one channel is used to monitor input and the other for the output voltage.

Reference Materials

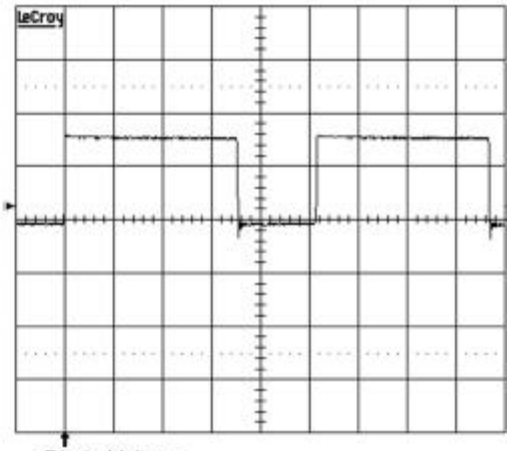
1. UTC TL5001 Data Sheet
2. IRF9Z34N Data Sheet
3. SBL 1660CT Data Sheet
4. Aluminum Electrolytic Capacitor, SC-series Data Sheet
5. Iron Power Data Sheet
6. Inductor Analysis T80-52 30U 4A



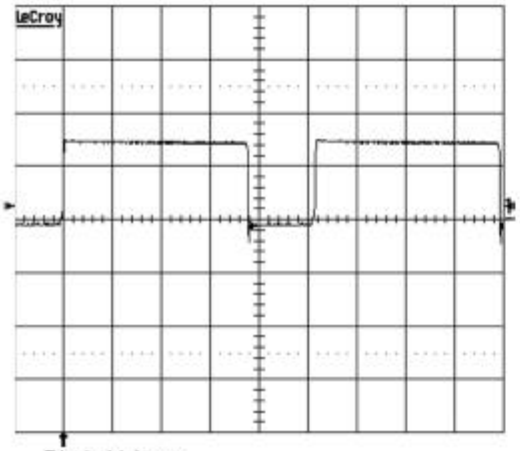
Diode Voltage
@Vin=8V, Io=0.1A
H : 2uS/div. V : 5V/div.



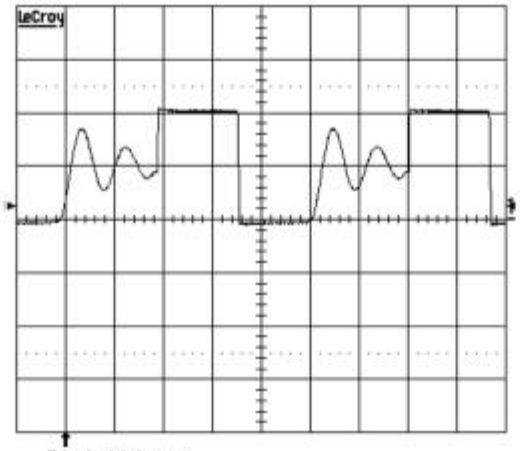
Diode Voltage
@Vin=8V, Io=0.19A (Boundary)
H : 2uS/div. V : 5V/div.



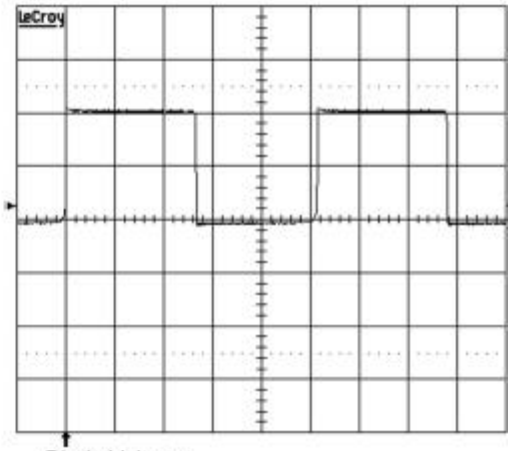
Diode Voltage
@Vin=8V, Io=2A
H : 2uS/div. V : 5V/div.



