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AN2011-04 MA3L080E07_EVAL
Evaluation Adapter Board for EconoPACK™ 4 3-Level Modules in NPC1-Topology

IFAG IMM INP M AE

Evaluation Adapter Board for EconoPACK™ 4 3-Level Modules

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The board described is an evaluation board dedicated for laboratory environment only. It operates at high voltages. This board must be operated by qualified and skilled personnel familiar with all applicable safety standards.

1 Introduction

The evaluation adapter board MA3L080E07_EVAL for 3-Level EconoPACK™ 4 modules as shown in Figure 1 was developed to support customers during their first steps designing applications with EconoPACK™ 4 3-Level modules. This evaluation board was designed in addition to the module driver board F3L020E07-F-P_EVAL [1] or could be a complementary part for an existing customer driver solution. For more details about the 3-Level topology, please refer to [1].

The board is available from Infineon in small quantities. The properties of this part are described in the datasheet chapter of this document, whereas the remaining paragraphs provide information intended to enable the customer to copy, modify and qualify the design for production, according to their own specific requirements.

Environmental conditions were considered in the design of the MA3L080E07_EVAL. Components qualified for a lead-free reflow soldering process were selected. The design was tested as described in this document but not qualified regarding manufacturing and operation over the whole operating temperature range or lifetime.

The boards provided by Infineon are subjected to functional testing only.

Due to their purpose evaluation boards are not subjected to the same procedures regarding Returned Material Analysis (RMA), Process Change Notification (PCN) and Product Discontinuation (PD) as regular products.

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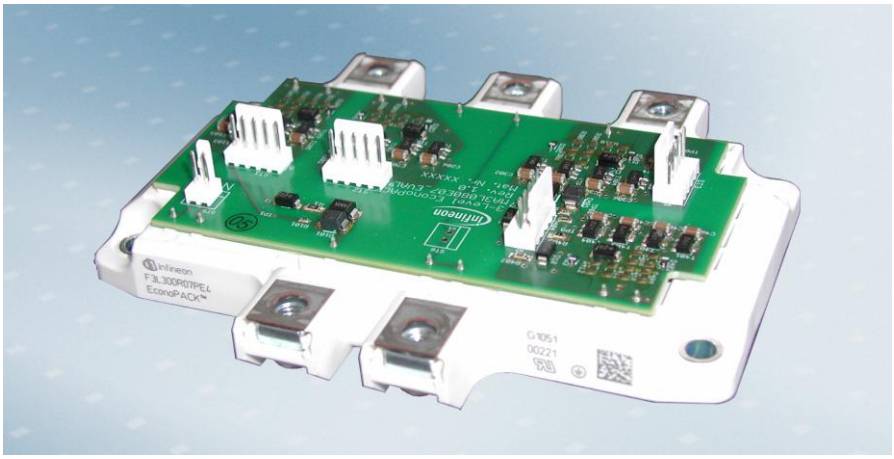
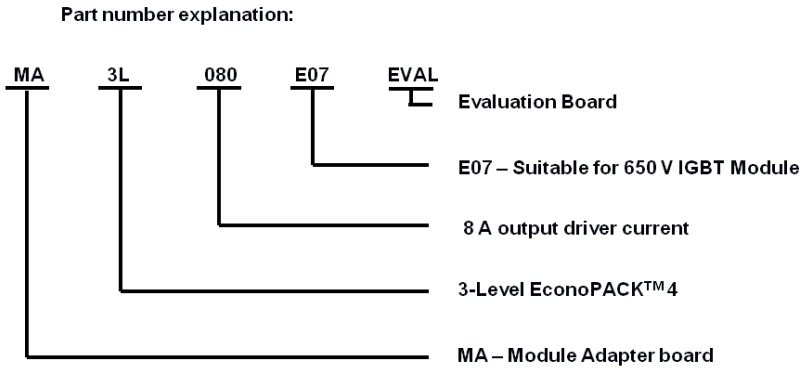


Figure 1: The Evaluation Adapter Board MA3L080E07_EVAL for EconoPACK™ 4 3-Level modules

1.1 Part Number explanation



[1] Evaluation Driver Board for 3-Level EconoPACK™ 4 AN2011-03

2 Design features

Electrical features of the evaluation board and mechanical dimensions including necessary interface connections are presented in following sections.

2.1 Main features

The evaluation board is developed to work in combination with the F3L020E07-F-P_EVAL driver board. [2] The F3L020E07-F-P driver board provides the following main features:

- Electrically and mechanically suitable for 3-Level EconoPACK™ 4 modules family
- Different gate resistor values for turning-on and -off are possible
- Active clamping protection for high and low-side IGBTs
- Desaturation output signal for short circuit monitoring
- Base plate temperature monitoring by internal NTC resistor
- Suitable for -8V/+15V or up to ±20V [3]

2.2 Key Data

All values given in the table below are typical values, measured at an ambient temperature of T_{amb} = 25 °C.

Table 1: General key data and characteristic values

Parameter	Description	Value	Unit
V_{DC}	maximum DC supply voltage	±20	V
I_G	continuous output current	±8	A
f_S	maximum PWM signal frequency	60	kHz
T_{op}	operating temperature (design target)	-40…+85	°C
T_{sto}	storage temperature (design target)	-40…+85	°C

The EconoPACK™ 4 3-Level IGBT module has four vertically aligned IGBTs. As a reference, Figure 2 presents the positions of the semiconductors with their designation used throughout this document.

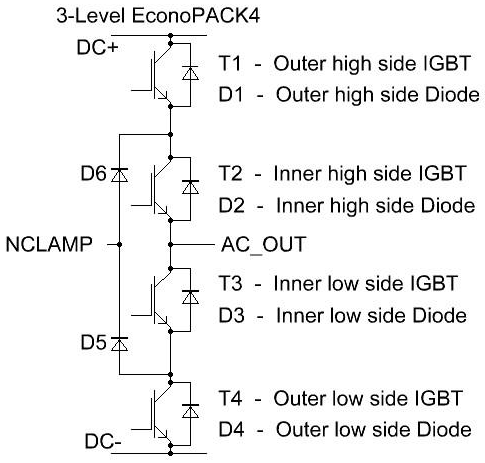
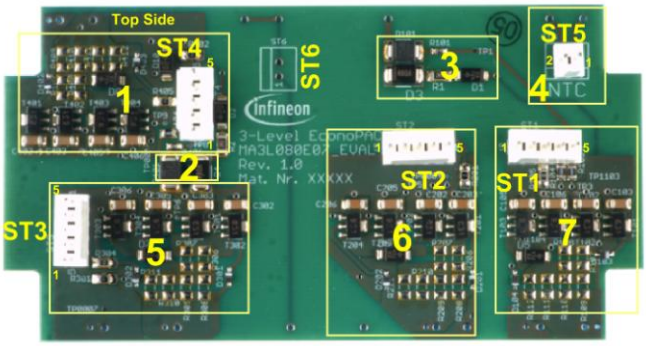


Figure 2: IGBT module with the designation of each IGBT

[2] Evaluation Driver Board for 3-Level EconoPACK™ 4 AN2011-03

[3] Due to IGBT short circuit performance a maximum value of V_{GE} ~15V is recommended.

