University of South-Eastern Norway
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Lab Assignment EPE2116: Power Electronics and Electrical Drives

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1 Introduction

In this lab we're looking at a simplified power electronics system consisting of a controller, a switch, and a circuit where these are used to form a power electronics converter. We'll start by investigating the switch controller and (somewhat briefly) the switch. Then we'll use these building blocks to make power converters and investigate some of their properties. We'll do the initial investigations by simulations in LTSpice. Then we'll investigate the circuit by building the actual circuits in the lab. The following chapters describe the circuits, the modelling, and the practical builds. Finally, in Chapter 5 we'll define the assignment.

2 Description of circuit

2.1 PWM Controller

In power electronic converters it is quite common to use pulse width modulation to control the switch. These signals are often obtained by comparing the value of digital counters to reference values. This can be done in software or in hardware in a computer or microcontroller system, but in this lab we'll use a more traditional way that is available for measurements in the lab. We'll make a circuit to generate a triangular voltage that we can compare to a reference level to obtain the pulse width signal like shown in Figure 1. Here we can se the PWM output goes high when the Vcontrol is lower than the Vtriangle.

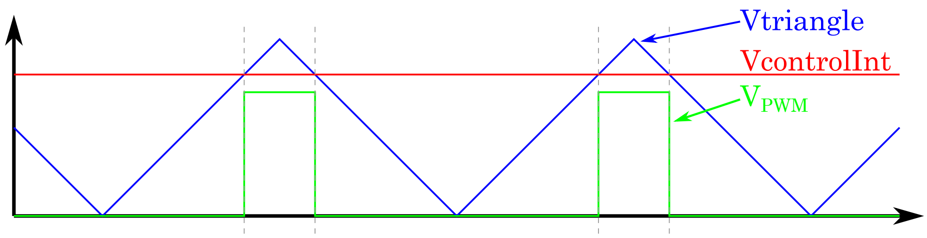


Figure 1: Comparing the triangular voltage with a reference level

2.1.1 Triangular voltage generator

A solution based on an op-amp is shown in Figure 2.
The circuit operates as follows: When the supply is turned on, the VCC will go to say +12V. The voltage on C4 is 0V. The voltage on pin 10 on the op-amp will be a positive value between VCC and 0V. The output of the op-amp (pin 8) will go high since the op-amp multiplies the difference between the voltage on the positive and negative input (by a factor depending on the op-amp type, maybe 10000). The op-amp will not be able to make the output go higher than the supply voltage, so

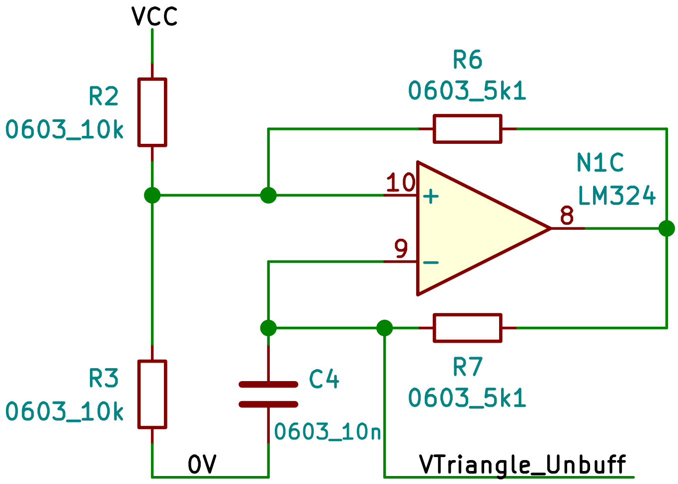


Figure 2: The triangular voltage generator

the output will be close to VCC. The voltage on the positive input can be calculated by seeing this as a voltage divider between R3 and the parallel connection of R2 and R6. At the same time the voltage on C4 Will be charged through R7. This will continue until the voltage on the negative input goes higher than the voltage on the positive input. At this point, the voltage on the output of the op-amp goes from positive to negative, i.e. from VCC to 0V. The voltage on the positive input of the op-amp is now defined by the voltage divider between R2 and the parallel coupling of R3 and R6, so the output will stay low until the voltage on C4 goes below the voltage on the positive input on the op-amp, when the voltage on the op-amp output goes high and the cycle repeats. We now have a circuit that charges and discharges C4 between two voltage levels. The capacitor, C4, is charged through resistor R7. If this voltage is loaded by a low impedance load, this load will influence the voltage on the capacitor, so a buffer is needed to disconnect the voltage on C4 from the load.

2.1.2 Comparator

We now have a triangular voltage. This can be compared to a reference voltage to produce a PWM (Pulse Width Modulation) signal. This is done with another op-amp as shown in Figure 3 When the voltage VController is higher than the Vtriange, the output is at VCC and when the when the voltage VController is lower than the Vtriange, the output is at 0V as shown in Figure 1.

