Arbeitskreis Hardware

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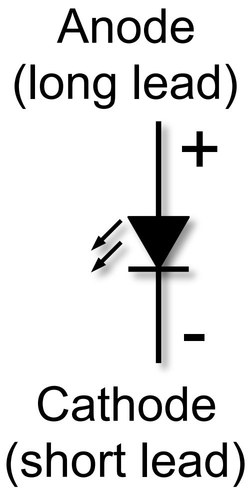
Schedule (preliminary)

Date	**Topic (preliminary)**
2.5.	Introduction to embedded interaction, microcontrollers, hardware & software tools
9.5.	*keine Veranstaltung (CHI)*
16.5.	soldering ISP adapter, AVR architecture
23.5.	LED displays, LED multiplexing, transistors, electronics basics
30.5.	AVR architecture, AVR assembler, sensors: light, force, capacity, acceleration, etc.
6.6.	PCB design & fabrication, EAGLE, 3D printing
13.6.	*keine Veranstaltung (Pfingsten)*
20.6.	I2C: interfacing to other chips (EEPROM, real-time clock, digital sensors)
27.6.	Displays (character LCDs, graphics LCDs), audio (speakers, amplification, op-amps)
4.7.	Actuation: stepper motors, servo motors
11.7.	Communication: fixed-frequency RF, ZigBee, Bluetooth
18.7.	Project
25.7.	Project

LEDs



- Quickly switchable, power-efficient light sources
  - different types covering different parts of the visible spectrum (and beyond: IR LEDs, UV LEDs)
- Anode (long lead) goes to positive potential
- Cathode (short lead) goes to negative potential
- LEDs operate like voltage-controlled switches
  - little current below turn-on voltage (silicon: 0.7V)
  - very high current above → LEDs need current-limiting resistors
- LEDs are diodes: no current in reverse direction
- Typical forward current: 20mA, typical forward voltage 2V

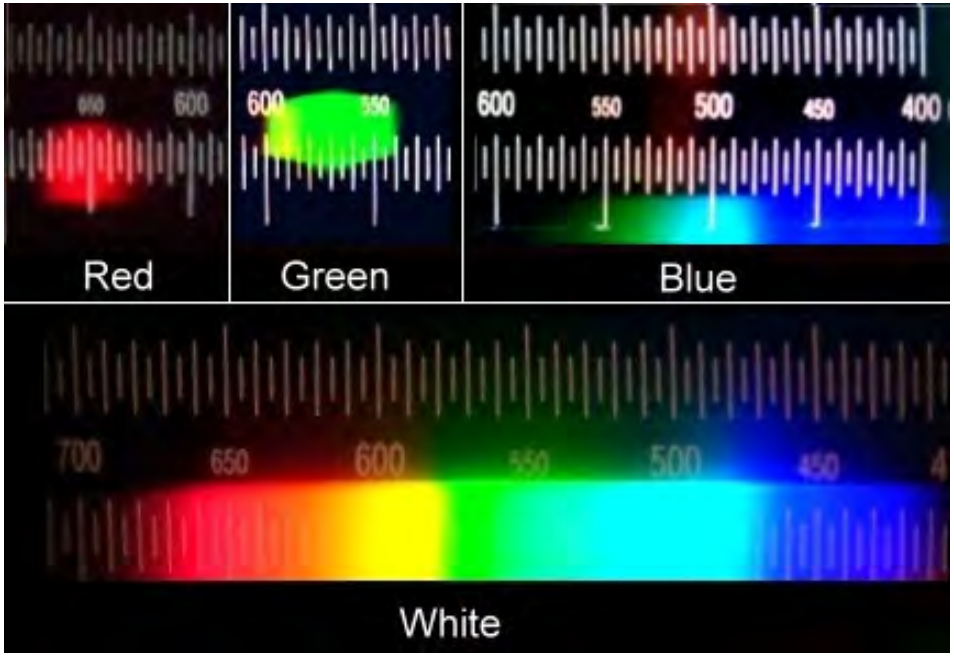
LEDs

- Intensity of light proportional to current
  - can also use PWM to control brightness
  - light covers narrow spectrum only, except for white LEDs
- Forward voltage drop depends on color, e.g.:

Color	Fwd. current	Fwd. voltage
red	20mA	2.0V
green	20mA	3.5V
blue	20mA	3.7V
white	20mA	3.5V

- Can go up to 100mA (peak current)

LED light spectra



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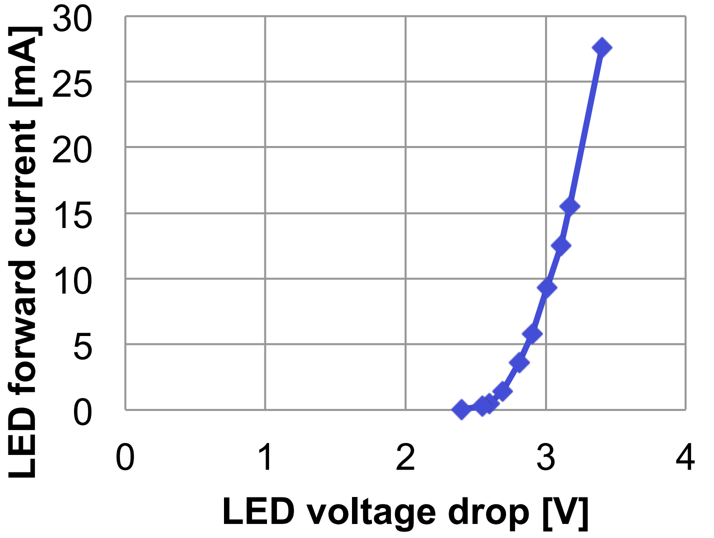
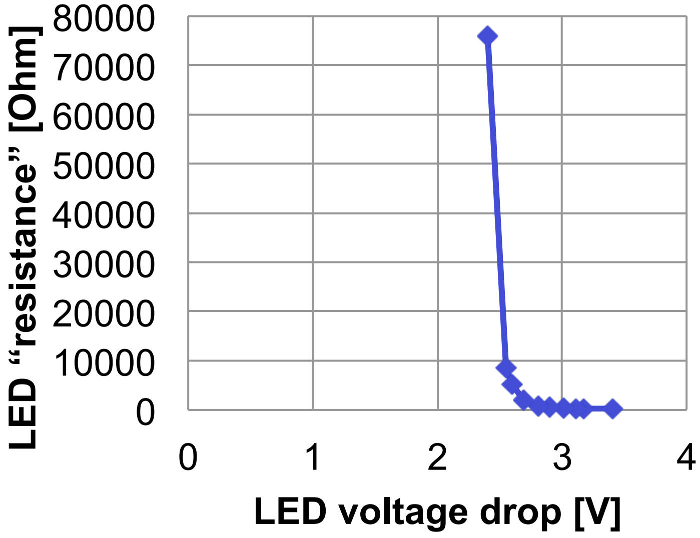
Example: Blue LED Voltage Drop

- $U_f = 3.2V$, $I_f = 20mA$
- Current limiting resistor: $U_R = U - U_f = 5 – 3.2 = 1.8V$
  $R = U_R / I = 1.8V / 0.020A = 90\Omega$



