Application Note

I C s f o r M o t o r C o n t r o l

TDA5142 output driver stages for supply voltages up to 30 V

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Summary:

The Motor Control ICs of the TDA514x series can handle supply voltages up to 18 volts. It is with these ICs not possible to drive directly brushless DC-motors that need a supply voltage higher than 18 volts.
The TDA5142 has external driver stages. In this paper a circuit diagram has been described, including some component calculations, in which the TDA5142 Motor Control IC is used with external driver stages for voltages higher than 18 volts.
The described circuit is built on a pc-board and this pc-board is meant to be used as an evaluation board for motor control in industrial applications for voltages up to 30 volts (24 volts ± 25%).
The circuit has been designed in such a way that it can be adapted for use at supply voltages lower than 18 volts. This can be done by leaving out some components and inserting some wire bridges.
The circuit contains an op-amp controlled current limiter as well.

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1. Introduction

The TDA5142 motor control IC has been designed for motor control applications for supply voltages up to 18 volts and for use with external driver stages.

For motor voltages greater than 18 V some interface circuitry has to be added to prevent that the rated voltages for the IC are exceeded.
The output stages can be built-up with power MOSFETS or bipolar transistors.
The pcb lay-out is made such that the output stages can be provided with MOSFETS or bipolar transistors as well.

The driver outputs NA, PA, NB, PB, NC and PC, the OTA output AMP-out and the inputs V_{mot}, Comp-A, Comp-B, Comp-C, MOT0 and AMPIN+ can not withstand voltages higher than 18 volts.

The component calculations have been carried-out for a V_{supply} up to 30 V. This is, however, not an absolute limit. With other components values the circuit can also be used for higher voltages.

In this report only the calculation of the components of the output driver section has been given. See the specification of the TDA5142 for the calculation of the timing capacitors C5 up to C8.

2. Circuit description

In figure 1 a circuit has been depicted for supply voltages up till 18 volts.

In this circuit we distinguish the following parts:

1. the V_{mot} control part with T10, R42, R30, R39, R40, C1, C2 and the OTA (inside to TDA5142) with AMPIN-, AMPIN+ and the AMPOUT.
2. the output drivers (T1 - T6) with fly-back diodes (D1 - D6) and the connections to the comparators inputs via the resistors R27 - R29 and R10.
3. the current limiter circuit with the op-amp IC2A, the current sense resistor R17A and B, the transistor T10 to limit the current of T10 and some additional components to set the current limit.

In this diagram one can see that the output driver stages, made with an N-channel and P-channel MOSFET pair, have been connected to the outputs of the TDA5142 via series resistor of 47 Ω. This resistor is necessary to prevent HF oscillations in the output power MOSFETS. These resistors must be mounted as close as possible to the MOSFET.
However, when the outputs stages are made with bipolar transistors these series resistors are used to determine the base current for the bipolar transistors.
If a bipolar output stage is used one can consider an output stage with an NPN/PNP transistor pair or with an NPN/PNP darlington transistor pair. This will be discussed later on in this report.

In figure 2 a circuit has been depicted with the interface circuit to make the system suitable for voltages higher than 18 volts.

In the next paragraphs the different interfaces will be discussed together with some component calculations.

