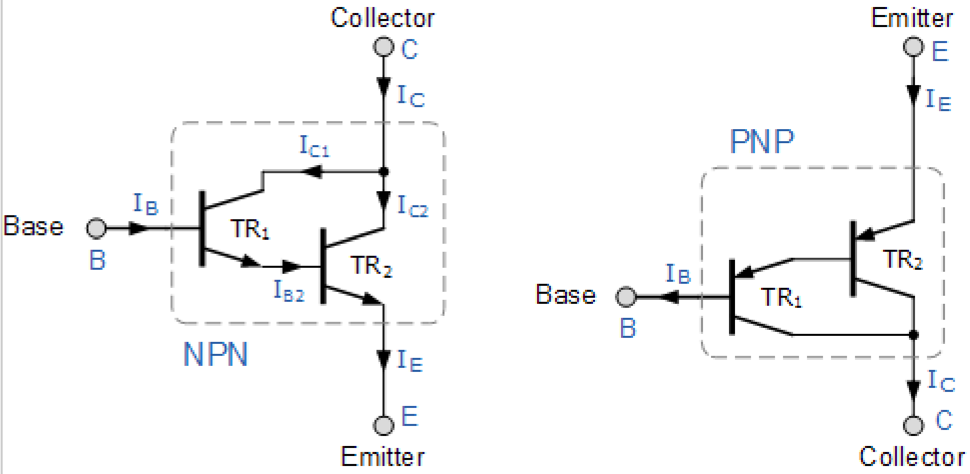


Darlington Transistors

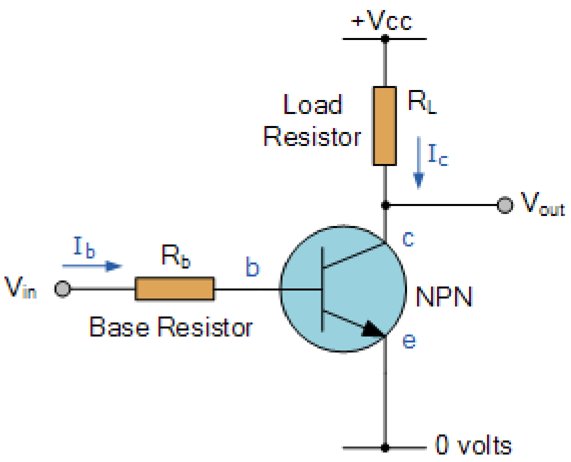
The Darlington Transistor configuration of two bipolar transistors offers increased current switching for a given base current

The **Darlington Transistor** named after its inventor, Sidney Darlington is a special arrangement of two standard NPN or PNP bipolar junction transistors (BJT) connected together. The Emitter of one transistor is connected to the Base of the other to produce a more sensitive transistor with a much larger current gain being useful in applications where current amplification or switching is required.

Darlington Transistor pairs can be made from two individually connected bipolar transistors or a one single device commercially made in a single package with the standard: Base, Emitter and Collector connecting leads and are available in a wide variety of case styles and voltage (and current) ratings in both NPN and PNP versions.

As we saw in our *Transistor as a Switch* tutorial, as well as being used as an amplifier, the bipolar junction transistor, (BJT) can be made to operate as an ON-OFF switch as shown.

Bipolar Transistor as a Switch



When the base terminal of the NPN transistor is grounded (0 volts), zero current flows into the base therfore Ib = 0. As the base terminal is grounded, no current flows from the collector to the emitter terminals therefore the non-conducting NPN transistor is switched “OFF” (cut-off). If we now forward biased the base terminal with respect to the emitter by using a voltage source greater than 0.7 volts, transistor action occurs causing in a much larger current to flow through the transistor between its collector and emitter terminals. The transistor is now said to be switched “ON” (conducting). If we operate the transistor between these two modes of cut-off and conduction, the transistor can be made to operate as an electronic switch.