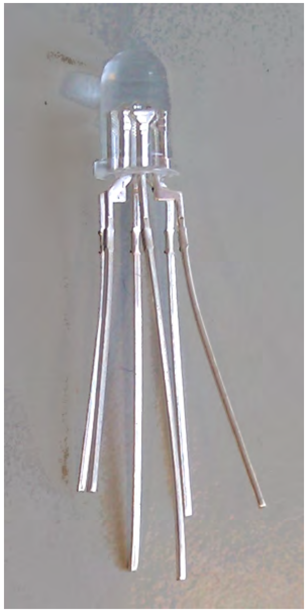


$R_f = U_f / I$

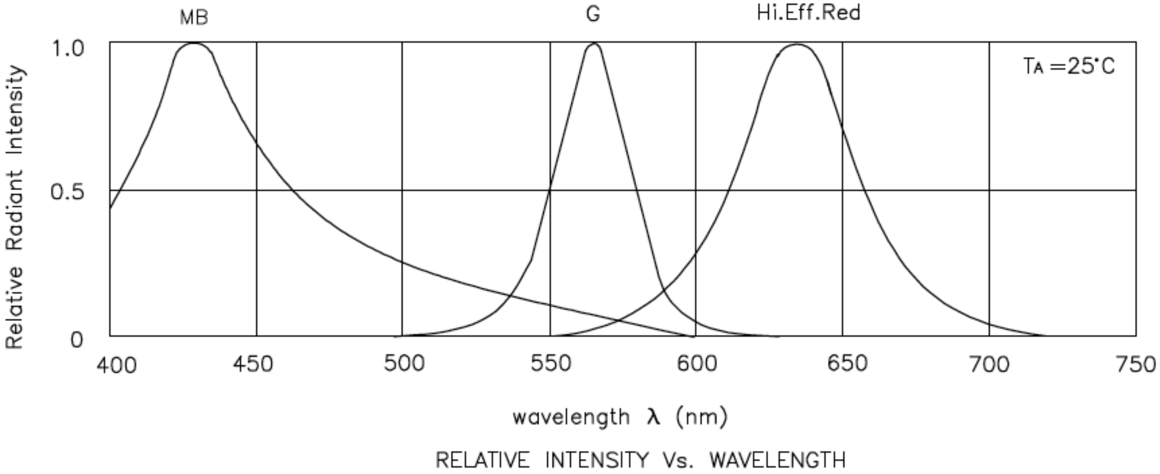
LED Brightness Experiment

- Assume LED brightness is proportional to current
- Is PWM duty cycle proportional to brightness? Hypothesis?
- For increasing values of PWM duty cycle value d
  - Set d for LED_1
  - Control current through LED_2 to match brightness of LED_1
    - Match brightness with potentiometer
    - Measure current
- Draw curve
  - x-axis = current
  - y-axis = matching PWM duty cycle value
- Check whether duty cycle is proportional to current (and thus brightness)

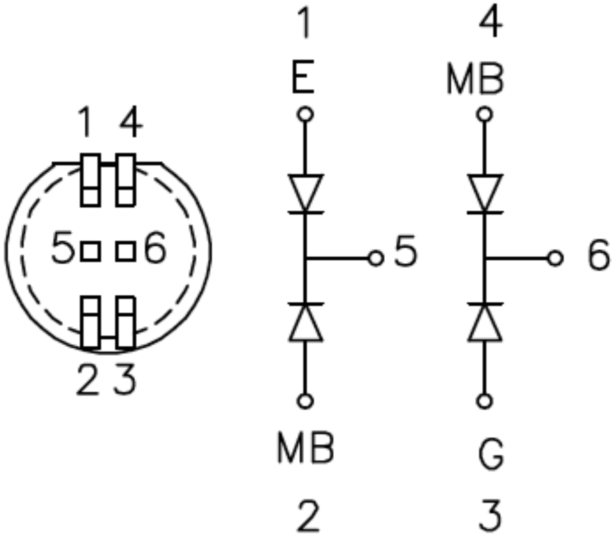
RGB LEDs



- Red, green, and blue in one package
- Different forward voltages (I_f = 20mA):
  - $U_{f,red}$ = 2.0V
  - $U_{f,green}$ = 2.2V
  - $U_{f.blue}$ = 3.8V
- Example (right): 30° angle, 2x blue



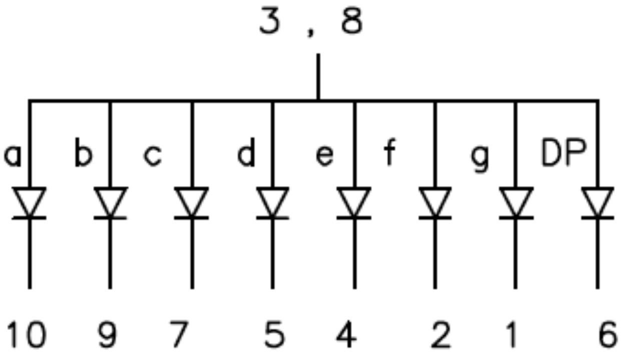
Source: Kingbright Datasheet



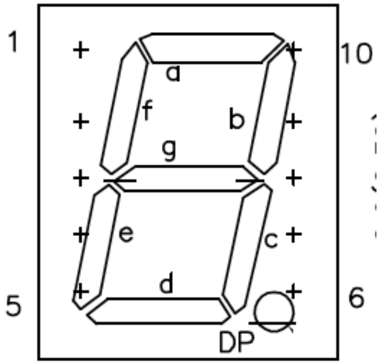
Source: Kingbright Datasheet

LED Displays: 7-Segment, 10-Bar

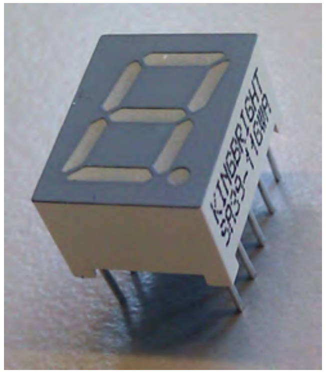
- 7-segment display (green)
  - $U_f = 2.2V$, $I_f = 20mA$



