TND6093/D

Low $V_{CE(sat)}$ BJT's in Automotive Applications

ON Semiconductor®

www.onsemi.com

TECHNICAL NOTE

Introduction

Low $V_{CE(sat)}$ Bipolar Transistors (BJTs) are an attractive alternative to planar MOSFETs for power switching in automotive management circuits. They are proving to be more ESD robust, consume less power than comparative size planar MOSFETs and often lower cost resulting in a lower system cost. This application note will address the use of Low $V_{CE(sat)}$ BJTs in automotive power management circuits.

ON Semiconductor's family of low $V_{CE(sat)}$ Bipolar Junction Transistors (BJT) are surface mount devices featuring ultra low saturation voltage $V_{CE(sat)}$ and high current gain capability in thermally efficient packages. In the automotive industry they are used as a load switch in air bag deployment, pre-drivers for high current Trench MOSFETs in fuel pumps, over voltage protection, low drop out regulation, LED backlight switching, Royer converter for LCD backlights in instrument cluster. The Linear Gain (Beta) of Low $V_{CE(sat)}$ BJT makes them ideal components in analog amplifiers and for driving directly from logic circuits.

Technology

The Low $V_{CE(sat)}$ BJT devices use a technology that was first developed over 30 years ago and was primarily used to achieve similar performance in a smaller die (die shrink). This technology is called a "Perforated Emitter" and today is being focused towards reducing the forward saturation voltage to achieve very low forward resistance. The perforated emitter is a method of extending the base electrical layer across the complete die to contact multiple perforations through the emitter. Each of these perforations creates miniature transistors within the device and thus allows the current to be distributed evenly and with greater efficiency.

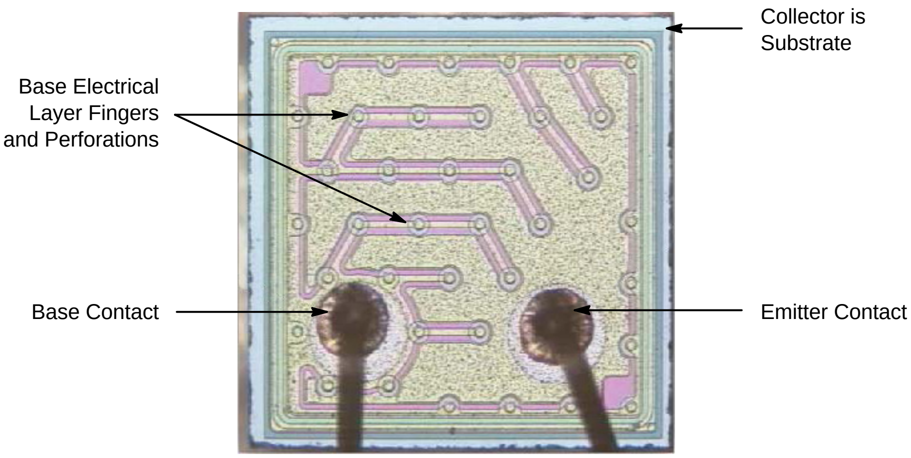

Figure 1. Photograph 1

Some of the new Low $V_{CE(sat)}$ BJT's are now available with a saturation voltage at 1 A of well under 50 mV. This equates to a forward resistance of under 50 mΩ, and proves very competitive against a higher cost MOSFET.

The Low $V_{CE(sat)}$ BJT's exhibit a temperature coefficient of resistance of approximately half that of MOSFETs, which can lead to higher efficiency at operating temperature, cooler running at high current densities and higher current per die area. The Low $V_{CE(sat)}$ BJT's block voltage in two directions, as specified by their $V_{(BR)EBO}$ or $V_{(BR)ECO}$ characteristic, which can eliminate the need for a series diode. The Low $V_{CE(sat)}$ BJT's are extremely rugged to ESD damage, and they have no difficulty passing Human Body Model discharge tests. Compared to MOSFETs where ESD damage always remains a risk, often resulting are ruptured or damaged gates.