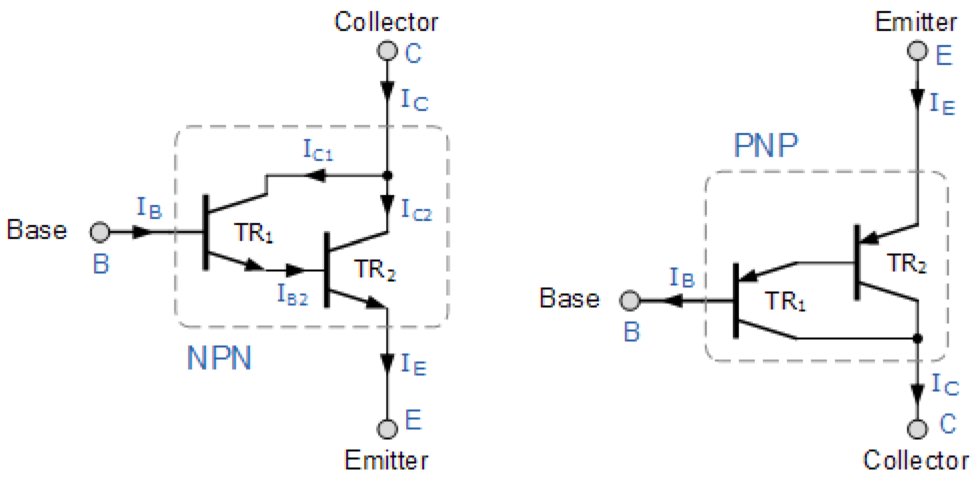
However, the transistors base terminal needs to be switched between zero and some positive value much greater than 0.7 volts for the transistor to fully conduct. A higher voltage causes an increased base current, Ib to flows into the device resulting in collector current Ic becoming large while the voltage drop across the colletor and emitter terminals, Vce becomes smaller. Then we can see that a smaller current flowing into the base terminal can cause a much larger current to flow between the collector and the emitter.

The ratio of collector current to base current (β) is known as the *current gain* of the transistor. A typical value of β for a standard bipolar transistor may be in the range of 50 to 200 and varies even between transistors of the same part number. In some cases where the current gain of a single transistor is too low to directly drive a load, one way to increase the gain is to use a Darlington pair.

A **Darlington Transistor** configuration, also known as a “Darlington pair” or “super-alpha circuit”, consist of two NPN or PNP transistors connected together so that the emitter current of the first transistor TR_1 becomes the base current of the second transistor TR_2. Then transistor TR1 is connected as an emitter follower and TR2 as a common emitter amplifier as shown below.

Also note that in this Darlington pair configuration, the collector current of the slave or control transistor, TR1 is “in-phase” with that of the master switching transistor TR2.

Basic Darlington Transistor Configuration



Using the NPN Darlington pair as the example, the collectors of two transistors are connected together, and the emitter of TR_1 drives the base of TR_2. This configuration achieves β multiplication because for a Base current i_b, the collector current is $\beta * i_b$ where the current gain is greater than one, or unity and this is defined as:

$$I_C = I_{C1} + I_{C2}$$
$$I_C = \beta_1.I_B + \beta_2.I_{B2}$$

But the base current, I_{B2} is equal to transistor TR1 emitter current, I_{E1} as the emitter of TR1 is connected to the base of TR2. Therefore:

$$I_{B2} = I_{E1} = I_{C1} + I_B = \beta_1.I_B + I_B = (\beta_1 + 1).I_B$$

Then substituting in the first equation:

$$I_C = \beta_1.I_B + \beta_2.(\beta_1 + 1).I_B$$

$$I_C = \beta_1.I_B + \beta_2.\beta_1.I_B + \beta_2.I_B$$

$$I_C = \left(\beta_1 + (\beta_2.\beta_1) + \beta_2\right).I_B$$

Where β_1 and β_2 are the gains of the individual transistors.

This means that the overall current gain, β is given by the gain of the first transistor multiplied by the gain of the second transistor as the current gains of the two transistors multiply. In other words, a pair of bipolar transistors combined together to make a single Darlington transistor pair can be regarded as a single transistor with a very high value of β and consequently a high input resistance.