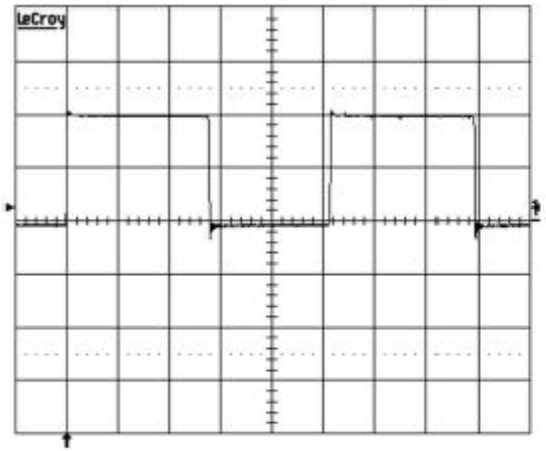
Diode Voltage
@Vin=8V, Io=4A
H : 2uS/div. V : 5V/div.



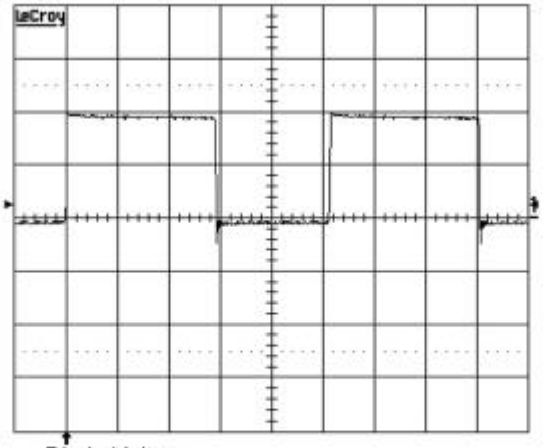
Diode Voltage
@Vin=10V, Io=0.1A
H : 2uS/div. V : 5V/div.



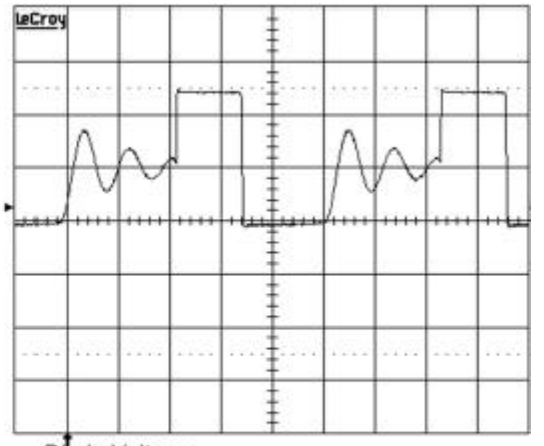
Diode Voltage
@Vin=10V, Io=0.245A (Boundary)
H : 2uS/div. V : 5V/div.



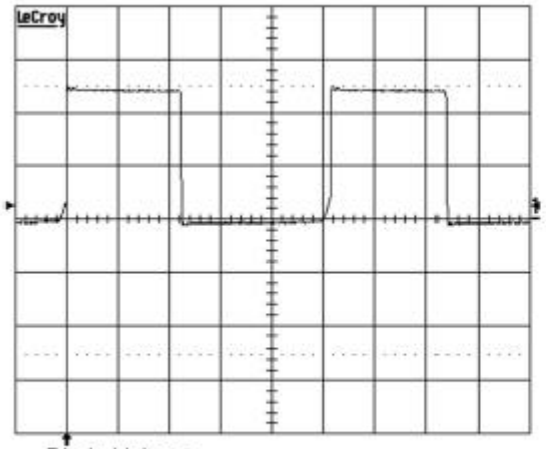
Diode Voltage
@Vin=10V, Io=2A
H : 2uS/div. V : 5V/div.



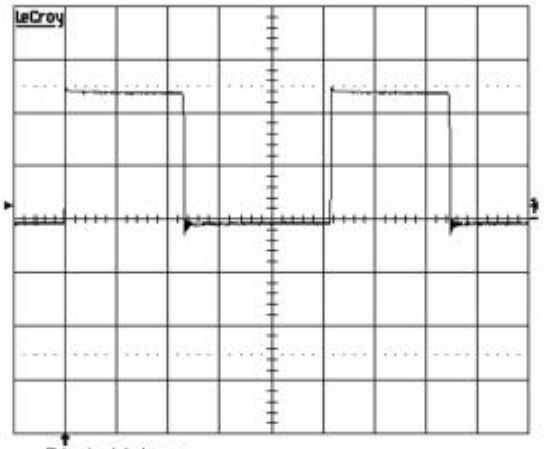
Diode Voltage
@Vin=10V, Io=4A
H : 2uS/div. V : 5V/div.