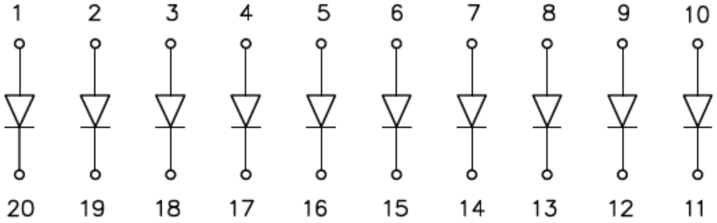
Source: Kingbright Datasheet



Source: Kingbright Datasheet



- 10-bar display (red)
  - $U_f = 2.0V$, $I_f = 20mA$



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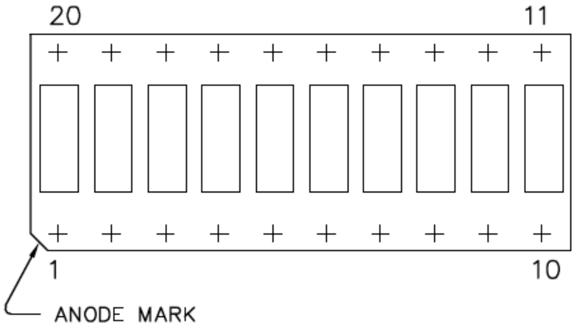
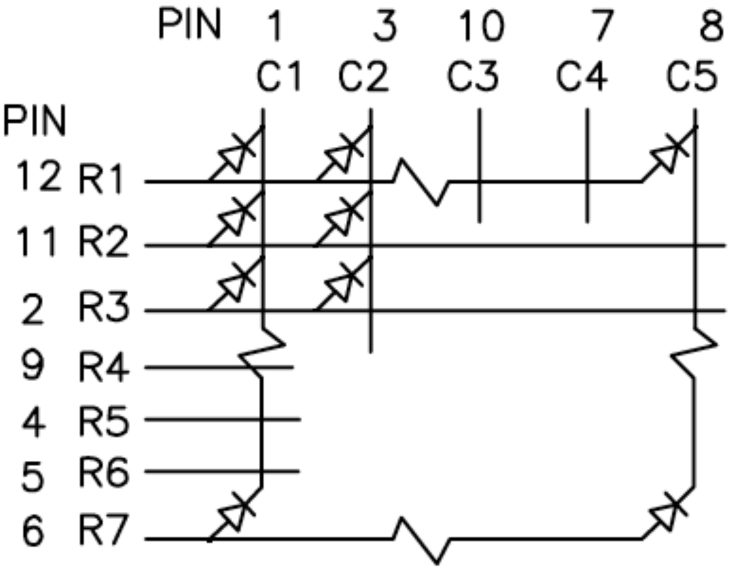


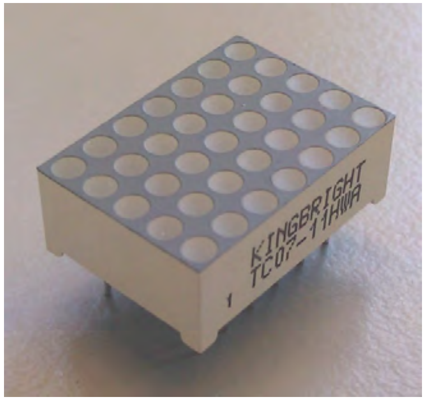
Source: Kingbright Datasheet

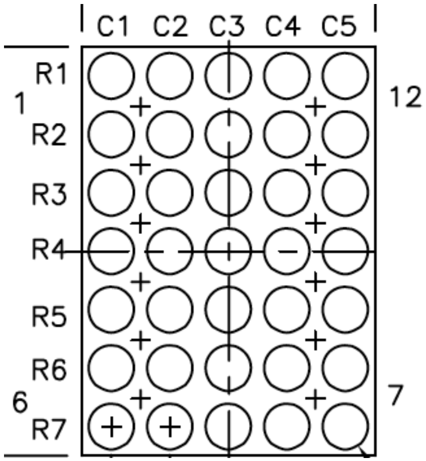
LED Displays: 5x7-Matrix

- 5x7 dot matrix display (red)
  - $U_f = 2.25V$, $I_f = 20mA$



Source: Kingbright Datasheet



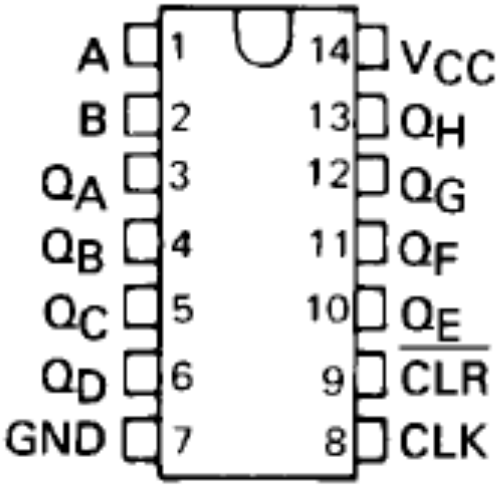


Source: Kingbright Datasheet

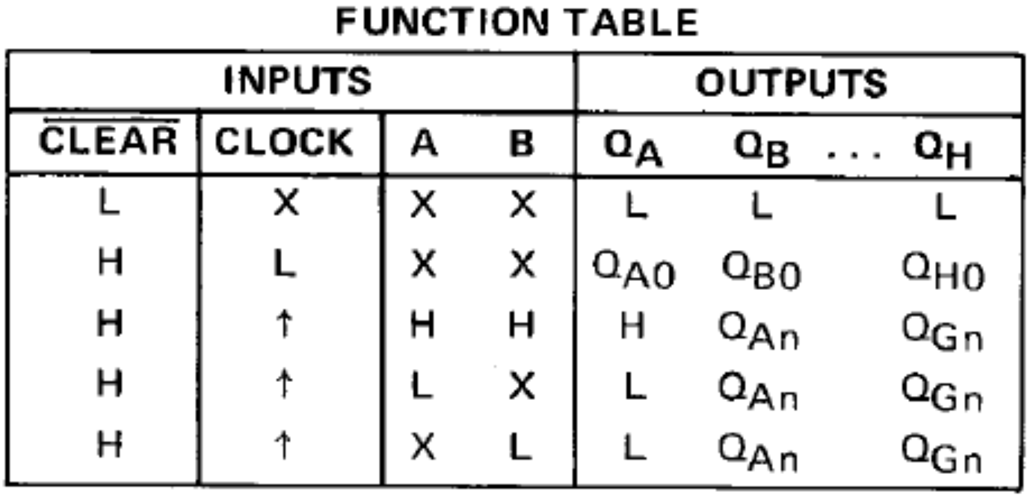
- Check total power consumption
  - ATtiny can only drive up to 40mA per pin
    → use transistor if necessary