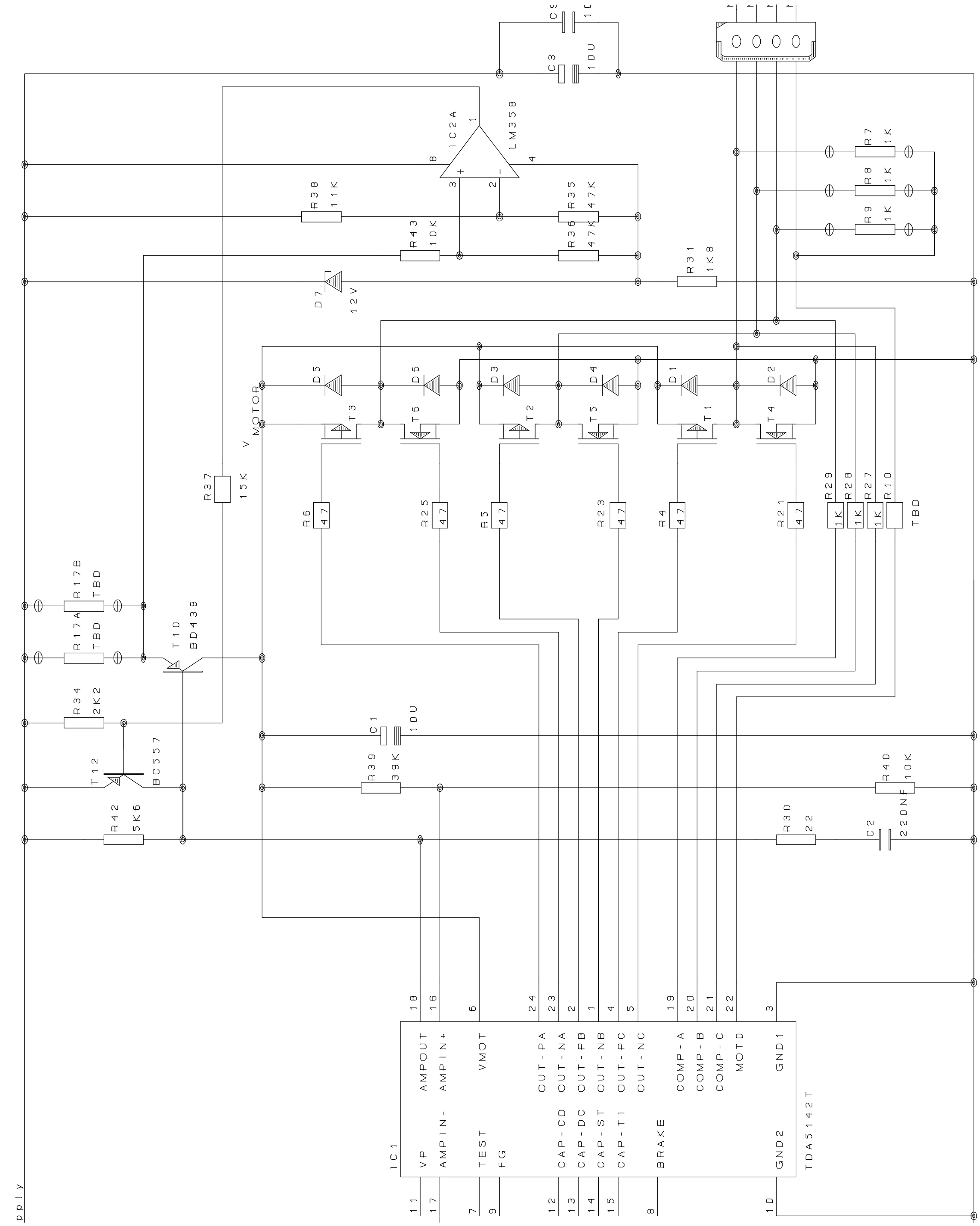

IC1
TDA5142T
IC2A
LM358
VP
AMPIN-
AMPOUT
AMPIN+
TEST
FG
VMOT
CAP-CD
CAP-DC
CAP-ST
CAP-TI
OUT-PA
OUT-NA
OUT-PB
OUT-NB
OUT-PC
OUT-NC
BRAKE
COMP-A
COMP-B
COMP-C
MOT0
GND1
GND2
V MOTOR
T10
BD438
T12
BC557
D7
12V
C1
10U
C2
220NF
C3
10U
R38
11K
R43
10K
R35
47K
R31
1K8
R37
15K
R34
2K2
R39
39K
R40
10K
R42
5K6
R30
22
R17A
TBD
R17B
TBD
R7
1K
R8
1K
R9
1K
R10
TBD

Figure 1

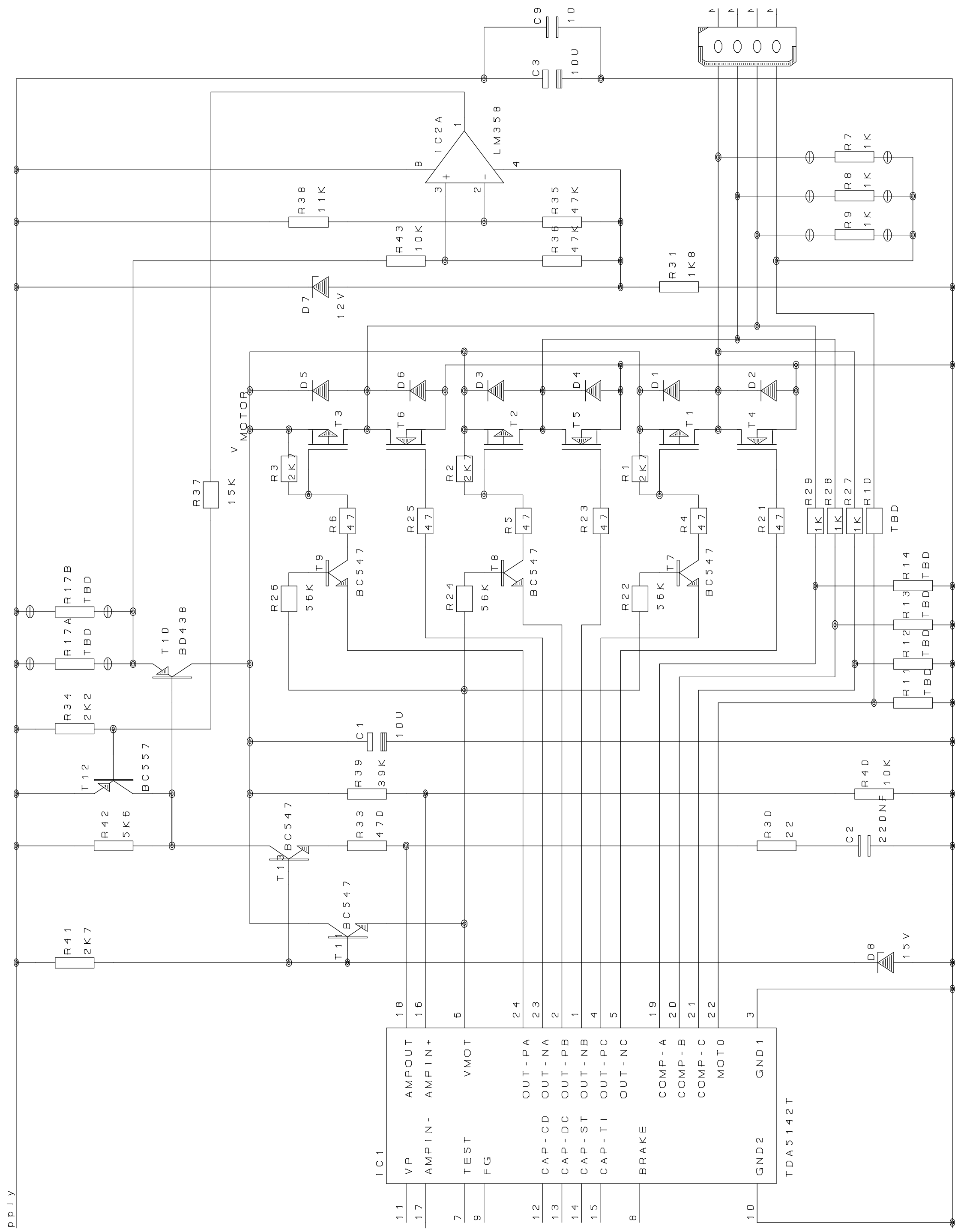


Figure 2

2.1 V_{mot} control adaptation

The motor speed can be controlled with the voltage V_{mot}.
In this system the control of V_{mot} is accomplished by using the on-chip OTA. The voltage V_{mot} is fed back via R39 and R40 to the AMPIN+ input of the OTA and AMPOUT drives a bipolar power transistor or a power P-channel MOSFET T10. The voltage V_{in}, connected to the AMPIN- input, controls the voltage V_{mot}. The relation between V_{in} and V_{mot} is as follows:

$$V_{mot} = V_{in} \frac{R39 + R40}{R40} \tag{1}$$

The supply for the OTA is retrieved from V_P. The maximum input voltage on the AMPIN inputs is V_P - 1.7 V, so, for a good control of V_{mot}, the voltage on these inputs may not exceed this value. The resistors R39 and R40 have to be determined in such a way that the required control range of V_{in} is covered and that the input voltage on the AMPIN inputs is lower than V_P - 1.7 V at the highest possible value of V_{mot}.

The output voltage of the OTA may not exceed 18 V. For $V_{mot} \geq 18$ V the output voltage of the OTA must be limited to 18 V. To achieve this the transistor T13 has been inserted. The maximum base voltage of T13 is determined by a zener diode (D8) and limits in this way the voltage on the AMPOUT pin. To have some margin, due to zener voltage tolerances, a zener diode of 15 V has been chosen.
The base voltage V_{bT13} is determined by V_{supply} - R33 x I_{bT13} and follows the V_{supply} until it is clamped by the zener diode D8.

Take for the zener diode a current of about 5 mA at V_{supply} is 30 V.

$$R41 = \frac{30 - V_{D8}}{5\ mA} = \frac{30 - 15}{5} = 3\ k\Omega \tag{2}$$

Take R41 = 2.7 kΩ.

The control circuit for V_{mot} can operate with both a bipolar power transistor or a P-channel power MOSFET. The evaluation board will be equipped with a BD438 or equivalent.

If a bipolar transistor is used the collector current I_{cT13} is mainly determined by the h_{fe} of T10 and the collector current of T10.
With an average collector current for T10 of 1 A and an h_{fe} for T10 of 50 this results in a base current for T10 of 20 mA. This means, with an h_{fe} of 50 for T13, a base current for T13 of 0.4 mA. The current through R41 is about 5 mA, so there is enough current to bias the zener diode D8 and to supply the base current for T13.

The base current for T10 of 20 mA, flowing through T13 into the TDA5142, may cause excessive heat dissipation in the transistor T13 and the TDA5142. The resistor R33 (470 Ω) has been inserted in the emitter line of T13 to limit the dissipation in the TDA5142 and transistor T13. This resistor is only necessary in case for T10 a bipolar transistor is used.
When for T10 a MOSFET is used the collector current I_{cT13} is determined by R1.
With the MOSFET the max. collector current of T13 is:

$$I_{cT13max} = \frac{V_{supply} - V_{ceT13min} - V_{AMPOUTmin}}{R42} = \frac{30 - 0 - 0}{5600} = 5.4\ mA \qquad (3)$$

R42 has been determined experimentally and with this resistor value a good control has been obtained.
The collector current I_{cT13} is, in case a MOSFET is used, lower than for the bipolar transistor. This means that components as determined for the bipolar transistor can also be used when a MOSFET is used.
The resistor R30 and capacitor C2 are needed for frequency stability of the circuit.

Note:

Because transistor T10 can dissipate much heat, room has been saved on the evaluation board to provide transistor T10 with a heat sink.

2.2 Output stage adaptation

In this chapter the output stages are discussed. Because for the output stages both power MOSFETS and bipolar transistors can be used the component calculations have been carried-out for both types of output stages.

2.2.1 MOSFET output stages.

In figure 3 one of the three output stages of TDA5142 has been depicted together with an external output stage with MOSFET transistors for $V_{mot} \leq 18$ V.

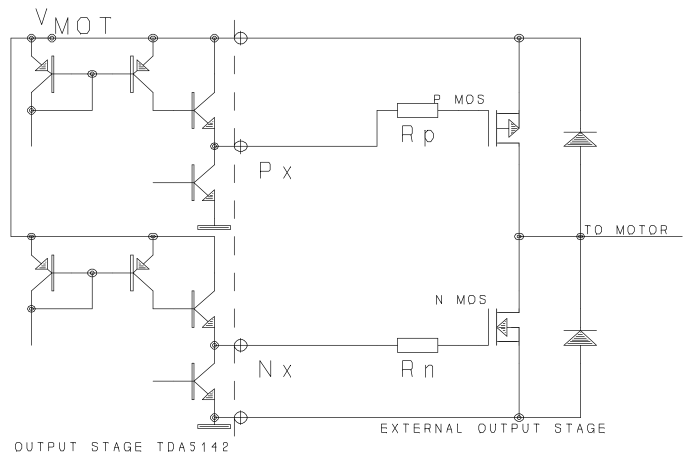


Figure 3

In this figure we see that the output voltage of the V_{mot} controller is connected to the V_{mot} input of the TDA5142 and to the common source line of P-channel MOSFETS.

In figure 4 the circuit is given for $V_{mot} \geq 18$ V. Here we see that the connection between the common source line has been interrupted and that an extra transistor has been connected between the TDA5142 output Px and the gate of the P-channel MOSFET. With this interface the voltage V_{motor} on the common source line can now be greater than 18 V.

