

Driving Nixies With Discrete Transistors

Version 1.0

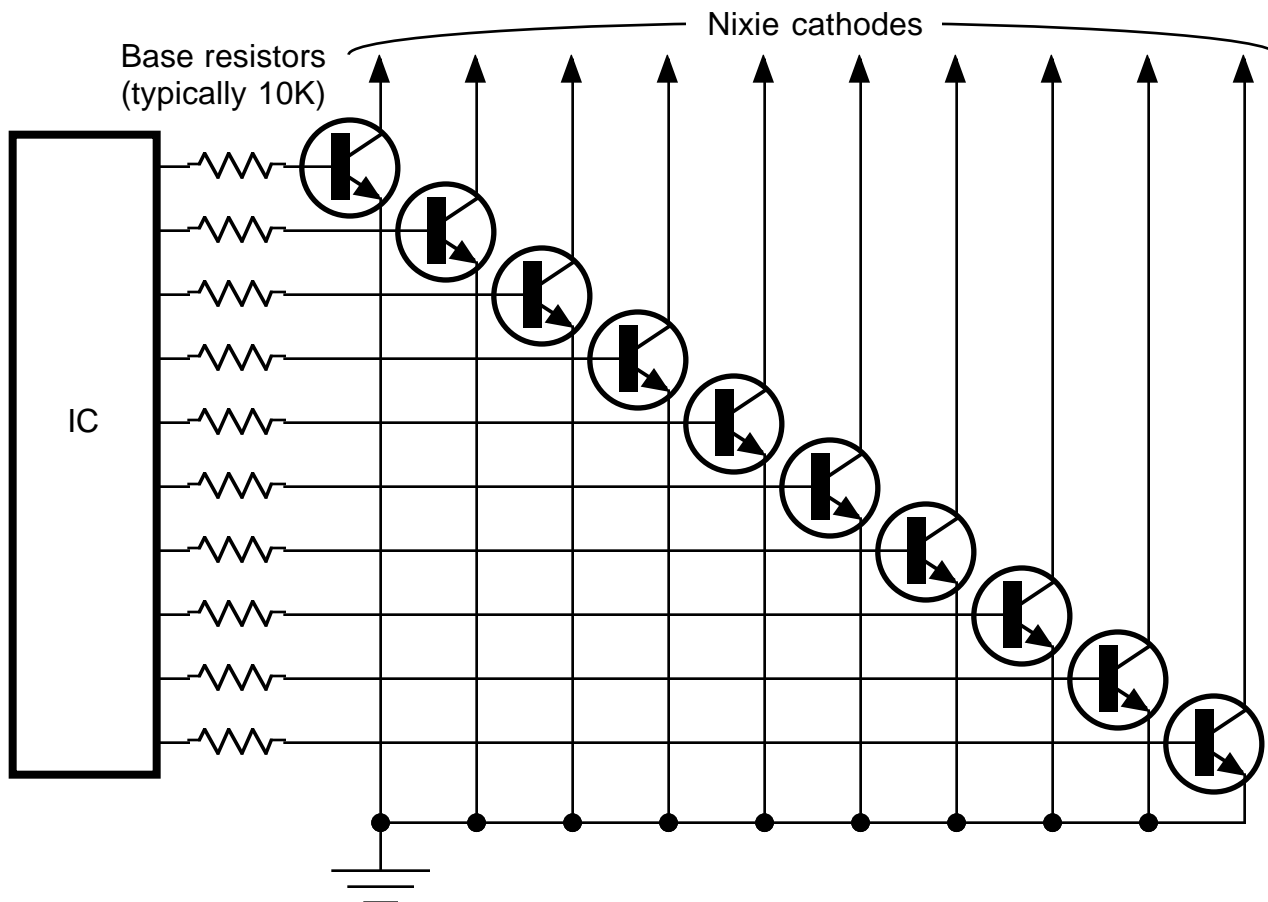
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There are a variety of integrated circuits capable of driving Nixie tubes, such as the vintage 7441, 7441A, and 74141 TTL chips, and modern high-voltage drivers such as those made by Supertex. However, there are still cases where using individual transistors is a good idea: they draw less power than the TTL chips, and are more readily available than most HV drivers. Also, they give you more flexibility in laying out the circuit board - you can't put half of a 74141 on each side of a Nixie if the entire chip won't fit on either side! This article will discuss ways of using transistors for driving Nixies in an otherwise IC-based design.

