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Low V_{CEsat} transistors in medium power loadswitch applications

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Document information

Info	Content
Keywords	NXP’s low VCEsat transistors, performance in loadswitch applications
Abstract	Different low V_{CEsat} transistors in loadswitch applications. Evaluation of low V_{CEsat} transistor key parameters like current gain h_{FE} and collector-emitter saturation voltage V_{CEsat} with respect to power losses, and choice of base drive.

Revision history

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1. Introduction

This application note describes different low V_{CEsat} Breakthrough In Small Signal (BISS) transistors from NXP and other discrete semiconductor suppliers in a typical loadswitch application (20 V, up to 1.5 A) with respect to the parameters current gain h_{FE} and collector-emitter saturation voltage V_{CEsat}. Power losses will be discussed for different low V_{CEsat} transistor types and a guideline will be evaluated to choose the right base drive.

1.1 Introduction to low V_{CEsat} transistors

When comparing a bipolar transistor to a MOSFET, the major drawback in the past was that the bipolar transistor was a current-driven device requiring a base drive capable of continuous currents. This however was true with conventional silicon Bipolar Junction Transistors (BJT). With the high current gain h_{FE} and very low saturation voltage V_{CEsat} (on-resistance) available from today's NXP's high-performance low V_{CEsat} (BISS) transistors, the power and base current requirements have been significantly reduced, making them a viable solution for low and high-voltage switching applications.

Low V_{CEsat} transistors were introduced to the industry over 10 years ago. They typically come in the range of 12 V to 100 V V_{CEO} and with collector currents up to several amperes in Surface-Mounted Device (SMD) packages like SOT23, SOT89 or SOT223.

Table 1. Parameter comparison bipolar transistors

Parameter	Conventional small-signal BJT	low V_{CEsat} BJT (PBSS-series)
h_{FE}	~100	200 to 600
V_{CEsat} at h_{FE}	a few 100 mV	down to 30 mV

The parameter h_{FE} and V_{CEsat} both affect typical applications of bipolar transistors, like loadswitching or signal amplification. High current gains for example reduce significantly the required amount of continuous base drive, which enables designers to switch a low V_{CEsat} transistor with small currents coming directly from a µ-controller. In addition, the losses across base bias resistors and V_{BE} are significantly reduced. Low V_{CEsat} saturation voltage drops, on the other hand, reduce the power losses across the collector-emitter junction when the transistor is operated as a low-frequency switch and enables significantly higher collector current I_C capabilities on a normalized chip area.

2. The loadswitch circuit

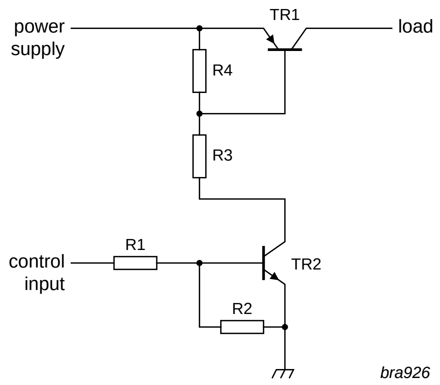


Fig 1. Basic loadswitch circuit

Figure 1 shows a basic loadswitch circuit, composed of two BJTs and their bias resistors. A small current from the control circuit, e.g. a µ-controller, switches on TR2 (NPN) with TR2 then providing the necessary base current $-(I_B)$ to switch on TR1 (PNP). Power is delivered from source to load.

Resistors R3 and R1 set the base current for TR1 and TR2 respectively, assuming a stable input supply. They also set the desired I_C/I_B ratio called current gain. In the next paragraph, power dissipation in the semiconductors and the resistors will be discussed, in order to give a guideline for the choice of bipolar transistor types and their necessary base drives.

2.1 Important parameter for BJTs in a loadswitch application

The data sheet of a semiconductor device defines maximum and typical values. The set of data sheet parameters makes it possible to compare one device to another and to make design decisions.

Besides the limiting values I_C, V_{CEO} and P_{tot}, the parameters h_{FE} and V_{CEsat} are important for the design. They define the performance of especially TR1 where most power losses occur. The control switch TR2 typically is a general-purpose transistor like a BC847 or PMBT3904, and has to deliver currents in the range of a few up to a hundred milliamperes as base drive for TR1. Typical values for h_{FE} are around hundred and V_{CEsat} is a few hundred millivolts. The power loss of TR2 is only a fraction of the whole losses in the application and therefore will not be discussed further on.