More LEDs than µC Pins

- 8-bit serial-in, parallel-out shift register 74LS164N



Source: TI Datasheet



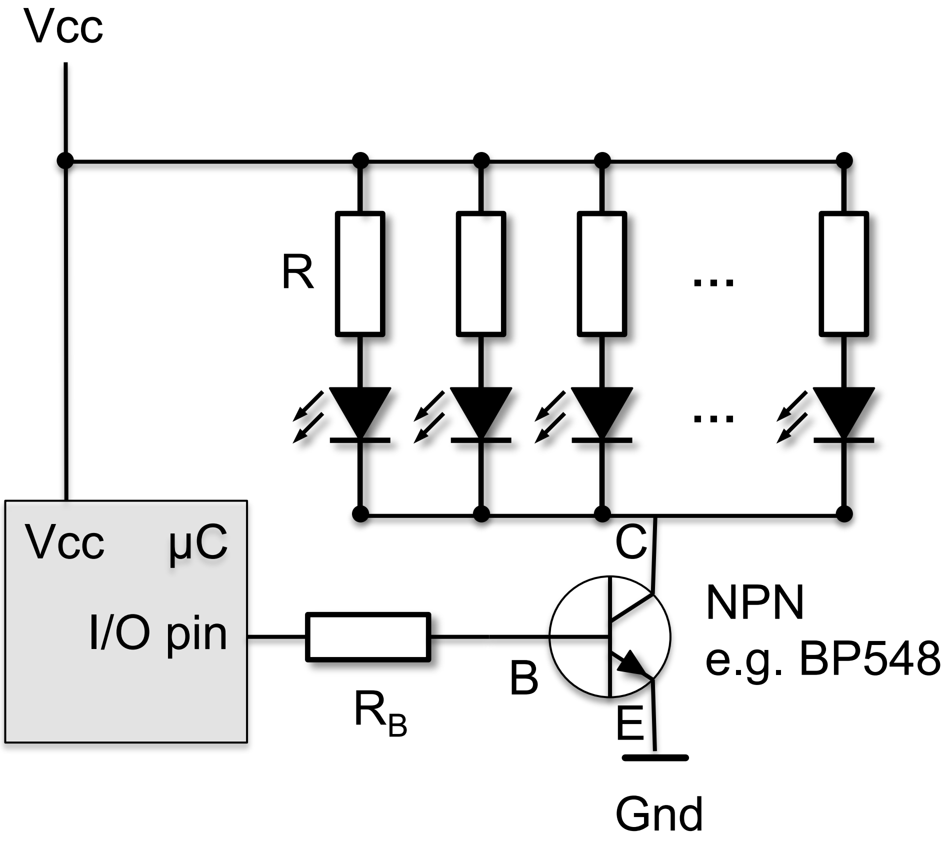
FUNCTION TABLE

INPUTS				OUTPUTS			
$\overline{\text{CLEAR}}$	CLOCK	A	B	Q_A	Q_B	. . .	Q_H
L	X	X	X	L	L		L
H	L	X	X	Q_{A0}	Q_{B0}		Q_{H0}
H	↑	H	H	H	Q_{An}		Q_{Gn}
H	↑	L	X	L	Q_{An}		Q_{Gn}
H	↑	X	L	L	Q_{An}		Q_{Gn}

Source: TI Datasheet

  - Q_A = A and B, unused input must be H
  - CLK: low-to-high shifts data one place right
  - maximum clock frequency: 25 MHz
  - V_{cc} = 5V, I_{CC} = 16mA
  - I_{OS} = -10..-27.5mA (short-circuit output current)

Driving more LEDs with a transistor



- Given

  VCC = 5V

  red LEDs: U_F=2V, I_F=20mA

  BC548A: $I_{C,max}$ = 100mA,
  current gain $\beta = h_{FE} = 110..220$

- Drive 5 LEDs: 100mA

  h_{FE} = 120 (@I_C=100mA,V_{CE}=5V)

  $V_{CE(sat)}$ = 0.2V (@I_C=100mA,V_{CE}=5V)

  $V_{BE(sat)}$ = 0.7V (@I_C=100mA,V_{CE}=5V)

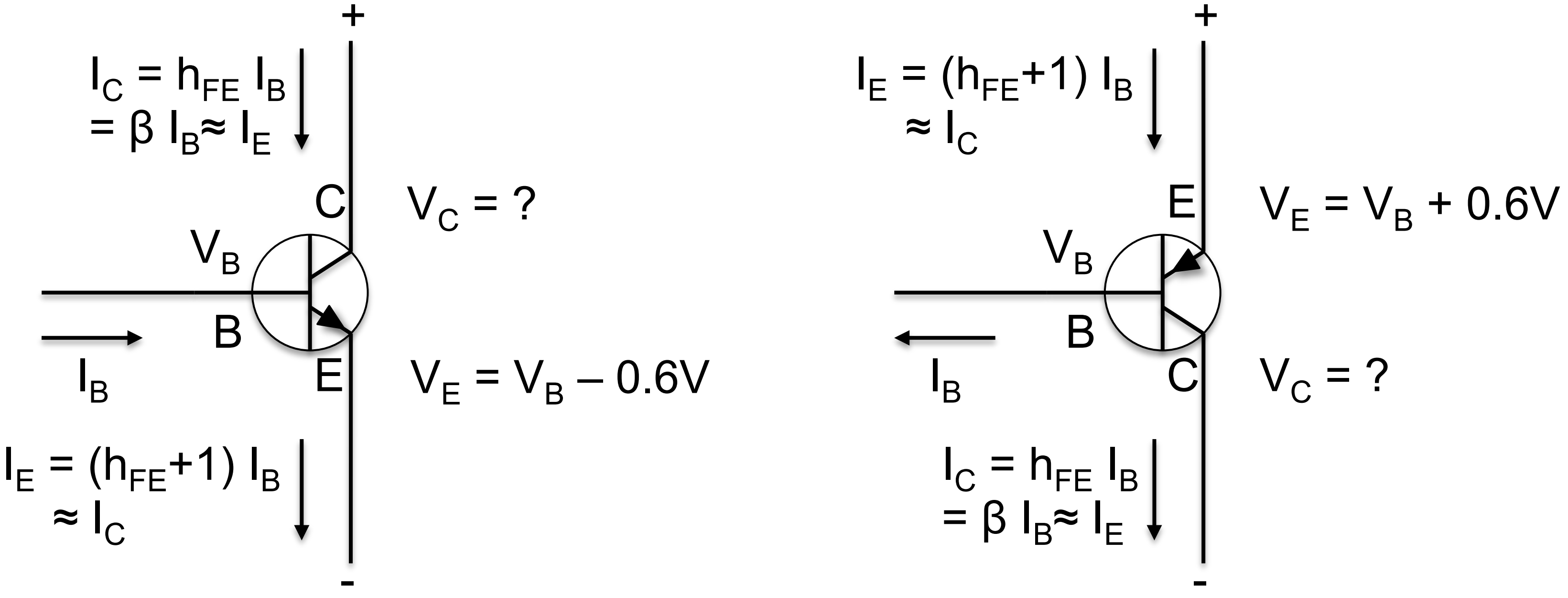
- R? R_B?

  $U_R = Vcc - V_{CE(sat)} - V_F$

  $R = U_R / I_F$

  $I_C = h_{FE} I_B$

Behavior of Transistors (active region)



NPN (e.g. BC548)

+

$I_C = h_{FE}\, I_B$
$= \beta\, I_B \approx I_E$

C

$V_C = ?$

V_B

B

I_B

E

$V_E = V_B - 0.6V$

$I_E = (h_{FE}+1)\, I_B$
$\approx I_C$

-

PNP (e.g. BC558)