Probably the most popular Nixie driver transistor is the MPSA42. It is quite suitable for the job, is in active production by several manufacturers, and is fairly cheap - I've seen prices as low as 5 cents (US) each in quantity 100. Its relevant characteristics are a collector-emitter and collector-base breakdown voltage of 300V, and a beta of at least 25. Its emitter-base breakdown voltage of 6V is not relevant in the most common driver circuit, but will be in some of the designs presented here.

First, a basic review of transistor operation. The base-emitter junction of a bipolar transistor is effectively a diode - for an NPN transistor, the base is the anode, and the emitter is the cathode. If the base-emitter voltage exceeds the voltage drop of this junction (typically 0.6V), current will flow through it (and this current must be externally limited, since the transistor itself will not place any limit on it short of physically melting down). While base-emitter current is flowing, an even larger current can flow from the collector to the emitter. The ratio of the possible collector current to the supplied base current is called the beta (or h_{FE}) of the transistor. The MPSA42 has a fairly low beta, compared to various other transistors with betas in the hundreds: this is a trade-off with its ability to withstand hundreds of volts more on its collector than those other transistors. Since with Nixies we are dealing with at most a few mA of collector current, the low beta is not a problem in practice.

The most common way of using a transistor as a switch is to ground the emitter, and apply a positive voltage to the base through a current-limiting resistor to turn it on. The load to be switched is connected between the collector and a positive voltage supply. This supply can be at a much higher voltage (up to the breakdown voltage of the transistor) than the switching signal. For a Nixie, the load will be one of the tube cathodes, with the tube anode connected to a supply of about 180V via a resistor. Multiplying this circuit by ten so that all cathodes of a common numeric Nixie can be controlled, we get the design shown below. The "IC" shown in the schematic can be anything that produces one logic high output and nine logic low outputs at any given time. Common choices are a microcontroller such as a Microchip PIC, a decimal decoder/driver such as the CD4017, or a shift register. (Note that it is possible in this design to turn on more than one transistor at a time, but this will generally NOT result in multiple, evenly lit digits. If you really want more than one digit lit at a time, the proper solution is to rapidly switch between them.)