BOARD DESIGN

Package Thermal Design Considerations

The Low $V_{CE(sat)}$ BJT is a current driven device, compared to the MOSFET which is a voltage driven device. For this reason the designer needs to understand the limitations of the power control circuits being used, to determine the specific circuit requirements when designing with a Low $V_{CE(sat)}$ BJT. For example, if the Low $V_{CE(sat)}$ BJT is to control a current of 1 Amp and it has a worst case gain (h_{FE}) of 100 then the base current will need to be a minimum of 10 mA (I_B) to ensure the Low $V_{CE(sat)}$ BJT goes into saturation. The output of the power control circuit must be able to supply the 10 mA for the Low $V_{CE(sat)}$ BJT to be driven directly; otherwise an additional drive stage would be required.

The power rating of the package for the Low $V_{CE(sat)}$ BJT has to be consider. For Example; the ON Semiconductor Low $V_{CE(sat)}$ BJT NSS40200LT1G in a SOT−23 package is mounted on a FR4 printed circuit board 500 mm^2 1 oz copper pad. The maximum power rating (P_D) with the specified pad is 540 mW.

The input voltage to be switched is < 40 V. The ambient temperature is 25°C. The typical $V_{CE(sat)}$ for the NSS40200LT1G at 1.0 A is 80 mV. This equates to a power dissipation of 80 mW. The Minimum Gain (h_{FE}) at 1.0 A is 180. Thus the drive current (I_B) would need to be a little over 6.0 mA. The maximum limit on $V_{CE(sat)}$ at 1.0 A is 170 mV (from Data Sheet with beta 100), this equating to 170 mW, well below the 540 mW rating for the package at 25°C.

Derating the Device for Temperature

The Thermal Resistance de-rating with 500 mm^2 1 oz copper is 4.3 mW/°C (From Data Sheet). The formula for de-rating the maximum power for the package is:

$$P_D \text{ @ } 25^{o}\text{C} - ((\text{Board Temp} - 25^{o}\text{C}) \times \text{De-rate}) \quad \text{(eq. 1)}$$

For an application with a maximum temperature of 85°C, the maximum allowable power dissipation for the package would become:

$$P_D = 540 - ((85 - 25) \times 4.3) = 282 \text{ mW} \quad \text{(eq. 2)}$$

The maximum calculated power of 170 mW still falls below the adjusted power when the device is de-rated for a higher temperature of 85°C.

PCB footprint, package height and drive circuit configuration play a major role as the designer tries to accommodate the ever increasing challenge to fit more into less space. The fewer devices to be placed on the PCB and the smaller the components are, the smaller the final product. SOT−723 feature a very thin profile 0.55 m & small footprint (1.2 × 1.2 mm), representing the best solution for today's infotainment requirements. If package height and footprint are not critical, then the designer has a wide selection of device packages to choose from.

ESD tolerance is becoming more critical as the proximity of ESD charges close to or on connectors is becoming more prominent. Due to the structure of a BJT (HB > 8000 V), it is dramatically more ESD tolerant than a MOSFET (HB > 300 V) and the need for external ESD protection is often eliminated, reducing component count.

Switching efficiency is important for circuits in which the losses caused by the switching time of the pass element would adversely affect the circuit operation. The High Pulse current capability makes them ideal for driving High Power MOSFETs. Low $V_{CE(sat)}$ BJT's are also suited for automotive applications where EMI and Harmonic Noise maybe a problem because there switching speed can be easily slowed through the use of a small capacitor, reducing the switching signature.

The Low turn on voltage is an attractive feature of the Low $V_{CE(sat)}$ BJT (0.7 V typical) compared to a MOSFET (typically 4.0–10.0 V). This makes them very attractive for low voltage circuits in situations where a controlled power down is required as the battery voltage drops and in the new "Stop Start" modes where the battery voltage drop for just a short period. The low turn on voltage would also eliminate the need for an oscillator and charge pump, normally needed for a MOSFET.