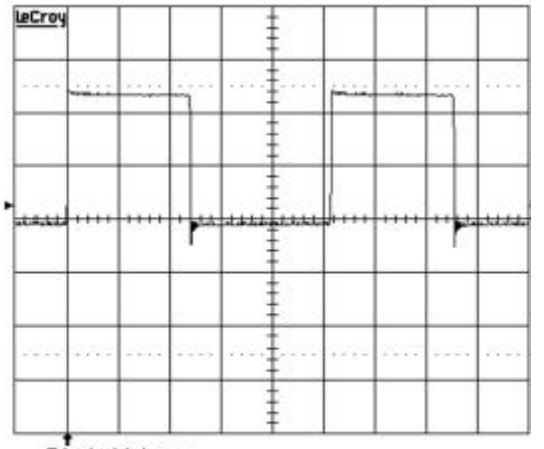
Diode Voltage
@Vin=12V, Io=0.1A
H : 2uS/div. V : 5V/div.



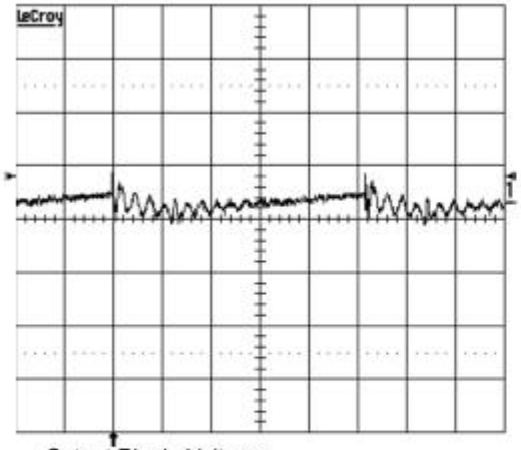
Diode Voltage
@Vin=12V, Io=0.27A (Boundary)
H : 2uS/div. V : 5V/div.



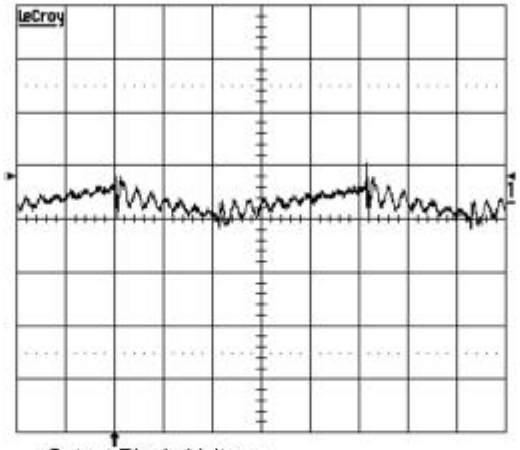
Diode Voltage
@Vin=12V, Io=2A
H : 2uS/div. V : 5V/div.



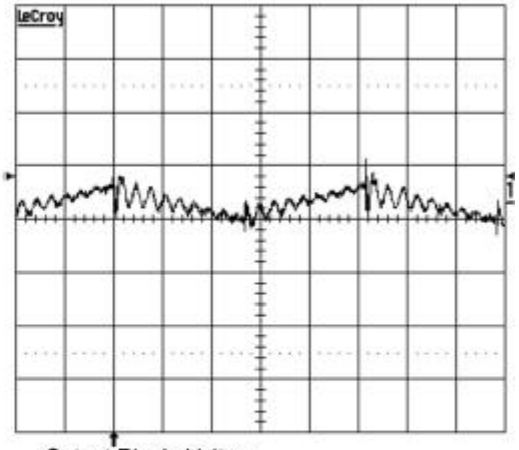
Diode Voltage
@Vin=12V, Io=4A
H : 2uS/div. V : 5V/div.