+

$I_E = (h_{FE}+1)\, I_B$
$\approx I_C$

E

$V_E = V_B + 0.6V$

V_B

B

I_B

C

$V_C = ?$

$I_C = h_{FE}\, I_B$
$= \beta\, I_B \approx I_E$

-

- $I_C = h_{FE}\, I_B = \beta\, I_B$
- $I_E = I_C + I_B$
- $I_E \approx I_C$

Typical Characteristics of BC548

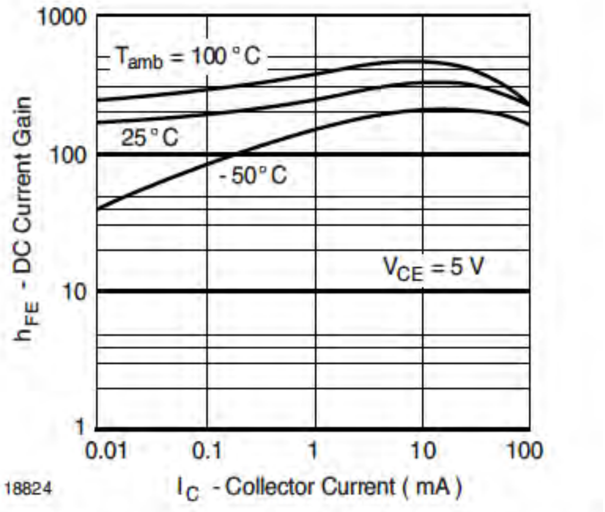


Figure 2. DC Current Gain vs. Collector Current

Source: Vishay Datasheet

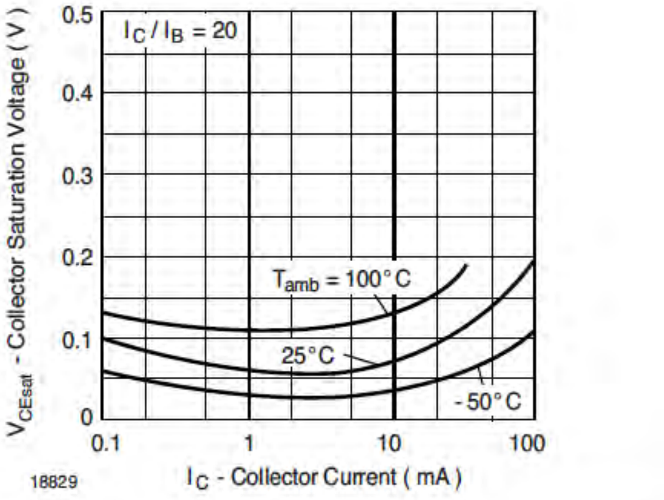
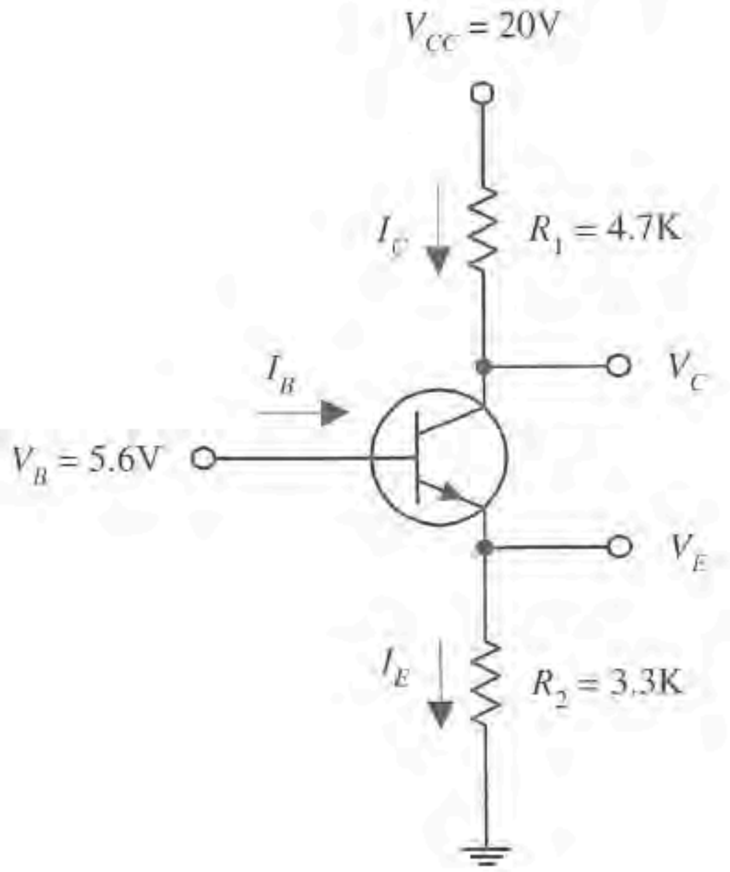


Figure 7. Collector Saturation Voltage vs. Collector Current

Source: Vishay Datasheet

- $I_C = h_{FE} I_B = \beta I_B$
- $I_E = I_C + I_B$
- $I_E \approx I_C$

EXAMPLE 1 Given $V_{CC} = +20\text{ V}$, $V_B = 5.6\text{V}$, $R_1 = 4.7\text{ k}\Omega$, $R_2 = 3.3\text{ k}\Omega$, and $h_{FE} = 100$, find V_E, I_E, I_B, I_C, and V_C.



$$V_E = V_B - 0.6\text{ V}$$

$$V_E = 5.6\text{ V} - 0.6\text{ V} = 5.0\text{ V}$$

$$I_E = \frac{V_E - 0\text{ V}}{R_2} = \frac{5.0\text{ V}}{3300\ \Omega} = 1.5\text{ mA}$$

$$I_B = \frac{I_E}{(1 + h_{FE})} = \frac{1.5\text{ mA}}{(1 + 100)} = 0.015\text{ mA}$$

$$I_C = I_E - I_B \approx I_E = 1.5\text{ mA}$$

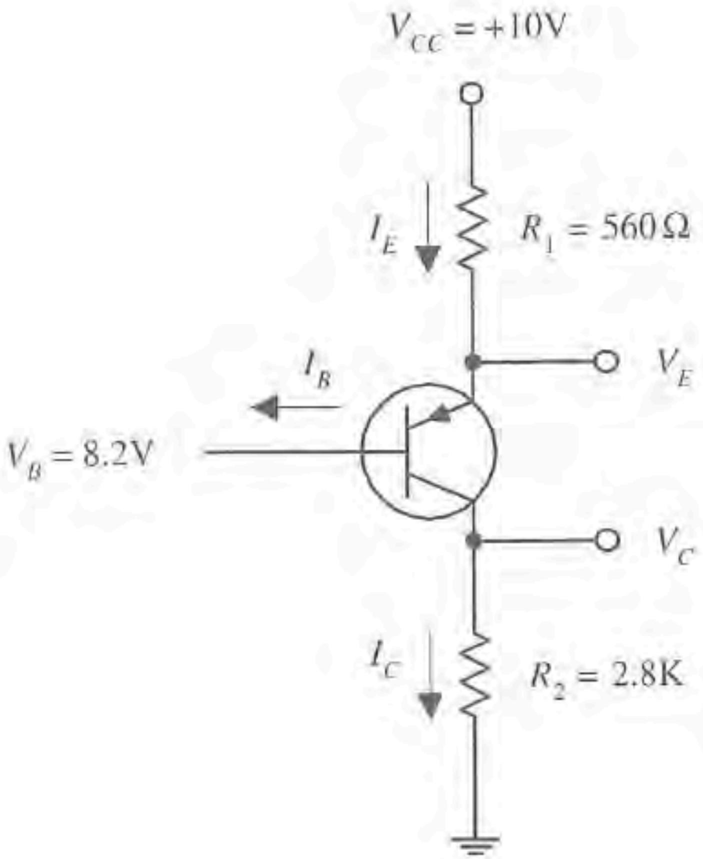
$$V_C = V_{CC} - I_C R_1$$

$$V_C = 20\text{ V} - (1.5\text{ mA})(4700\ \Omega)$$

$$V_C = 13\text{ V}$$

Source: Paul Scherz: Practial Electronics for Inventors. 2^{nd} edition, McGraw-Hill, 2007.