Figures 3 shows the functional groups of the MA3L080E07 evaluation board top side.



1: Booster for outer low side IGBT
2: Desat and Active clamp for outer low side IGBT
3: Desat and Active clamp for outer high side IGBT
4: Temperature measurement
5: Booster for inner high side IGBT
6: Booster for inner low side IGBT
7: Booster for outer high side IGBT

Figure 3: Functional groups of the evaluation board MA3L080E07_EVAL top side

2.3 Mechanical dimensions

The dimensions of the MA3L080E07 adapter board are given in Figure 4.

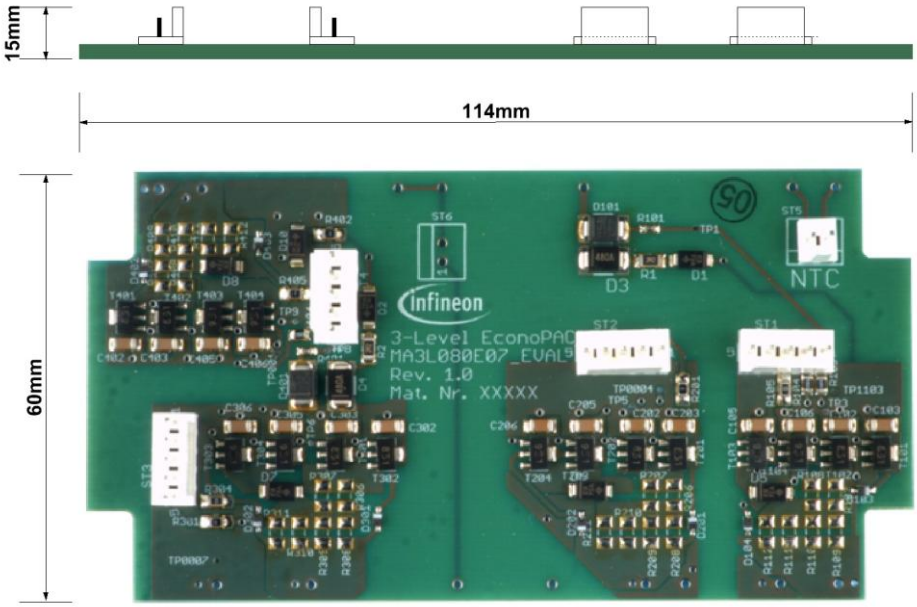


Figure 4: Mechanical dimensions of the MA3L080E07_EVAL

3 Pin assignments

All PWM, logic signals and voltage supplies have to be applied as listed in the following tables.

Table 2: Pin assignment of the connector ST1 of the outer high side IGBT

Pin name	Pin function
ST1-1	+15V_T1
ST1-2	GND_T1
ST1-3	-8V_T1
ST1-4	PWM_T1
ST1-5	DESAT1

Table 3: Pin assignment of the connector ST2 of the inner high side IGBT

Pin name	Pin function
ST2-1	+15V_T2
ST2-2	GND_T2
ST2-3	-8V_T2
ST2-4	PWM_T2
ST2-5	NC (not connected)

Table 4: Pin assignment of the connector ST3 of the inner low side IGBT

Pin name	Pin function
ST3-1	+15V_T3
ST3-2	GND_T3
ST3-3	-8V_T3
ST3-4	PWM_T3
ST3-5	NC (not connected)

Table 5: Pin assignment of the connector ST4 of the outer low side IGBT

Pin name	Pin function
ST4-1	+15V_T4
ST4-2	GND_T4
ST4-3	-8V_T4
ST4-4	PWM_T4
ST4-5	DESAT4

Table 6: Pin assignment of the connector ST5 of the temperature output signal

Pin name	Pin function
ST5-1	NTC+
ST5-2	NTC-

Table 7: Pin assignment of the connector ST6

Pin name	Pin function
ST6-1	NCLAMP (IGBT neutral clamping point)
ST6-2	AC_OUT (IGBT AC output)

The optional connector ST6 can be used to measure the voltage between the AC-output and the neutral point of the DC-Link capacitor.

4 Functionality of the board

The MA3L080E07_EVAL adapter board is a complementary part of the evaluation kit to drive one 3-Level IGBT module as shown in Figure 5. The adapter board should be pressed on the EconoPACK™ 4.

F3L020E07-F-P_EVAL

MA3L080E07_EVAL

F3L300R07PE4

Figure 5: Mounting sequence of the Evaluation Kit

The IGBT module is not a part of this evaluation kit. The needed IGBT module can be purchased separately.

4.1 Power supply

The MA3L080E07_EVAL as represented in Figure 6 needs four external -8V/+15V isolated power supplies when it is driven by F3L020E07-F-P_EVAL. If the MA080E07 adapter board is not used in conjunction with the F3L020E07-F-P_EVAL, it can be supplied with an isolated power supply providing max. ±20V.

The input PWM voltage level should be selected according to the power supply voltage level. If an asymmetrical supply voltage of -8V/+15V is applied, the PWM signal should not exceed +15V and should not be lower than -8V.

The voltage sources are applied to the corresponding driver channels using the connectors ST1, ST2, ST3 and ST4.

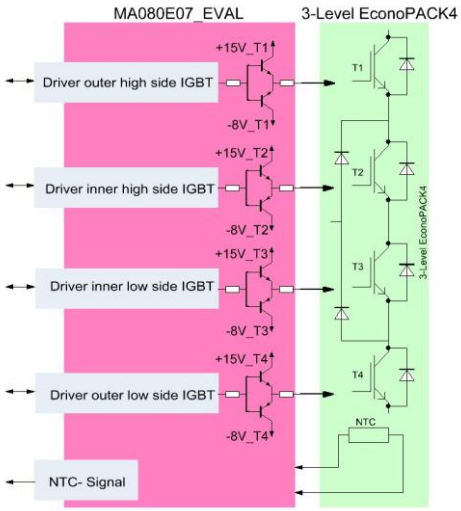


Figure 6: Principle diagram of the MA3L080E07_ EVAL

Figure 7 gives hints about the power as a function of the switching frequency. This power is needed to drive one IGBT of an F3L300R07PE4 EconoPACK™ 4 3-Level module equipped with the adapter board at T_{case} = 125°C and T_{amb} = 25°C. The adapter board is supplied with -8V/+15V.