TR2 is a NPN transistor and is also referred to as a low-side switch. R2 makes sure that the base is at ground with the switch open. Choosing high-ohmic values results in very small sink currents, so that the on-operation is not affected. TR1 as the high-side switch is a PNP transistor which has its base pulled to V_{CC} via R4, while in off-condition.

We will limit the discussion of the loadswitch to ohmic loads and DC current so no additional drive circuits need to be included (as it should for switching inductive loads or circuits driven from AC). In order to switch DC power to an ohmic load, choose the base resistors in a way to get enough of excess base currents, making sure the transistor is in saturation. Saturation results in low (and deep saturation in lowest) V_{CE} drops which reduces the power losses of TR1. As saturation is dependent on excess base currents of the transistors, it affects the power losses of R3, too. Next, V_{CEsat}, the I_C/I_B ratio and the resulting power losses will be compared to the base currents in order to find the optimal working point for switching 0.5 A, 1 A and 1.5 A to an ohmic load.

2.1.1 Comparison between different low V_{CEsat} transistors in a loadswitch application

Different low V_{CEsat} transistors will be compared in a loadswitch application, i.e. one low V_{CEsat} transistor in SOT223 from NXP, two low V_{CEsat} transistors in a SOT23 package from NXP, and two low V_{CEsat} transistors from competitive semiconductor suppliers (Y and Z), both in the SOT23 package. The two competitor devices shall be regarded as the closest crosses to the NXP portfolio in SOT23 as available in the market today.

The basis of the comparison is the cost-efficient SOT23 package in order to show the cost and space-saving opportunities when using low V_{CEsat} transistors. In addition, also a device in SOT223 is included whereas it is provided that with the bigger package also more silicon is used, naturally resulting in higher performance, but at higher costs.

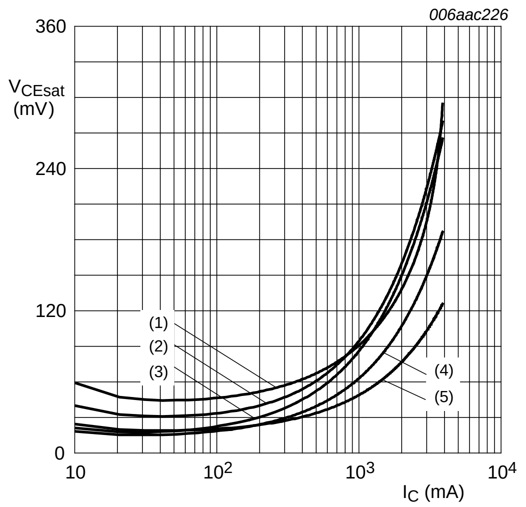
The data sheets limit all of the parts to 20 V V_{CEO} whereas the collector current I_C limits are different. The I_C-limit strongly depends on the silicon technology and on V_{CEsat} and h_{FE} performance. Besides, an important and often neglected factor are different specification guidelines and measurement conditions at the supplier side, resulting in different values in the data sheets. In this chapter, we will compare the real power losses of the loadswitch with 0.5 A to 1.5 A load current based on Simulation Program with Integrated Circuit Emphasis (SPICE) simulations.

Table 2. Device list

Type number	Breakdown voltage V_{CEO} (V)	Maximum current I_{CM} (A)	Package
PBSS5320T	20	3	SOT23
PBSS302PZ	20	5.5	SOT223
PBSS4021PT	20	3.5	SOT23
Competitor Y	20	2	SOT23
Competitor Z	20	4	SOT23

The following simulation results either show V_{CEsat} characteristics of the switching device TR1 or power losses of TR1 in comparison to power losses of TR1 plus the losses of resistor R3 (TR1 base resistor). The graphs make it possible to compare the performance of different devices and to find an optimum working point - especially for the base drive I_B. The losses in the base resistor R3 are taken into account as in some applications the P_{tot} of the whole circuit is more important than optimizing the P_{tot} of the semiconductor switch.

The graphs were generated using the SPICE models as provided on the web pages of the suppliers.