EXAMPLE 2 Given $V_{CC} = +10\,\text{V}$, $V_B = 8.2\,\text{V}$, $R_1 = 560\,\Omega$, $R_2 = 2.8\,\text{k}\Omega$, and $h_{FE} = 100$, find V_E, I_E, I_B, I_C, and V_C.



$$V_E = V_B + 0.6\,\text{V}$$

$$V_E = 8.2\,\text{V} + 0.6\,\text{V} = 8.8\,\text{V}$$

$$I_E = \frac{V_{CC} - V_E}{R_1} = \frac{10\,\text{V} - 8.8\,\text{V}}{560\,\Omega} = 2.1\,\text{mA}$$

$$I_B = \frac{I_E}{(1 + h_{FE})} = \frac{2.1\,\text{mA}}{(1 + 100)} = 0.02\,\text{mA}$$

$$I_C = I_E - I_B \approx I_E = 2.1\,\text{mA}$$

$$V_C = 0\,\text{V} + I_C R_2$$

$$V_C = 0\,\text{V} + (2.1\,\text{mA})(2800\,\Omega)$$

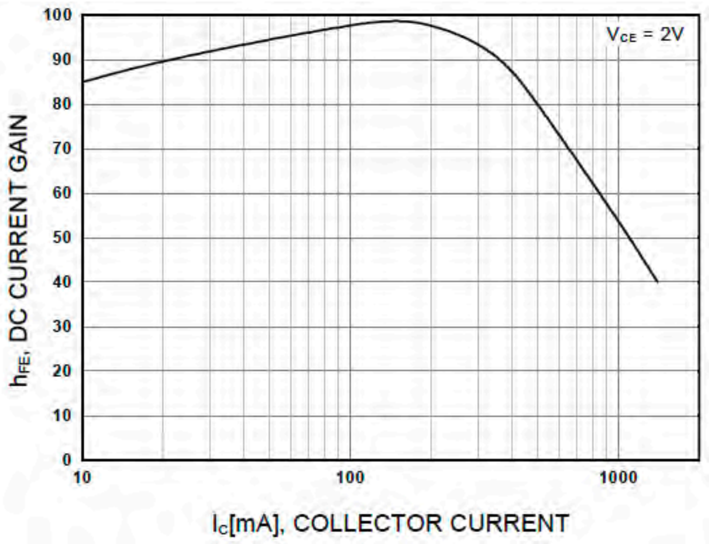
$$V_C = 5.9\,\text{V}$$

Source: Paul Scherz: Practial Electronics for Inventors. 2nd edition, McGraw-Hill, 2007.

Transistors

- BD139 – NPN
  - maximum ratings:
    I_C = 1.5A, I_B = 0.5A
  - $V_{CE(sat)}$ = 0.5V, V_{BE} = 1V
  - h_{FE} = 63..160 @ I_C = 150mA, V_{CE} = 2V

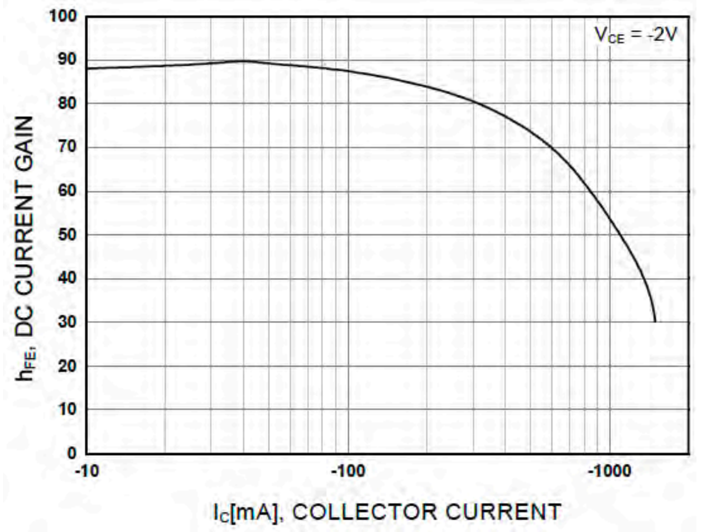
BD139 h_{FE}



Source: Fairchild Datasheet

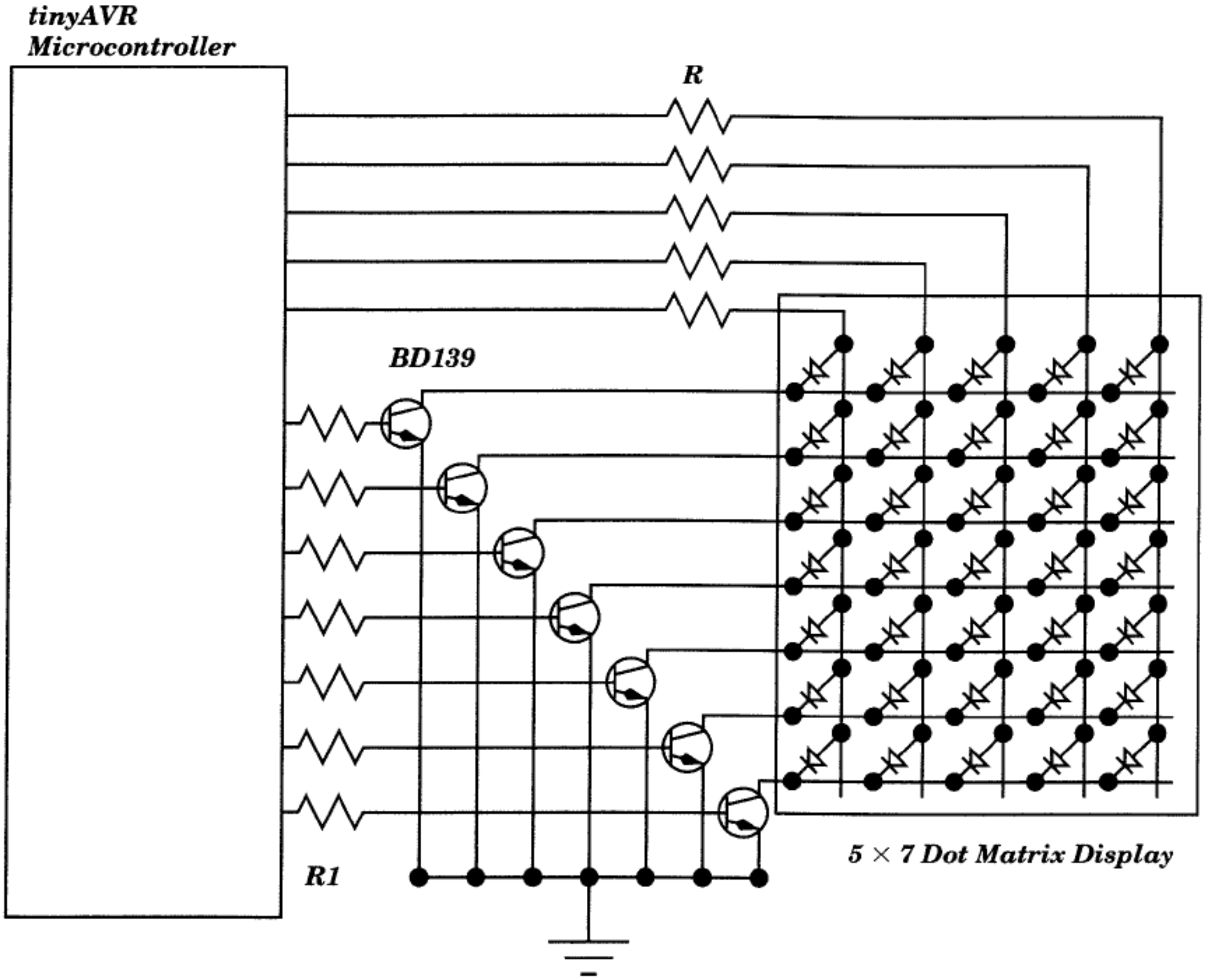
- BD140 – PNP
  - maximum ratings:
    I_C = -1.5A, I_B = -0.5A
  - $V_{CE(sat)}$ = -0.5V, V_{BE} = -1V
  - h_{FE} = 40..250 @ I_C = -150mA, V_{CE} = -2V