Darlington Transistor Example No1

Two NPN transistors are connected together in the form of a **Darlington Pair** to switch a 12V 75W halogen lamp. If the forward current gain of the first transistor is 25 and the forward current gain (Beta) of the second transistor is 80. Ignoring any voltage drops across the two transistors, calculate the maximum base current required to switch the lamp fully-ON.

Firstly, the current drawn by the lamp will be equal to the Collector current of the second transistor, then:

$$I_C = I_{LAMP}$$

$$\therefore I_{LAMP} = \frac{P}{V} = \frac{75}{12} = 6.25\,\text{Amps}$$

Using the equation above, the base current is given as:

$$\beta_1 = 25, \quad \beta_2 = 80$$

$$I_C = \left(\beta_1 + (\beta_2.\beta_1) + \beta_2\right).I_B$$

$$\therefore I_B = \frac{I_C}{\beta_1 + (\beta_2.\beta_1) + \beta_2} = \frac{6.25}{2105} = 3.0\,\text{mA}$$

Then we can see that a very small base current of only 3.0mA, such as that supplied by a digital logic gate or the output port of a micro-controller, can be used to switch the 75 Watt lamp “ON” and “OFF”.

If two identical bipolar transistors are used to make a single Darlington device then β_1 is equal to β_2 and the overall current gain will be given as:

If $\beta_1 = \beta_2$

$$I_C = \left(\beta_1 + (\beta_2.\beta_1) + \beta_2 \right).I_B$$

$$\therefore\ I_C = \left(\beta^2 + 2\beta \right).I_B$$

Generally the value of β^2 is much greater than that of 2β, in which case it can be ignored to simplify the maths a little. Then the final equation for two identical transistors configured as a Darlington pair can be written as:

Identical Darlington Transistors

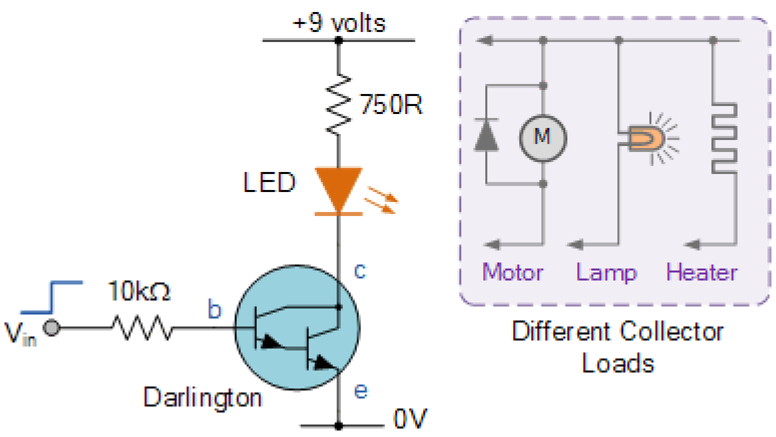
$$I_C = \left(\beta^2 \times I_B \right)$$

Then we can see that for two identical transistors, β^2 is used instead of β acting like one big transistor with a huge amount of gain. Darlington transistor pairs with current gains of more than a thousand with maximum collector currents of several amperes are easily available. For example: the NPN TIP120 and its PNP equivalent the TIP125.

The advantage of using an arrangement such as this, is that the switching transistor is much more sensitive as only a tiny base current is required to switch a much larger load current as the typical gain of a Darlington configuration can be over 1,000 whereas normally a single transistor stage produces a gain of about 50 to 200.

Then we can see that a darlington pair with a gain of 1,000:1, could switch an output current of 1 ampere in the collector-emitter circuit with an input base current of just 1mA. This then makes darlington transistors ideal for interfacing with relays, lamps and motors to low power microcontroller, computer or logic controllers as shown.

Darlington Transistor Applications



The base of the Darlington transistor is sufficiently sensitive to respond to any small input current from a switch or directly from a TTL or 5V CMOS logic gate. The maximum collector current $I_C(max)$ for any Darlington pair is the same as that for the main switching transistor, TR_2 so can be used to operate relays, DC motors, solenoids and lamps, etc.

