Measuring Transistor Characteristic Curves

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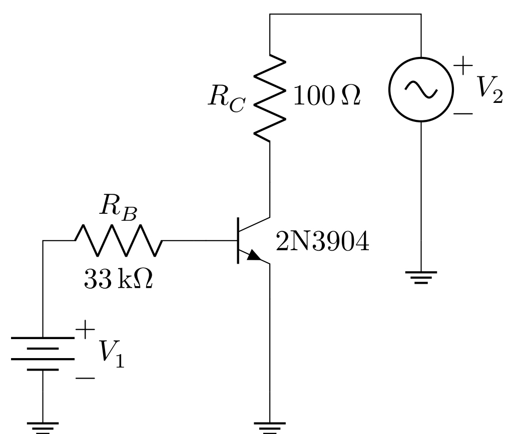
This note documents how to measure transistor characteristic curves using an oscilloscope as described in (Buyl 2010). The circuit is also based on Lab 33 in (Buchla 2010).

The collector-emitter characteristic curves for a bipolar junction transistor show how collector current, I_C, varies with the collector-emitter voltage, V_{CE}, for various specified values of base current, I_B.

In this case, we use a 2N3904 NPN bipolar junction transistor.

We can measure transistor characteristics using the following circuit



where V_1 is a DC voltage source that can be set to various voltages that will determine the base current, I_B. In this circuit,

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

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.

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. This lets us measure

$$V_2 = V_{CH1}$$

and

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

where V_{CH1} and V_{CH2} are the measured channel 1 and channel 2 voltages, respectively.

Each cycle of the sawtooth waveform V_2 traces out a characteristic curve.

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

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

For each of these, we capture the output of the oscilloscope as a CSV file.

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

We then use R to read the oscilloscope data, from which we can compute and plot the characteristic curves.

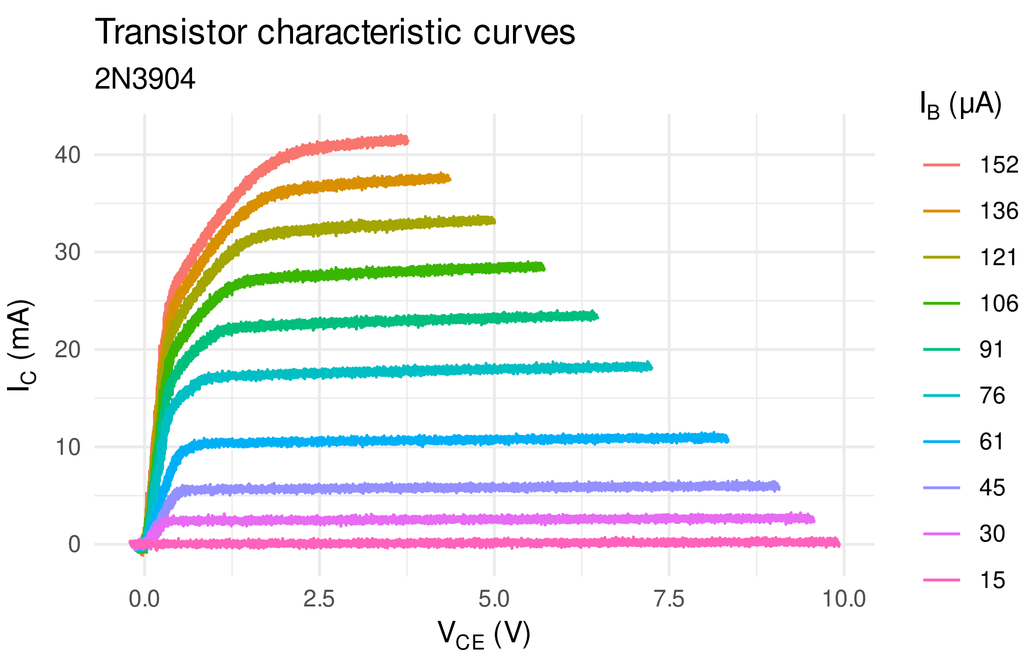
This is the code to read and combine the CSV files.

```r
library(tidyverse)
```

```r
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 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.