BD140 h_{FE}



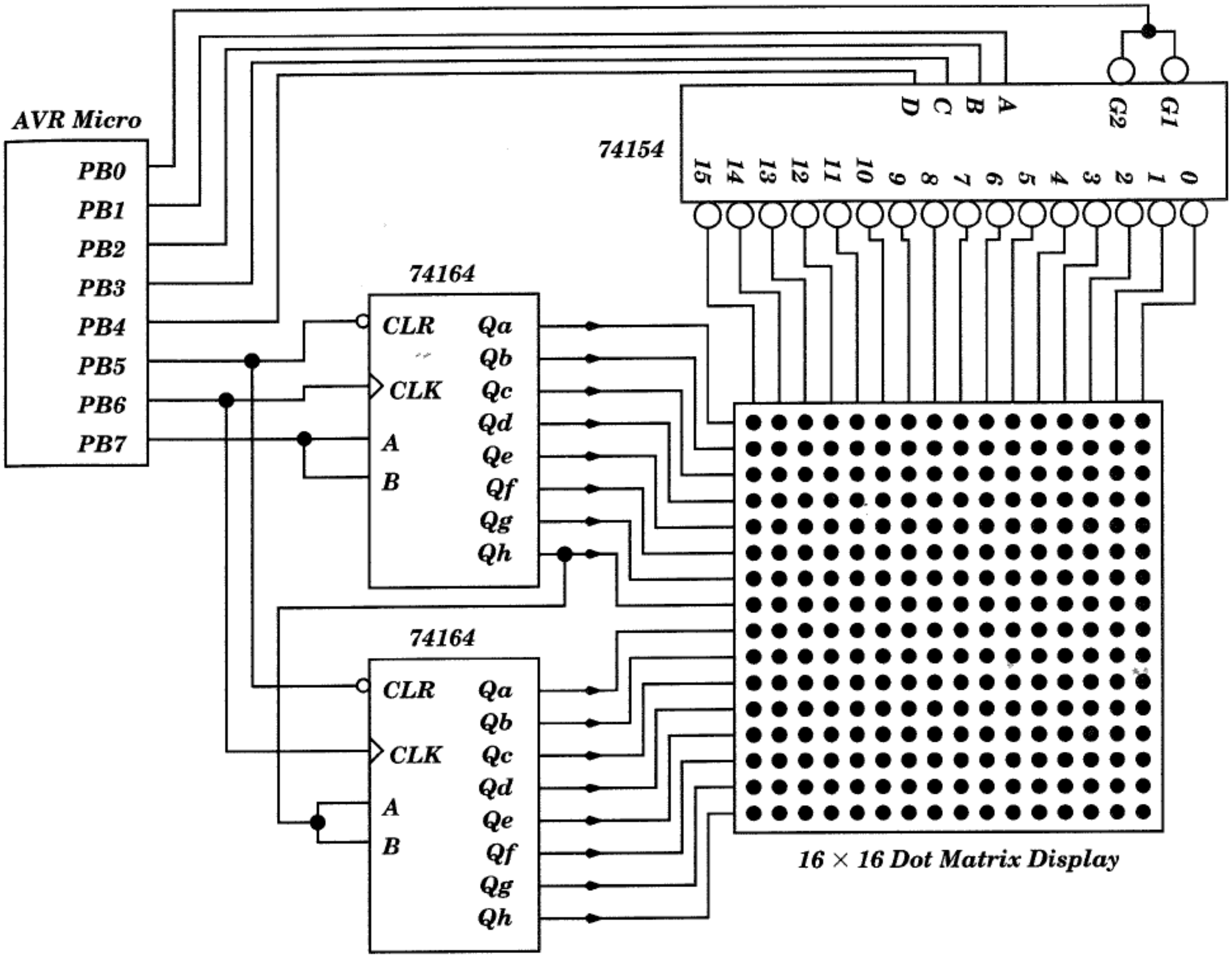
Source: Fairchild Datasheet

Multiplexing LEDs



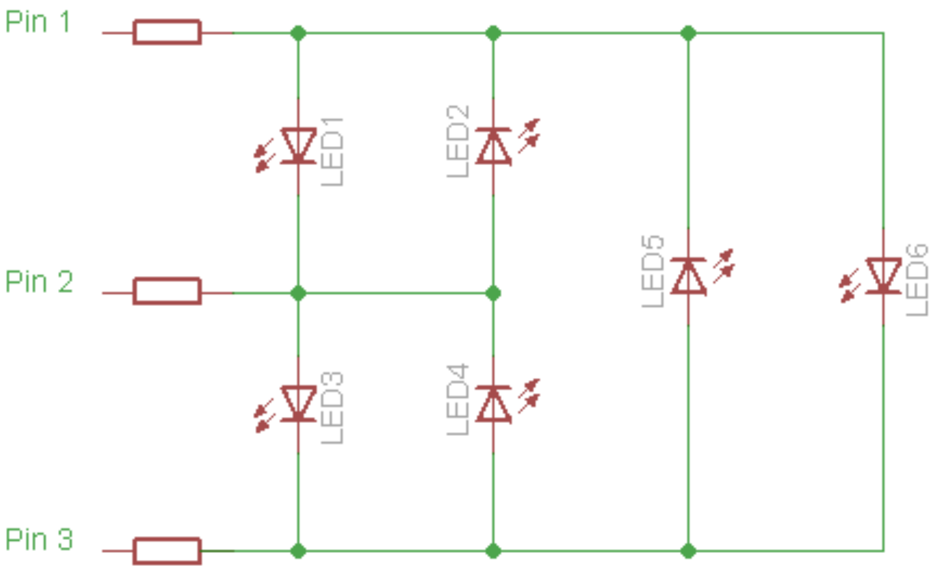
Source: Gadre, Malhotra: tinyAVR Microcontroller Projects for the Evil Genios. McGraw-Hill, 2011.

Multiplexing LEDs



Source: Gadre, Malhotra: tinyAVR Microcontroller Projects for the Evil Genios. McGraw-Hill, 2011.