2.2 Switch-driver

The PWM signal generated by the proceeding circuit is too weak (too high impeedance) to drive the transistor we want to use as our switch directly, so we need

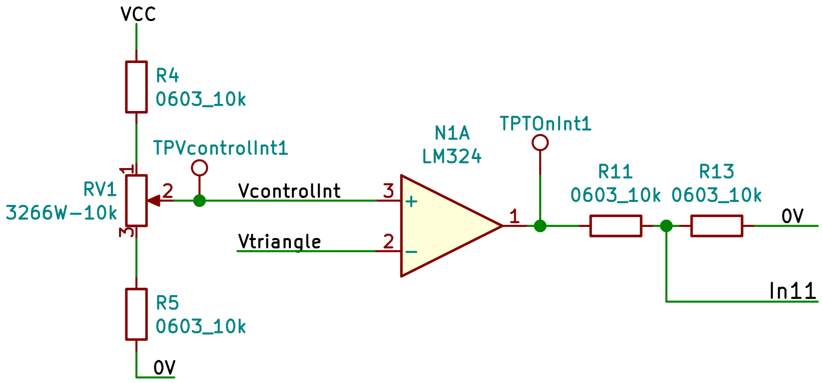


Figure 3: Comparing the triangular voltage with a reference level

a buffer (driver). Often the driver has galvanic separation and circuitry to protect the transistor for instance in over current situations, but we'll use a simple driver to do this. We'll use the EL7202 as shown in Figure 4.

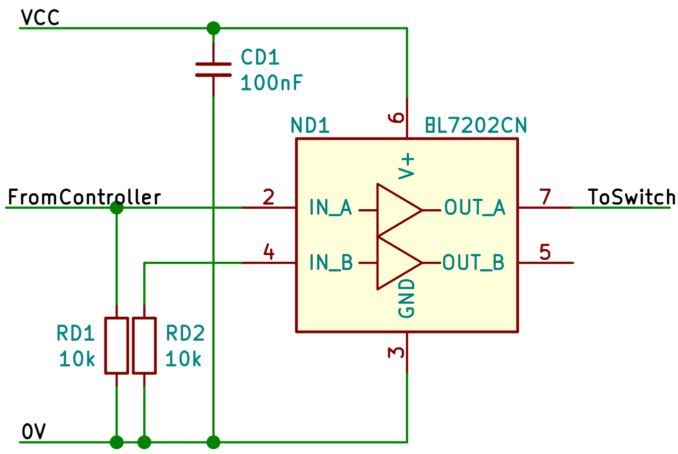


Figure 4: Transistor switch driver (EL7202)

2.3 Switch

Now, we have obtained a driver signal suitable to control our switch. Since the driver signal is referenced to 0V, the emitter of the IGBT should also be connected to 0V. As our switch we'll use the STGP5H60DF IGBT that is shown in Figure 5. The connections are shown in 6.

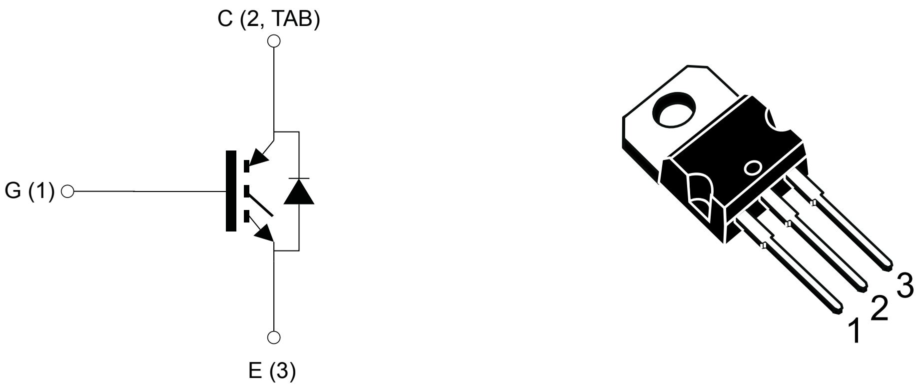


Figure 5: Transistor switch device (STGP5H60DF)

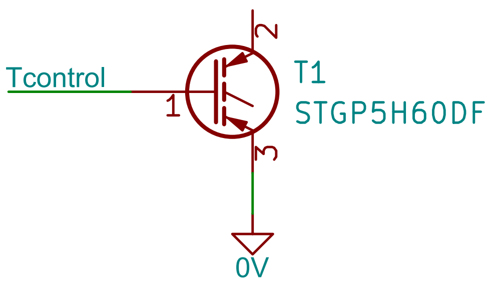


Figure 6: Transistor switch circuit (1-G, 2-E, and 3-C)

2.4 Output circuit

To the transistor switch we'll connect two different output circuits. They are described in the following.

