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AN11641

Relay replacement by NXP high-power bipolar transistors in LFPAK56

Rev. 1 — 21 May 2015 Application note

Document information

Info	Content
Keywords	High-power bipolar transistors, PHPT series, LFPAK56, relay
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.

Revision history

Rev	Date	Description
1	20150521	Initial version

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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_{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_{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 $T_{j(max)}$ = 175 °C high-temperature capability.

1.1 Features and benefits

- High power dissipation (P_{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:

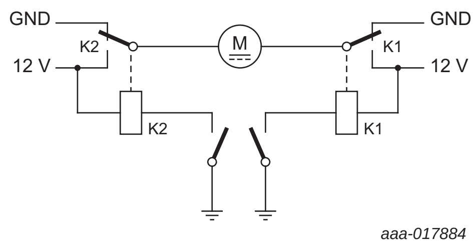
- Power windows
- Wipers
- Blower motors (heating / cooling)
- Trunk lifter
- Steering wheel adjustment
- Seat adjustment

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

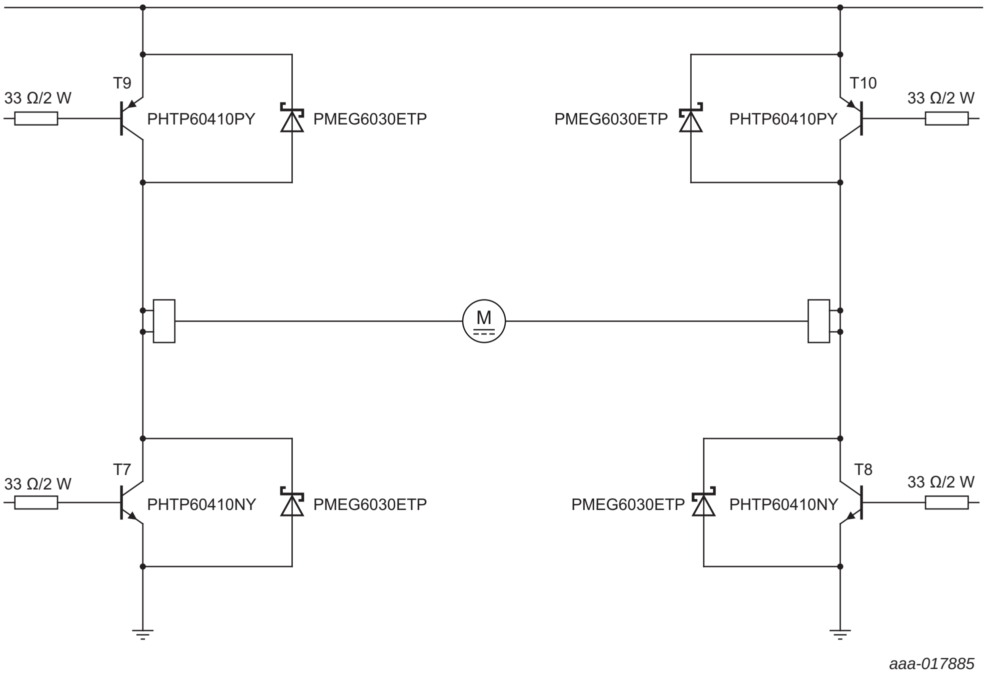
2.1 Relay operation



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

Fig 1. Relay schematic

2.2 Bipolar Junction Transistor (BJT) operation



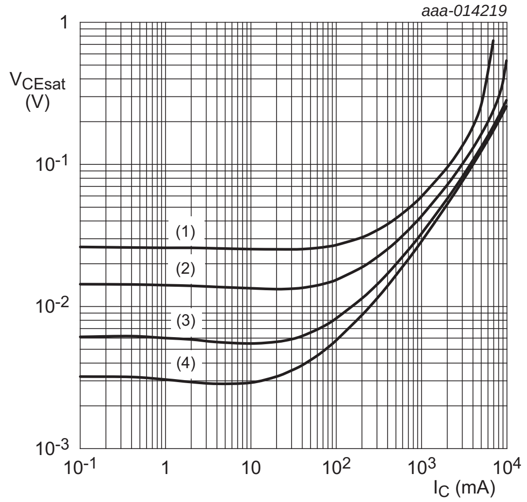
A PWM signal is used to control T9 / T8 or T10 / T7 to turn the motor left or right

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_{CEsat} of PHPT60410NY.



