Re: how to control LED array? (follow−up)

Source: http://sci.tech−archive.net/Archive/sci.electronics.basics/2005−05/msg00825.html

- *From*: Jonathan Kirwan <jkirwan@xxxxxxxxxxxxxx>
- *Date*: Sun, 29 May 2005 10:37:17 GMT

On Fri, 27 May 2005 23:28:42 −0500, Michael Noone
<mnoone.uiuc.edu@xxxxxxxxx> wrote:

>"Ban" <bansuri@xxxxxx> wrote in
>news:maSle.952901$b5.41512298@xxxxxxxxxxxx:
>
>> Did Mr. Fields also advise to take these 56 ohms base resistors?
>
>Now that I'm looking back − He used different values.

Probably so. Your base resistors are incredibly low−valued.

>> They will consume more current than the LEDs.
>
>The idea is that there'd be 15ma going through the 56ohm transistors,
>saturating the transistors. (I believe they're saturated at 15ma?) Did I
>mess up somewhere in my calculation?

Yes.

>> You can use 470 ohms for them.
>
>But unless I'm looking at something wrong − that wouldn't saturate the
>transistor, and if it's not saturated my understanding is that you can't
>accurately predict voltage and current through it.

You can saturate a BJT with a lot less than 15mA into the base. It
all depends on the circuit around it and the BJT. Of course, with 56
ohms, you'd probably be getting more than 15mA, as well.

>> with 8mA you can drive easily 100mA collector current in case
>> you multiplex.
>
>It will need to be able to drive 240ma − 8*30ma = 240ma. I want to run
>these at max brightness due to the 1/8 duty cycle.

You can probably run them with even more than 30mA, given that they
will only be on for 1/8 duty. You might want to make this an
adjustable setting so you can change things later on.

>> You have to calculate the voltage across the resistor,
>> not the transistor. when you have 4.5V control signal (typical PIC)
>> and 0.75V Ube, then R= 3.75V/8mA = 468 ohm. You can even take 1k if
>> you use transistors with beta of 150 or more.
>
>Oops − you're quite right about that. Not quite sure where my head
>was there.
>
>> Uce sat will be a bit lower than 0.4V, maybe 0.15V, so it is better to
>> use 47 ohm for 30mA.
>
>Oh damn − just realized that Vcesat is not constant − it varies
>depending on collector current. That's no good... I'm not quite sure
>what exactly to do about that as collector current should be anywhere
>between 0 and 240ma − which presents a fairly wide range of Vcesat
>voltages.

Then design things to work.

>> But if you always multiplex them and the program
>> doesn't get stuck with one LED always on, you can probably even put
>> 100mA through the LED with a duty cycle of 1/8. It would be better to
>> make a current source for the Leds then you do not need these
>> resistors at all and can easily adjust the brightness.
>
>Could you advise on how to make such a current source?

Actually, I don't think you need to worry about controlled current sources or sinks. The topology you have is just fine for getting the job done. You could try and design something else, but I'd recommend getting the design you already have laid out working reasonably well. Then, once you understand it well enough, you can always work on various improvement ideas later on.

Let's look at a slightly modified version of your design. I've made the PNPs the high−current sources that may need to drive many LEDs at once and the NPNs the lower−current sinks that will never need to sink more than one LED's current. You can always arrange it the other way, of course. Here's a 3X3 design that is expandable to the 8x8 on which you appear to be working:

```
: Vcc
: |
: | Vcc
: \ |
: / Ra3 |
: \ 47k |
: / |
: Rb3 | |<e Q3
: 3−−−/\/\−+−−−−−−−−−−−−−−−−−−−| PNP
```

```
: |\c
: |
: | COL 3
: +−−−−−−−−−−−−−−−−−−−+−−−−−−−−−−−−−−−−−−−+−− ~~~ −−−−,
: | | | |
: Vcc | | | \
: | | | | / R3
: | Vcc | | | \ 47k
: \ | −−− −−− −−− /
: / Ra2 | ~ \ / D3A ~ \ / D3B ~ \ / D3C |
: \ 47k | −−− −−− −−− |
: / | | | | gnd
: Rb2 | |<e Q2 | | |
: 2−−−/\/\−+−−−−−−−−−−−−| PNP | | |
: |\c | | |
: | | | |
: | | | | COL 2
: +−−−−−−−−−−−−−−−−−−−+−−−−−−−−−−−−−−−−−−−+−−−−−−−−−− ~~~ −−−−,
: | | | | | | |
: Vcc | | | | | | \
: | | | | | | | / R2
: | Vcc | | | | | | \ 47k
: \ | −−− | −−− | −−− | /
: / Ra1 | ~ \ / D2A | ~ \ / D2B | ~ \ / D2C | |
: \ 47k | −−− | −−− | −−− | |
: / | | | | | | | gnd
: Rb1 | |<e Q1 | | | | | |
: 1−−−/\/\−+−−−−−| PNP | | | | | |
: |\c | | | | | |
: | | | | | | |
: | | | | | | | COL 1
: +−−−−−−−−−−−−−−−−−−−+−−−−−−−−−−−−−−−−−−−+−−−−−−−−−−−−−−−−− ~~~ −−−−,
: | | | | | | | | | |
: | | | | | | | | | \
: −−− | | −−− | | −−− | | / R1
: ~ \ / D1A | | ~ \ / D1B | | ~ \ / D1C | | \ 47k
: −−− | | −−− | | −−− | | /
: | | | | | | | | | |
: | | | | | | | | | |
: | ROW A| | | ROW B| | | ROW C| | gnd
: +−−−−−−+−−−−−−'.. +−−−−−−+−−−−−−'.. +−−−−−−+−−−−−−'..
: | | |
: \ \ \
: / RA / RB / RC
: \ \ \
: / / /
: | | |
: | | |
: RbA |/c QA RbB |/c QB RbC |/c QC
: ,−−/\/\−+−| NPN ,−−/\/\−+−| NPN ,−−/\/\−+−| NPN
: | | |>e | | |>e | | |>e
```

```
: | | | | | | | | |
: A \ | B \ | C \ |
: RaA / gnd RaB / gnd RaC / gnd
: 47k \ 47k \ 47k \
: / / /
: | | |
: gnd gnd gnd
```