$I_C/I_B = 62.5$

(1) Competitor Z

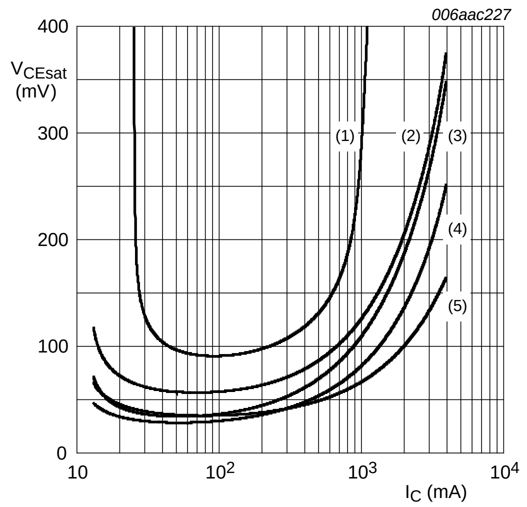
(2) Competitor Y

(3) PBSS5320T

(4) PBSS4021PT

(5) PBSS302PZ

Fig 2. Collector-emitter saturation voltage as a function of collector current



$I_C/I_B = 125$

(1) Competitor Z

(2) Competitor Y

(3) PBSS5320T

(4) PBSS4021PT

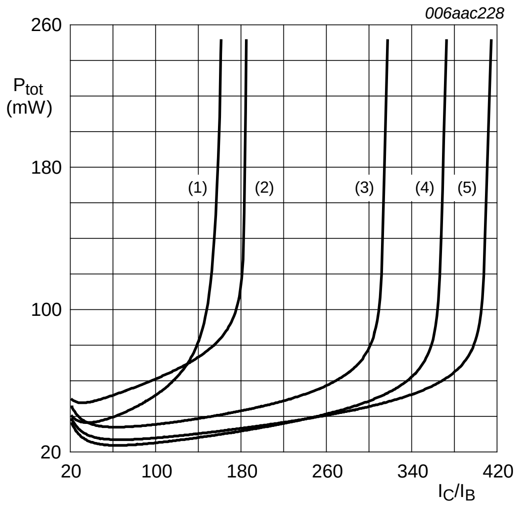
(5) PBSS302PZ

Fig 3. Collector-emitter saturation voltage as a function of collector current

Figure 2 and Figure 3 show V_{CEsat} characteristics as a function of collector current I_C. The smaller the I_C/I_B ratio (high I_B current), the deeper the transistor is in saturation, and the lower the voltage drop across the collector-emitter junction, V_{CEsat}. Deep saturation results in lowest V_{CEsat} drops which corresponds directly to the on-resistance of the device R_{CEsat} (or R_{DSon} in case of a MOSFET). At high collector currents I_C, the needed base drive for acceptable low V_{CEsat} values accounts for an increase of the total power losses in the application as on one hand the current gain h_{FE} drops at high collector currents and, therefore, more base current I_B is needed (refer to an h_{FE} curve of a BJT data sheet). On the other hand, V_{CEsat} increases with higher collector currents leading to higher losses.

In the first part of a V_{CEsat} characteristic the V_{CEsat} value is mainly determined by recombination effects of the semiconductor (curve nearly flat, see Figure 2), and in the second part ohmic contributions of the package and bond wires account for a slow increase. The third part is dominated by injection effects resulting in a steep increase. The higher the I_C before injection occurs, the better the performance, especially at higher h_{FE} values.

A high-performance device gives the user more flexibility in choosing h_{FE} and I_C and will reduce the needed amount of silicon, package outlines and therefore costs.



I_C = 0.5 A

(1) Competitor Z

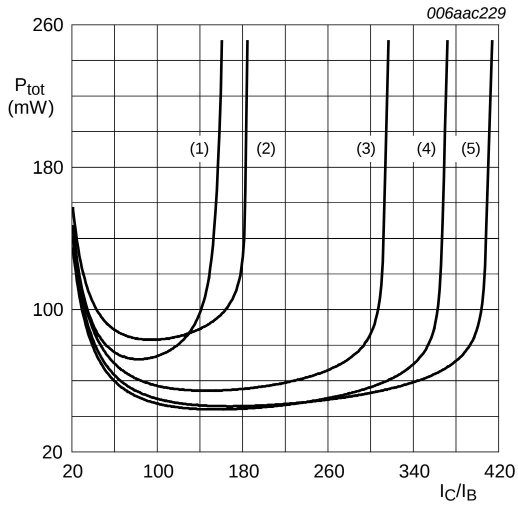
(2) Competitor Y

(3) PBSS5320T

(4) PBSS302PZ

(5) PBSS4021PT

Fig 4. TR1: Total power dissipation as a function of collector current to base current ratio