One of the main disadvantage of a Darlington transistor pair is the minimum voltage drop between the base and emitter when fully saturated. Unlike a single transistor which has a saturated voltage drop of between 0.3v and 0.7v when fully-ON, a Darlington device has twice the base-emitter voltage drop (1.2 V instead of 0.6 V) as the base-emitter voltage drop is the sum of the base-emitter diode drops of the two individual transistors which can be between 0.6v to 1.5v depending on the current through the transistor.

This high base-emitter voltage drop means that the Darlington transistor can get hotter than a normal bipolar transistor for a given load current and therefore requires good heat sinking. Also, Darlington transistors have slower ON-OFF response times as it takes longer for the slave transistor TR_1 to turn the master transistor TR_2 either fully-ON or fully-OFF.

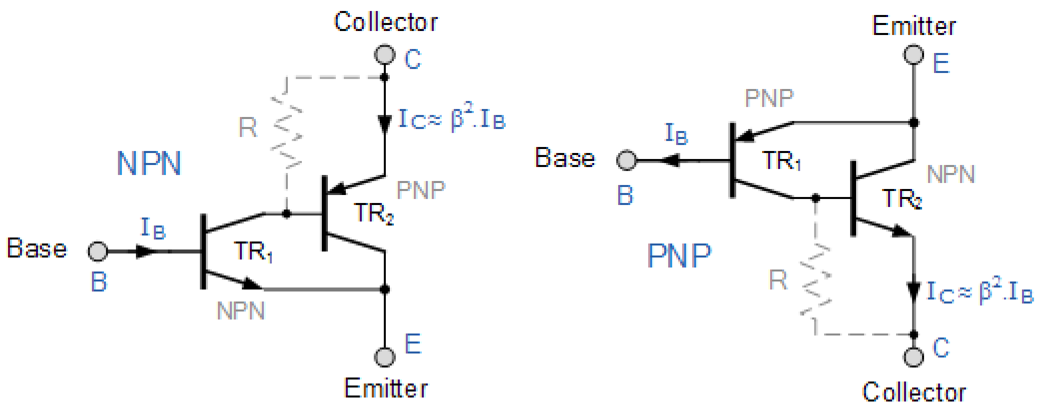
To overcome the slow response, increased voltage drop and thermal disadvantages of a standard **Darlington Transistor** device, complementary NPN and PNP transistors can be used in the same cascaded arrangement to produce another type of Darlington transistor called a **Sziklai Configuration**.

Sziklai Transistor Pair

The **Sziklai Darlington Pair**, named after its Hungarian inventor George Sziklai, is a complementary or compound Darlington device that consists of separate **NPN** and **PNP** complementary transistors connected together as shown below.

This cascaded combination of NPN and PNP transistors has the advantage that the Sziklai pair performs the same basic function of a Darlington pair except that it only requires 0.6v for it to turn-ON and like the standard Darlington configuration, the current gain is equal to β^2 for equally matched transistors or is given by the product of the two current gains for unmatched individual transistors.

Sziklai Darlington Transistor Configuration



We can see that the base-emitter voltage drop of the Sziklai device is equal to the diode drop of a single transistor in the signal path. However, the Sziklai configuration can not saturate to less than one whole diode drop, i.e. 0.7v instead of the usual 0.2v.

Also, as with the Darlington pair, the Sziklai pair have slower response times than a single transistor. Sziklai pair complementary transistors are commonly used in push-pull and class AB audio amplifier output stages allowing for one polarity of output transistor only. Both the Darlington and Sziklai transistor pairs are available in both NPN and PNP configurations.

Darlington Transistor IC's

In most electronics applications it is sufficient for the controlling circuit to switch a DC output voltage or current "ON" or "OFF" directly as some output devices such as LED's or displays only require a few milliamps to operate at low DC voltages and can therefore be driven directly by the output of a standard logic gate.