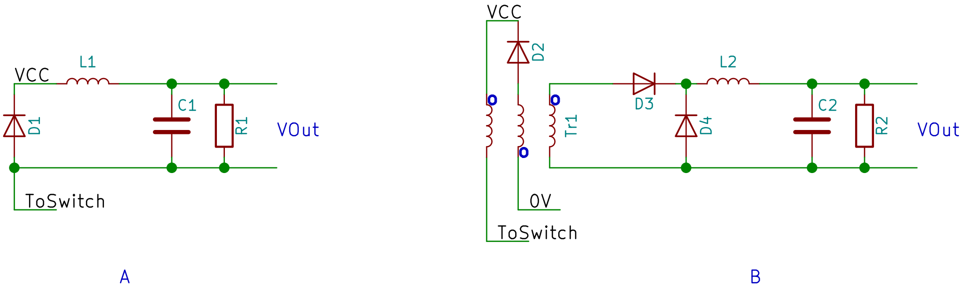


Figure 7: Output circuits. A, Buck and B, Forward

2.4.1 Step-down

The step-down converter (or Buck converter) is shown in Figure 7,A. Here we'll use a 500uH inductance (the Bourns 5256, see Figure 15). Use a 100uF capacitor (note that the negative terminal, often marked with a line, must face away from the inductance). As a load resistor, use a decade resistor with an initial setting of 29 Ohms. As diode, use the VS-12CWQ10FNPBF (see datasheet in Figure 14).

2.4.2 Forward converter

The forward converter can be based on the parts used in the step-down converter. Use the same diode, inductance, capacitor, and load resistor, but add the transformer (datasheet shown in Figure 16) and an extra VS-12CWQ10FNPBF diode (see datasheet in Figure 14). The circuit must be connected as shown in Figure 7,B. Note the dots on the transformer.

3 Simulations

The circuit to be simulated is shown in Figures 8 and 9.

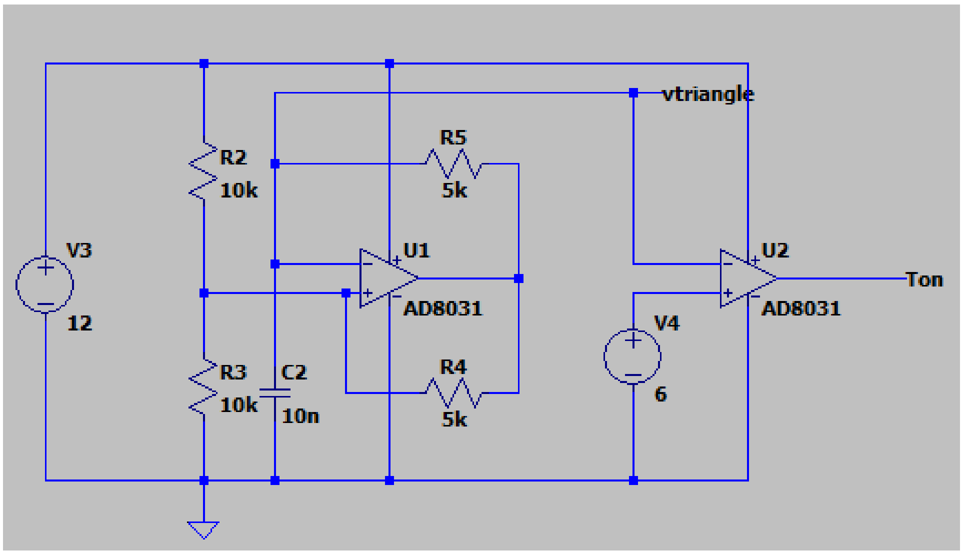


Figure 8: LTSpice circuit, PWM-part

Note the spice directives to the left if Figure 9. They are needed. The switch, S1 will need a SPICE model of "switch" which is defined by the ".model switch vswitch (RON=0.01)" SPICE directive.
Make sure all connections are correct. Two lines crossing without a junction dot are not connected. Also a wire not connected perfectly to a component connection is not connected. These things may be difficult to figure out, so be a bit careful with this.
When doing simulations, make sure to simulate long enough to obtain steady state, but don't exaggerate. Don't waste time simulating far into steady state.