T_{amb} = 25 °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

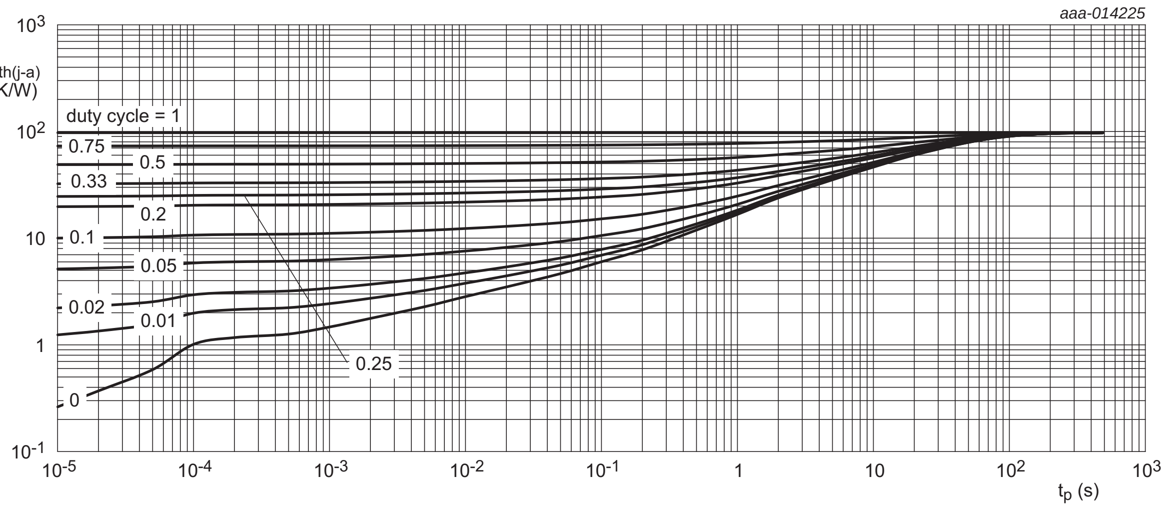
Fig 3. PHPT60410NY: Collector-emitter saturation voltage as a function of collector current; typical values

At h_{FE} = 50 (base current I_B = 160 mA) and at maximum motor current (I_{Cmax}), a 300 mV voltage drop across collector and emitter must be expected. The outcome of this is P_{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.



FR4 PCB, standard footprint

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

Given that:

$$P_{tot} = \frac{T_{j(max)} - T_{amb}}{R_{th(j-a)}} \quad (1)$$

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.

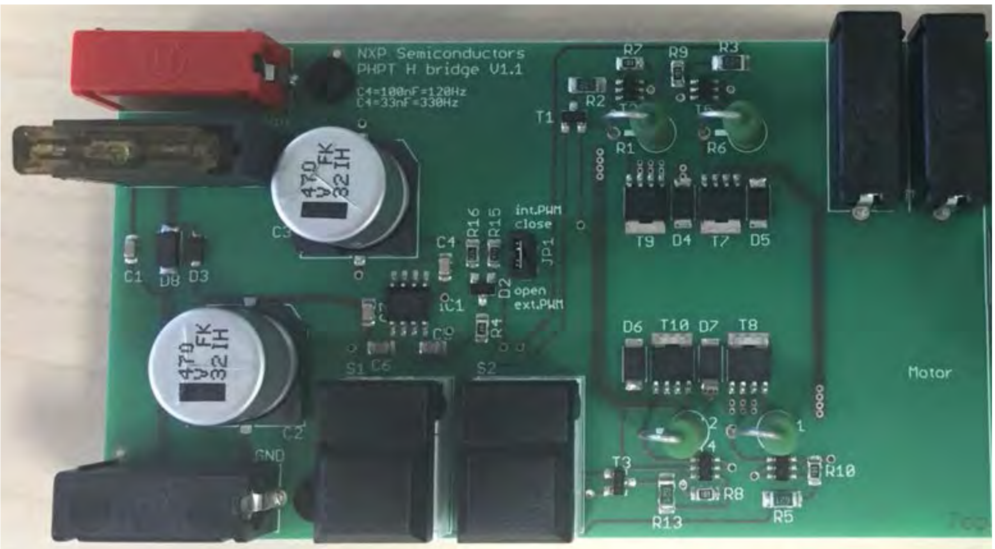


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Fig 5. Test board with a PMW-driven H-bridge