I've used ~~~ and .. to indicate places where more rows and columns may be added. (I think that it should be clear enough, given that you've already been laying out an 8x8.)

The diodes shown above are the LEDs, of course.

Let's take it in sections. The current sink is:

```
: |
: \
: / RA
: \
: /
: |
: |
: RbA |/c QA
: ,−−/\/\−+−| NPN
: | | |>e
: | | |
: A \ |
: RaA / gnd
: 47k \
: /
: |
: gnd
```

This section sinks the current for one LED, only. The NPN, QA, is operated as a switch (assumed saturated.) The input point called "A" is the place where your logic−level control enters to control the switch, QA.

Let's make the design assumption that the beta we want should be about 20 (a figure that is well below the peak beta for most common devices today.) If you expect to sink 30mA per LED, then you would expect (30mA/20) or 1.5mA for the base drive. At about 1mA or so, typical Vbe is very close to the usual 0.7V assumption, so let's go with that as an approximation. So the base of QA will be at 0.7V when sinking.

If your logic level control is nominally 5V and CMOS and having to provide 1.5mA or so, let's choose an estimate of about 4.8V at the pin of your micro (it's not uncommon to find output resistance slopes of about 60−150 ohms for micro pins; so use the worse value of 150 ohms at 1.5mA to get 0.225V drop −− I just called this 5−.2 or 4.8V.) This means that RbA should be (4.8V−0.7V)/1.5mA or 2733 ohms. A standard value at or below this figure should be fine. 2700 ohms, then.

If you wanted to sink 100mA, instead, the computation would be to figure a base drive of 100mA/20 or 5mA. Your micro's output would probably drop to something like 4.2V, supplying that much current (you can always examine the data sheets to get a better figure for this.)
This means your RbA value should be (4.2V−0.7V)/5mA or 700 ohms. Call it 680 ohms to pick up on a standard value.

What about the dissipation? Well, for QA, the operating Vce at a beta of 20 might be around 0.1V or so. Looking at the 2N2222A from Motorola, I see that at an Ic=10mA and an Ib of 0.5mA (beta=20), the Vce is typically below 0.05V at 25C. I also see that an IC=150mA and an Ib of 7.5mA (again, beta=20), the Vce is typically below 0.1V.
Let's use the higher Vce, or 0.1V. That makes things look worse, heating wise, so it will be a conservative estimate if you choose to run at 30mA instead of 100mA. With Vce=0.1 you get 0.1V*30mA or 3mW at 30mA and you get 0.1V*100mA or 10mW at 100mA. Both dissipations are easily handled by a 2N2222. Also, by a 2N3904, if you prefer.
The TO−92 plastic package will be just fine.

Luckily then, no need to go find large NPNs.

By the way, I've added RaA here as a 47k value designed to ensure that if there is no signal input at "A", then the base will be clearly pulled to ground keeping the NPN base from floating and firmly off.
At a base voltage of about 0.7V when ON, this resistor will sink another 15uA. It won't be noticed. Or even a 10k @ 70uA won't be noticed. But tying it down like this may help in a stand−alone display with a connector, where the signal lines might just "float in space," otherwise.

Forget RA for the moment and lets go on to the high side "column driver" section:

```
: Vcc
: |
: | Vcc
: \ |
: / Ra1 |
: \ 47k |
: / |
: Rb1 | |<e Q1
: 1−−−/\/\−+−−−−−| PNP
: |\c
: |
: |
```

Very similar. Except that there may be a problem due to the amount of current sourcing required. Let's see if there is a problem, first.

This section sources the current for up to eight LEDs in your design. The PNP, Q1, is also operated as a switch (assumed saturated.) The input point called "1" is the place where your logic−level control enters to control the switch, Q1.