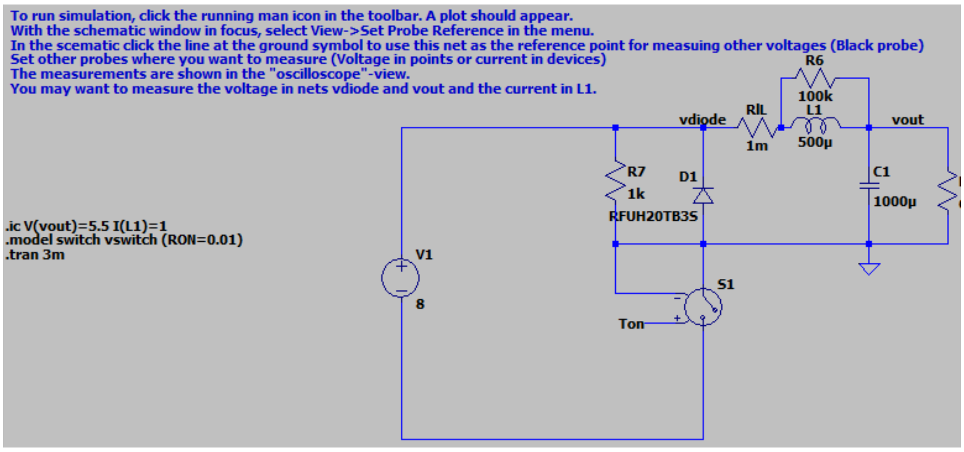


Figure 9: LTSpice circuit, Buck-part, Output resistor value is 22Ohms

4 Practical Model

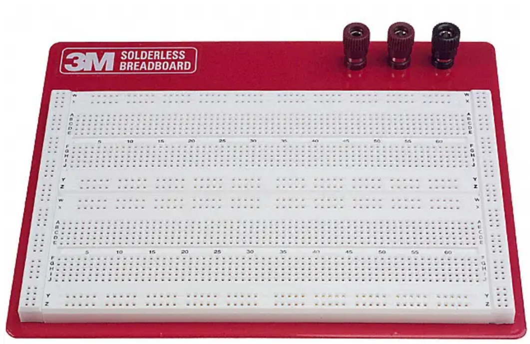


Figure 10: Example of a solderless breadboard

The PWM circuit is to be built as shown in Figures 2 and 3. We'll use the MC33074 instead of the LM324 shown in the figures. The LM324 is not fast enough for our needs here (slew rate for the LM324 is 0.5 V/us vs 14V/us for the MC33074). The pinout of the two integrated circuits are the same, so pin numbers from all schematics are the same.
We'll connect the output of the PWM-generator via a driver (as shown in Figure 4) to a transistor switch (as shown in Figure 6 and then to the output circuit in Figure 7,A in the lab and verify the operation. Figure 17 shows details of the PWM-circuit. The load of the output circuit will be a decade resistor load, initially set to 29 Ohms. The circuit can be connected on experiment/prototype boards as shown in Figure 10. Note that the different holes are generally connected in rows on top and bottom and in columns in the middle. Verify connections with the multimeter.

5 Assignment

Lab tasks must be documented in a simple lab report to be handed in. Up to five students can contribute to one report. Illustrate answers with figures and show how you have obtained the results. Oscilloscope screen shots can be downloaded by using an usb-stick or you can just take a picture with your phone. The lab report should describe the following elements.

5.1 Simulation

Simulate the PWM-controller as described in Chapter 3.

a. Is the Triangular voltage as expected? Comment!

b. Try modifying the value of R3, R6, R7 and C4. What is the influence of each of these components? (Try doubling or halving their values to see the influences)

c. What is the voltage range of the triangle?

d. What is duty cycle, D, when the control voltage is 2, 4, 6, 8 and 10V? (V4 in Figure 8)

5.2 Experiment

The practical circuit is described in Chapter 4.

5.2.1 PWM controller and switch

First build the PWM controller circuit

a. Is the Triangular voltage as expected? What about the signal on the output of the op-amp? Comment!

b. What is the voltage range of the triangle?

c. Verify that the PWM-signal on the output of N1A (pin 1 in Figure 3) can be controlled by RV1 from 0 to 100% duty cycle. Make sure the duty cycle increase as the pot is turned clockwise. Note the voltage of VcontrolInt at 10, 50, and 90% duty cycle.

d. Connect the driver and the transistor switch (see Figures 4 and 6). Connect the collector of the switch to positive supply through a resistor. Measure the gate and the collector of the switch with a scope. How do they relate?

Table 1: Components for Buck output circuit

D1	VS-12 (see datasheet in Figure 14)
L1	500uH (see datasheet in Figure 15)
C1	1000 uF
R1	Decade Resistor set at 29 Ohms

5.2.2 Buck converter

Build the Buck output circuit as shown in Figure 7,A. Use components as shown in Table **??**.

a. Connect the Buck output circuit between the collector of the transistor switch and the positive supply. If the number of power supplies permits, a second power supply may be used for the output circuit (both supplies negative terminal is connected together on the same 0V). Connect a variable load resistor to the output of the circuit. Set the load to 29 Ohm. If there are two power supplies in the circuit, set the second supply to +5V.

b. Increase the duty cycle from 0 to 100% in steps of 10%. Draw a graph of the output voltage vs duty cycle. Is it as expected? Is the circuit operating in discontinous or continous mode?

c. How can the circuit be improved to help the problem in the previous point?

d. How does the actual circuit correspond to the simulations?