4.1 Electrical verification

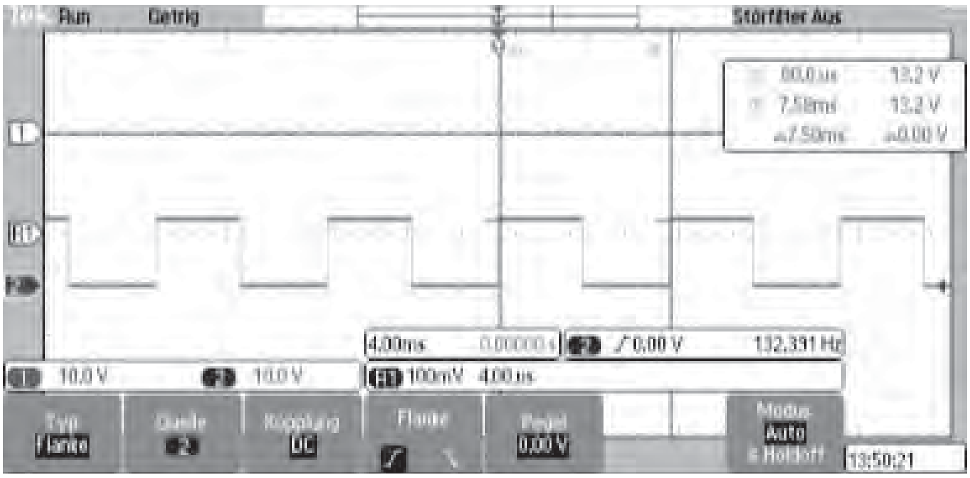

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Fig 6. PWM signal

PWM control signal is running with a frequency of 130 Hz and a duty cycle δ 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.