The Temperature Coefficient of the Low $V_{CE(sat)}$) BJT is typically better compared to a MOSFET. The variation from Cold to Hot is significantly less, resulting in a more consistent design compared to a design using a MOSFET. The Low $V_{CE(sat)}$ BJT coefficient is a little positive, resulting in the circuit becoming more efficient as it warms up. The MOSFET circuit becoming less efficient as the RDS-ON often doubles at high temperature.

The High Gain of the Low $V_{CE(sat)}$ BJT makes them ideal for driving directly from low voltage logic circuit. By connecting a Low $V_{CE(sat)}$ BJT to a logic gate the circuit becomes a Power Logic circuit.

The Low Cost of the Low $V_{CE(sat)}$ BJT will reduce the total system cost. Comparing the listed price to a similar MOSFET results in a $0.24 savings.

NTF2955T1G 60 V 2.6 A SOT−223 Web price $0.42

NSS60600MZ4T1G 60 V 6.0 A SOT−223 Web Price $0.18

APPLICATIONS

ASIC with an External Pass Transistor

The need for smaller size and more intelligence in the control circuit is causing a migration to dedicated ASICs for each functional area in the vehicle. The circuits, for the control of currents under 500 mA, are typically all imbedded within the ASIC, including the final pass transistor. However, for the control of currents from 500 mA to 5 A an external pass transistor (MOSFET) is the typical design of choice. An alternative to the MOSFET is to use a lower cost Low $V_{CE(sat)}$ BJT. The new family of Low $V_{CE(sat)}$ BJTs offer potential savings of 5 to 20 cents compared to designs using MOSFETs. Low $V_{CE(sat)}$ BJTs perform the same function as a MOSFET at a lower cost, and as an added bonus, in many cases provide for improved power consumption.

Load Switch – Back Light Control in Automotive Dashboards

Dashboards often use multiple arrays of LEDs for illumination of the different functions. Figure 2 is an illustration using a Low $V_{CE(sat)}$ BJT to control the LED backlights.