5.2.3 Forward converter

Connect the transformer (type, see Figure 16) between the transistor and the Buck circuit as shown in in Figure 7,B. Use connections 9 & 12 for the primary winding, 8 & 11 for the demagnetizing winding, and 7 & 10 for the output winding. There are two diodes in each VS-12.

a. Increase the duty cycle from 0 to 100% in steps of 10%. Draw a graph of the output voltage vs duty cycle. Is everything operating as expected?

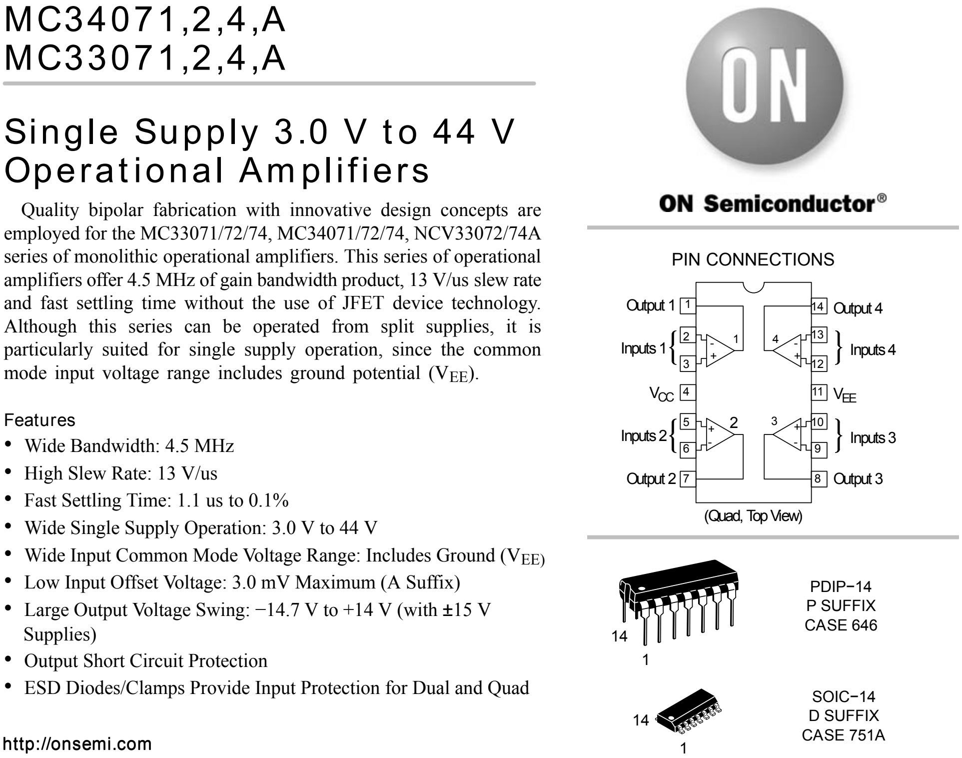
b. There is an extra winding connected through a diode to the power supply. What is this winding called and what is the purpose? Test the circuit with this circuit disconnected. Describe what happens?

c. What is the advantages and disadvantages of the forward circuit? Compare with the Buck and Flyback converter.

A Datasheets

This section shows the pinout and some basic info about some of the components we'll use in this lab. For more details, see the full datasheets from the manufacturers. Go to one of the electronics suppliers to find more info. Digikey.com or Farnell.com are good candidates.

A.1 MC33074



MC34071,2,4,A
MC33071,2,4,A

Single Supply 3.0 V to 44 V Operational Amplifiers

Quality bipolar fabrication with innovative design concepts are employed for the MC33071/72/74, MC34071/72/74, NCV33072/74A series of monolithic operational amplifiers. This series of operational amplifiers offer 4.5 MHz of gain bandwidth product, 13 V/us slew rate and fast settling time without the use of JFET device technology. Although this series can be operated from split supplies, it is particularly suited for single supply operation, since the common mode input voltage range includes ground potential (V_{EE}).