I_C = 0.5 A

(1) Competitor Z

(2) Competitor Y

(3) PBSS5320T

(4) PBSS302PZ

(5) PBSS4021PT

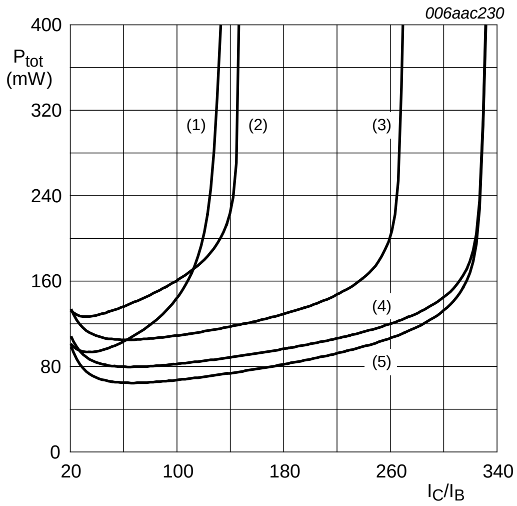
Fig 5. TR1 + R3: Total power dissipation as a function of collector current to base current ratio

At 0.5 A load current, Figure 4 and Figure 5 show that with NXP's high-performance silicon (e.g. latest low V_{CEsat} generation PBSS4021PT), the power dissipation improves of about 25 %, compared to a conventional low V_{CEsat} device from NXP (PBSS5320T). Looking at the total power dissipation of the system (here P_{tot} of transistor TR1 and its base resistor), the improvement is less as the power dissipation in the base resistor will not change assuming the same I_C/I_B ratio. But still, overall system efficiency improves of about 17 %, and the designer is able to choose operating points with much lower base drives.

In the figures above also a SOT223 low V_{CEsat} transistor is shown (PBSS302PZ) to show that the latest NXP low V_{CEsat} transistor generation (here PBSS4021PT) can compete with much bigger dies in medium power packages.

The optimum working point with respect to the total power losses (P_{tot} (TR1) plus P_{tot} (R3)) is found at an I_C/I_B ratio of about 120 with NXP's low V_{CEsat} transistors.

For both competitor devices, much more base current must be spent in order to reach an acceptable level of performance. However, this will still not reach the performance of NXP's PBSS series.



I_C = 1 A

(1) Competitor Z

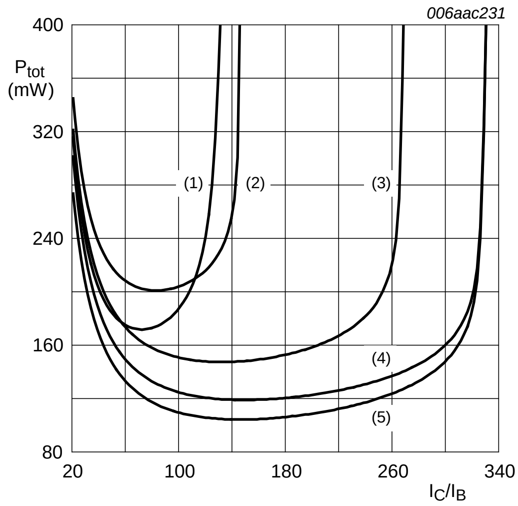
(2) Competitor Y

(3) PBSS5320T

(4) PBSS4021PT

(5) PBSS302PZ

Fig 6. TR1: Total power dissipation as a function of collector current to base current ratio