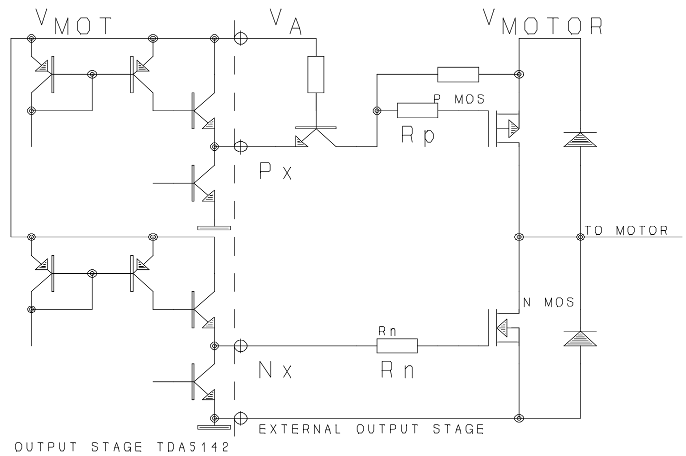


Figure 4

The voltage on the V_{mot} input of the TDA5142 may not exceed 18 V and therefore the V_{mot} input has been connected to an auxiliary voltage source V_A, that has a voltage lower than 18 V.

The base current for the interface transistor in series with the gate of the P-channel MOSFET is retrieved, via a resistor, from the voltage source V_A.
The resistors Rp and Rn are needed, as described earlier, to suppress HF oscillations. The circuit of figure 4 has been implemented into the overall diagram as has been given in figure 2.

For the calculation of the components we refer to the reference numbers as mentioned in figure 2.

The auxiliary voltage source V_A has been built-up with transistor T11, zener diode D8 and resistor R41 , the same reference as has been used for transistor T13.
The current to be supplied by this voltage source is determined by the current that flows into the gate drive circuitry of the MOSFETS.
The output voltage V_{PA} of the TDA5142 switches between V_A and GND.

For the interface transistor T9 a BC547 type transistor has been chosen, because the collector current is low, the switching speed is not very critical and this transistor can withstand a collector voltage of at least 50 V.
Transistor T9 is switched in the emitter line and is conducting when TDA5142 output is at GND level. The max. collector current is:

$$I_{cT9max} = \frac{V_{motor} - V_{ceT9min} - V_{PAmin}}{R3 + R6} \quad (4)$$

For R3 a value of 2.7 kΩ has been chosen, that gives with a general purpose P-channel MOSFET a turn-off time of about 5 µs. If a faster turn-off time is required a lower value for R3 has to be chosen.
The resistor R6, to prevent HF oscillations, has a value of 47 Ω and this value has been determined experimentally.

To determine the maximum value of I_{cT9} the voltages V_{ceT9} and V_{PAmin} are considered to be zero and V_{motor} = 30 V

$$I_{cT9} = \frac{30}{2700 + 47} \approx 11\ mA \quad (5)$$

The base drive for T9 is determined by R26 and the voltage V_A.

The auxiliary voltage source V_A has, as already has been mentioned, been built-up with transistor T11, zener diode D9 and resistor R41. The diode has an initial tolerance of ± 5%.
So, the minimum value of V_A = 0.95 x 15 - V_{beT11} ≈ 13.5 V.
The auxiliary voltage source V_A has to supply the collector and the base currents for T9, T8 and T7 and the drive current for the output stages of the TDA5142.
The currents through T9, T8 and T7 do not flow simultaneously. Only one of the three transistors is conducting at a time, so the maximum current to be supplied by the transistor T11 is the sum of the base and collector current of T9 or T8 or T7.

When the transistor T9 turns-on the collector current of T9 is as follows:

$$I_{cT9} = \frac{30 - V_{ceT9min} - V_{PAmin}}{R3 + R6} = \frac{30 - 0 - 0}{2700 + 47} \approx 11\ mA \quad (6)$$

with h_{feT9} = 50,

$$I_{bT9} \geq \frac{11\ mA}{50} = 0.22\ mA \quad (7)$$

$$R_{26} = \frac{V_A - V_{beT9}}{I_{beT9}} = \frac{13.5 - 0.75}{0.22} = 58\ k\Omega \quad (8)$$

Choose R26 = 56 kΩ

The current to supply the output drivers inside the TDA5142 has not been specified, but assume that this current is about equal to currents through the other transistors.
Let us assume a total current of 20 mA to be supplied by T11, this means with an h_{fe} for T11 of 50 a base current of about 0.4 mA.
The current through the zener diode D8 is about 5 mA and this current is large enough to supply the base current of 0.4 mA for T11 as well.

2.2.2 Bipolar output stages.

When bipolar output stages are used the component values have to be adapted and some components have to be added. In the output stages both single transistors or darlington transistor can be used.
For bipolar transistors base current has to be supplied. The amount of base current to be supplied is dependent on the magnitude of the collector (motor) current. The motor current is high as long as the motor is not running and decreases during the start-up.
To assure that the conducting output transistors are well saturated the base drive for the transistors must be based upon the highest output collector current.
Assume that at a collector current of about 1 A the ratio between the collector current and the base for a single transistor of 25 and for a darlington transistor of 250.
This means for a single transistor a minimum base current of at least 40 mA and for a darlington a base current of only 4 mA.
From this we see that for the single transistor the fairly high base current has to be supplied and that this current always flows, regardless of the magnitude of the collector current. A single transistor, however , has a lower saturation voltage than a darlington transistor.
Despite of the lower saturation voltage of a single transistor (typ. 0.5 V) with respect to the darlington transistor (typ. 1.2V) the darlington has a higher efficiency. For higher values of V_{motor} the difference between the saturation voltages of both types of transistors is negligible. Considering all this the darlington transistor has been chosen as output driver.