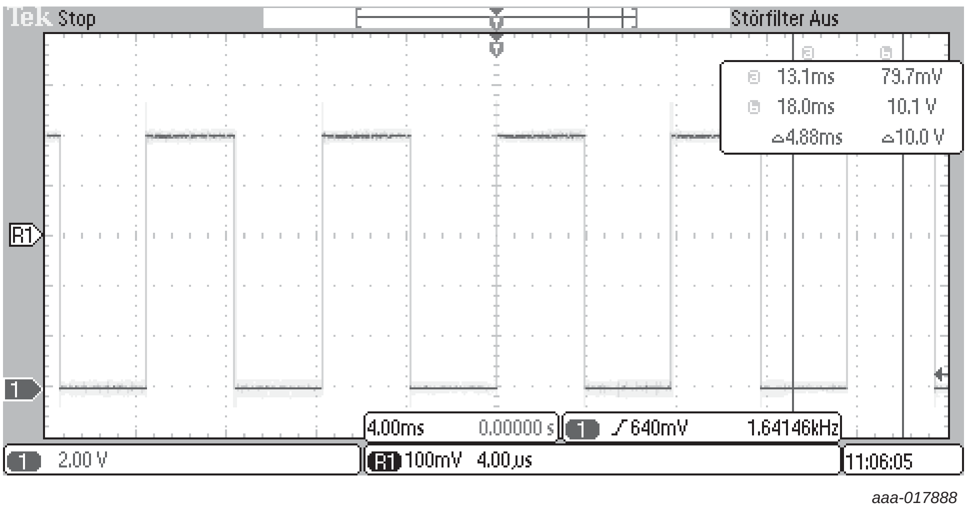

Fig 7. Signal at base resistor of high-side PNP

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

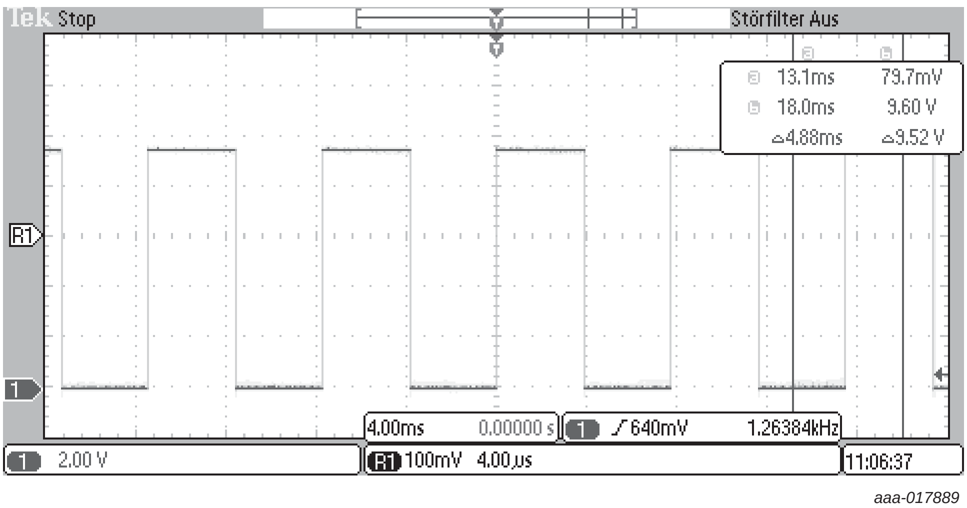

Fig 8. Signal at base resistor of low-side NPN

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

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 mΩ and shows following motor current:

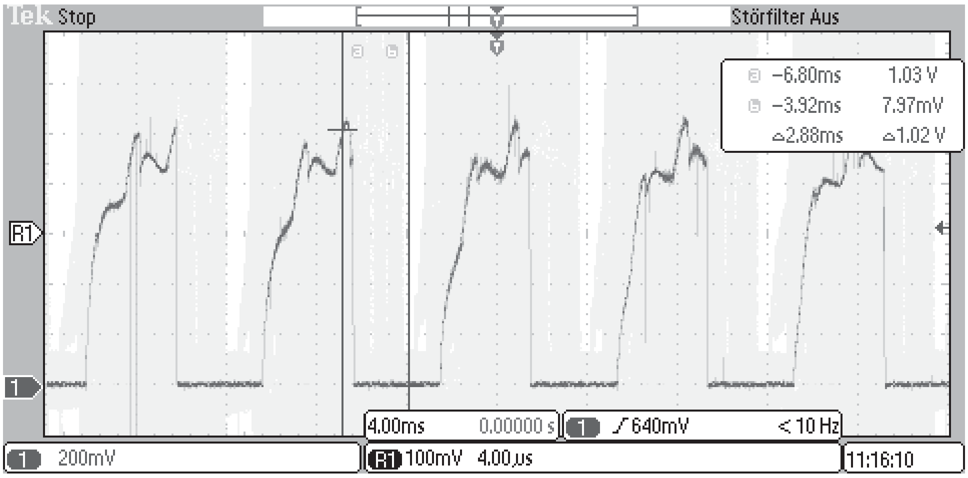

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Fig 9. Motor current

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.

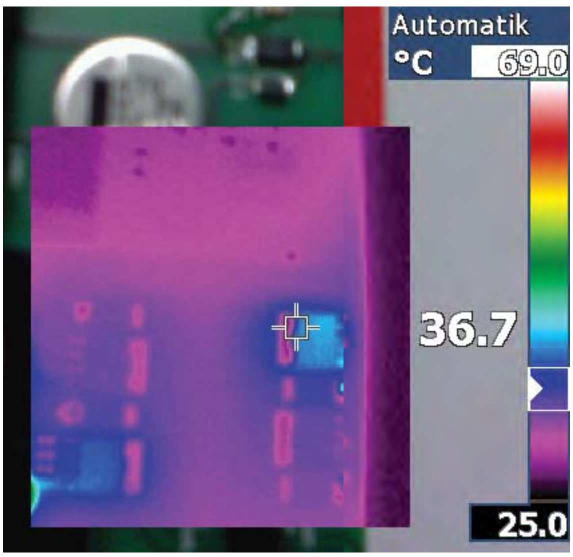

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Fig 10. High-side PNP transistor: collector pad temperature (cursor) approximately 37 °C