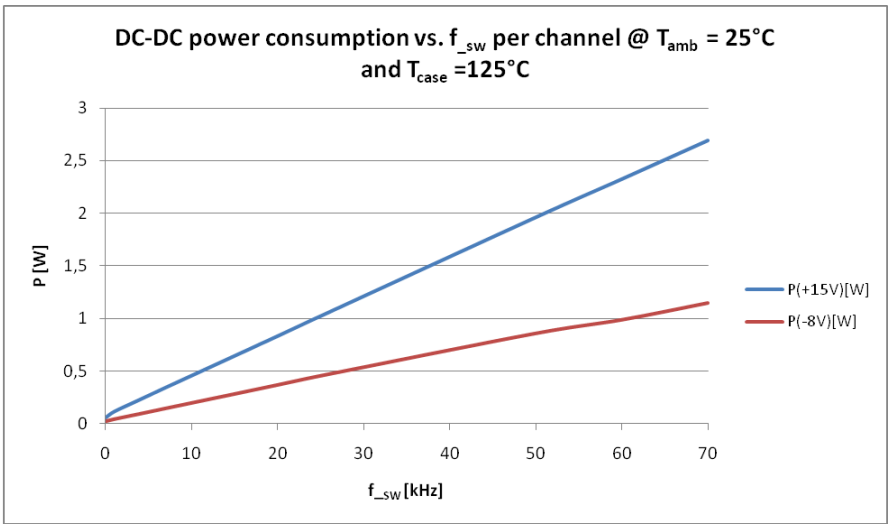


Figure 7: Power consumption of one IGBT of the 3-Level leg

4.2 Booster

Figure 8 shows the booster circuit where two complementary pairs of transistors are used to amplify the input PWM signal. This allows to drive IGBTs that need more current than the driver IC can deliver. Two NPN transistors are used for turning-on the IGBT and two PNP transistors for turning-off the IGBT.

The transistors are dimensioned to provide enough peak current to drive all EconoPACK™ 4 3-Level IGBT modules.

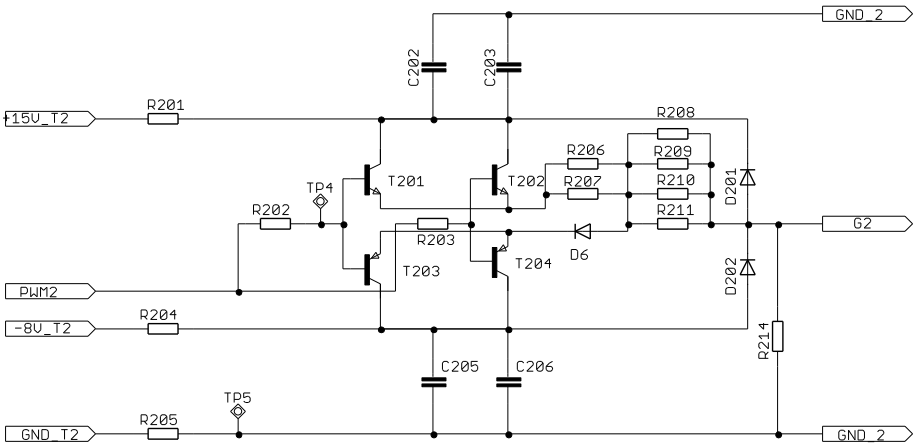


Figure 8: Schematic details of the output stage for a single IGBT driver

Gate resistors are connected between the booster stage and the IGBT module's gate terminals. These resistors should have a suitable rating for repetitive pulse power to avoid degradation.

4.3 V_{CE} monitoring for short circuit detection; active clamping function

The short circuit protection of the outer high side and outer low side IGBTs are based on the monitoring of the V_{CE} voltage for the corresponding IGBT using the active clamp feature as represented in Figure 9. If the IGBT conducts a current a few times higher than the nominal value, the transistor desaturates and the voltage across the device increases. This behavior can be used for short circuit detection and to turn-off of the IGBT. The short circuit withstand time for Infineon IGBT modules is 10µs. During this time the short circuit needs to be detected and the IGBT has to be turned off without exceeding its maximum blocking voltage.

When the MA3L080E07_EVAL is connected to a F3L020E07-F-P_EVAL driver board, each 1ED020I12-F Coreless Transformer driver IC of the outer high side and outer low side IGBTs detects and handles the short circuit separately.

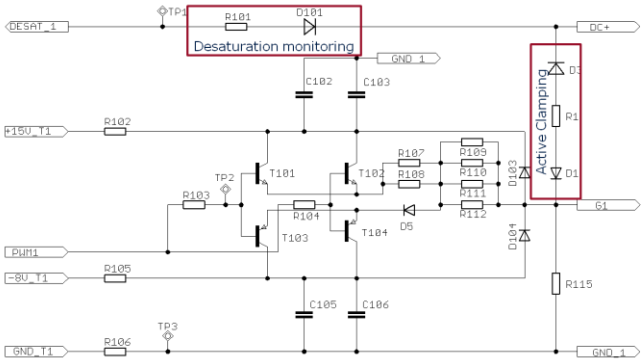


Figure 9: Desaturation protection and active clamping diodes

Active clamping is a technique which keeps transient overvoltage below the critical limits when the IGBT turns off. The standard approach for active clamping is to use a TVS[4] diodes connected between the auxiliary collector and the gate of an IGBT module. When the Collector-Emitter voltage exceeds the diodes breakdown voltage the diodes current sums up with the current from the driver output. Due to the increased gate-emitter voltage the transistor is held in an active mode and the turn-off process is prolonged. The dI_C/dt slows down which results in a limited voltage overshoot. Avalanche diodes conduct high peak currents during the time in which the clamping is actively limiting the overvoltage.

A typical turn-off waveform of a F3L300R07PE4 module at room temperature without overvoltage limiting function can be seen in Figure 10a. Figure 10b shows the waveform with the same load conditions as Figure 10a with active clamping function.

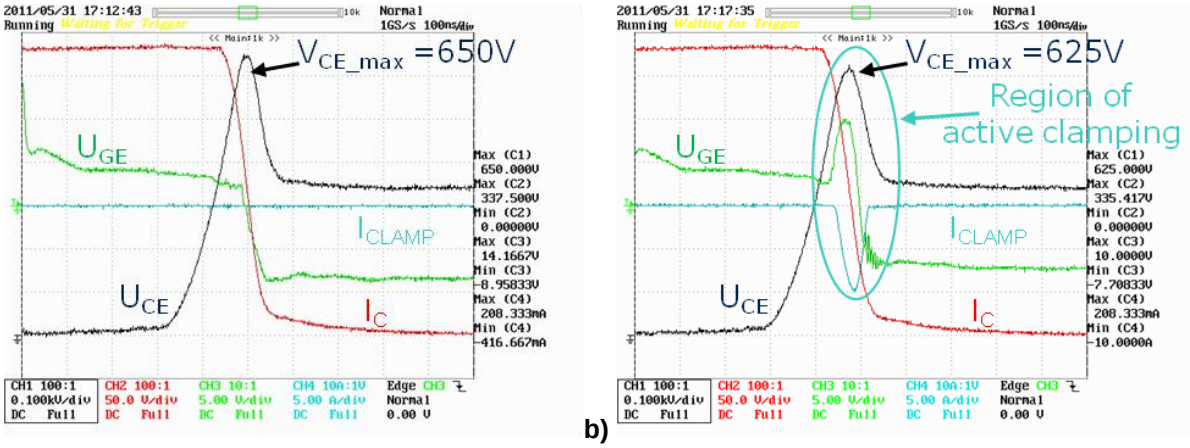


Figure 10: a) turn-off without active clamping **b) with active clamping function**

[4] TVS Transient voltage suppressor diode

4.4 Maximum switching frequency

The switching frequency on the adapter board is limited either by the maximum output power of the driver power supply or by the maximum temperature of the PCB due to the power losses in the external gate resistors. These power losses in the gate resistors depend on the IGBT gate charge, gate voltage magnitude and on the switching frequency of the IGBT. Due to the power losses in the external gate resistors, heat will be generated, which leads to an increase of the PCB temperature in the neighborhood of these resistors. This temperature must not be higher than the maximum working temperature of the PCB, i.e. 105°C for a standard FR4 material.

