Measuring Transistor Characteristic Curves

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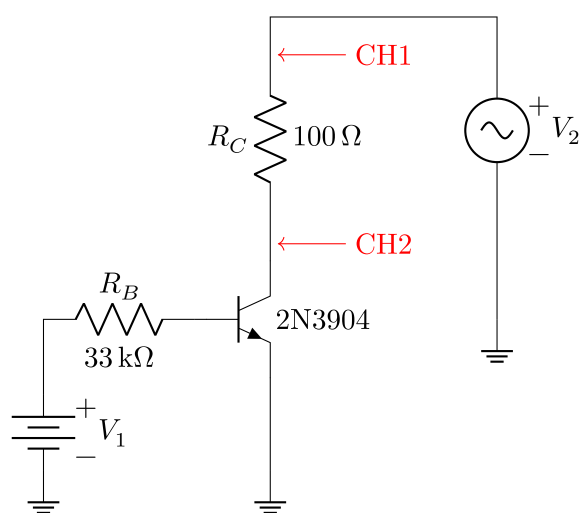
This note documents how to measure transistor characteristic curves using an oscilloscope as described in (Buyl 2010). The circuit is also based on Lab 33 in (Buchla 2010).

The collector current, I_C, of a bipolar junction transistor varies with the collector-emitter voltage, V_{CE}, as well as the transistor's base current, I_B. A collector-emitter characteristic curve is a plot of I_C against V_{CE} for a specified value of I_B. By setting various values of I_B, we can measure and plot a family of characteristic curves.

We can measure transistor characteristics using the following circuit



V_1 is a DC voltage source that can be set to various voltages to determine various levels of base current, I_B. Because the transistor's internal emitter resistance, r_e, is small relative to R_B, in this circuit

$$I_B \approx \frac{V_1}{R_B} = \frac{V_1}{33k\Omega}$$

The characteristic curve is I_C as a function of V_{CE}. In this circuit

$$I_C = \frac{V_2 - V_{CE}}{R_C}$$

We connect the oscilloscope channel 1 at the top of R_C, and channel 2 at the collector, as indicated in the circuit diagram above. This lets us measure

$$V_2 = V_{CH1}$$

and

$$V_{CE} = V_{CH2}$$

So

$$I_C = \frac{V_{CH1} - V_{CH2}}{R_C} = \frac{V_{CH1} - V_{CH2}}{100\Omega}$$

which we will plot against V_{CE}.

For a given voltage, V_1, we can trace out a characteristic curve by setting V_2 to a sawtooth waveform with a frequency of 100 Hz and voltage of 0V to 10V. Each cycle of the sawtooth waveform V_2 traces out a characteristic curve.

We set the DC voltage source V_1 to each the following voltages:

$0.5V$, $1.0V$, $1.5V$, $2.0V$, $2.5V$, $3.0V$, $3.5V$, $4.0V$, $4.5V$, $5.0V$

and capture the output of the oscilloscope as a CSV file for each voltage.

Here is a representative set of waveforms from the oscilloscope for $V_1 = 2.5V$.

