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**Abstract**

This application note describes NXP Semiconductors low $V_{CEsat}$ bipolar PHPT portfolio. It gives a guideline which parameters must be taken into account to drive a brushed DC motor.
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1. Introduction

NXP’s bipolar power transistors in LFPAK use the latest BISS (Breakthrough In Small Signal) transistor technology. They include mesh-emitter-design technology IP-platform to achieve high-power devices with low $V_{\text{CEsat}}$ (saturation collector-emitter voltage) voltage drop and high current gain. By this upmarket development, NXP wants to extend its powerful and successful BISS transistor portfolio into the medium power and power range in order to reach full traction for its high-power low $V_{\text{CEsat}}$ and high-current mesh-emitter technology. To achieve this aim NXP uses a package supporting the high power dissipation demand of its transistor portfolio. LFPAK offers superior low thermal impedance $Z_{th}$ and therefore high thermal power capability up to 5 W.

Key parameters are current distribution (which should be as homogenous as possible) over chip volume, and little spreading resistance in the metallization on the front of the chip. In the case of BISS transistors, a homogeneous current distribution in the chip is achieved by the latest mesh-emitter-design technology IP-platform, which breaks the transistor down into corresponding cell structures. Soft-solder capable front and back metallization combine this wafer technology with the LFPAK-package platform requirements introducing new-developed metal stack interfaces for chip front and back interface. They are optimized for low-resistivity contact of all transistor terminals to the package outline.

The high-performance/high-reliability package platform LFPAK provides clip-bond for emitter and base contact. This achieves low electrical and thermal resistivity of the devices on all terminals. The electrical package resistivity is below 1 mΩ. The overall thermal impedance of the power transistors in the current chip-size range is below 6 K/W. Soft-solder die and clip attach establish a rugged package architecture with up to $T_{j(\text{max})} = 175$ °C high-temperature capability.

1.1 Features and benefits

- High power dissipation ($P_{\text{tot}}$)
- Suitable for high-temperature applications (175 °C)
- Space-saving 5 × 6 mm: package outline is half the size of equivalent transistors in DPAK, SOT223, and other packages
- Low profile (1 mm)
- High reliability and mechanical ruggedness thanks to solid copper clip (no wires)
- High energy efficiency due to less heat generation
- AEC-Q101 qualified
- Future-proof, growing portfolio
2. Brushed DC motor control

Modern DC motors are used in various applications:
- Power windows
- Wipers
- Blower motors (heating / cooling)
- Trunk lifter
- Steering wheel adjustment
- Seat adjustment

A lot of these applications are using relays for driving the brushed DC motor. This application note shows which parameter must be taken into account to replace relays by bipolar transistors in H-bridge configuration controlled by a Pulse Width Modulation (PWM) signal.

The used DC brushed motor for this application note has following characteristics:
- Nominal operating voltage: 12 V
- Nominal operating current: 3 A
- Blocked operating current: 8 A

2.1 Relay operation

Every tactile switch turns a relay on and the motor turns left or right.

![Relay schematic](aaa-017884)

Fig 1. Relay schematic
2.2 Bipolar Junction Transistor (BJT) operation

A PWM signal is used to control T9 / T8 or T10 / T7 to turn the motor left or right.

**Fig 2. Schematic H-bridge configuration**
3. Parameters of NXP high-power bipolar transistors (PHPT series)

Due to the maximum motor current of 8 A, the voltage across collector and emitter must be aligned with the power dissipation of the LFPAK56 package. 

Figure 3 shows a typical value for $V_{CE\text{sat}}$ of PHPT60410NY.

![Diagram showing typical $V_{CE\text{sat}}$ values for PHPT60410NY]

$T_{\text{amb}} = 25 ^\circ\text{C}$

- (1) $I_C/I_B = 100$
- (2) $I_C/I_B = 50$
- (3) $I_C/I_B = 20$
- (4) $I_C/I_B = 10$

At $h_{FE} = 50$ (base current $I_B = 160$ mA) and at maximum motor current ($I_{C\text{max}}$), a 300 mV voltage drop across collector and emitter must be expected. The outcome of this is $P_{\text{tot}} = 2.4$ W in continuous mode.

For this application note, following PWM parameters have been chosen:

- PWM frequency = 125 Hz / $t_p = 8$ ms
- Duty cycle = 0.5
Figure 4 shows the thermal impedance of a PHPT60410NY under these conditions.

![Figure 4](aaa-074225)

FR4 PCB, standard footprint

**Fig 4. PHPT60410NY: Transient impedance from junction to ambient as a function of pulse duration; typical values**

Given that:

\[
P_{tot} = \frac{T_{j(max)} - T_{amb}}{R_{th(j-a)}}
\]  

(1)

then, at \(T_{j(max)} = 175\) °C, if \(Z_{th(j-a)} = 50\) K/W, then \(P_{tot} = 3\) W at \(T_{amb} = 25\) °C or \(P_{tot} = 2.4\) W at \(T_{amb} = 55\) °C on standard footprint.
4. Demoboard

In order to verify all theoretical approaches, NXP designed a test board with a PWM-driven H-bridge and for comparison tow relays to drive a brushed DC motor. Each tactile switch turns the motor left or right. The relay part is isolated from the PWM stage.