Features

- Wide Bandwidth: 4.5 MHz
- High Slew Rate: 13 V/us
- Fast Settling Time: 1.1 us to 0.1%
- Wide Single Supply Operation: 3.0 V to 44 V
- Wide Input Common Mode Voltage Range: Includes Ground (V_{EE})
- Low Input Offset Voltage: 3.0 mV Maximum (A Suffix)
- Large Output Voltage Swing: −14.7 V to +14 V (with ±15 V Supplies)
- Output Short Circuit Protection
- ESD Diodes/Clamps Provide Input Protection for Dual and Quad

http://onsemi.com

Figure 11: Excerpt of datasheet for MC33074

A.2 EL7202

RENESAS

DATASHEET

EL7202, EL7212, EL7222

High Speed, Dual Channel Power MOSFET Drivers

FN7282
Rev 2.00
July 3, 2006

The EL7202, EL7212, EL7222 ICs are matched dual-drivers that improve the operation of the industry standard DS0026 clock drivers. The Elantec versions are very high speed drivers capable of delivering peak currents of 2.0 amps into highly capacitive loads. The high speed performance is achieved by means of a proprietary “Turbo-Driver” circuit that speeds up input stages by tapping the wider voltage swing at the output. Improved speed and drive capability are enhanced by matched rise and fall delay times. These matched delays maintain the integrity of input-to-output pulse-widths to reduce timing errors and clock skew problems. This improved performance is accompanied by a 10 fold reduction in supply currents over bipolar drivers, yet without the delay time problems commonly associated with CMOS devices. Dynamic switching losses are minimized with non-overlapped drive techniques.

Pinouts

E7202
(8-PIN PDIP, SO)
TOP VIEW

NON-INVERTING
DRIVERS

Features

- Industry standard driver replacement
- Improved response times
- Matched rise and fall times
- Reduced clock skew
- Low output impedance
- Low input capacitance
- High noise immunity
- Improved clocking rate
- Low supply current
- Wide operating voltage range
- Pb-Free available (RoHS compliant)

Applications

- Clock/line drivers
- CCD Drivers
- Ultra-sound transducer drivers
- Power MOSFET drivers
- Switch mode power supplies
- Class D switching amplifiers
- Ultrasonic and RF generators
- Pulsed circuits

RENESAS

Figure 12: Excerpt of datasheet for EL7202

A.3 IGBT

life.augmented

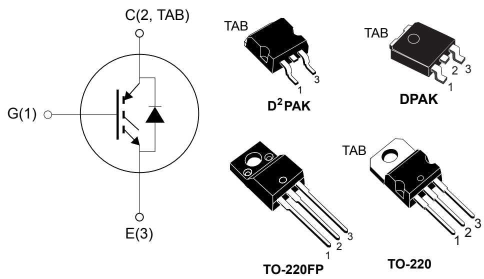
STGB5H60DF, STGD5H60DF
STGF5H60DF, STGP5H60DF

Datasheet

Trench gate field-stop 600 V, 5 A high speed H series IGBT

Features

- High-speed switching
- Tight parameter distribution
- Safe paralleling
- Low thermal resistance
- Short-circuit rated
- Ultrafast soft recovery antiparallel diode



Applications

- Motor control
- UPS, PFC

Description

These devices are IGBTs developed using an advanced proprietary trench gate field-stop structure. These devices are part of the H series of IGBTs, which represents an optimum compromise between conduction and switching losses to maximize the efficiency of high switching frequency converters. Furthermore, a slightly positive $V_{CE(sat)}$ temperature coefficient and very tight parameter distribution result in safer paralleling operation.

Figure 13: Excerpt of datasheet for STGP5H60DF

A.4 Diode

VISHAY

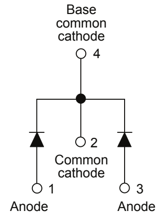
www.vishay.com

VS-12CWQ10FN-M3

Vishay Semiconductors

High Performance Schottky Rectifier, 2 x 6 A

D-PAK (TO-252AA)



PRODUCT SUMMARY

Package	D-PAK (TO-252AA)
$I_{F(AV)}$	2 x 6 A
V_R	100 V
V_F at I_F	0.65 V
I_{RM}	4 mA at 125 °C
T_J max.	150 °C
Diode variation	Common cathode
E_{AS}	6 mJ

FEATURES

- Low forward voltage drop
- Guard ring for enhanced ruggedness and long term reliability
- Popular D-PAK outline
- Center tap configuration
- Small foot print, surface mountable
- High frequency operation
- Meets MSL level 1, per J-STD-020, LF maximum peak of 260 °C
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912

Pb RoHS COMPLIANT HALOGEN FREE

DESCRIPTION

The VS-12CWQ10FN-M3 surface mount, center tap, Schottky rectifier series has been designed for applications requiring low forward drop and small foot prints on PC board. Typical applications are in disk drives, switching power supplies, converters, freewheeling diodes, battery charging, and reverse battery protection.