The calculation of the power losses in the gate resistors can be done by utilizing equation (1):

$$P_{dis} = P(R_{EXT}) + P(R_{INT}) = \Delta V_{out} \cdot f_s \cdot Q_G \quad (1)$$

where:

P_{dis} = dissipated power
$P(R_{EXT})$ = dissipated power external gate resistors
$P(R_{INT})$ = dissipated power internal gate resistor
ΔV_{out} = voltage magnitude at the driver output
f_s = switching frequency
Q_G = IGBT gate charge for the given gate voltage range

The complete gate resistor consists of the internal gate resistor together with an external gate resistor and due to that, a part of the IGBT drive power losses will be dissipated directly in the PCB, whereas the other part of the losses will be dissipated to the ambient air. The ratio of the losses dissipated internally $P(R_{INT})$ and externally $P(R_{EXT})$ corresponds directly to the ratio of the mentioned R_{INT} and R_{EXT} resistors. Corresponding to -8/+15V operation the datasheet value of Q_{GE} needs to be reduced by 20%.

Due to the PCB temperature criteria the power dissipated in external gate resistors $P(R_{EXT})$ has to be considered for the thermal design.

Figure 11 shows the PCB board temperature around the gate resistors depending on the switching frequency under following conditions: T_{case} = 125°C, T_{amb} = 25°C, V_{GE} = -8V/+15V.

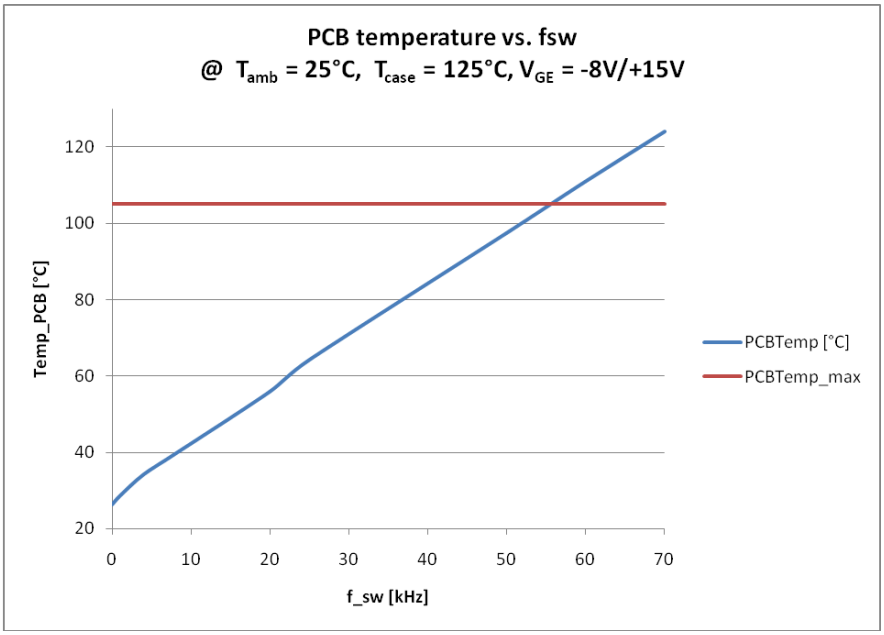


Figure 11: Local temperature development of the MA3L080E07_EVAL adapter board

5 Paralleling

In contrast to the operation of one single IGBT, where the working point is relatively easy to set up, the switching of paralleled IGBT modules on the same operation point is not trivial. This can be explained by the fact that the IGBTs have a certain variation in their characteristics. A direct consequence of this is a slight current imbalance between the IGBTs. The biggest challenge is to minimize the deviation of the leg current to achieve highly efficient systems and an improved reliability.

Two main factors have a primary role in the current maldistribution:

- the difference between the impedance of each leg of the paralleled setup
- and the difference in the output voltages of the individual leg of the paralleled setup

5.1 Static current imbalance

The static current imbalance can be caused due to:

- the variation of the collector-emitter-voltage of each leg of the paralleled setup
- the variation of the resistance of the main current path

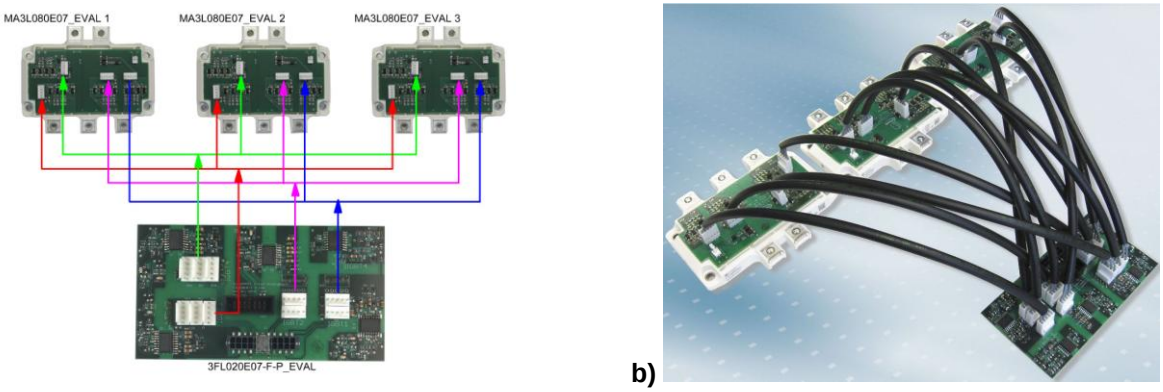
5.2 Dynamic current imbalance

The dynamic current imbalance can be caused by

- the variation of the transmission characteristics caused by the different V_{GEth} of each IGBT
- the variation of the impedance of the main current path
- the stray inductance of the internal and external commutation path of the IGBT module
- the IGBT driver output resistance in the paralleled legs
- the transfer characteristic $I_C = f(V_{GE})$

5.3 Paralleling with MA3L080E07_EVAL

The MA3L080E07_EVAL was designed primarily to work with the evaluation driver board 3FL020E07-F-P_EVAL, which allows the parallel connection of up to three modules, each equipped with one MA3L080E07 adapter board as represented in Figure 12a. In case of paralleling, the driver board doesn't need to be plugged into the complementary adapter board. The connection from the driver to the adapter boards is done utilizing the connectors on the top side of the driver board as shown in Figure 12b.



a) **b)**

Figure 12: a) Principle of parallel connection, b) Photo of the setup

Figure 12b shows a parallel connection of three 3-Level IGBT modules. The wires to connect the driver to the adapter boards should have the same length to avoid differences of signal run time between the gates of the three legs. Star connection of the IGBTs improves the reduction of cross flow in the auxiliary emitter paths after the switching sequence. The MA3L080E07_EVAL boards are equipped with 4R7 resistors in the auxiliary emitter path and other power supply lines (-8V / +15V) to reduce the current cross flow between the units of the paralleled circuits.