Let's make the design assumption that the beta we want should be about 20 (again, a figure that is well below the peak beta for most common devices today.) If you expect to sink 8*30mA per LED, then you would expect (240mA/20) or 12mA for the base drive. As this is about 10X the base current for the sinking driver above, that implies about 60mV greater Vbe −− let's just call it 0.8V. So the base of Q1 will be as low as 0.8V below 5V, or 4.2V, when sourcing.

If your logic level control is nominally 5V and CMOS and having to sink some 12mA or so, let's choose an estimate of about 1.1V at the pin of your micro (it's not uncommon to find output resistance slopes of about 60−90 ohms for the low side of CMOS micro pins; so use the worse value of 90 ohms at 12mA to get 1.08V drop −− I just called this 1.1V.) This means that Rb1 should be (4.2V−1.1V)/12mA or 258 ohms. A standard value at or below this figure should be fine. 220 ohms, then.

What about the dissipation at 8*30mA? Well, for Q1 as a 2N4403, the operating Vce at a beta of 20 might be around 0.35V or so (guessing from the curves on the data sheet.) With Vce=0.35V you get 0.35V*240mA or 84mW. Plus some for the base drive of 0.9V*12mA (0.9V comes from the data sheet and the 12mA comes from 240mA/20), which is another 11mW for a total of some 95mW. Call it 100mW. The junction to ambient thermal resistance is 200, so this means 20C over ambient. Livable in the 2N4403, I think.

Luckily then, no need to go find large PNPs, if you are satisfied with 30mA LED currents.

If you wanted to sink 100mA for each LED, instead, the computation would be to figure a base drive of (8*100mA)/20 or 40mA. Your micro's output probably cannot sink this much. So this would mean that you need another BJT. If you chose to use a Darlington arrangement, your Vce would be about 1V or so, a serious loss from your 5V supply, and assuming things could still work at 800mA that would still amount to a dissipation of 800mW −− a lot. So perhaps no Darlington arrangement.

Oh, well. You might even want to use two BJTs in the case at 12mA base drive for the 30mA/LED case, so let's look at one of several possible ideas:

```
: Vcc
: |
: | Vcc
```

```
: \ |
: / Ra1 |
: \ 47k |
: / |
: | |<e Q1p
: ,−−+−−−−−| PNP
: | |\c
: | |
: Rb1 |/c Q1n |
: 1−−/\/\−−−| NPN
: |>e
: |
: |
: \ Re1
: /
: \
: /
: |
: gnd
```

In this case, the base drive for Q1p is now provided by Q1n and doesn't have to be supplied by a microcontroller's pin. Also, the sense of the "1" input is inverted from before, but that's a minor point.

Now, we can still go with Q1p's beta being 20. So we will need to still sink about 40mA of Q1p base current.

At these kinds of currents, can a 2N4403 handle the dissipation?? With 800mA, the Vcesat will be about 0.6V, so that is 480mW. Plus 40mA*Vbesat or at least 40mA*1.1V which is another 44mW. Call it something on the order of 550mW. The junction−to−ambient thermal resistance is, again, 200 for the 2N4403, so the change over ambient is .55*200 or 110 C. Way too hot.

We need to select a different device. Perhaps something in a TO−220 package. A TIP−30A, for example, has a junction−to−ambient figure of 62.5. I think the Vce would still be about 0.6V and the Vbe would still be in the area of 1.1V (something less than 1.3V, according to the sparse data sheet from STMicro) so the temp change would be ..55*62.5 or 34.5 C. Livable change, I think.

Let's go with the TIP−30A for figuring purposes. We'll stay with Vcesat=0.6V when sourcing 800mA. The Vbe could be argued to be less than 1.3V, but let's just call it 1.3V and not quibble about it, for now. This means that Vc of Q1n will be 1.3V below 5V, or 3.7V. Let's keep Q1n's Vce to about 1.5V (out of saturation) so that its beta will probably be in the vicinity of 200, or so. This means that Ve of Q1n will be about 2.2V. Vbe of Q1n will probably be close to 0.7V, so Vb will be 2.9V. Since Re1 must handle our 40mA of base drive for Q1p plus a little base current for Q1n, we can figure that Re1 must be a tiny bit less than 2.2V/40mA or <55 ohms. We can select 47 as a standard value, then. Rb1 should be (5V−2.9V)/(40mA/200) or 10,500 ohms. Call it 8.2k just to be sure.

That's about it. If you go back to the fuller design I listed, you will also see R1, R2, and R3. I just added those pull−downs to keep the nodes at ground when the column isn't being actively driven. I don't know if floating them would be a problem, but if you use a scope to probe those points it would probably be nice to have the pull−downs in place.

Jon
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- ***Follow−Ups***:
    - ***Re: how to control LED array? (follow−up)***
        - *From:* Jonathan Kirwan
- ***References***:
    - ***how to control LED array? (follow−up)***
        - *From:* Michael Noone
    - ***Re: how to control LED array? (follow−up)***
        - *From:* Ban
    - ***Re: how to control LED array? (follow−up)***
        - *From:* Michael Noone
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