MAJOR RATINGS AND CHARACTERISTICS

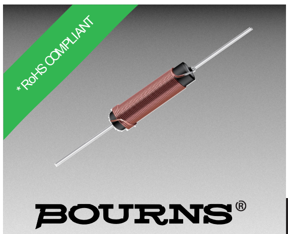
SYMBOL	CHARACTERISTICS	VALUES	UNITS
$I_{F(AV)}$	Rectangular waveform	12	A
V_{RRM}		100	V
I_{FSM}	t_p = 5 µs sine	330	A
V_F	6 A_{pk}, T_J = 125 °C (per leg)	0.65	V
T_J	Range	-55 to +150	°C

VOLTAGE RATINGS

PARAMETER	SYMBOL	VS-12CWQ10FN-M3	UNITS
Maximum DC reverse voltage	V_R	100	V
Maximum working peak reverse voltage	V_{RWM}		

Figure 14: Excerpt of datasheet for VS-12CWQ10

A.5 Inductance



Features
- Formerly J.W. Miller® model
- Current rating up to 20 A
- Inductance range: 3.35 µH to 1000 µH
- RoHS compliant*

Applications
- EMI flters
- Output chokes
- Smoothing coils

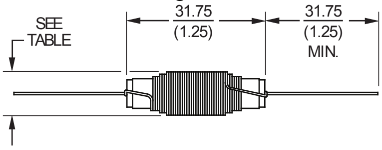
5200 Series - Hash Choke

Electrical Specifcations

Part Number	Inductance (µH)	Tol.	Test Freq.	DCR (Ω) Max.	I dc (A)	Lead Wire Size (AWG)	Figure	Diameter Max.
5256-RC	500	±20 %	1.0 KHz	0.26	2.0	20	C	14.22 [mm]

Product Dimensions

Figure C



General Specif cations

Rated Current......Inductance drop 10 % or 35 °C temperature rise at I dc
Operating Temperature ....-55 °C to +105 °C

Materials

Core Material
5230-RC through 5258-RC ....Ferrite
Wire ....Enameled copper
Terminal Coating................................Sn

Marking

.............Marking on label on bag only

Electrical Schematic

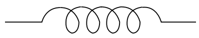
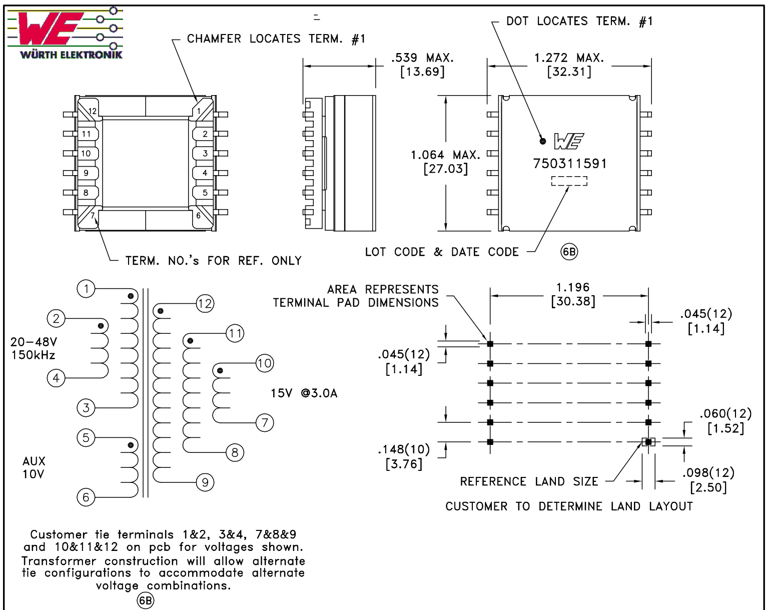


Figure 15: Excerpt of datasheet for Bourns inductance 5256

A.6 Transformer



ELECTRICAL SPECIFICATIONS @ 25°C unless otherwise noted:

PARAMETER		TEST CONDITIONS	VALUE
D.C. RESISTANCE	1–3	tie(1+2, 3+4), @20°C	0.015 ohms max.
D.C. RESISTANCE	12–9	tie(12+11+10, 9+8+7), @20°C	0.012 ohms max.
D.C. RESISTANCE	5–6	@20°C	0.018 ohms max.
INDUCTANCE	1–3	150kHz, 100mVAC, Ls	8.00uH ±10%
SATURATION CURRENT		20% rolloff from initial	20A
LEAKAGE INDUCTANCE	1–3	tie(1+2, 3+4, 5+6, 7+8+9+10+11+12), 100kHz, 100mVAC, Ls	200nH typ., 400nH max.
DIELECTRIC	1–12	tie(1+2+5, 7+8+9), 1875VAC, 1 second	1500VAC, 1 minute
6B DIELECTRIC	10–11	tie(11+12), 625VAC, 1 second	500VAC, 1 minute
6B DIELECTRIC	11–12	625VAC, 1 second	500VAC, 1 minute
6B DIELECTRIC	1–2	625VAC, 1 second	500VAC, 1 minute
TURNS RATIO		(1–3):(5–6)	2.25:1, ±1%
TURNS RATIO		(1–3):(12–9)	1.50:1, ±1%