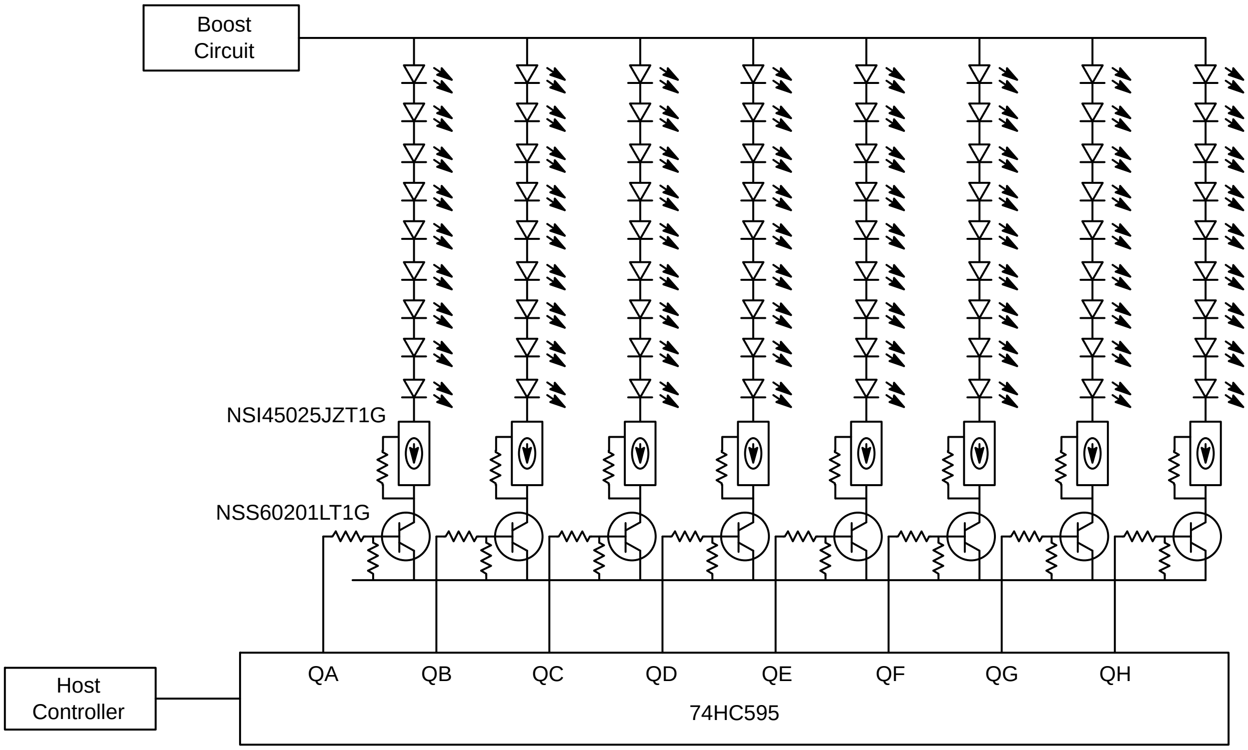

Figure 2. Large LED Array using a Logic Gate to Control the Low $V_{CE(sat)}$ BJT Switch

Load Switch – Seat Warmer

A Low $V_{CE(sat)}$ BJTs is an ideal switch for controlling functions within a vehicle that are on or off. The seat warmer is good example, Figure 3 is an illustration of the use of a Low $V_{CE(sat)}$ BJTs, being controlled with a Digital Transistor, to turn the seat warmer on and off.

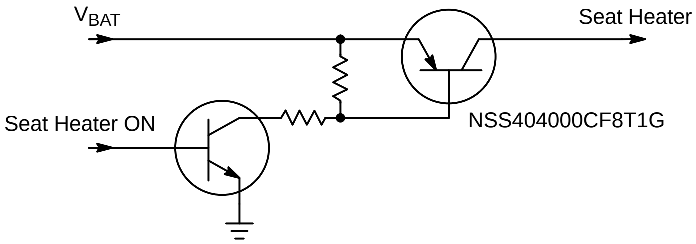

Figure 3. Load Switch − Seat Warmer

MOSFET Gate Driving

High Power low $R_{DS(on)}$ MOSFETs need to be switched at high frequencies to satisfy the power conversion reqirements of high efficiency. To achieve this the gate driver circuit has to deliver instantaneous currents of several amps. Low $V_{CE(sat)}$ BJTs are very suitable as they feature superior switching in linear mode, high pulse-current capability through high current density.

One of the most popular and cost-effective drive circuits is a bipolar, non-inverting totem-pole driver. As power dissipation is low, this can use a co-packaged complementary pairs in small outline surface mount packages (NSS40302PDR2G).

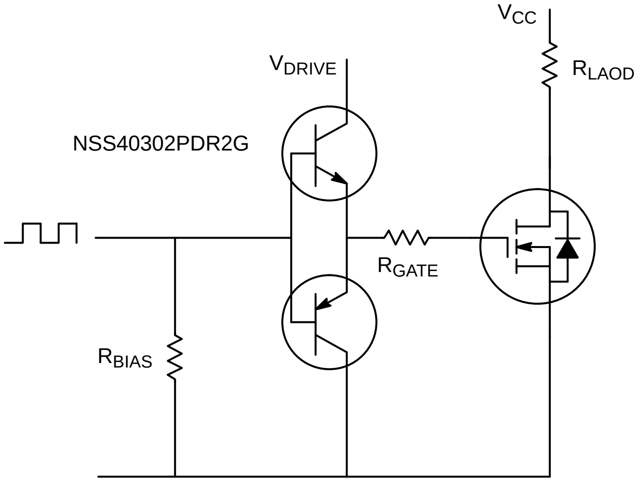

Figure 4. MOSFET Gate Driving

H-Bridge Drive for Window Motors

Turning on Q1 and Q4 the motor turns forward. Turning on Q2 and Q3 the motor reverses.