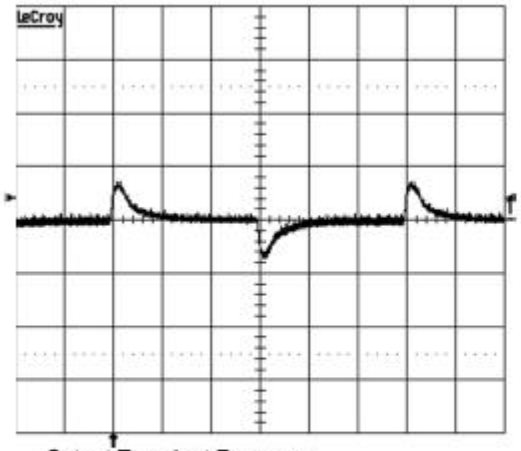
Output Ripple Voltage
@Vin=8V, Io=4A
H : 2uS/div. V : 20mV/div.



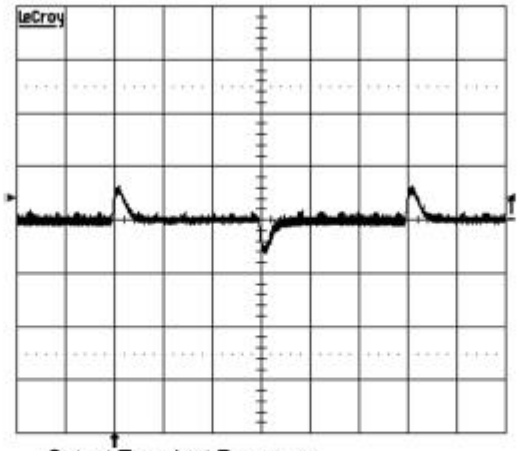
Output Ripple Voltage
@Vin=10V, Io=4A
H : 2uS/div. V : 20mV/div.



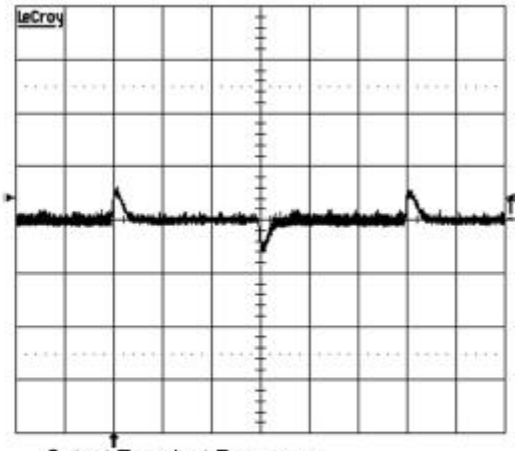
Output Ripple Voltage
@Vin=12V, Io=4A
H : 2uS/div. V : 20mV/div.



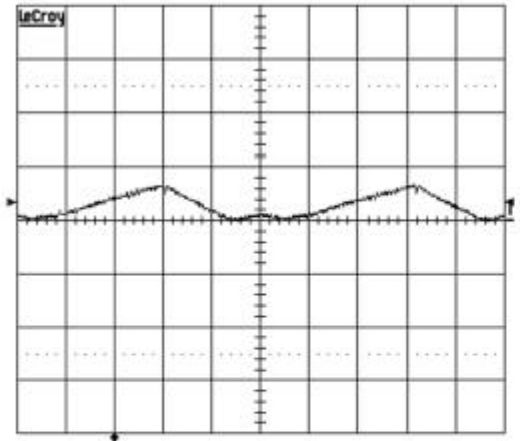
Output Transient Response
@Vin=8V, Io=2 to 4A, 0.1A/uS
H : 0.5mS/div. V : 100mV/div.



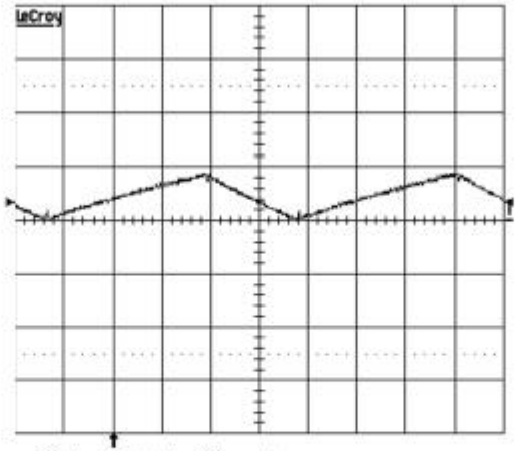
Output Transient Response
@Vin=10V, Io=2 to 4A, 0.1A/uS
H : 0.5mS/div. V : 100mV/div.