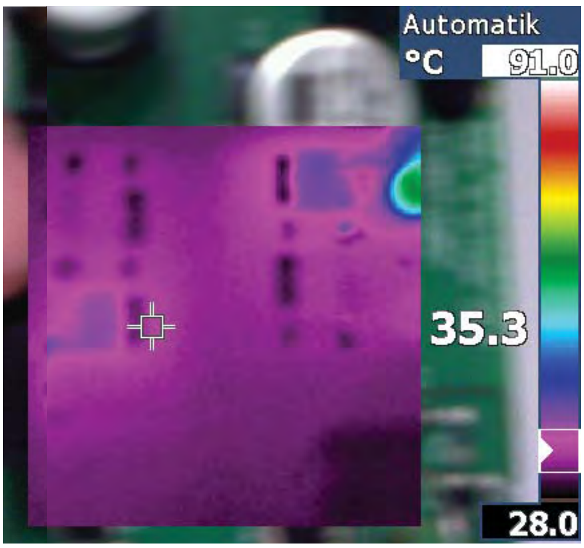

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Fig 11. Low-side NPN transistor: collector pad temperature (cursor) approximately 36 °C

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

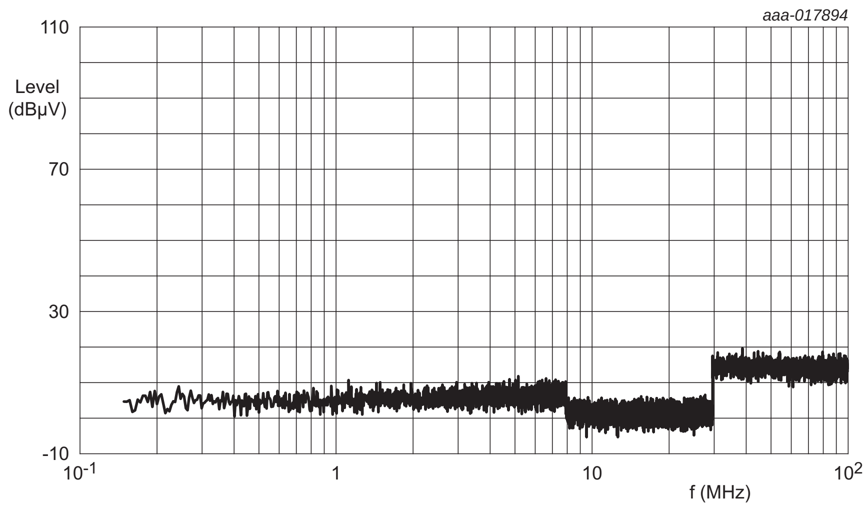
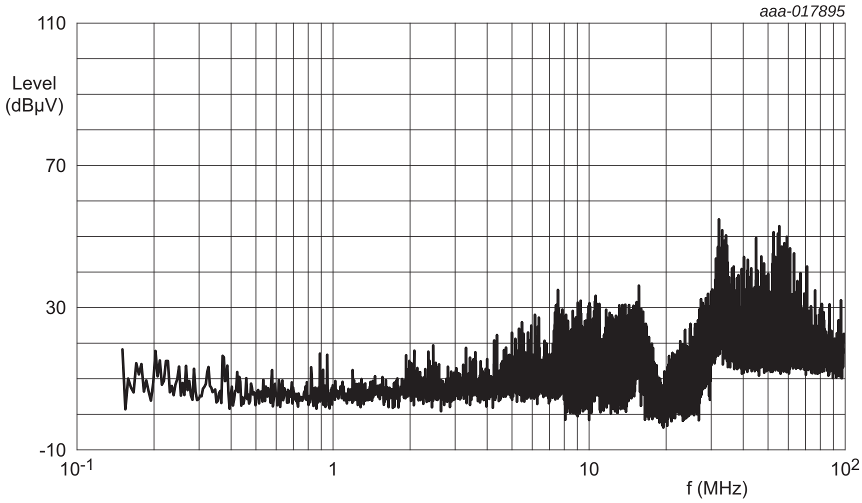


Fig 12. Powered Device Under Test (DUT) (no action)