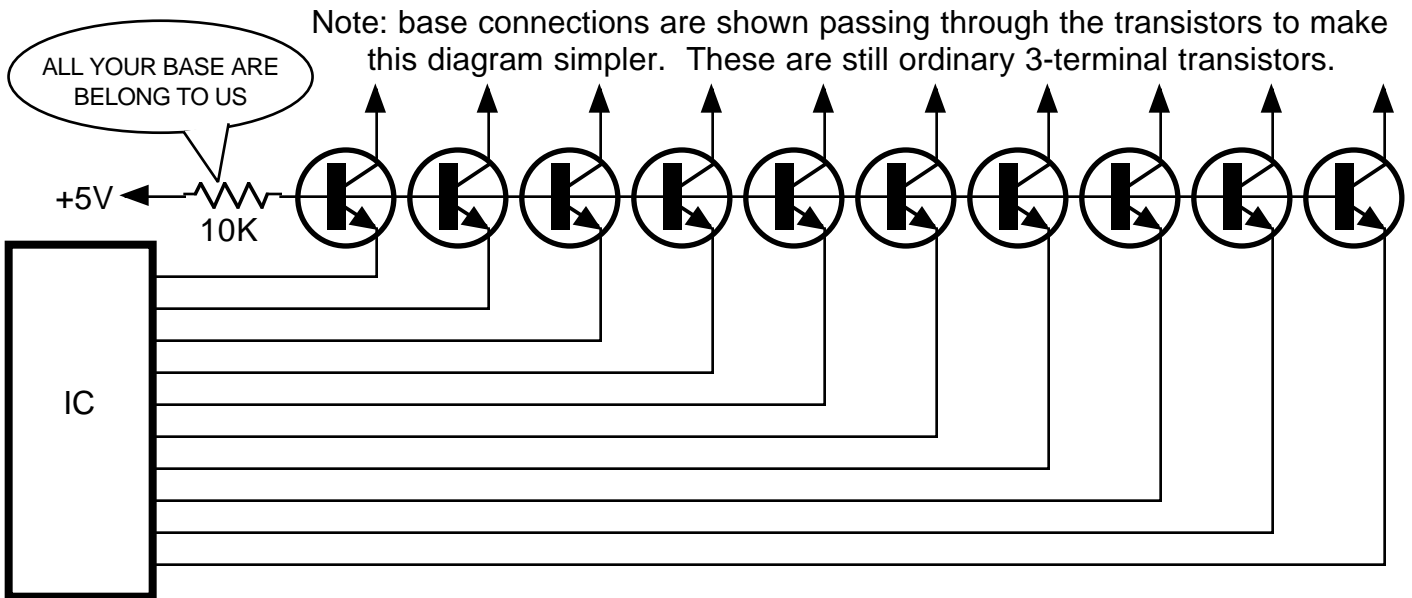
Aside: to calculate the proper value for the base resistors, use this formula:

$$\text{maximum base resistor value (in kilohms)} = \frac{\left(\begin{array}{l} \text{IC's high output} \\ \text{voltage} \\ \text{(typically close to 5V)} \end{array} - \begin{array}{l} \text{transistor's B-E} \\ \text{voltage drop} \\ \text{(typically 0.6V)} \end{array} \right) \times \text{transistor's worst-case beta (25)}}{2 * \text{desired Nixie current in milliamps (typically 1-3)}}$$

Using a smaller resistor will just waste a bit of current. 10K will work in just about all cases.

Now, this circuit does the job just fine. Many a Nixie clock has been built using this exact design. However, there is room for improvement. Obviously the number of transistors cannot be reduced if all ten digits are to be displayed on the tube, but those ten resistors represent a fair amount of circuit board space and soldering work (if perhaps not a lot of cost). And needing ten control lines (only one of which is active at a time) adds to the complexity of the circuit, especially if it is based on a microcontroller. Many builders have used shift registers, driven by about 3 microcontroller pins, to add an arbitrary number of output pins. Let's see if we can do things a bit better...

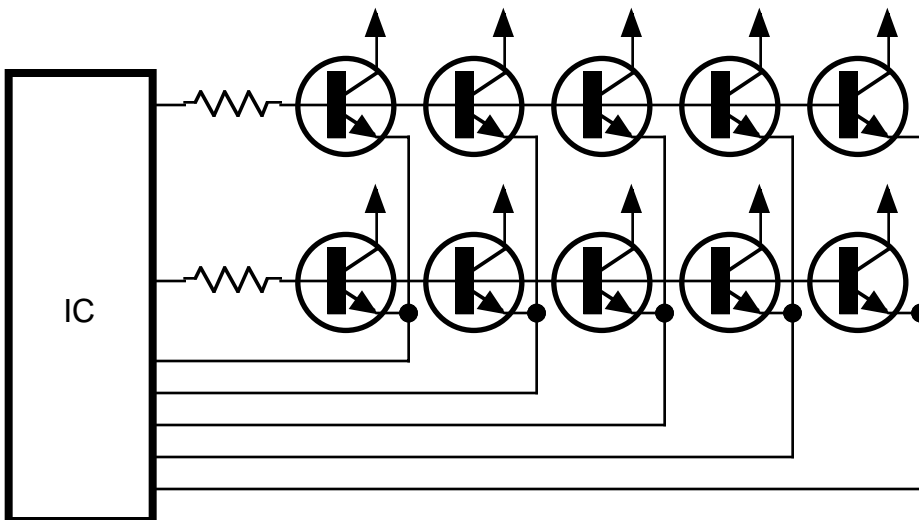
First of all, notice that the emitter grounded/base driven configuration is not the only way to turn on a transistor. Anything that makes the base at least 0.6V positive with respect to the emitter will do the job: it works just as well to hold the base at a positive voltage and drive the emitter low. A base resistor is still needed to limit current, but it is now possible to share the base resistor among all the transistors driving a single tube. (This assumes that at most one transistor will be on at a time. This technique doesn't work with segmented Nixies unless you are multiplexing the segments such that only one is lit at a time.)



