Circuits Lab 3

Thomas Nattestad and Dimitar Dimitrov

February 2015

1 Experiment 1: Bipolar Transistor Characteristics

We connected the transistor as described and swept voltages from around .3 to around .8 to get the desired emitter current range. In figure Figure 1 on the following page is a semilog plot showing the collector and base currents as a function of base voltage. Since this is very linear on a log scale, we can determine that the collector current follow an exponential relationship with the base voltage. We get from the fit that I_s is around 10 fA and that U_T is about 25.7 mV.

In figure Figure 2 on page 3 we look at the relationship between beta and the base current. The current gain (beta) is not constant for all values of base current but is fairly constant region between .820 nanoAmps and 800 miliAmps and is around 237.

In figure Figure 3 on page 3 we plot the incremental resistance as a function of base current. The theoretical fit matches the data very well.

In figure Figure 4 on page 4 we plot the transconductance gain as a function of collector current. The theoretical fit matches the data very well.

2 Experiment 2: Emitter-Degenerated Bipolar Characteris- tics

We picked three resistors: 100Ω, $1k\Omega$ and $10k\Omega$. We modified the circuit from experiment 1 by adding the first resistor between the emitter of the 2N3904 transistor and the positive terminal of Channel 2 of the SMU (which acts as an ammeter) and we modified the Python script to sweep between 0 and 5V (keeping 101 values) and to break and repeat three times, giving us an opportunity to switch out the resistor. The data was saved in a .csv file.

We added the measured emitter and base currents for each voltage for each resistor to approximate the collector current. The collector current for each

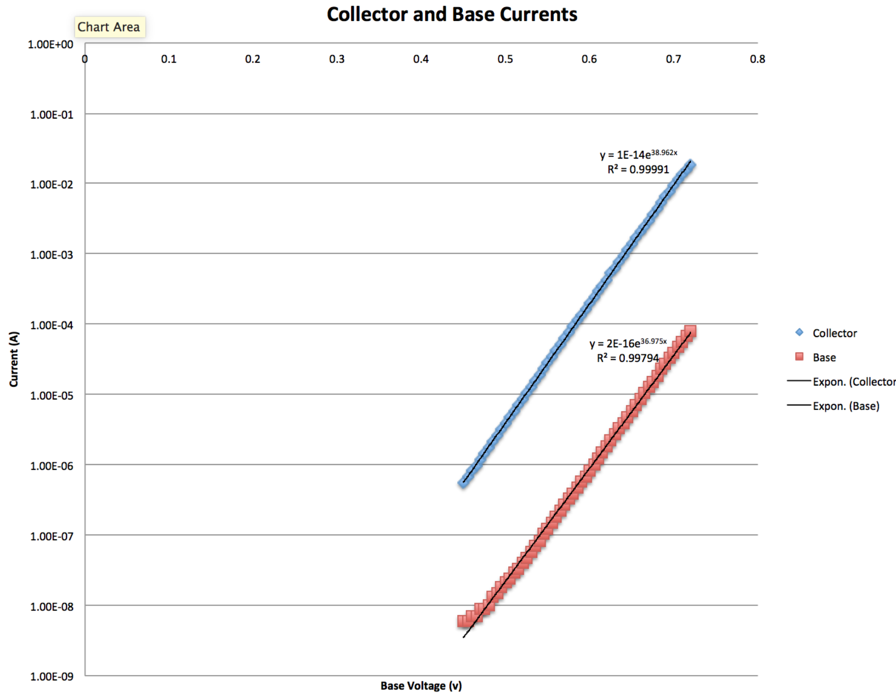

Figure 1: Collector and Base current as function of base voltage

resistor is plotted against the base-emitter voltage in Figure 1. The graph clearly shows two qualitative regions - a region of very little current before about half a volt, and a region of steady logarithmic increase of current at voltages greater than half a volt. As discussed in previous labs, the SMU cannot accurately measure current greater than about 20mA, so there is an artificial plateau at higher voltages for the 100Ω resistor. These qualitative regions correspond to our predictions in the prelab.

Based on Experiment 1, we have the following approximations:

$U_T = 25mA$

$I_s = 10fA$

$\beta = 237$

$\alpha = \frac{\beta}{1+\beta} = .996$

$V_{on} = U_T \log(\frac{U_T \alpha}{RI_S}) = .598, .540, .483$ for $R = 100\Omega, 1k\Omega, 10k\Omega$

Based on the prelab, we know that for voltages lower than V_{on}, $I_c \approx I_s e^{V_b/U_T}$ and for voltages higher, $I_c \approx \frac{V_b - V_{on}}{R}$. These curves are also shown in Figure 5 on page 5, and they fit the data extremely well.