However as we have seen above, sometimes more power is required to operate the output device such as a DC motor than can be supplied by an ordinary logic gate or micro-controller. If the digital logic device cannot supply sufficient current then additional circuitry will be required to drive the device.

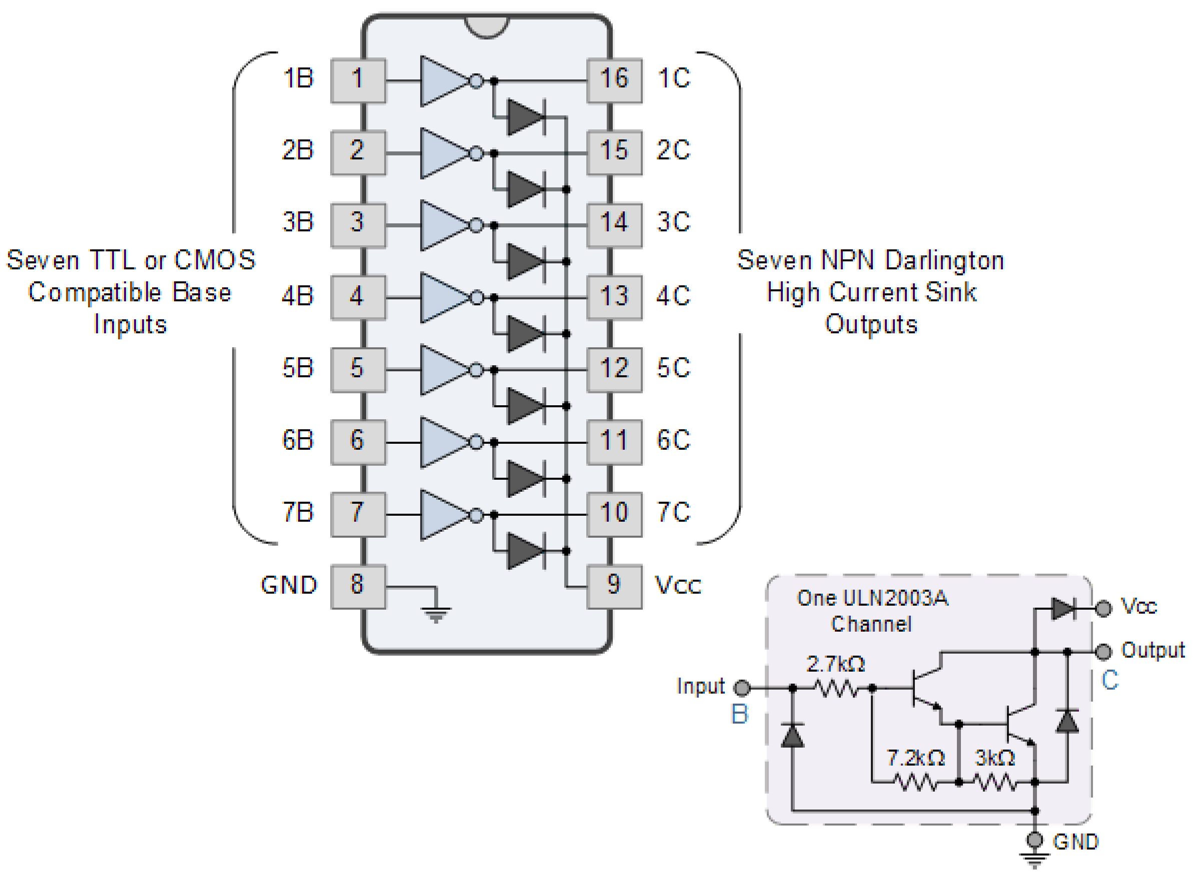
One such commonly used Darlington transistor chip is the **ULN2003** array. The family of darlington arrays consist of the ULN2002A, ULN2003A and the ULN2004A which are all high voltage, high current darlington arrays each containing seven open collector darlington pairs within a single IC package.