Charlieplexing LEDs



Source: Wikipedia, Author: Dan Kouba, public domain

LED	Pin1	Pin2	Pin3
D1	1	0	Z
D3	Z	1	0
D6	1	Z	0
D4	Z	0	1
D2	0	1	Z
D5	0	Z	1

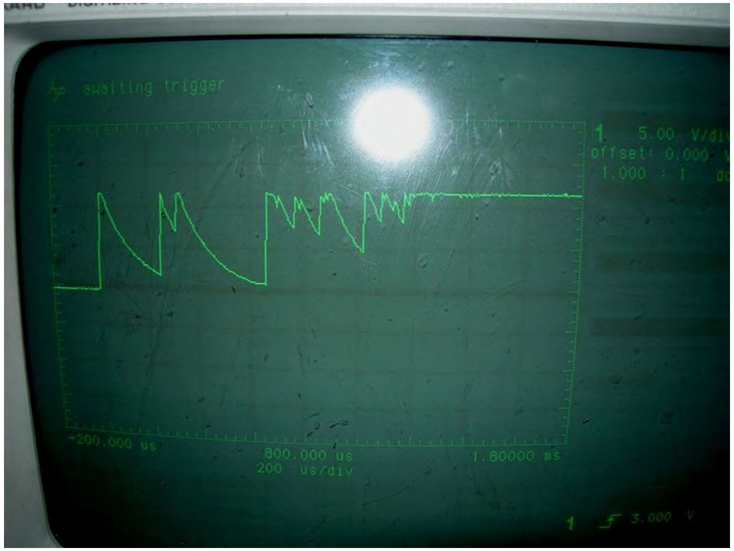
- Enables one LED at a time
  - N LEDs, each only on 1/Nth of the time
- Z = tri-state (high impedance state, “no” current)

Exercise: Controlling LEDs

- Control brightness of two LEDs with PWM
  - Attach 2 LEDs to an ATtiny13
  - Periodically
    - Over 2s: increase brightness of LED_1 from dark to maximum, decrease brightness LED_2 from maximum to dark
    - Over 2s: increase brightness of LED_2 from dark to maximum, decrease brightness LED_1 from maximum to dark
    - Over 2s: no change in LED brightness
  - Use timers and interrupts as needed
- Control brightness of an LED using PWM and two buttons
  - Attach LED to an ATtiny13
  - While $button_1$ is pressed, slowly increase brightness
  - While $button_2$ is pressed, slowly decrease brightness

Button De-Bouncing

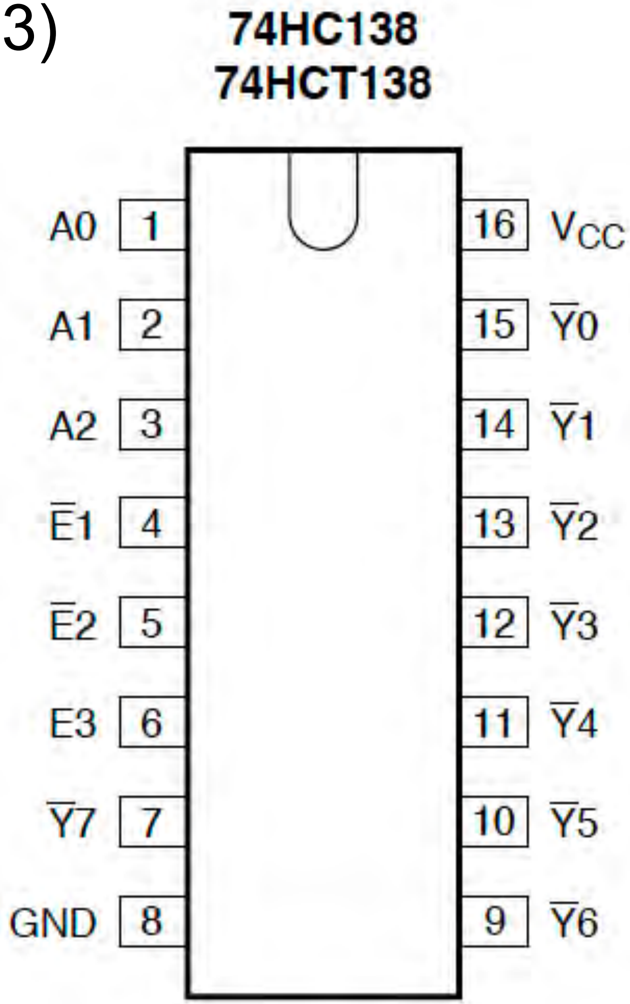
- Activate pull-up resistor on pin
  - Pull-up puts pin into defined state
  - (see previous slides on pin configurations)
- Connect button to GND
  - Pin will be high until button pressed
- De-Bouncing
  - Button contacts bounce, which generates many spikes
  - Hardware solutions: SR latch, capacitor
  - Software solution:
  - wait for 10-20ms after first event



Source: Wikipedia, Author: Tomoldbury, public domain

74HC138:
3-to-8 Line Decoder/Demultiplexer

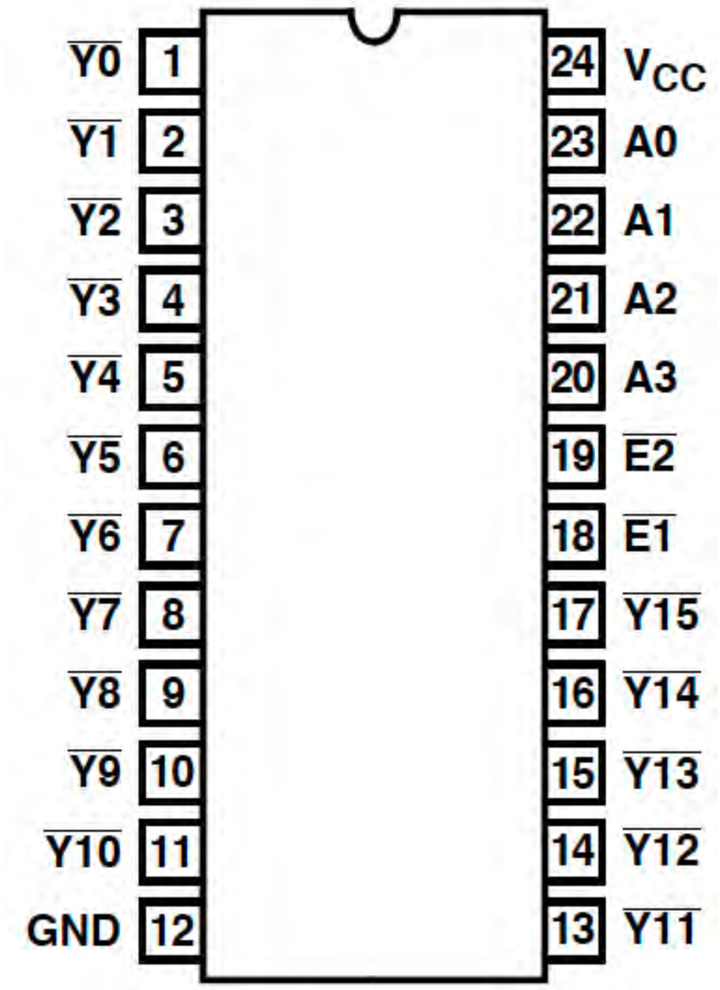
- Input x = (not(E1) and not(E2) and E3)
- Address lines A0,A1,A2
  to select output $Y_{A0,A1,A2}$
- Output $Y_{A0,A1,A2}$ = not(x)
- other outputs: $Y_i = 1$
- $V_{cc} = 5V$
- $I_{OUT} = \pm 25mA$



Source: Philips Datasheet

74HC154:
4-to-16 Line Decoder/Demultiplexer

- Input x = (E1 or E2)
- Address lines A0,A1,A2 to select output $Y_{A0,A1,A2}$
- Output $Y_{A0,A1,A2}$ = x
- other outputs: $Y_i = 1$
- V_{cc} = 5V
- I_{OUT} = ±50mA



Source: Harris Semiconductor Datasheet