Figure 7 on page 6, Figure 6 on page 6 and Figure 8 on page 7 show the same graphs on a linear plot, illustrating clearly the turn-on voltage. They are fitted linearly, and the values in the estimated equation match our previously

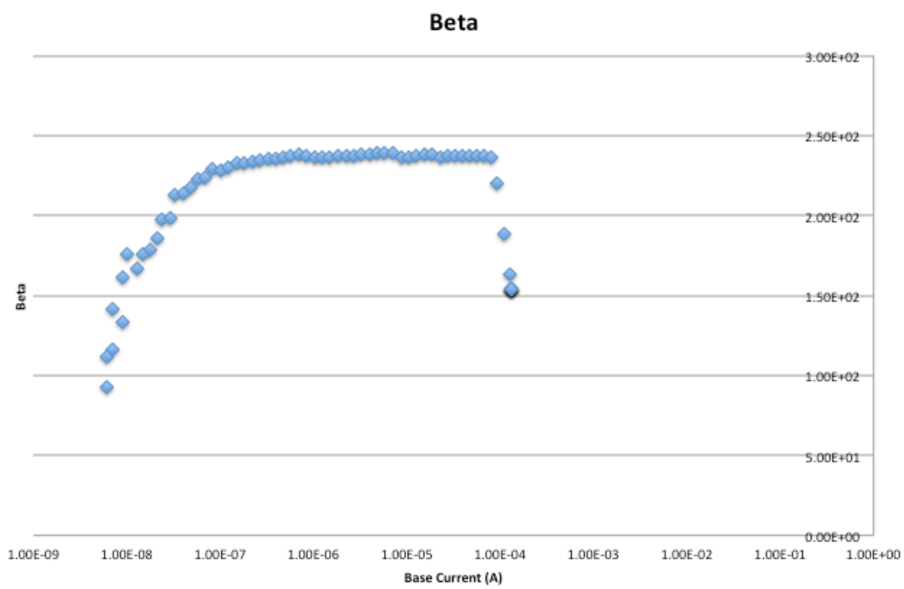

Figure 2: Beta as a function of base current

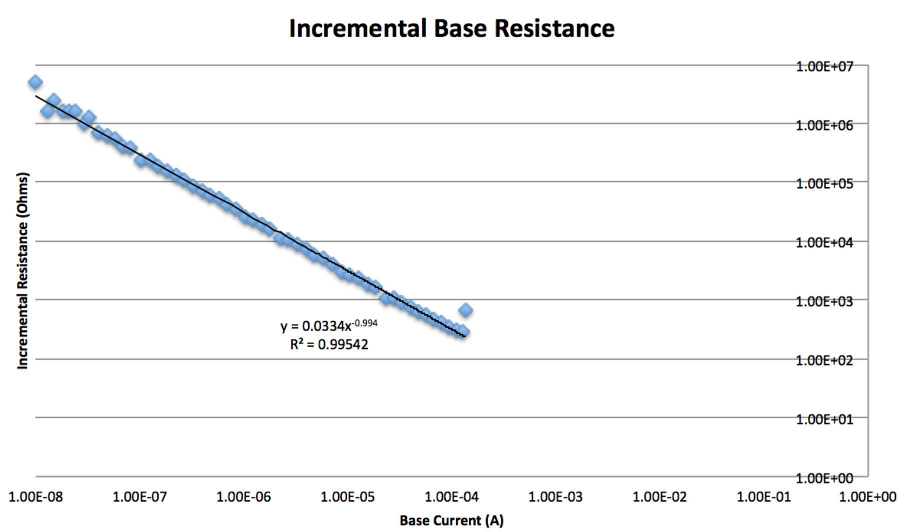

Figure 3: Incremental Resistance as a function of base current

calculated values for V_{on} and R well.

Figure 9 on page 7 shows values for R_b for each of the resistors at various base currents. The experimental value is determined by dividing the difference