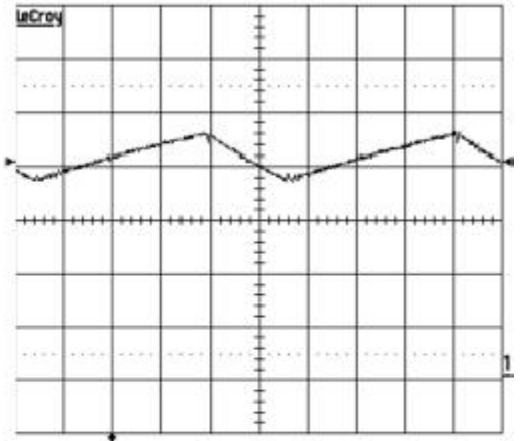
Output Transient Response
@Vin=12V, Io=2 to 4A, 0.1A/uS
H : 0.5mS/div. V : 100mV/div.



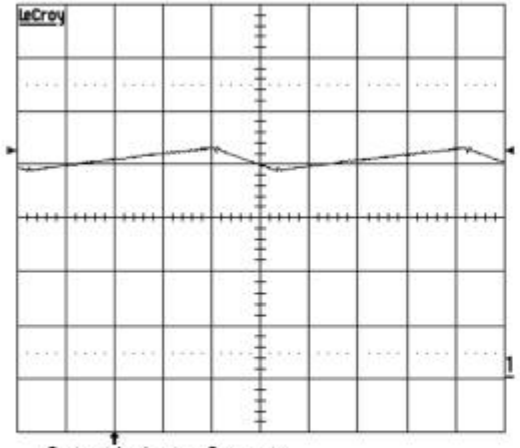
Output Inductor Current
@Vin=8V, Io=0.1A
H : 2uS/div. V : 0.5A/div.



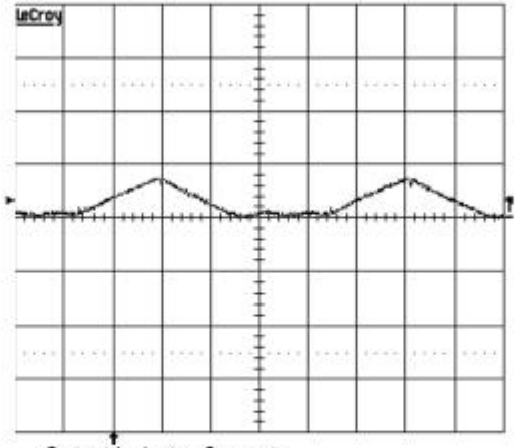
Output Inductor Current
@Vin=8V, Io=0.19A (Boundary)
H : 2uS/div. V : 0.5A/div.



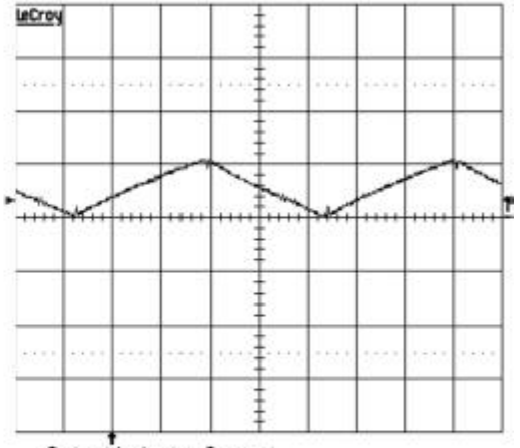
Output Inductor Current
@Vin=8V, Io=2A
H : 2uS/div. V : 0.5A/div.



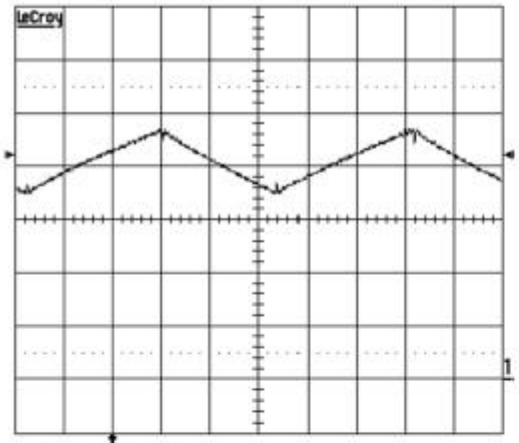
Output Inductor Current
@Vin=8V, Io=4A
H : 2uS/div. V : 1A/div.