Each channel of the array is rated at 500mA and can withstand peak currents of up to 600mA making it ideal for controlling small motors or lamps or the gates and bases of high power semiconductors. Additional suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify the connections and board layout.

The ULN2003A Darlington Transistor Array

The **ULN2003A** is a inexpensive unipolar darlington transistor array with high efficiency and low power consumption making it useful for driving a wide range of loads including solenoids, relays DC Motor's and LED displays or filament lamps. The ULN2003A contains seven darlington transistor pairs each with an input pin on the left and an output pin opposite it on the right as shown.

ULN2003A Darlington Transistor Array



The ULN2003A Darlington driver has an extremely high input impedance and current gain which can be driven directly from either a TTL or +5V CMOS logic gate. For +15V CMOS logic use the ULN2004A and for higher switching voltages up to 100V it is better to use the SN75468 Darlington array.

When an input (pins 1 to 7) is driven "HIGH" the corresponding output will switch "LOW" sinking current. Likewise, when the input is driven "LOW" the corresponding output switches to a high impedance state. This high impedance "OFF" state blocks load current and reduces leakage current through the device improving efficiency.

Pin 8, (GND) is connected to the loads ground or 0 volts, while pin 9 (Vcc) connects to the loads supply. Then any load needs to be connected between +Vcc and an output pin, pins 10 to 16. For inductive loads such as motors, relays and solenoids, etc, pin 9 should always be connected to Vcc.

The ULN2003A is capable of switching 500mA (0.5A) per channel but if more switching current capability is required then both the Darlington pairs inputs and outputs can be paralleled together for higher current capability. For example, input pins 1 and 2 connected together and output pins 16 and 15 connected together to switch the load.

Darlington Transistor Summary

The **Darlington Transistor** is a high power semiconductor device with individual current and voltage ratings many times higher than a conventional small signal junction transistors.

The DC current gain values for standard high power NPN or PNP transistors are relatively low, as low as 20 or even less, compared to small signal switching transistors. This means that large base currents are required to switch a given load.

The Darlington arrangement uses two transistors back to back, one of which is the main current carrying transistor, while the other being a much smaller "switching" transistor provides the base current to drive the main transistor. As a result, a smaller base current can be used to switch a much larger load current as the DC current gains of the two transistors are multiplied together. Then the two transistor combination can be regarded as one single transistor with a very high value of β and consequently a high input resistance.

As well as standard PNP and NPN Darlington transistor pairs, complementary Sziklai Darlington transistors are also available which consist of separate matching NPN and PNP complementary transistors connected together within the same Darlington pair to improve efficiency.

Also Darlington arrays such as the ULN2003A are available which allow high power or inductive loads such as lamps, solenoids and motors to be safely driven by microprocessor and micro-controller devices in robotic and mechatronic type applications.

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- 1. Bipolar Transistor
- 2. NPN Transistor
- 3. PNP Transistor
- 4. Transistor as a Switch
- 5. Junction Field Effect Transistor
- 6. The MOSFET
- 7. MOSFET as a Switch
- 8. Transistor Tutorial Summary
- 9. Darlington Transistors
- 10. FET Current Source
- 11. Open Collector Outputs

54 Comments

Join the conversation

- *naeem*

  This detail of Darlington TRANSISTOR is useful please add a practical testing of Darlington like ke with a potentiometer
  Regards
  naeem

  Posted on March 16th 2022 | 9:31 pm
  Reply
- *Rajatsekhar*

  I am grateful to you the way you clarified our doubts regarding the topic discussed. I thank you very much. ❣️

  Posted on January 11th 2022 | 1:53 am
  Reply
- *Ron dumont*

  Great review thank you

  Posted on November 21st 2020 | 9:16 pm
  Reply
- *mudassir*

  #When the base of the NPN transistor is grounded (0 volts) and no base current, Ib flows, no current flows from the emitter to the collector and the transistor is therefore switched "OFF". If the base is forward biased by more than 0.7 volts, a current will flow from the emitter to the collector and the transistor is said to be switched "ON". When operated in these two modes, the transistor operates as a switch.#

  how can current flow from emitter to collector since the transistor is NPN please correct it:)

  Posted on June 07th 2020 | 8:57 am
  Reply
  - *P.C. Bloot*

    Hetgeen in de tekst staat klopt niet. De stroom door een geleidende ("AAN") transistor loopt altijd in de richting van de emitterpijl. Bij een NPN loopt er dan een (conventionele) stroom van collector via de emitter naar min (Massa).