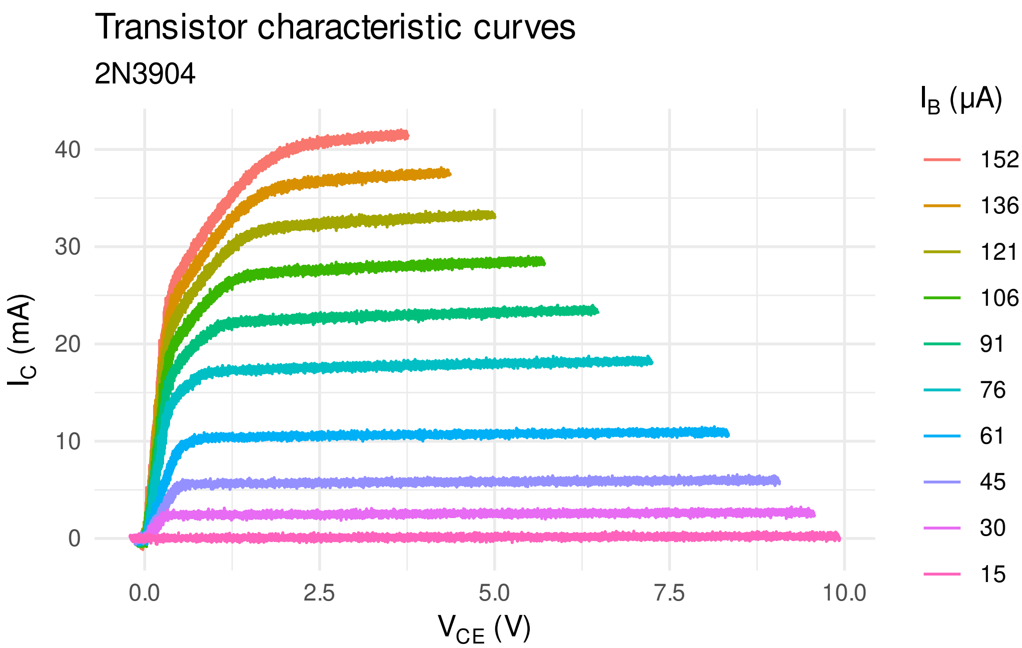
We then use the R language to read and combine the oscilloscope data.

```
library(tidyverse)
```

```
V1_05 <- read_csv("2N3904/RigolDS0.csv", col_types = "dd??")
V1_05$V1 <- 0.5

V1_10 <- read_csv("2N3904/RigolDS1.csv", col_types = "dd??")
V1_10$V1 <- 1.0

V1_15 <- read_csv("2N3904/RigolDS2.csv", col_types = "dd??")
V1_15$V1 <- 1.5

V1_20 <- read_csv("2N3904/RigolDS3.csv", col_types = "dd??")
V1_20$V1 <- 2.0

V1_25 <- read_csv("2N3904/RigolDS4.csv", col_types = "dd??")
V1_25$V1 <- 2.5

V1_30 <- read_csv("2N3904/RigolDS5.csv", col_types = "dd??")
V1_30$V1 <- 3.0

V1_35 <- read_csv("2N3904/RigolDS6.csv", col_types = "dd??")
V1_35$V1 <- 3.5

V1_40 <- read_csv("2N3904/RigolDS7.csv", col_types = "dd??")
V1_40$V1 <- 4.0

V1_45 <- read_csv("2N3904/RigolDS8.csv", col_types = "dd??")
V1_45$V1 <- 4.5

V1_50 <- read_csv("2N3904/RigolDS9.csv", col_types = "dd??")
V1_50$V1 <- 5.0

t_df <- rbind(V1_05, V1_10, V1_15, V1_20, V1_25,
              V1_30, V1_35, V1_40, V1_45, V1_50)
```

Finally, we compute I_B, I_C, and V_{CE}, and plot the characteristic curves.

```
t_df |>
  mutate(IB = as.factor(round((V1 / 33000)*1e6)),
         IC = ((CH1V - CH2V)/100)*1000, VCE = CH2V) |>
  ggplot(aes(VCE, IC, color = fct_reorder2(IB, VCE, IC))) +
  geom_line() +
  labs(title = "Transistor characteristic curves",
       subtitle = "2N3904",
       x = expression(paste(V[CE], " (V)")),
       y = expression(paste(I[C], " (mA)")),
       color = expression(paste(I[B], " ( A)"))) +
  theme_minimal()
```



References

Buchla, David M. 2010. *Experiments in Electronics Fundamentals and Electric Circuits Fundamentals*.

Buyl, Pierre de. 2010. "A Digital Oscilloscope Setup for the Measurement of a Transistor's Characteristics." *arXiv*. https://doi.org/10.48550/ARXIV.1006.0954.