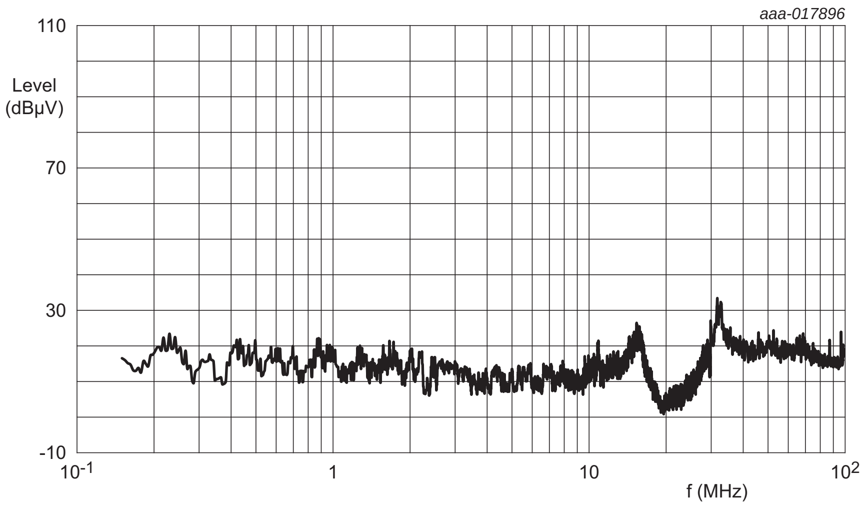
4.3.2 Relay operated



Maximum at 32 MHz = 55 dBµV

Fig 13. Powered DUT (relay)

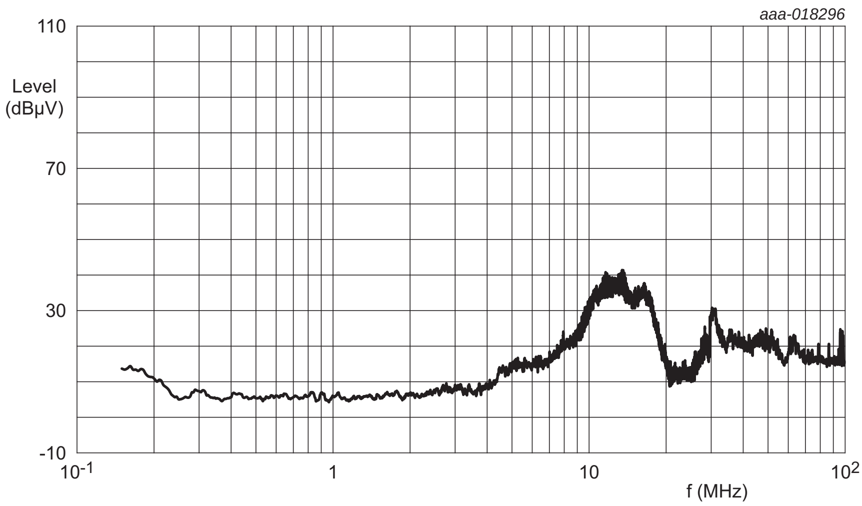
4.3.3 H-bridge operated



Maximum at 16.5 MHz = 49 dBµV

Fig 14. Powered DUT (BJT)

4.3.4 H-bridge operated in PWM Mode



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

Table 1. NXP's product portfolio in LFPAK

Type number	Configuration	V_{CEO}	I_C	AEC-Q101
PHPT60406NY	NPN	40 V	6 A	YES
PHPT60406PY	PNP	40 V	6 A	YES
PHPT60410NY	NPN	40 V	10 A	YES
PHPT60410PY	PNP	40 V	10 A	YES
PHPT60603NY	NPN	60 V	3 A	YES
PHPT60603PY	PNP	60 V	3 A	YES
PHPT60606NY	NPN	60 V	6 A	YES
PHPT60606PY	PNP	60 V	6 A	YES
PHPT60610NY	NPN	60 V	10 A	YES
PHPT60610PY	PNP	60 V	10 A	YES
PHPT61002NYC	NPN	100 V	2 A	NO
PHPT61002PYC	PNP	100 V	2 A	NO
PHPT61003NY	NPN	100 V	3 A	YES
PHPT61003PY	PNP	100 V	3 A	YES
PHPT61006NY	NPN	100 V	6 A	YES
PHPT61006PY	PNP	100 V	6 A	YES
PHPT61010NY	NPN	100 V	10 A	YES
PHPT61010PY	PNP	100 V	10 A	YES

7. Sources

- NXP Semiconductors - PHPT60410PY Product data sheet Rev. 1 - 21 January 2015
- NXP Semiconductors - PHPT60410NY Product data sheet Rev. 1 - 21 January 2015

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