The circuit for the bipolar output stages needs some adaptations with respect to MOSFET solution. The circuit for one bipolar output stage has been depicted in figure 5.

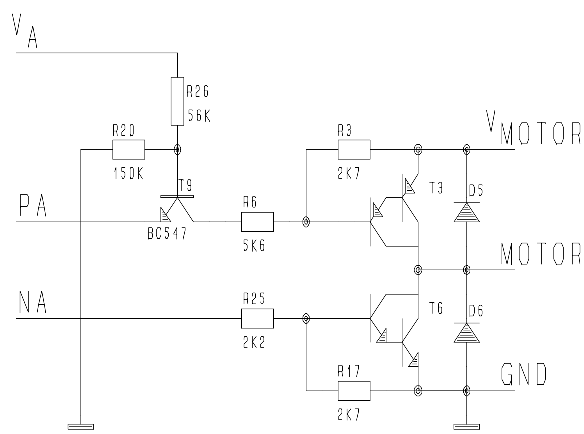


Figure 5

This output stage replaces the output stage with MOSFETS as depicted in figure 2.
Compared to MOSFET output stages in figure 2 we see two extra resistors, R20 and R17.
With these resistors a better switch-off of T9 and T6 is ensured.
When these resistors are left out the switch-off delay between V_{PA} or V_{NA} and the output will be about 10 µs in stead of 5 µs.
The resistor R20 has to be determined in such a way that the base emitter breakdown voltage (max. 5 V) of T9 is not exceeded when T9 is in cut-off.
When T9 is in cut-off state the base emitter voltage of T9 must be lower than 5 V. This maximum voltage is determined by R20.

$$R20 \geq R26 \times \frac{V_{Amax} - 5}{5} = 56 \times \frac{18 - 5}{5} = 145.6 \;\; k\Omega \qquad \textbf{(9)}$$

Take R20 = 150 kΩ. The calculation applies for R39 and R40.

The base current for the PNP darlington transistor is mainly determined by V_{motor} and the base current for the NPN darlington by the auxiliary voltage V_A.
For this application a base current I_{bDAR} for both darlington transistors is assumed of about 4 mA.

$$R6 \leq \frac{V_{motor} - V_{beDAR} - V_{ceT9max} - V_{PAmax}}{I_{bDAR} + I_{R3}} \qquad \textbf{(10)}$$

$$I_{R3} = \frac{V_{beDAR}}{R3} = \frac{2}{2.7} = 0.74 \;\; mA \qquad \textbf{(11)}$$

$$R6 \leq \frac{30 - 2 - 0.5 - 0.45}{4 + 0.74} = 5.7 \;\; k\Omega \qquad \textbf{(12)}$$

Take R6 = 5.6 kΩ.
The same applies for R5 and R4.

With a minimum value of V_A = 13.5 V and with $I_{R17} = I_{R3}$ = 0.74 mA, we can calculate for R7:

$$R25 \leq \frac{V_A - V_{beDAR} - V_{NAmax}}{I_{bDAR} + I_{R17}} = \frac{13.5 - 2 - 0.45}{4 + 0.74} = 2.33 \;\; k\Omega \qquad \textbf{(13)}$$

Take R25 = 2.2 kΩ.
The same applies for R23 and R21.

For R26 (56 kΩ) the same value has been taken as has been calculated for the MOSFET output stages.

In figure 6 has been depicted the circuit diagram of a system with output darlington transistors and in figure 7 a drawing of the pc-board.
A complete circuit diagram with MOSFET output drivers can be derived from figure 2