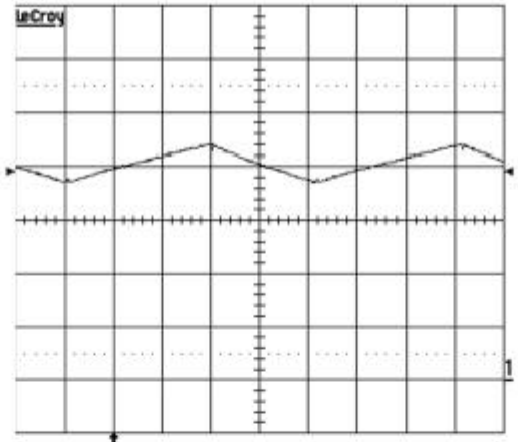
Output Inductor Current
@Vin=10V, Io=0.1A
H : 2uS/div. V : 0.5A/div.



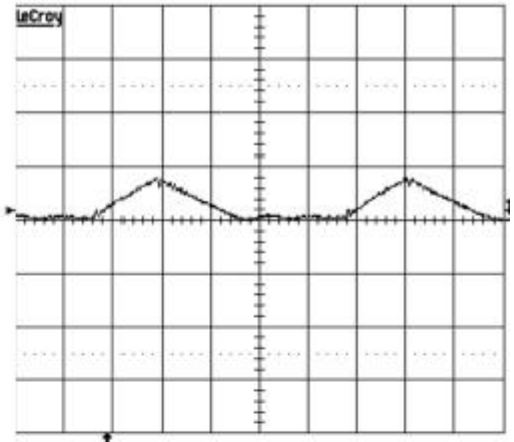
Output Inductor Current
@Vin=10V, Io=0.245A (Boundary)
H : 2uS/div. V : 0.5A/div.



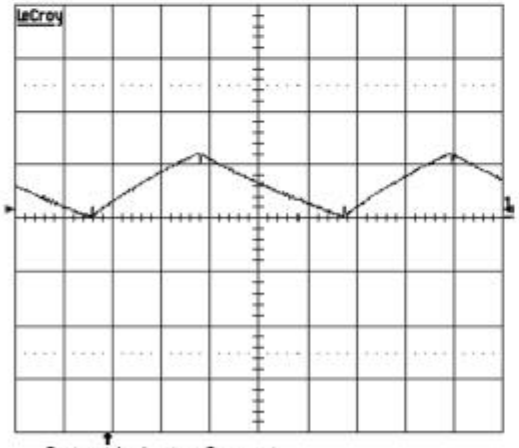
Output Inductor Current
@Vin=10V, Io=2A
H : 2uS/div. V : 0.5A/div.



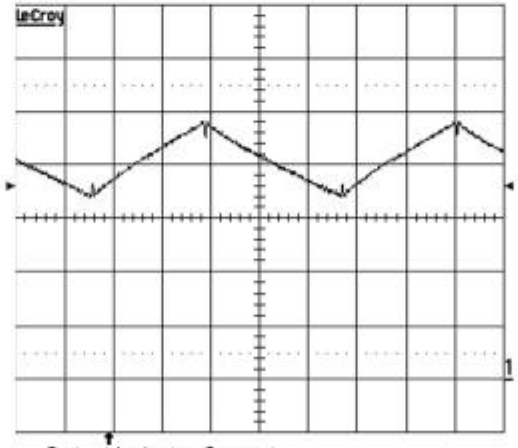
Output Inductor Current
@Vin=10V, Io=4A
H : 2uS/div. V : 1A/div.