The MA3L080E07 adapter board is equipped with 4R7 decoupling resistors in the power supply lines. This avoids currents in the emitter path between the paralleled modules.

Figure 13a gives a hint about the balancing current flowing in the emitter paths when MA3L080E07_EVAL is equipped with 0R decoupling resistance. Balancing currents of up to 5A can be measured after the switching sequences. With a standard equipped adapter board, the balancing current is reduced to a few mA as represent in Figure 13b.

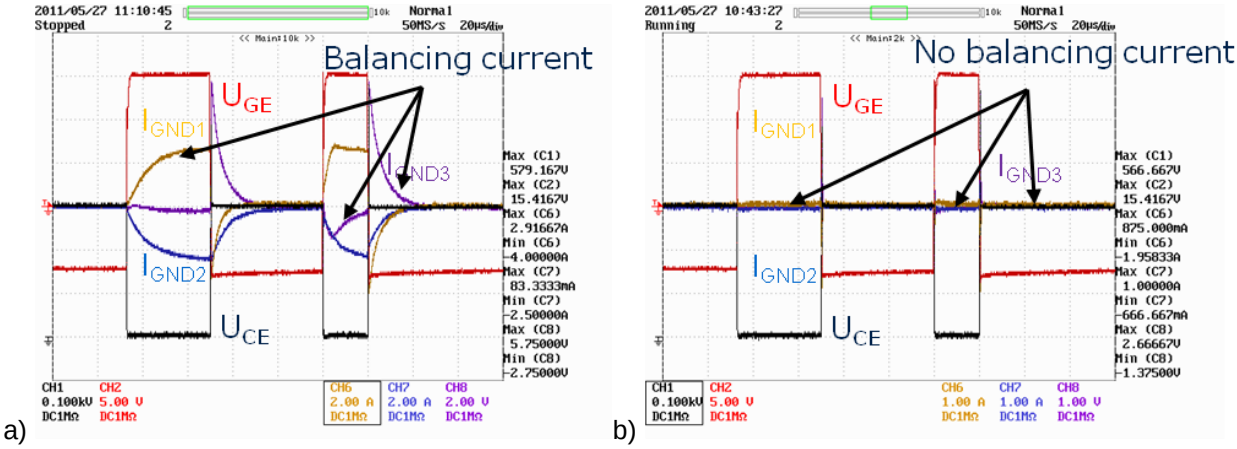


Figure 13: Current distribution in the auxiliary emitter paths

a) With 0R as decoupling resistor **b) With 4R7 as decoupling resistor**

Figure 14 shows the turn-on and turn-off behavior of 3 IGBT modules in parallel and their current sharing on the AC terminals.

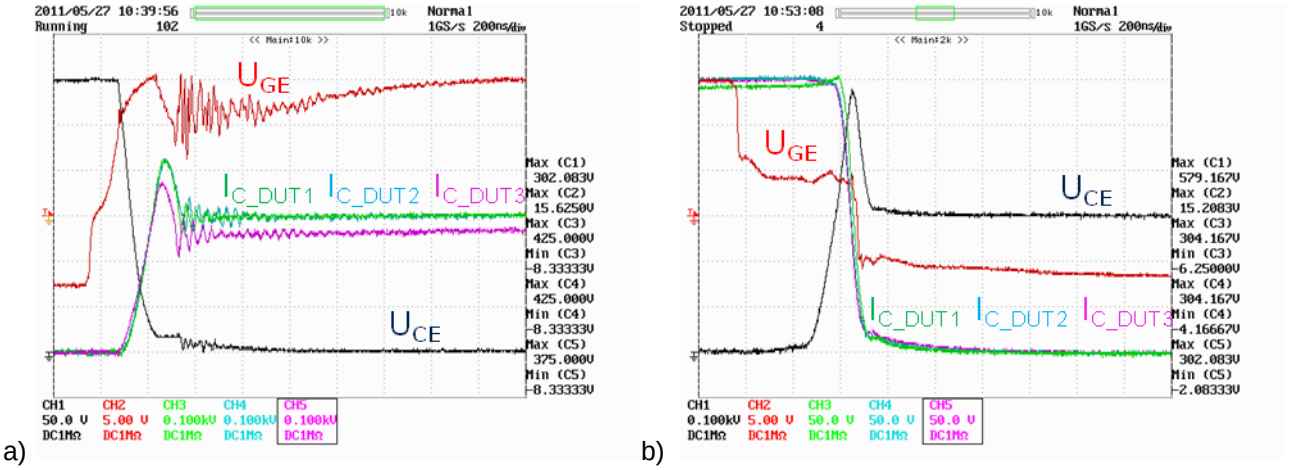


Figure 14: Current distribution on the AC terminals of 3 parallel F3L300R07PE4 modules

a) Turn-on **b) Turn-off**

The E_{on} and E_{off} values measured with a gate resistance $R_{gon} = R_{goff} = 2R$ and at ambient temperature of 25°C are listed in 0.

Datasheet values of E_{on} and E_{off} for F3L300R07PE4: $E_{on} = 1.5mJ$; $E_{off} = 14mJ$

Table 8: Overview of E_{on} and E_{off} of three paralleled F3L300R07PE4 modules

Device under Test	DUT1	DUT2	DUT3
E_{on} [mJ]	2.3	3.5	4
E_{off} [mJ]	14.28	13.24	14

Compared to the datasheet values, the measured E_{off} values are similar. The variation in E_{on} is higher and in general higher than the datasheet values. Nevertheless the influence of E_{off} is dominating.

6 Base plate temperature monitoring by internal NTC resistor

The MA3L080E07_EVAL adapter board offers to monitor the IGBT case temperature. If the MA3L080E07_EVAL Adapter board is equipped with F3L020E07-F-P_EVAL driver board, no further effort would be necessary for the acquisition of the temperature signal from the NTC. For driver solutions different to F3L020E07-F-P_EVAL driver board, an external circuit would be required for the acquisition of the NTC signal. Electronic acquisition of the NTC temperature requires an external circuit and some examples of circuits and details of the NTC characteristics are described in the application note: AN2009-10.

Notice: This temperature measurement is not suitable for short circuit detection or short term overload and may be used to protect the module from long term overload conditions or malfunction of the cooling system.

An electrical isolation must be assured between the NTC input signal (IGBT side) and the NTC output control signal.

7 Schematics and Layouts

To meet the individual customer requirements and to make the Evaluation Adapter Board simple for development or modification, all necessary technical data like schematic, layout and components are included in this chapter.

7.1 Schematics

Figure 15 to Figure 18 depict the driving circuit of the IGBTs.