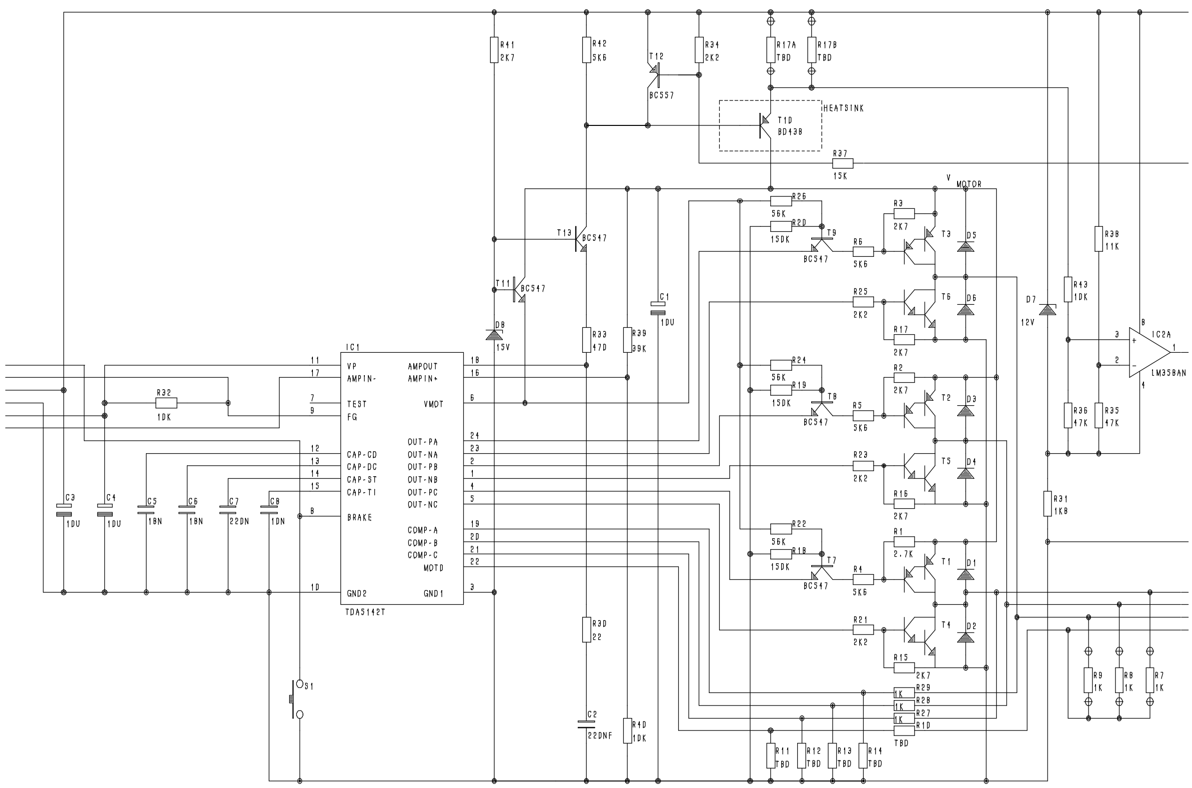
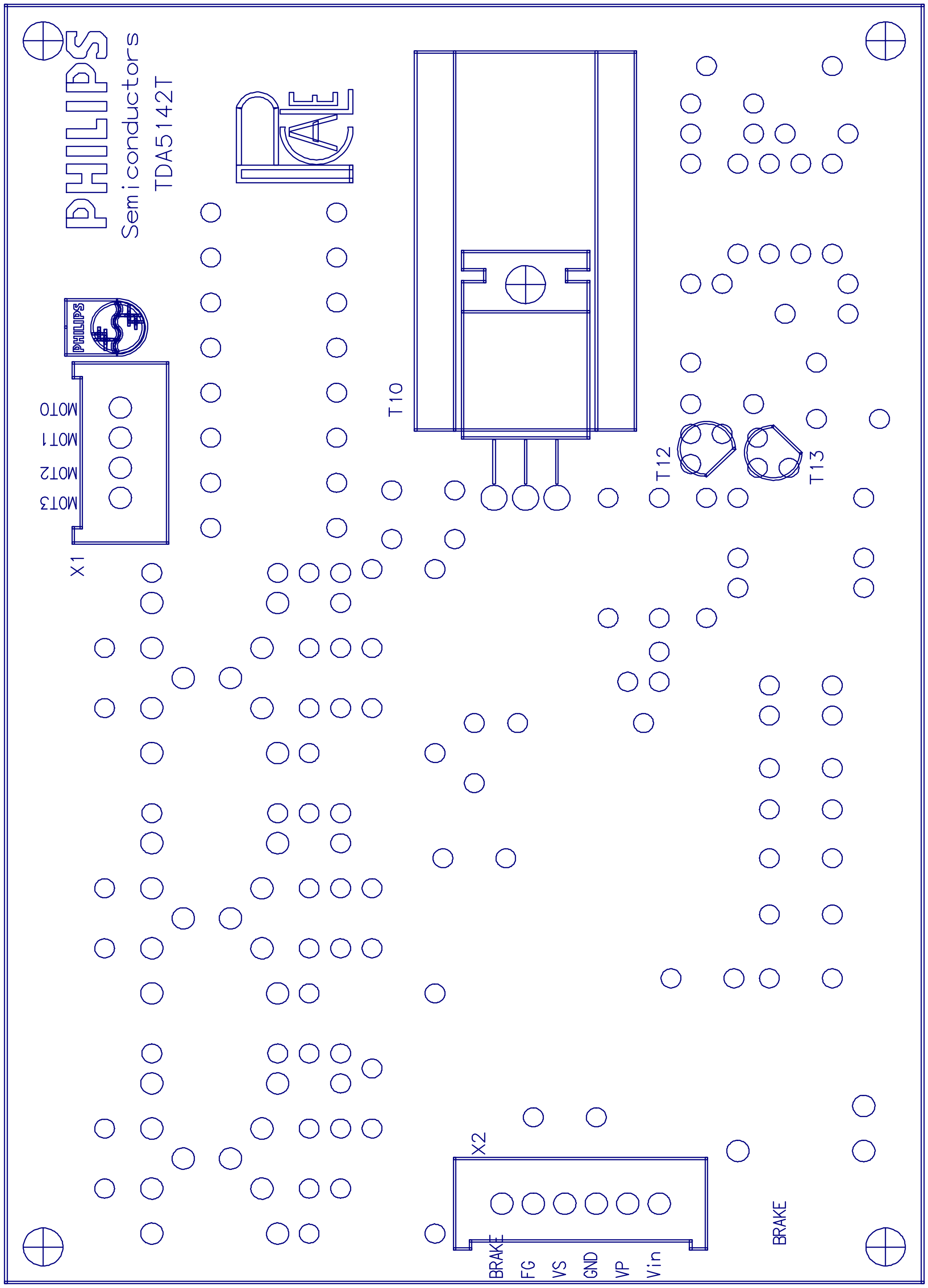

IC1
TDA5142T
VP
AMPIN-
TEST
FG
CAP-CD
CAP-DC
CAP-ST
CAP-TI
BRAKE
GND2
AMPOUT
AMPIN+
VMOT
OUT-PA
OUT-NA
OUT-PB
OUT-NB
OUT-PC
OUT-NC
COMP-A
COMP-B
COMP-C
MOTO
GND1
HEATSINK
T10
BD438
T12
BC557
T13
BC547
T11
BC547
IC2A
LM358AN
V MOTOR
S1

Figure 6


PHILIPS
Semiconductors
TDA5142T
MOT0
MOT1
MOT2
MOT3
X1
T10
T12
T13
X2
BRAKE
FG
VS
GND
VP
Vin
BRAKE