Some things to keep in mind about this design:

- The control signals are now active low - there should be one low and nine highs at any given time. This would be a simple program change in a microcontroller-based design, however the CD4017 decimal counter is no longer usable since its outputs are inherently active high.
- The IC pins now have to be capable of sinking the entire Nixie current - the transistors are only providing voltage gain in this configuration, not current gain. This is not a problem with a PIC (whose outputs can typically sink 20 mA) or most other microcontrollers, but may be a concern with 4000-series CMOS or other chips with wimpy drive capability.

Emitter-driven transistors require just as many control lines as the traditional base-driven design, however by combining the two techniques it is possible to make improvements here as well. The trick is to drive both the bases and emitters, in a grid that allows any one (and only one) transistor to have its base positive with respect to its emitter. There are several possible ways to arrange this grid, but probably the most straightforward is this 2x5 grid using 7 control lines:

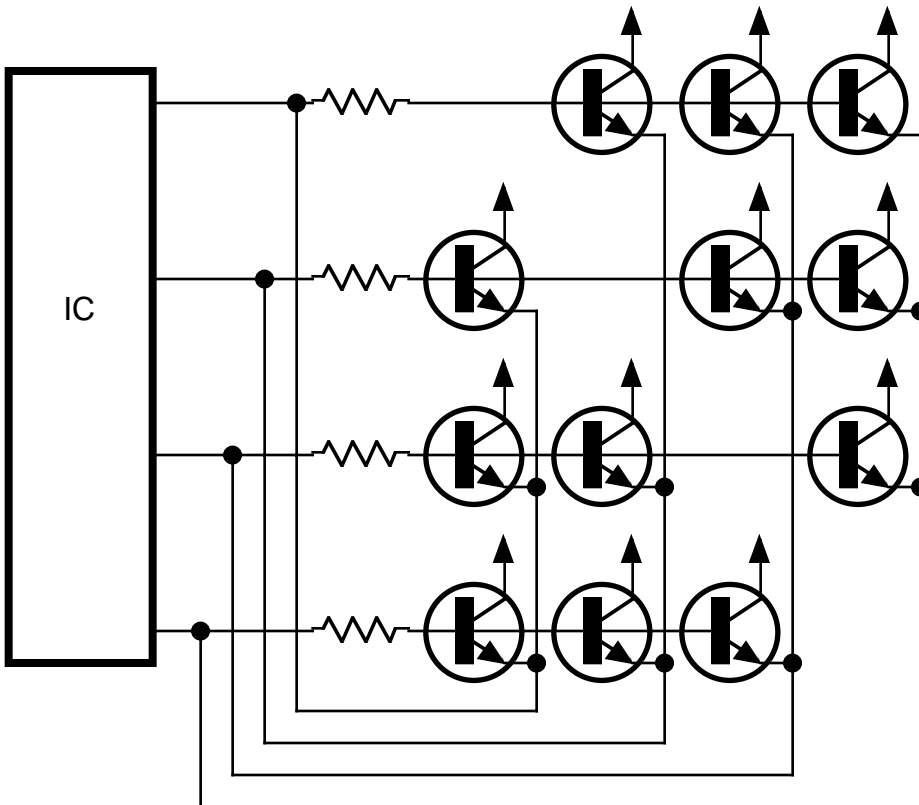


To turn on a particular transistor, set one of the two base control lines high, and one of the five emitter control lines low - only the transistor at the intersection will see a positive B-E voltage. To blank the Nixie, set all control lines low. (All high would also work, but it's probably better for any leakage current passing through the transistors to be dumped to the ground rail rather than your +5V supply.)