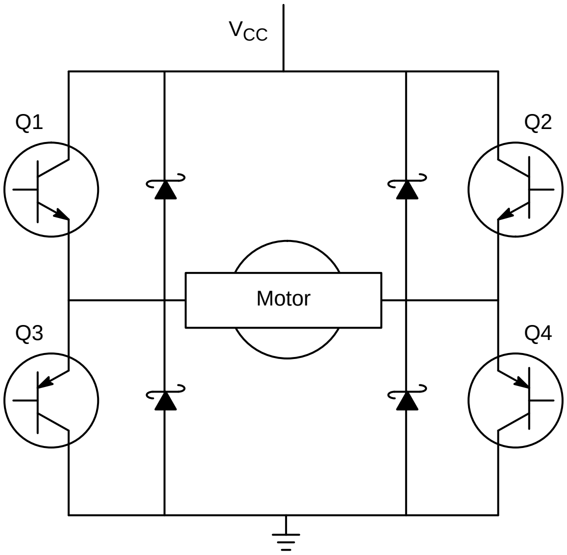

Figure 5. H-Bridge Drive for Window Motors

Over Voltage Protection

The Low $V_{CE(sat)}$ BJTs are ideal for a simple over voltage protection circuit. Zener D1 is selected for the trip voltage, Zener D2 is selected to ensure higher peaks that may get past the BJT are still clamped from reaching the load. Diode D3 acts as a Bakers Clamp improving the switching time of Q1 to under 100 ns.

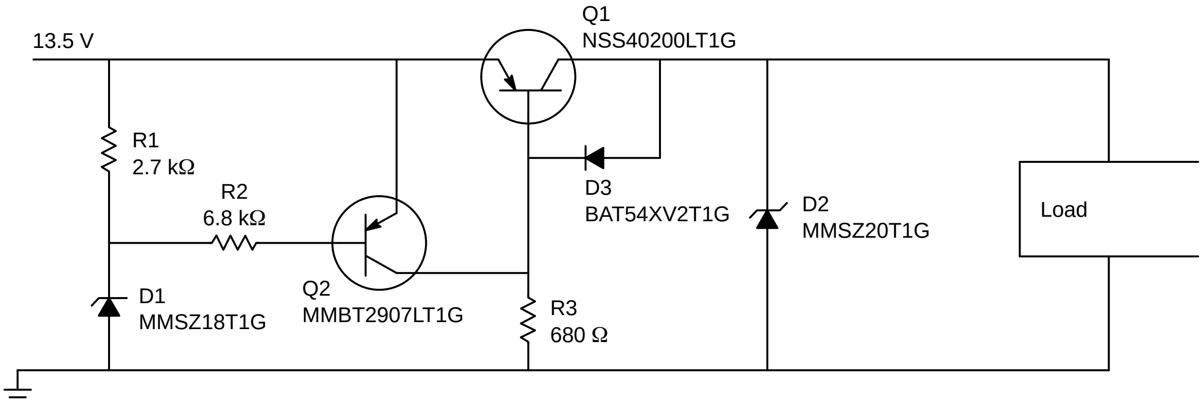

Figure 6. Over Voltage Protection

Conclusion

Low $V_{CE(sat)}$ Bipolar Transistors (BJTs) are an attractive alternative to planar MOSFETs for power switching in automotive management circuits. They are proving to be more ESD robust, consume less power and often resulting in a small Bill Of Material (BOM) and thus lower system cost.

Table 1.