2.3 Comparator input adaptation.

For detection of the zero-crossings of the motor back-EMF the motor windings and the star point of the motor are connected via the series resistors R10 and R27 - R29 to the comparator inputs of the TDA5142. These resistors are needed for current limiting and protection in case of short overvoltages on the comparator inputs. The value of these resistors is not critical and have been determined experimentally. This means R29 = R28 = R27 = 1 kΩ and R10 = 330 Ω. With this choice a good input current balancing is achieved.
The supply for the comparators is retrieved from V_{mot}. So, the maximum comparator input voltage is related to the voltage on the V_{mot} input of the TDA5142. As described in the previous chapter this pin has been connected to the auxiliary voltage V_A.
According to the specification the comparator input voltage may exceed the voltage V_A by 0.5 V. The means that the maximum value of the comparator input voltage must smaller than the minimum value of V_A + 0.5 V.

$$V_{Amin} = 0.95 \times V_{D8} - V_{beT11min} + 0.5 = 0.95 - 0.6 + 0.5 = 14.15\ V \qquad (14)$$

When a motor is used without an external available star point connection an artificial symmetry point must be created for connection to the MOT0 pin of the TDA5142. This can be done by connecting the MOT0 input via three 1 kΩ resistors to the motor stator windings (R9, R8, R7 in figure 1).
In a 30 V system the comparator input voltages must be limited to maximum 14.15 volts. This can be achieved with the voltage divider resistor R11 for the MOT0 input and with, R14, R13 and R12 for the Comp-A, B and C inputs.

For a maximum motor voltage of 30 V and with R27, R28 and R29 = 1 kΩ the value for the resistors R12, R13 and R14 can be determined as follows:

$$R12 \le \frac{14.5 \times R27}{V_{motmax} - 14.5} = \frac{14.15 \times 1\ k\Omega}{30 - 14.15} = 0.89\ k\Omega \qquad (15)$$

Take, to have some margin, R12 = R13 = R14 = 0.82 kΩ

For the calculation of R10 and R11 two possibilities have to be distinguished: with or without an artificial star point.
In case of an artificial star point also the equivalent resistance of the star point connection must be taken into account.
When for these star point resistors a value of 1 kΩ is chosen, then the equivalent resistance is equal to the parallel resistance of the three resistors R7, R8 and R9, thus R_{eq} = 1000/3 = 333 Ω.

For a motor with a star point connection the ratio between R10 and R11 must equal to the ratio between R27 and R12.

For a motor with artificial star point the resistor R10 has to be determined in such a way that the equivalent star point resistance R_{eq} (333 Ω) is included as well.
In the calculation above the relation between R12 and R27 has been determined:

R12 = 0.82 x R27,

The same relation applies for R11 and R10, so:
⇒ **R11 = 0.82 x R10 = 270 Ω,** with star point

⇒ **R11= 0.82 x (R10 + 333),** with artificial star point.

Determine for R10 such a value from the E24 resistor range, that for R11 a resistor value from the E24 range can be found as well.

When R10 = 240 Ω, then R11 = 0.82 x (240 + 333) = 470 Ω

In figure 2 these resistor have been indicated as TBD (to be determined).

3. Current Limiter.

In figure 1 the circuit of an op-amp controlled current limiter has been given. This current limiter has been built-up with the op-amp IC2A, the transistor T11, the resistors R34, R17A/B R35 up to R37 and R43, the zener diode D7 and the decoupling capacitor C3 and C9.
The resistor R17A/B is the current sense resistor and the voltage drop V_{cs} over this resistor is compared with reference voltage connected pin 3 of the op-amp. The output of the op-amp drives the transistor T12.
The op-amp used for this circuit (LM358A) can not withstand supply voltages greater than 32 V. To obtain a general circuit that can be used for supply voltages greater than 32 V as well, the current limiter circuit has been referenced to the positive supply voltage V_{supply}. The supply voltage for the op-amp is determined by the zener diode voltage V_{D7}.
The op-amp cannot operate with input voltages that are close to the positive supply rail of the op-amp and therefore the input voltages have to be shifted to a level of at least 2 V below the supply voltage.
The DC-voltage shift is determined by the op-amp supply voltage (V_{D7}) and the voltage divider R38 and R35 for the V- input and by R43 and R36 for the V+ input.
When a supply voltage of 30 volts is used for D7 a zener diode BZX79C12 (12 V) can be choosen. The diode voltage may vary according to the specification @ 25 °C between 11.4 and 12.7 V.
To obtain a minimum required DC voltage shift of 2 V the resistor then:

$$R43 \geq \frac{2}{V_{D7min}} R36 = 0.212 \ x \ R36 \qquad \textbf{(16)}$$

When R43 = 10 kΩ, then R36 = 47 kΩ.
The current through D7 is determined by resistor R31. For this resistor a value of 1.8 kΩ is chosen.
At a lower supply voltage V_s, i.e. 12 volt, for the zener diode D7 a lower voltage must be taken. In that case the resistors the resistors R35 and R36 have to be adapted as well.