Some notes on the B/E grid design:

- Whenever one of the transistors is turned on, some of the others will experience a base voltage that is negative with respect to their emitter - a condition that bipolar transistors have only a limited ability to withstand. The MPSA42 is rated for 6V maximum from emitter to base, which is barely adequate assuming a 5V logic supply. If you use any other transistor, you **MUST** check its datasheet to make sure it is suitable - I have seen transistors with a specified reverse breakdown voltage as low as 2V.
- The emitter control lines only need to sink current, never source it. Therefore, an open-drain or open-collector IC output (such as the RA4 pin on most PICs) can be used for these lines.
- The required control signals do not correspond to the outputs available from any counter IC that I'm aware of, so this technique is probably only usable in microcontroller-based designs.

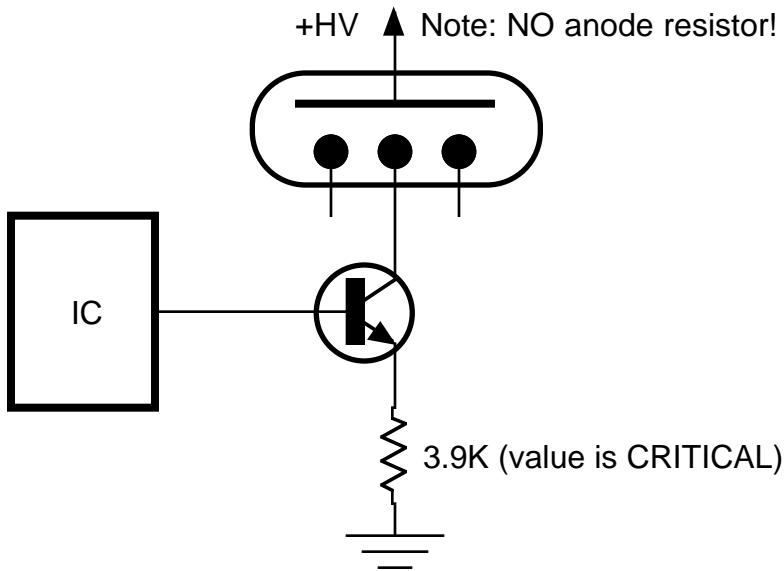
Taking this idea a bit further, it should be possible to reduce the pin count even more by using the same pins to drive both bases and emitters. Obviously, a transistor whose base and emitter are connected to the same pin could never be turned on, however a 4x4 grid (driven by 4 pins) would still have 12 usable transistor locations (two of which would be omitted for typical Nixie use). Here's the schematic, but please note that I have not actually tried this circuit yet:



To turn on a particular transistor, you set one control line high, one line low, and the remaining two such that they drive neither high nor low - this state may be described as an input pin, or as a tri-stated output pin depending on the IC used. Many microcontrollers are capable of setting individual pins as inputs that will neither source nor sink any significant current: it's no problem on a PIC, unless you're trying to use half of PortB for this purpose and want to turn on the internal PortB weak pull-up resistors. However, my understanding is that there are some microcontrollers (8051 variants, I think) which have a permanent pull-up resistor on all I/O pins: such chips **CANNOT** use this technique. A chip that could only set the data direction for an entire 8-bit port, rather than on a pin-by-pin basis, would also be unsuitable.