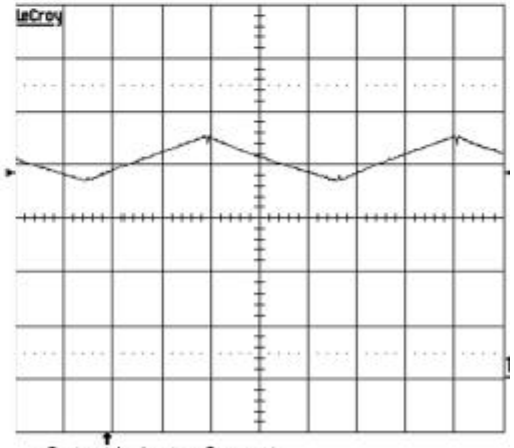
Output Inductor Current
@Vin=12V, Io=0.1A
H : 2uS/div. V : 0.5A/div.



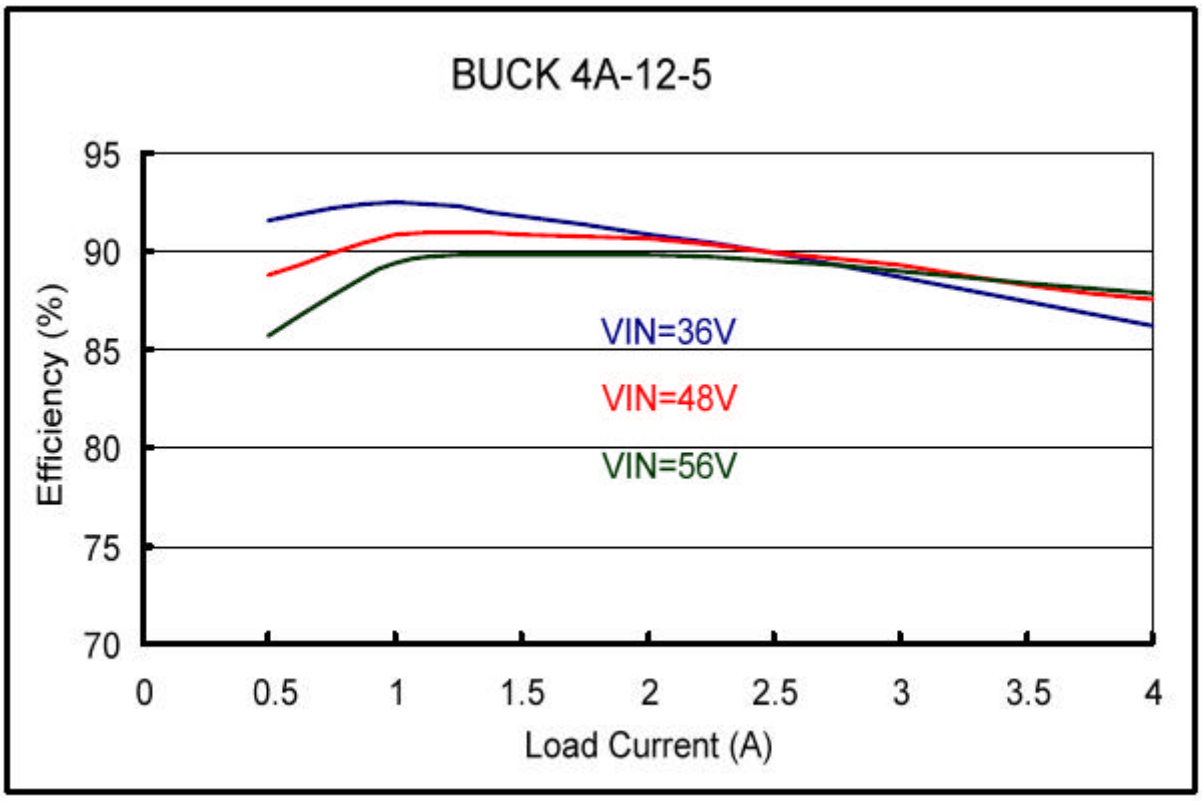
Output Inductor Current
@Vin=12V, Io=0.27A (Boundary)
H : 2uS/div. V : 0.5A/div.



Output Inductor Current
@Vin=12V, Io=2A
H : 2uS/div. V : 0.5A/div.



Output Inductor Current
@Vin=12V, Io=4A
H : 2uS/div. V : 1A/div.


BUCK 4A-12-5
95
90
85
80
75
70
Efficiency (%)
VIN=36V
VIN=48V
VIN=56V
0
0.5
1
1.5
2
2.5
3
3.5
4
Load Current (A)