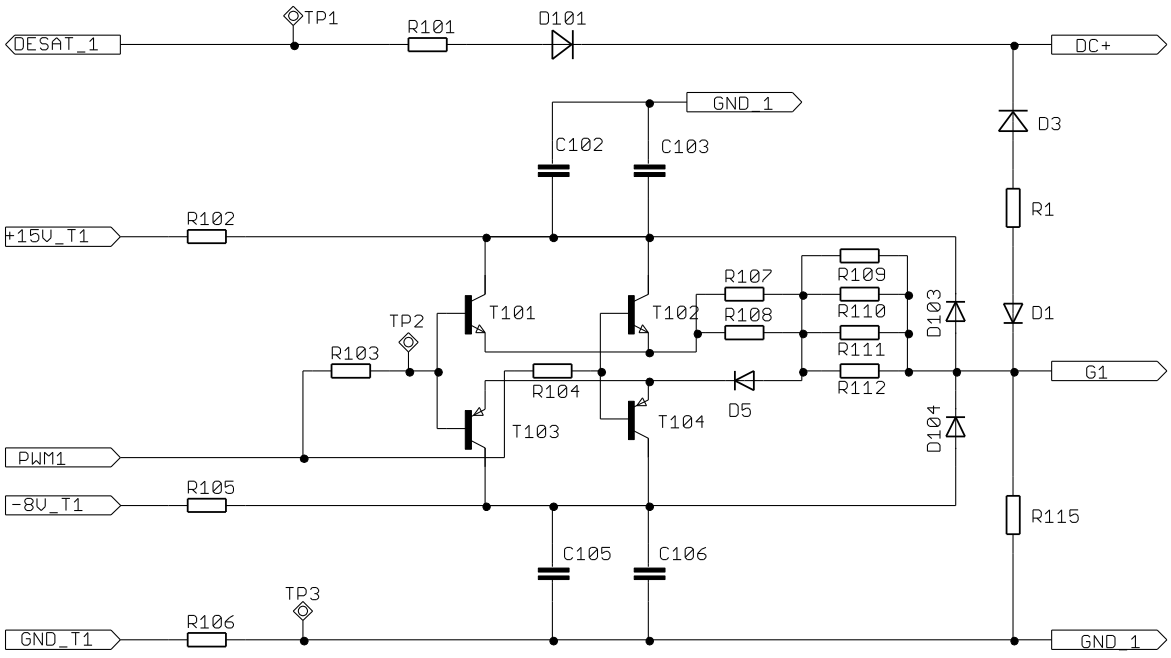


Figure 15: Driving circuit of the outer high side IGBT

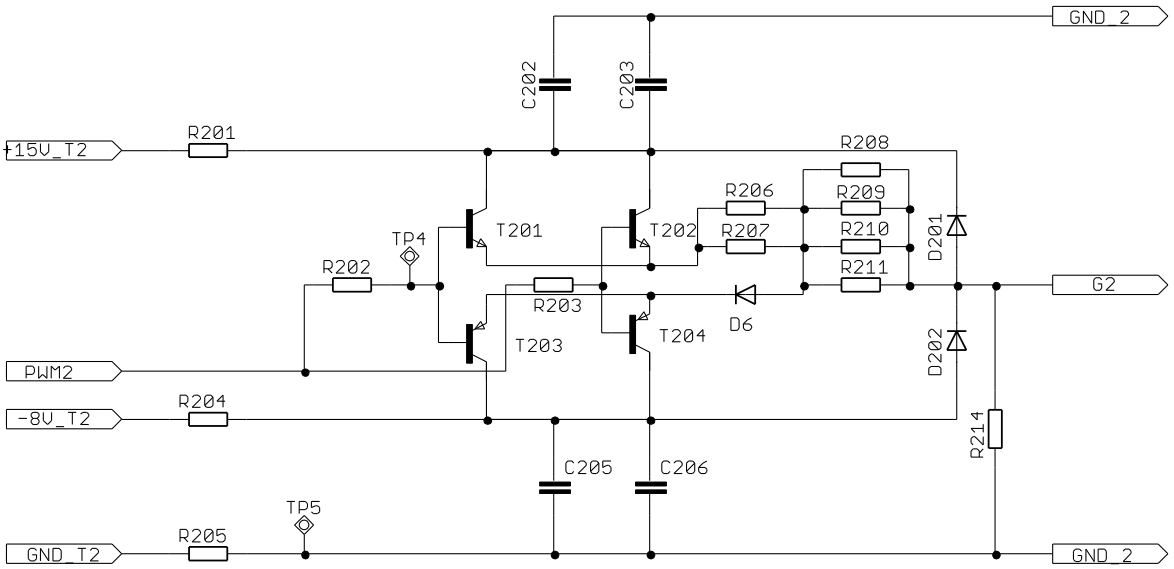


Figure 16: Driving circuit of the inner high side IGBT

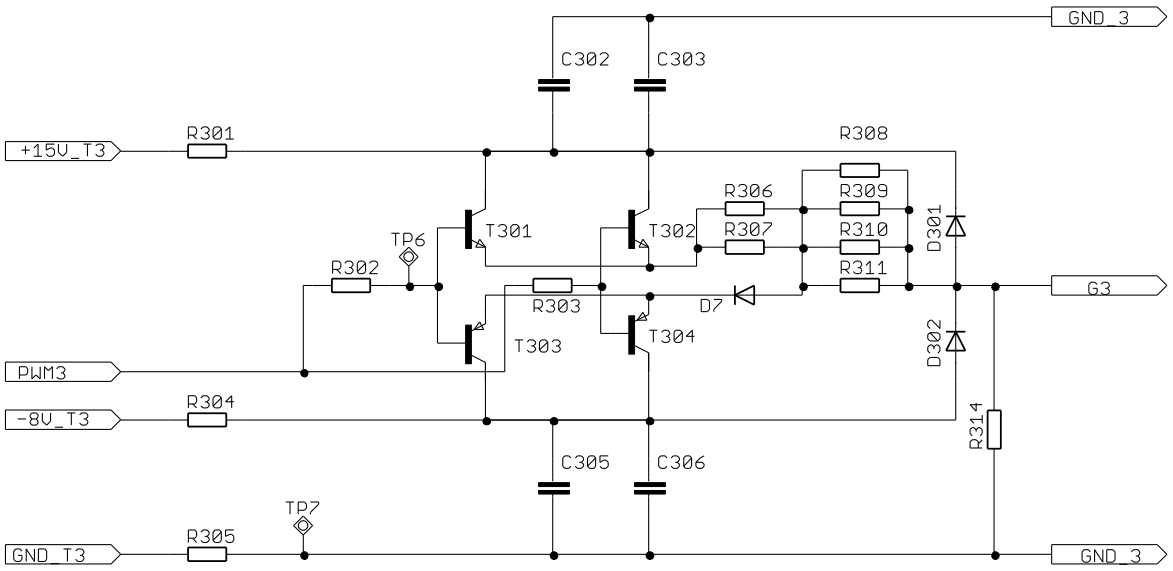


Figure 17: Driving circuit of the inner low side IGBT

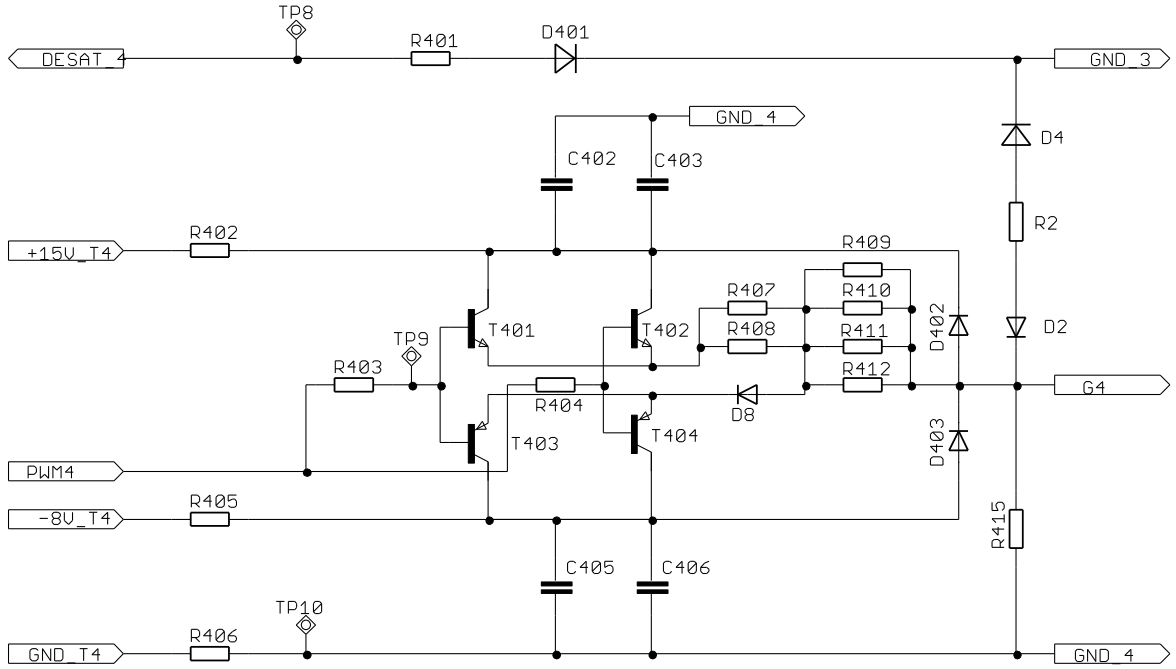


Figure 18: Driving circuit of the outer low side IGBT

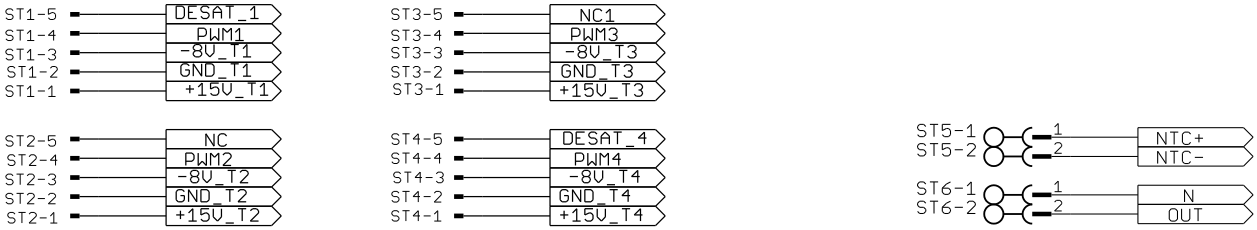


Figure 19: Pin description of the connectors of the MA3L080E07_EVAL

7.2 Layouts

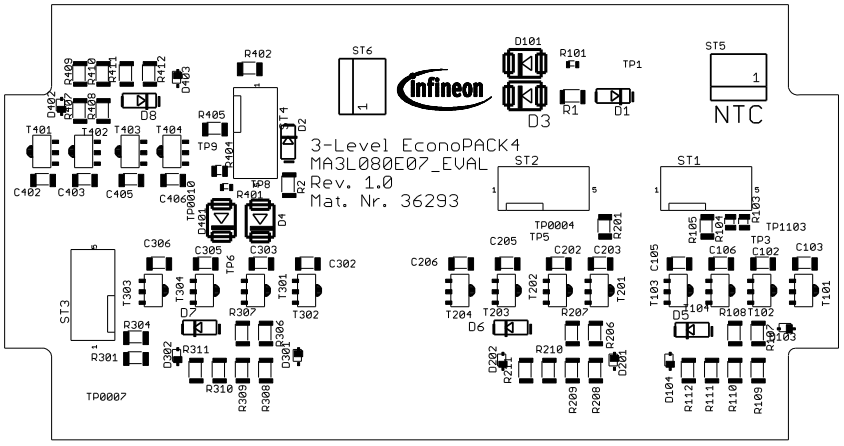


Figure 20: Component placement, top side

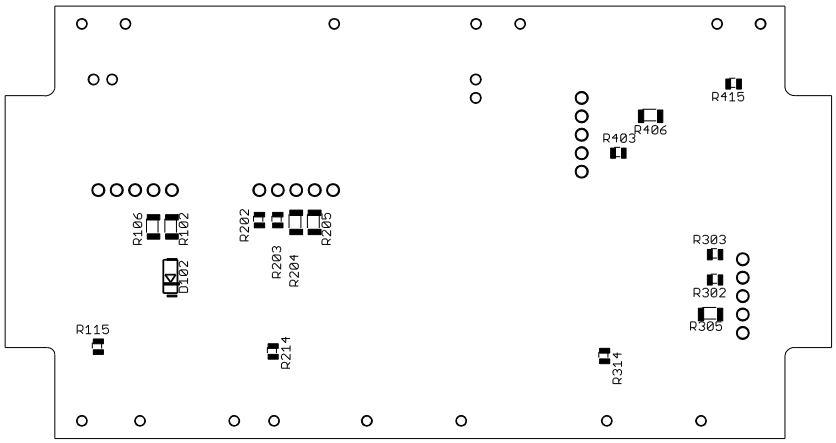


Figure 21: Component placement, bottom side

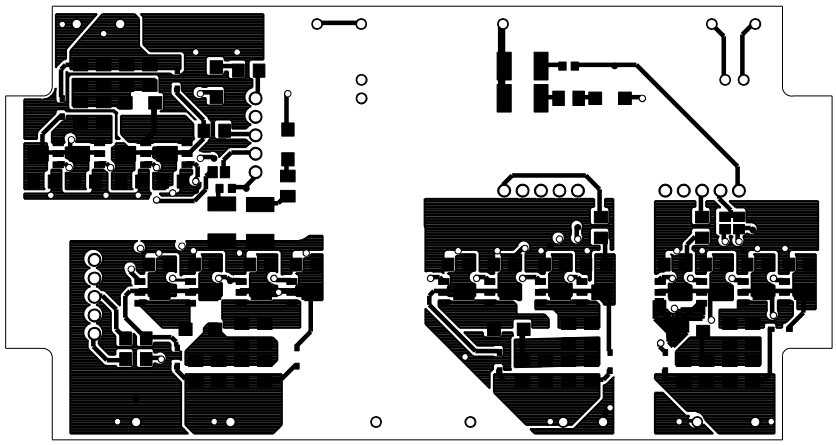


Figure 22: Top- Layer

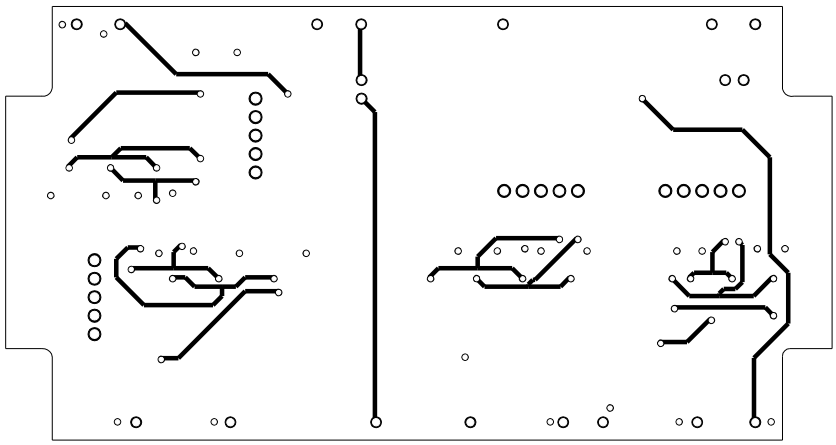


Figure 23: Layer 2

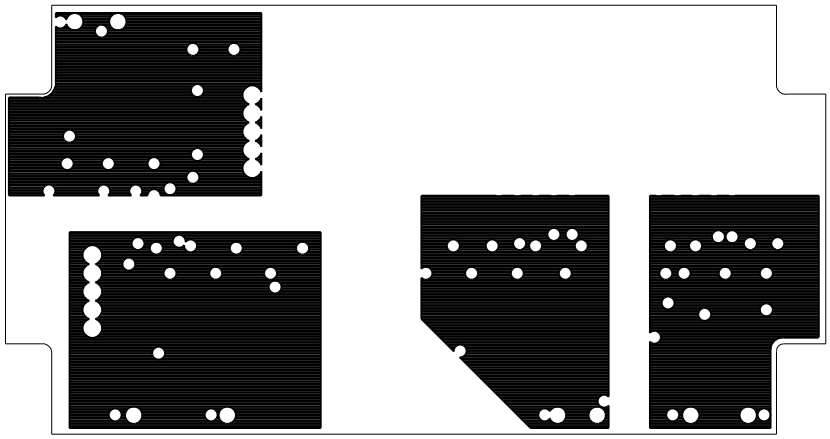


Figure 24: Layer 3

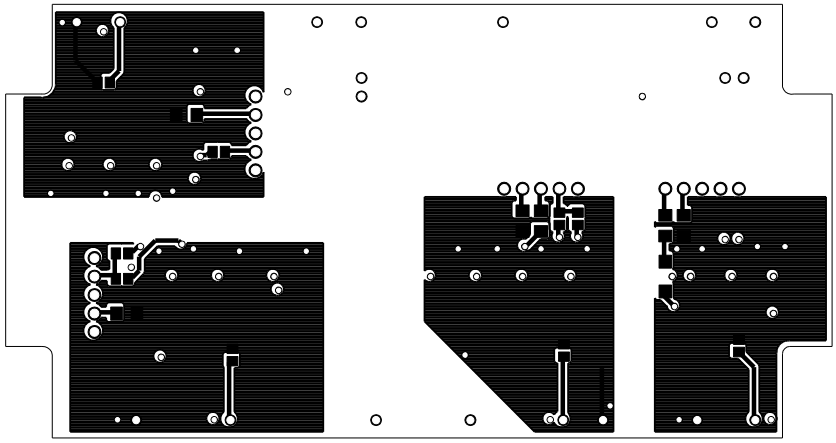


Figure 25: Bottom- Layer

8 Bill of Material of MA3L080E07_EVAL

The bill of material includes a part list as well as assembly notes.