Constant-Current Drivers

All of the circuits so far have limited the transistor's B-E current with a resistor in series with the base. Consider now this circuit in which the limiting is done on the emitter side instead:



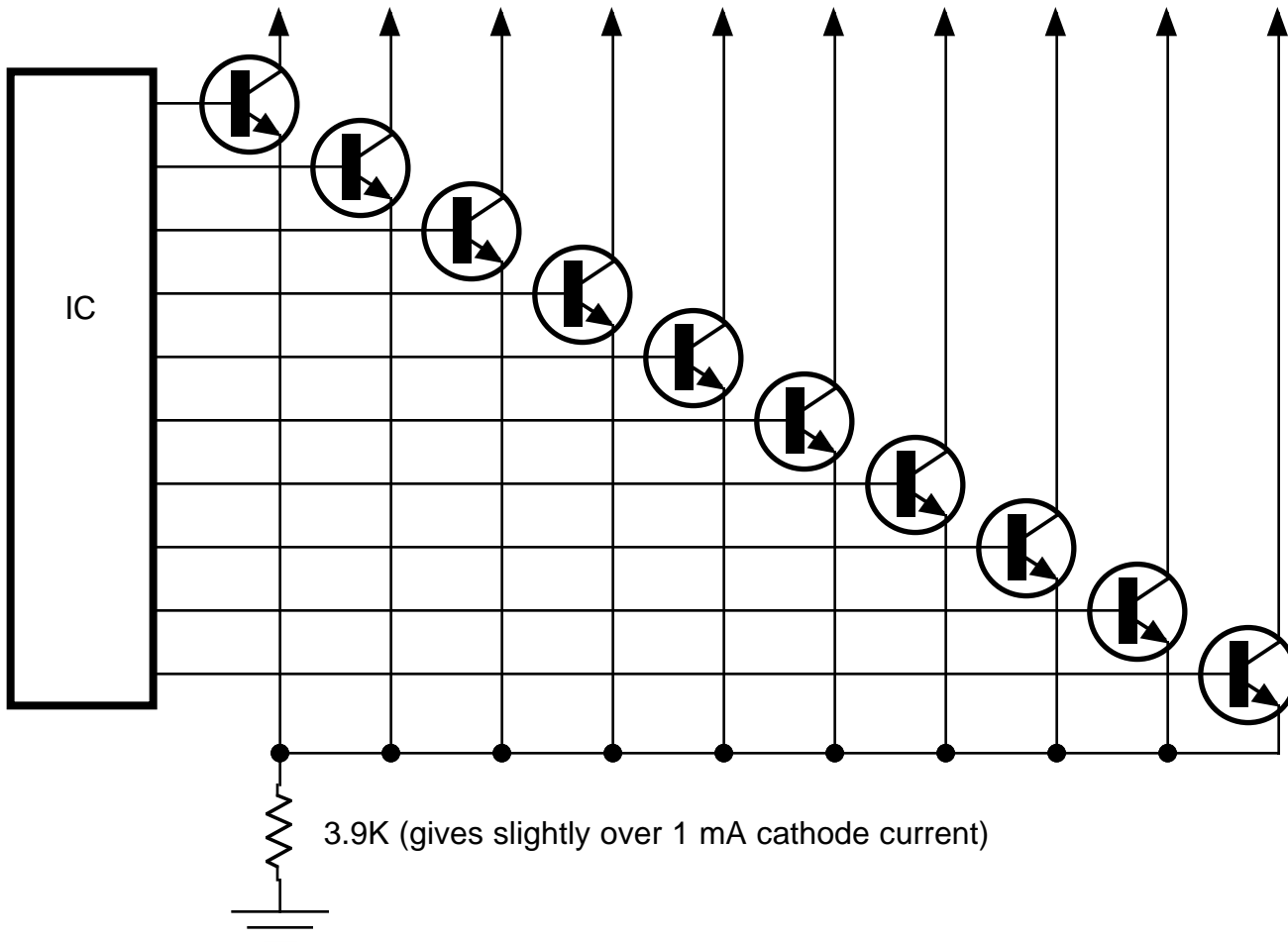
If the transistor is turned on, the voltage across the resistor will be pretty much constant - it will be the IC's V_{OH} minus the transistor's V_{BE} drop. Ohm's Law then suffices to determine the current through the resistor: a bit over 1 mA as shown, assuming a CMOS IC running at 5 volts. But note that in this configuration, the C-E current flows through the resistor as well - if this tried to increase beyond the value calculated above, the voltage drop across the resistor would increase, the transistor's B-E voltage would drop correspondingly, and the transistor would be less strongly turned on (thus reducing the collector current). The effect is to keep the current flow more or less constant. It's not especially accurate, since there are at least five factors affecting the current:

- The IC's supply voltage.
- How close to the supply rail the IC can pull its output (this is load- and temperature-dependant).
- The transistor's B-E drop (also temperature-dependant).
- The actual value of the resistor (obviously you can't just use a 10K resistor all the time with this circuit).
- The actual beta of the transistor.

An important detail to keep in mind about this circuit is that it still draws a constant current, even if there is no collector load at all - the current comes entirely from the base in that case. This could happen if the Nixie is dead, removed from its socket, or simply hasn't ignited yet. It's not likely to be a problem at typical Nixie currents, but this makes the technique unsuitable for heavier loads. (The problem can be fixed by adding a base resistor to limit the worst-case current, but this makes the "constant" current even more variable.)

Also, the transistor will generally be operating in its linear region, rather than being fully saturated, so it will tend to produce more heat than normal. This is heat that would otherwise be dissipated by the anode resistor, and is only likely to be a problem at excessively high tube currents or supply voltages.

Duplicating this circuit ten times, and assuming that only one transistor at a time will be turned on, you could drive a Nixie as shown next:



I can think of a couple of reasons why you might want to use this design, despite the inaccurate current regulation:

- This lets you use a 4017 decimal counter with one resistor rather than ten.
- If your high-voltage supply is very poorly regulated (perhaps it's a switching power supply of some sort with no feedback), a fixed anode resistor might produce even more widely varying tube current. However, a HV regulator (such as the Supertex LR6 or LR8) configured as a current regulator might be a better answer in such cases.

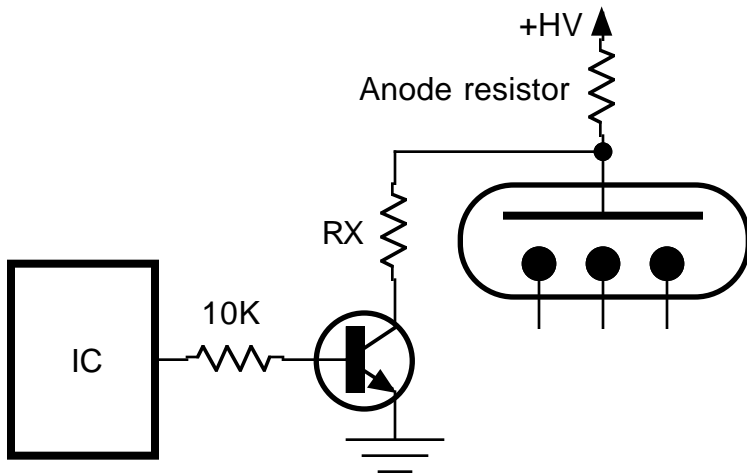
The constant-current driver could be combined with one of the base/emitter grid designs discussed earlier, to reduce the number of control lines needed. However, this adds yet another variable to the current flow: how close to ground the IC is capable of pulling a low output.