Application	Feature	Benefit
Load Switch	• Low $V_{CE(sat)}$ • $h_{FE} > 200$ • Low R_{CE}/mm^2 • Small Size − 5.4 mm^2 • Low Profile – 1.0 mm • PNP Transistor	• High Efficiency • High Gain • Low Cost vs. MOSFET • Less Board Space • More Compact Design • High Side Control
MosFET Gate Drive	• High Pulse Current • High Frequency • $h_{FE} > 200$ • Low R_{CE}/mm^2 • Small Size − 5.4 mm^2 • Low Profile – 1.0 mm • PNP/NPN Transistor	• Fast Switching Time • Fast Switching Time • High Current gain • Low Cost vs. MOSFET • Less Board Space • More Compact Design • High/Low Switch
Low Drop Out (LDO) Regulator	• Low $V_{CE(sat)}$ • High Power Dissipation/mm^2 • $h_{FE} > 200$ • Low R_{CE}/mm^2 • Small Size − 5.4 mm^2 • Low Profile – 1.0 mm • PNP/NPN Transistor	• High Efficiency • High Current Control • High Gain • Low Cost vs. MOSFET • Less Board Space • More Compact Design • High or Low Side Control
Servo Motor Drive	• PNP/NPN Transistor • Low $V_{CE(sat)}$ • High Frequency • $h_{FE} > 200$ • Low R_{CE}/mm^2 • Small Size − 5.4 mm^2 • Low Profile – 1.0 mm	• High/Low Bridge • High Efficiency • Low Switching Losses • High Current Gain – Lower Control Current • Low Cost vs. MOSFET • Less Board Space • Design Flexibility
Over Voltage Protection	• PNP/NPN Transistor • Low $V_{CE(sat)}$ • High Power Dissipation/mm^2 • High Frequency • $h_{FE} > 200$ • Low R_{CE}/mm2 • Small Size − 5.4 mm^2 • Low Profile – 1.0 mm	• High/Low Bridge • High Efficiency • High Current Control • Low Switching Losses • High Current Gain – Lower Control Current • Low Cost vs. MOSFET • Less Board Space • Design Flexibility

Table 2. PNP PORTFOLIO OF LOW $V_{CE(sat)}$ BJT

Part Number	V_{CE} (V)	I_C DC (A)	I_C Peak (A)	Package	Typical $V_{CE(sat)}$ 1 A Beta 10	Typical h_{FE} @ 5 V, 100 mA	Status
NSS12100UW3	12	1	2	WDFN3	400 mV	300	Released
NSS12100M3	12	1	2	SOT−723	280 mV	250	Released
NSS12100XV6	12	1	2	SOT−563	280 mV	250	Released
NSS12200W	12	2	3	SC−88	150 mV	250	Released
NSS12200L	12	2	4	SOT−23	65 mV	250	Released
NSS12500UW3	12	5	7	WDFN3	55 mV	250	Released
NSS20200L	20	2	4	SOT−23	65 mV	250	Released
NSS20300MR6	20	3	5	TSOP−6	80 mV	250	Released
NSS20500UW3	20	5	7	WDFN3	60 mV	250	Released
NSS30070MR6	30	0.7	2	SC−74	205 mV	310	Released
NSS30100L	30	1	2	SOT−23	200 mV	98	Released
NSS35200MR6	35	2	5	TSOP−6	78 mV	234	Released
NSS35200CF8	35	2	7	ChipFET	79 mV	253	Released
NSS40200L	40	2	4	SOT−23	80 mV	300	Released
NSS40200UW6	40	2	4	WDFN6	100 mV	250	Released
NSS40300MZ4	40	3	5	SOT−223	50 mV	250	Released
NSS40500UW3	40	5	6	WDFN3	65 mV	250	Released
NSS40600CF8	40	6	8	ChipFET	50 mV	250	Released
NSS60200L	60	2	4	SOT−23	80 mV	250	Released
NSS60600MZ4	60	6	12	SOT−223	80 mV	250	Released
NSS1C200L	100	2	4	SOT−23	100 mV	300	Released
NSS1C200MZ4	100	2	3	SOT−223	125 mV	250	Released
NSS1C300E	100	3	6	DPAK	150 mV	180	Released