### 4.1 Electrical verification

PWM control signal is running with a frequency of 130 Hz and a duty cycle $\delta$ of 0.5.
The PWM is generated by a simple NE555 circuit. At a jumper, the signal can be disconnected from the tactile switches. That is why the frequency decreases to 125 Hz during motor operation.

In peak, the base current $I_B$ can be calculated with voltage $V = 10 \text{ V}$ and resistance $R = 33 \text{ } \Omega$. The outcome of this is $I_B = 300 \text{ mA}$ or $I_B = 150 \text{ mA}$ in average.

In real application, the transistors are running at a slightly higher $h_{FE}$. The base resistor and workpoint were calculated with respect to high blocking current of 8 A. In normal application, the motor current is measured by a microcontroller in order to stop the turning of the motor on security reason. The following scope trace (Figure 9) was measured across a resistor of 235 m$\Omega$ and shows following motor current:

**Figure 7. Signal at base resistor of high-side PNP**

In peak, the current is 288 mA, in average 144 mA.

**Figure 8. Signal at base resistor of low-side NPN**

In peak, the current is 288 mA, in average 144 mA.
In peaks, the motor current is 4.25 A. In average, the motor is running with 2.125 A. From this, $h_{FE} = 15$ in normal operation mode.

### 4.2 Thermal results

All measurements were performed with a motor in normal operation mode.

**Fig 9.** Motor current

![Motor current graph](aaa-017890)

**Fig 10.** High-side PNP transistor: collector pad temperature (cursor) approximately 37 °C

![High-side PNP transistor temperature](aaa-017892)

**Fig 11.** Low-side NPN transistor: collector pad temperature (cursor) approximately 36 °C

![Low-side NPN transistor temperature](aaa-017893)
4.3 EMI results

Used equipment to measure the ElectroMagnetic Interference (EMI) performance of the H-bridge with PHPT-series ($V_{CE} = 40$ V, $I_C = 10$ A) versus a standard automotive relay (12 V; 50 mA coil current, 15 A max):

- Power supply: WIMO GSV3000
- Artificial network: Schwarzbeck NNBM 8125
- LFPAK demoboard
- DC Motor: Bosch AHC 12V
- EMI test receiver: Rohde & Schwarz ESCI3

4.3.1 Board-powered no-switch

![Fig 12. Powered Device Under Test (DUT) (no action)](aaa-017894)
4.3.2  Relay operated

Maximum at 32 MHz = 55 dBμV

Fig 13. Powered DUT (relay)

4.3.3  H-bridge operated

Maximum at 16.5 MHz = 49 dBμV

Fig 14. Powered DUT (BJT)
4.3.4 H-bridge operated in PWM Mode

![Graph showing frequency response](image)

Maximum at 366 kHz = 59 dBμV

Fig 15. Powered DUT (PWM)

5. Results

If all necessary parameters are taken into account, relays can be replaced by bipolar transistors, like NXP’s PHPT-series in LFPAK.

The advantages of a silicon-based solution compare to relay are:

- Reliable performance over lifetime (AEC-Q101)
- Significantly better EMI performance
- No contact bouncing
- Less board space
6. Product portfolio in LFPAK

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7. Sources

- NXP Semiconductors - PHPT60410PY Product data sheet Rev. 1 - 21 January 2015
- NXP Semiconductors - PHPT60410NY Product data sheet Rev. 1 - 21 January 2015
8. **Legal information**

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9. Contents

1 Introduction .............................................. 3
1.1 Features and benefits ................................. 3
2 Brushed DC motor control ............................... 4
  2.1 Relay operation ........................................ 4
  2.2 Bipolar Junction Transistor (BJT) operation ....... 5
3 Parameters of NXP high-power bipolar transistors (PHPT series) ................ 6
4 Demoboard ................................................. 8
  4.1 Electrical verification ................................. 8
  4.2 Thermal results ....................................... 10
  4.3 EMI results ........................................... 11
  4.3.1 Board-powered no-switch ......................... 11
  4.3.2 Relay operated ..................................... 12
  4.3.3 H-bridge operated ................................. 12
  4.3.4 H-bridge operated in PWM Mode ................. 13
5 Results ..................................................... 13
6 Product portfolio in LFPAK .............................. 14
7 Sources ................................................... 14
8 Legal information ......................................... 15
  8.1 Definitions ........................................... 15
  8.2 Disclaimers .......................................... 15
  8.3 Trademarks ........................................... 15
9 Contents .................................................. 16