I_C = 1 A

(1) Competitor Z

(2) Competitor Y

(3) PBSS5320T

(4) PBSS4021PT

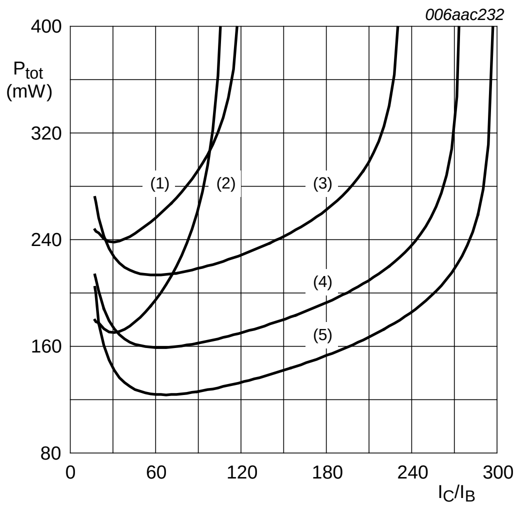
(5) PBSS302PZ

Fig 7. TR1 + R3: Total power dissipation as a function of collector current to base current ratio

At 1 A load current, the optimum I_C/I_B ratio for lowest power dissipation in the load transistor would be about 65 for NXP devices resulting in about 15 mA TR1 base drive (or TR2 I_C current).

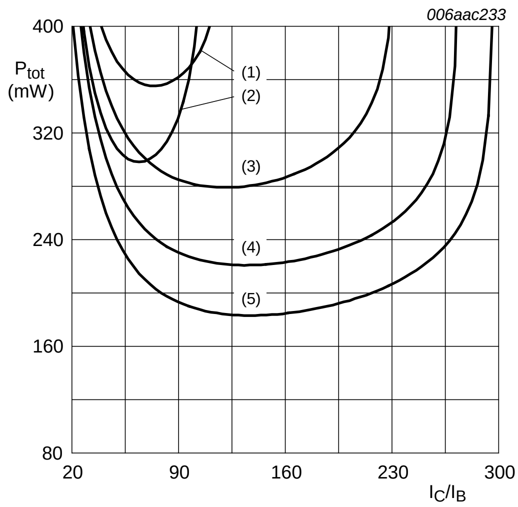
An I_C/I_B ratio of about 150 would optimize the power dissipation of the system TR1 plus R3, still with only less than 90 mW P_{tot} and only 6.66 mA base drive in the example of TR1 = PBSS4021PT (SOT23 package). Remember this is a 1 A application.

The two competitor devices chosen here are not able to follow the performance at I_C/I_B ratios greater than 50. Taking a maximum P_{tot} of 250 mW to 300 mW for a SOT23-sized device into account, typical competitor devices would only work with big heat sinks and high losses in their base bias resistors (high I_B base currents for TR1).



I_C = 1,5 A
(1) Competitor Y
(2) Competitor Z
(3) PBSS5320T
(4) PBSS4021PT
(5) PBSS302PZ

Fig 8. TR1: Total power dissipation as a function of collector current to base current ratio



I_C = 1,5 A
(1) Competitor Y
(2) Competitor Z
(3) PBSS5320T
(4) PBSS4021PT
(5) PBSS302PZ

Fig 9. TR1 + R3: Total power dissipation as a function of collector current to base current ratio

At 1.5 A load current, the optimum I_C/I_B ratio for lowest power dissipation in the load transistor would be about 60, for the whole system 130 with NXP's transistors. At I_C/I_B = 130, the base current I_B would be about 12 mA resulting in a 5 V application in about 50 mW power dissipation in TR1's base resistor R3.

3. Summary

The performance of a bipolar transistor in a loadswitch application strongly depends on V_{CEsat} and h_{FE} at desired load currents. The latest generation of NXP's low V_{CEsat} (BISS) transistors offers outstanding values in both, with a typical h_{FE} of 200 to 400 and V_{CEsat} values significantly below 100 mV at high collector currents. For applications with requirements below 500 mA even 35 mV V_{CEsat} and less is possible which actually is comparable to today's typical trench MOSFETs.

Lower power dissipation and with it lower heat generation allow the design of highly efficient circuits and support the demand towards miniaturization in many of today's consumer products. NXP's low V_{CEsat} platform supports the needs towards cost-efficient bipolar low V_{CEsat} transistors leading the market in technology and performance.

Table 3. 4th Generation low V_{CEsat} (BISS) transistors in SOT23 for load switching

Type number	V_{CEO} (V)	Polarity	I_C (A)	$R_{CEsat(typ)}$ (mΩ) at I_C; I_C/I_B = 10
PBSS4021NT	20	NPN	4.3	36
PBSS4021PT	20	PNP	3.5	55
PBSS4041NT	60	NPN	3.8	45
PBSS4041PT	60	PNP	2.7	80

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