DRAWING TITLE
TRANSFORMER
PART NO.
750311591
eiSos p/n: 750311591
compliant RoHS
SPECIFICATION SHEET 1 OF 1

Figure 16: Excerpt of datasheet for transformer WE 750311591

B Controller Circuit

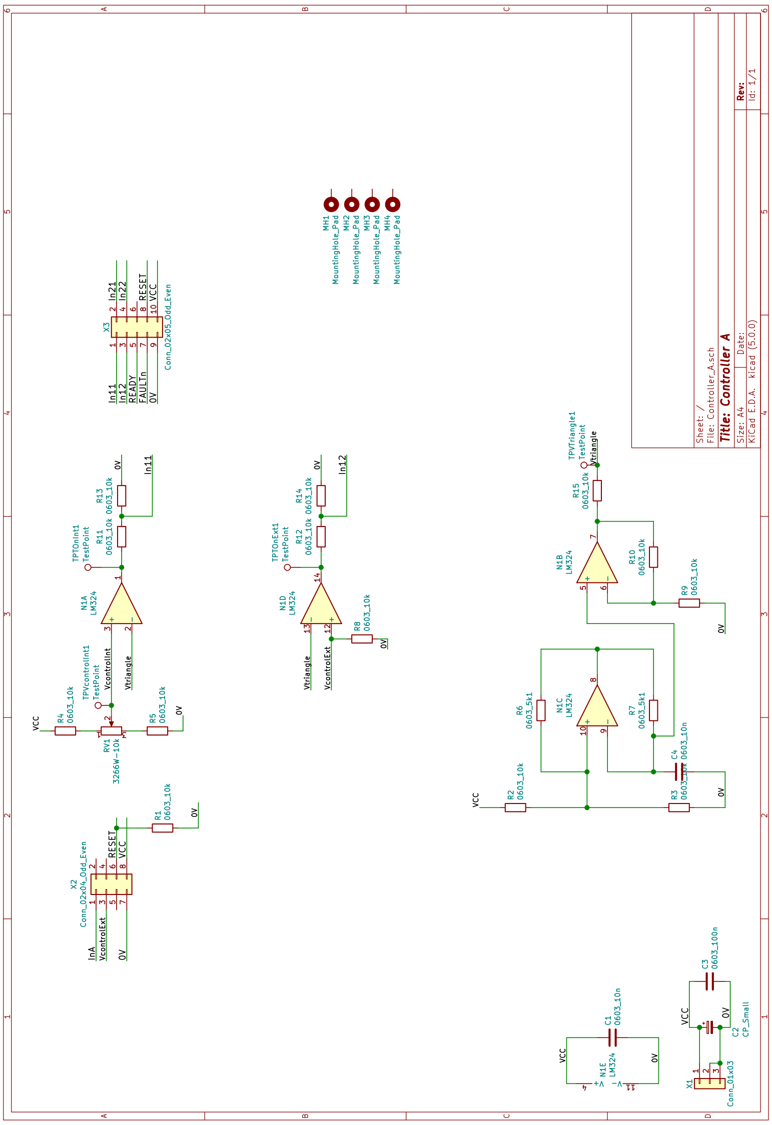


Figure 17: Schematics of the Controller_A Board

C Controller PCB

A PCB (Printed Circuit Board) is made for the Controller. See Figures 18 and 19.

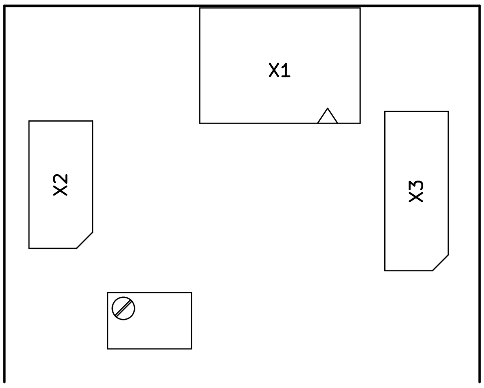


Figure 18: Front side of Controller_A Board

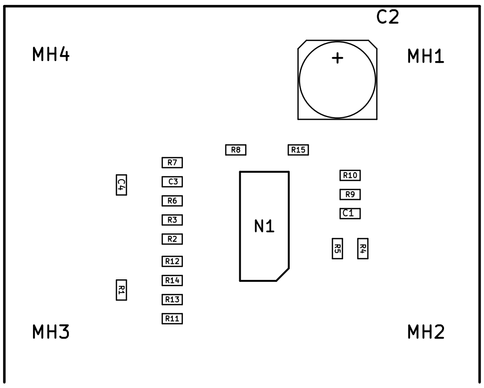


Figure 19: Back side of Controller_A Board