High-Side (Anode) Drivers

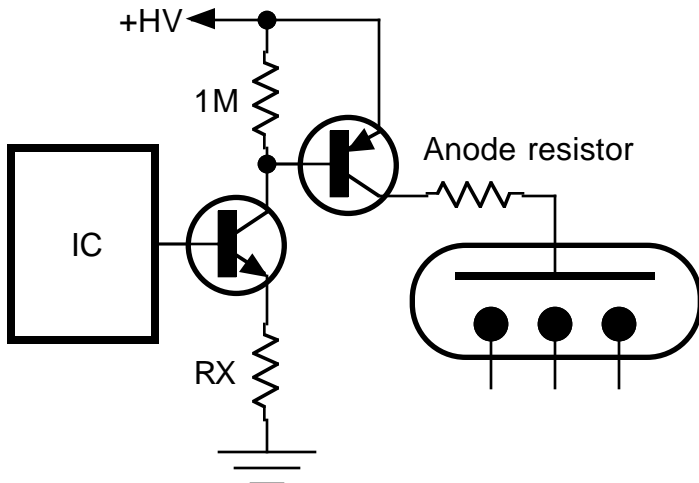
The discussion so far has concerned controlling the Nixie tube cathodes. You may also need to individually control the tube anodes: this can also be done with discrete transistors, and that may be a reasonable choice even if you are using a HV driver chip for the cathodes. You will need anode drivers under the following conditions:

- Any sort of multiplexed display.
- If you want to be able to blank the tubes, or dim them using PWM, but your cathode drivers are incapable of shutting off all outputs completely. This will be the case with 7441 or 7441A chips, and may be a problem with a 74141 as well.
- If you are using biquinary Nixie tubes, which have separate anodes for the even and odd digits.

Here's the simplest possible anode driver:



RX needs to be chosen so that when the transistor is conducting, the tube anode gets pulled below the voltage at which the Nixie can light. It will typically be about equal to the anode resistor. The problem with this circuit is that it is quite wasteful - a blanked tube draws more power (dissipated mainly in the anode resistor and RX) than a lit one! A proper high-side switch, that turns off the current rather than just redirecting it, is easiest done with a PNP transistor. Fortunately, there is a PNP complement to the MPSA42 available: the MPSA92. Here's a better (but untested) circuit, using one of each type of transistor:

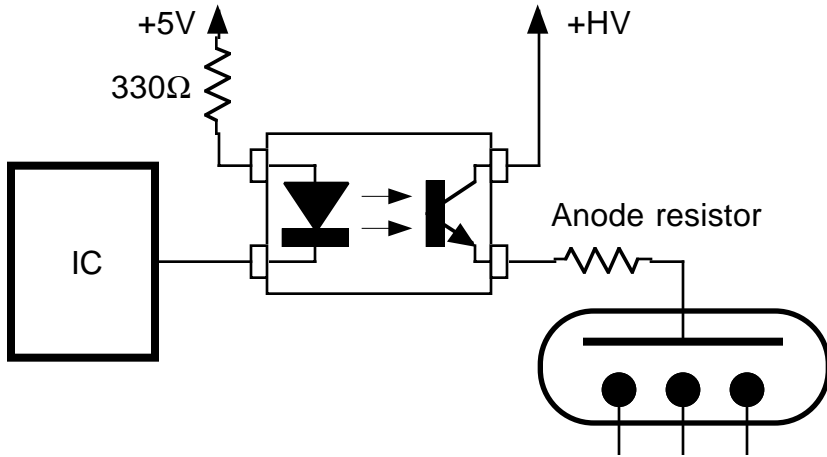


Anode current (mA)	RX value (K)
1	51
2	27
3	18
4	12
5	10
6	8.2

RX and the NPN transistor form a constant current driver as described earlier. It is set to pass just enough current to turn on the PNP transistor for the required amount of anode current. Note that the control line from the IC is active high, unlike the previous circuit.

The 1 megohm resistor makes sure that the PNP transistor isn't turned on by leakage current passing through the NPN. Its value isn't critical, and it could probably be omitted without any visible effect.

Another popular form of anode switch is a high-voltage optoisolator, such as the Toshiba TLP627. Compared to the 2-transistor design above, an optoisolator design would have a lower component count, slightly higher cost, and slightly higher power consumption. Here's a typical circuit:



Putting together many of the ideas in this article, here's a proposed circuit for driving a biquinary Nixie using four microcontroller pins (three of which must be capable of being set as a true input). It needs one TLP627-2, five MPSA42's, and 6 or 8 resistors.