The tolerances for resistors should be less or equal to ±1 %, for capacitors of the type C0G less or equal to ±5 % and for capacitors of the type X7R less or equal to ±10 %.

Type	Value	Package	QTY	Name Part	Manufacturer
Resistor	1R8	R-EU_1206	2	R1, R2	-
Resistor	Puls resistors optional	R-EU_1206	24	R107,R108, R109, R110, R111, R112, R206, R207, R208, R209, R210, R211, R306, R307, R308, R309, R310, R311, R407, R408, R409, R410, R411, R412	-
Resistor	4R7	R-EU_1206	12	R102, R105, R106, R201, R204, R205, R301, R304, R305, R402, R405, R406	-
Resistor	1k	R-EU_0603	2	R101, R401	
Resistor	39R	R-EU_0805	8	R103, R104, R202, R203, R302, R303, R403, R404	-
Resistor	10k	R-EU_0805	4	R115, R214, R314, R415	-
Capacitor	4µ7/25V/X7R	C1206	16	C102, C103, C105, C106, C202, C203, C205, C206, C302, C303, C305, C306, C402, C403, C405, C406	Murata
Diode	ES1D	DO214AC	6	D1, D2, D5, D6, D7, D8	
Diode	P6SMB480C	SMB	2	D3, D4	
Diode	STTH112U	SOD6	2	D101, D401	-
Diode	BAT165	SOD323R	8	D103, D104, D201, D202, D301, D302, D402, D403	Infineon
Bipolar transistor	ZXTN2010Z	SOT89	8	T101, T102, T201, T202, T301, T302, T401, T402	Diodes
Bipolar transistor	ZXTP2012Z	SOT89	8	T103, T104, T203, T204, T303, T304, T403, T404	Diodes
Connector	MOLEX 2223-2051	PITCH KK	4	ST1, ST2, ST3, ST4	Molex
Connector	MOLEX 2223-2021	PITCH KK	1	ST5	Molex
Connector	MOLEX 2223-2021	PITCH KK	N.C	ST6	Molex

9 How to order the Evaluation Adapter Board

Every Evaluation Adapter Board has its own IFX order number and can be ordered via your Infineon Sales Partner.

Information can also be found at the Infineon's Web Page: www.infineon.com

CAD-data for the board described here are available on request. The use of this data is subjected to the disclaimer given in this AN. Please contact: WAR-IGBT-Application@infineon.com

IFX order number for MA3L080E07_EVAL:	36293
IFX order number for F3L020E07-F-P_EVAL:	36294

10 Literature

[1] Zhang Xi, Uwe Jansen, Holger Rüthing : 'IGBT power modules utilizing new 650V IGBT3 and Emitter Controlled Diode3 chips for 3-Level converter' ISBN: 978-3-8007-3158-9 Proceedings PCIM Europe 2009 Conference

[2] AN2009-10 : 'Using the NTC inside a power electronic module', is available on Infineon's website

[3] Evaluation Driver Board for EconoPACK™ 4 3-Level modules AN2011-03