Table 3. NPN PORTFOLIO OF LOW $V_{CE(sat)}$ BJT

Part Number	V_{CE} (V)	I_C DC (A)	I_C Peak (A)	Package	Typical $V_{CE(sat)}$ 1 A Beta 10	Typical h_{FE} @ 5 V, 100 mA	Status
NSS12201L	12	2	4	SOT−23	35 mV	300	Released
NSS12501UW3	12	5	7	WDFN3	31 mV	300	Released
NSS12601CF8	12	6	8	ChipFET	30 mV	300	Released
NSS20101J	20	1	2	SC−89	220 mV	500	Released
NSS20201L	20	2	4	SOT−23	37 mV	300	Released
NSS20201MR6	20	2	3	TSOP−6	103 mV	200	Released
NSS20501UW3	20	5	7	WDFN3	31 mV	300	Released
NSS20601CF8	20	6	8	ChipFET	31 mV	300	Released
NSS30071MR6	30	0.7	2	SC−74	205 mV	317	Released
NSS30101L	30	1	2	SOT−23	103 mV	200	Released
NSS30201MR6	30	2	3	TSOP−6	103 mV	200	Released
NSS40201L	40	2	4	SOT−23	44 mV	300	Released
NSS40301MZ4	40	3	5	SOT−223	50 mV	250	Released
NSS40501UW3	40	5	7	WDFN3	38 mV	300	Released
NSS40601CF8	40	6	8	ChipFET	31 mV	300	Released
NSS60201L	60	2	4	SOT−23	80 mV	250	Released

Table 3. NPN PORTFOLIO OF LOW $V_{CE(sat)}$ BJT (continued)

Part Number	V_{CE} (V)	I_C DC (A)	I_C Peak (A)	Package	Typical $V_{CE(sat)}$ 1 A Beta 10	Typical h_{FE} @ 5 V, 100 mA	Status
NSS60601MZ4	60	6	12	SOT−223	80 mV	250	Released
NSS1C201L	100	2	4	SOT−23	100 mV	250	Released
NSS1C201MZ4	100	2	3	SOT−223	100 mV	250	Released
NSS1C301E	100	2	6	DPAK	45 mV	200	Released

Table 4. DUAL PNP/NPN/COMPLEMENTARY PORTFOLIO OF LOW $V_{CE(sat)}$ BJT

Part Number	Polarity	V_{CE} (V)	I_C DC (A)	I_C Peak (A)	Package	Typical $V_{CE(sat)}$ 1 A Beta 10	Typical h_{FE} @ 2 V, 1 A	Status
NSS40301MD	NPN	40	3	6	SOIC−8	44 mV	340	Released
NSS40300MD	PNP	40	3	6	SOIC−8	75 mV	300	Released
NSS40300DD	PNP	40	3	6	SOIC−8	75 mV	300	Released
NSS40302PD	NPN/PNP	40	3	6	SOIC−8	44/75 mV	340/300	Released

ON Semiconductor and are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at www.onsemi.com/site/pdf/Patent−Marking.pdf. ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

PUBLICATION ORDERING INFORMATION

LITERATURE FULFILLMENT:
Literature Distribution Center for ON Semiconductor
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA
Phone: 303−675−2175 or 800−344−3860 Toll Free USA/Canada
Fax: 303−675−2176 or 800−344−3867 Toll Free USA/Canada
Email: orderlit@onsemi.com

N. American Technical Support: 800−282−9855 Toll Free USA/Canada
Europe, Middle East and Africa Technical Support:
Phone: 421 33 790 2910
Japan Customer Focus Center
Phone: 81−3−5817−1050

ON Semiconductor Website: **www.onsemi.com**

Order Literature: http://www.onsemi.com/orderlit

For additional information, please contact your local Sales Representative