    Posted on October 17th 2020 | 7:02 pm

Reply

- *JYOTIK SIMARIA*

  Fabulous Notes found so far , in Internet .Everything is covered with utmost Basics.

  Posted on April 23rd 2020 | 5:56 am
  Reply
- *Ahmed essa*

  Prove that the total current gain for the Darlington connection Bt=B1*B2

  Posted on December 04th 2019 | 4:21 pm
  Reply
- *Transoceanic85232*

  Really great & helpful !
  Wonderful way to offer help and information

  Posted on August 11th 2019 | 12:48 am
  Reply
- *Chiddy*

  Many thanks.
  I really appreciate the work done here. It's helpful.

  Posted on May 16th 2019 | 3:04 pm
  Reply
- *hillbilly*

  I have heaps of uln2003 chips but they switch GND or Vss To the outputs. (Ie active high)
  I need to drive multiple Common CATHODE LED displays and need active LOW OUTPUT from my darlington arrays.
  Any suggestions on a 7 Tx array?
  I am guessing a PNP one.
  Cheers billy

  Posted on April 30th 2019 | 4:09 am
  Reply
  - *Wayne Storr*

    The UDN2981A can be used with common cathode displays

    Posted on April 30th 2019 | 7:23 am
    Reply
- *Laxman Rao*

  Nice sir. Good information. But there is no brief explanation and don't drive the voltage and current gains and input, output resistances

  Posted on September 10th 2018 | 8:58 am
  Reply
- *maysan*

  Thank you very much .

  Posted on August 17th 2018 | 10:13 am
  Reply
- *Ken Proctor*

  Really appreciate your tutorial pages/site! Hope to discover more on any electronics subject. Thanks again!

  Posted on August 13th 2018 | 5:14 pm
  Reply
- *Volkan*

  Thank you very much for information. I really appreciate it. To make the document deeper, can you please also include power loss calculation of these type of transistors with understandable easy examples ?

  Kind regards..

  Posted on February 25th 2018 | 2:39 pm
  Reply
- *cdbstock*

  what is the voltage across the output of a ULN2004A when 'on'

  Posted on December 31st 2017 | 11:54 am
  Reply
- *sunil gamini ratnasingha*

  your letter is very important to all of us.
  thanks.
  s.g.ratnasingha
  srilanka

  Posted on November 26th 2017 | 9:37 am
  Reply
- *Damian*

  Thank you for this!!!

Posted on [November 03rd 2017 | 4:00 am]
[Reply]

- *rubi sindhika*

  Hello!
  I just want to know whether the darlington pair connected in voltage divider bias configuration can have their beta values equal? i.e., Beta1=Beta2?

  Posted on [July 20th 2017 | 12:52 pm]
  [Reply]

- *anil*

  if i want to make this darlington pair then what diode(like 4148,4007 etc)i should use?or what transistor(name) should i use?

  Posted on [July 07th 2017 | 4:28 am]
  [Reply]

- *vikas*

  very happy

  Posted on [April 13th 2017 | 2:52 am]
  [Reply]

- *Jacob Smart*

  I have 2 questions actually. Both relating to the basic functionality of the darlington setup. In the diagram above labeled “One ULN2003A Channel” there’s a diode with the cathode leading off towards the positive Vcc supply. wouldn’t this reverse bias the diode and not allow current to flow through the transistors? And also The load is not in series in this diagram like the diagram above under the heading “darlington transistor applications”, instead it has the output path leading off towards the load,, why the difference?

  Posted on [March 29th 2017 | 11:07 pm]
  [Reply]

  - More