The resistors R34 and R37 determine the base current for transistor T12. This transistor has to cut-off the base current of T10 in case the current limiter becomes active. The relation between R34 and R37 has to be made such that T12 is switched-off when the output voltage of the op-amp is at its high level (≈ V_{supply} -2 V). This means that R16 ≈ 7 x R3. When for R24 a value of 2.2 kΩ is chosen, then R37 = 15 kΩ. With these resistor values a base current for T12 is obtained of about 0.33 mA at V_{D7} = 11.4 V, that can give a enough collector current for T12 to limit the current through transistor T10.
The voltages on the V- and V+ input of the op-amp at a typ. zener diode voltage of 12 V can be calculated as follows:

$$V+ = V_{supply} - V_{D7} + (V_{D7} - V_{cs}) \frac{R36}{R43 + R36} \quad (17)$$

$$V- = V_{supply} - V_{D7} + V_{D7} \frac{R35}{R38 + R35} \quad (18)$$

With V- = V+ and R35 = R36 the following equation for V_{cs} can be derived:

$$V_{cs} = V_{D7} \frac{R38 - R43}{R38 + R36} \quad (19)$$

With the increase of the motor current the voltage on the V+ input becomes more negative with respect to V_{supply}. The current limiting starts as soon as the voltage on the V+ input is equal to the voltage on the V- input.
Above the component calculations have been carried-out for a motor supply voltages greater than 18 V. If the circuit is used for voltages lower than 18 V then the current limiter circuit has to be adapted.
For a supply voltage of 12 V the zener diode voltage must be decreased to 8.2 V. With the reduction of the zener voltage the resistors R43 and R38 have to be adapted as well. These resistors can be calculated in the same way as with the 12 V zener diode.
For V_{D7} = 8.2 V the resistors R35 and R36 remain unchanged and R43 becomes 16 kΩ.

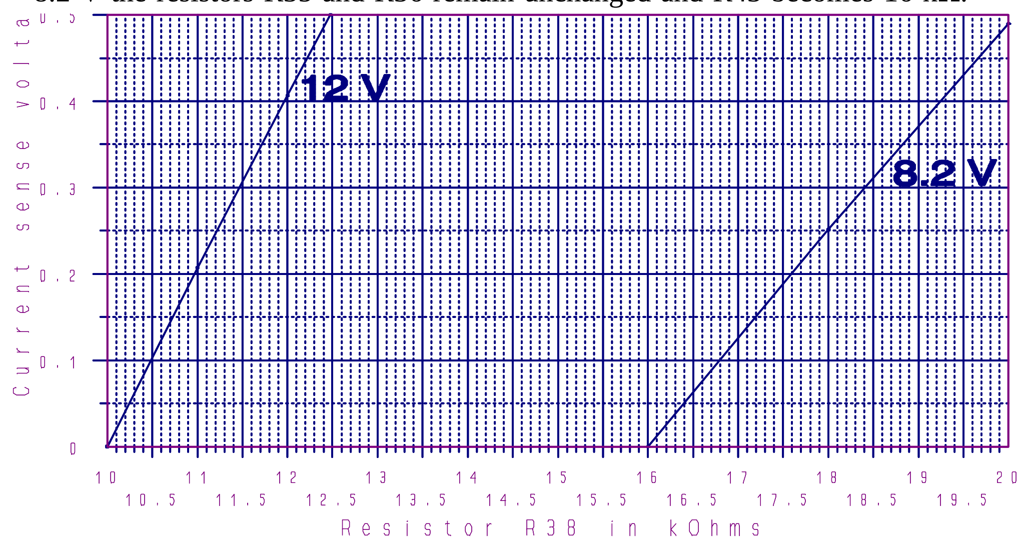


Figure 8

In the figure 8 the relation has been given between the current sense voltage V_{cs} and the resistor R38 for the V_{D7} = 12 V and for V_{D7} = 8.2 V.

For a certain motor control system has to be determined, what maximum current sense voltage V_{cs} can be allowed. With this V_{cs} and the current limiting value the resistor R17 can be determined.

The pc-board has been designed such that for R17 two resistors can be used in parallel. The resistor R38 will be mounted on solder pins so that this resistor can easily be changed into other values.

4. Parts list

Below the parts list of both the circuit of figure 6 for as well the MOSFET and the darlington transistor output stage is given.

	MOSFET outputs	Darlington transistor outputs
Item	**Value**	**Value**
C1, C3, C4, C10	10 µF	10 µF
C2, C7	0.22 µF	0.22 µF
C5, C6	0.018 µF	0.018 µF
C8	0.01 µF	0.01 µF
C9	0.1 µF	0.1 µF
R1 - R3	2.7 kΩ	2.7 kΩ
R4 - R6	47 Ω	5.6 kΩ
R7 - R9	1 kΩ	1 kΩ
R10 - R14	TBD	TBD
R15 - R17		2.7 kΩ
R18 - R20		150 kΩ
R21, R23, R25	47 Ω	2.2 kΩ
R22, R24, R26	56 kΩ	56 kΩ
R27 - R29	1 kΩ	1 kΩ
R30	22 Ω	22 Ω
R31	1.8 kΩ	1.8 kΩ
R32	10 kΩ	10 kΩ
R34	2.2 kΩ	2.2 kΩ
R35, R36	47 kΩ	47 kΩ
R37	15 kΩ	15 kΩ
R38 (D7 = BZX79C12)	11 kΩ	11 kΩ
R38 (D7 = BZX79C8V2)	16 kΩ	16 kΩ
R39	39 kΩ	39 kΩ
R40	10 kΩ	10 kΩ
R41	2.7 kΩ	2.7 kΩ
R42	5.6 kΩ	5.6 kΩ
R43 (D7 = BZX79C12	10 kΩ	10 kΩ
R43 (D7 = BZX79C8V2)	16 kΩ	16 kΩ

	MOSFET outputs outputs	Darlington transistor
Item	**Value**	**Value**
D1 - D6	BYV10-40	BYV10-40
D7	BZX79 C12	BZX79 C12
D7	BZX79 C8V2	BZX79 C8V2
D8	BZX79 C15	BZX79 C15
T1, T2, T3	BD680	BD680
T4, T5, T6	BD679	BD679
T10	BD438	BD438
T12	BC557	BC557
T7, T8, T9, T11, T13	BC547	BC547