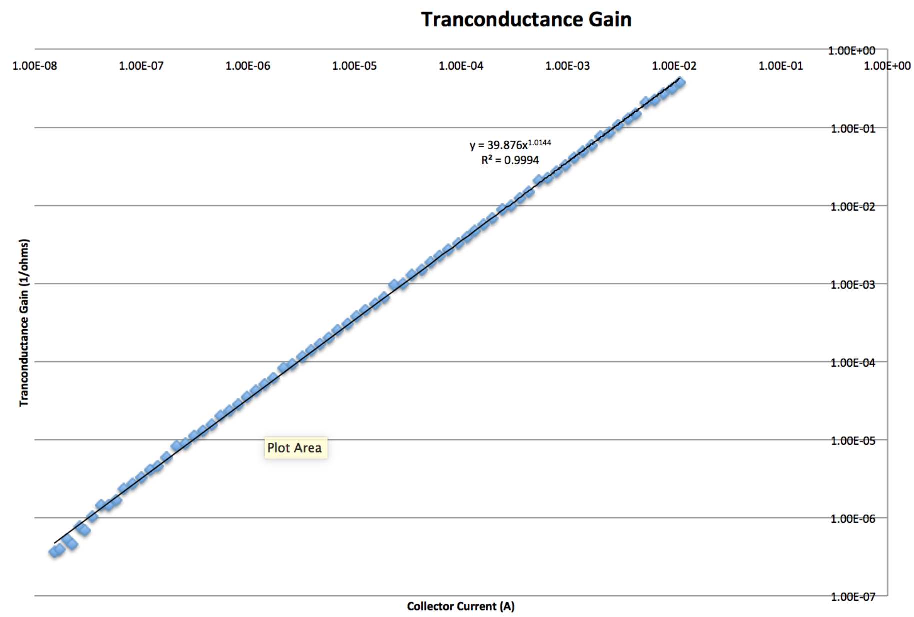

Figure 4: Transconductance Gain as a function of collector current

of consecutive current readings by the voltage difference (i.e. .05V). The theoretical curve is determined by plugging current reading into the formula we derived in the prelab. They match extremely well. Figure 10 on page 8 shows values for G_m for each of the resistors at various collector currents. The experimental value is determined by dividing the voltage difference (i.e. .05V) by the difference of consecutive current readings. The theoretical curve is determined by plugging current readings into the formula we derived in the prelab. Again, the data matches very well.

3 Experiment 3: Follower Voltage Transfer Characteristics

The plotted emitter-follower's voltage transfer characteristic is plotted in figure Figure 11 on page 8. The voltage of Vout follows fairly perfectly that of Vin. Because of this, the incremental voltage gain is 1. The difference between Vin and Vout is only a tiny offset of around .24 likely caused by the natural resistance of the transistor or just measurement error. The voltage difference is determined by the transistor specifics, such as I_s and U_T.

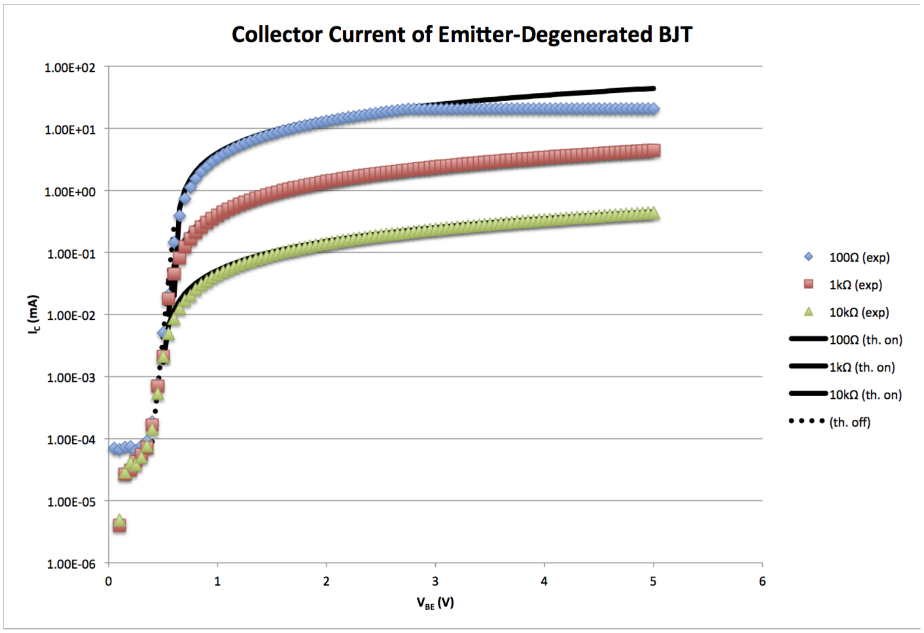

Figure 5: Collector Current of Emitter-Degenerated BJT

4 Experiment 4: Inverter Voltage Transfer Characteristics

We used a 100Ω resistor to degenerate the emitter of the BJT. In series with the collector, we placed a 100Ω, 200Ω, 300Ω and 400Ω resistor, using a Python script similar to the one we used in Experiment 2. The VTS of each configuration, along with the VTS of the 100Ω trial of Experiment 3 and theoretical values based on the fact that

$V_{out} = V_{cc} - mRI_c$

and

$I_c = (V_b - V_{on})/R$ in the turn-on region

are graphed in Figure 12 on page 9. The theoretical data matches very well.

The gains for the four configurations are -1,-2,-3 and -4 for m=1,2,3 and 4, respectively. m determines the gain.

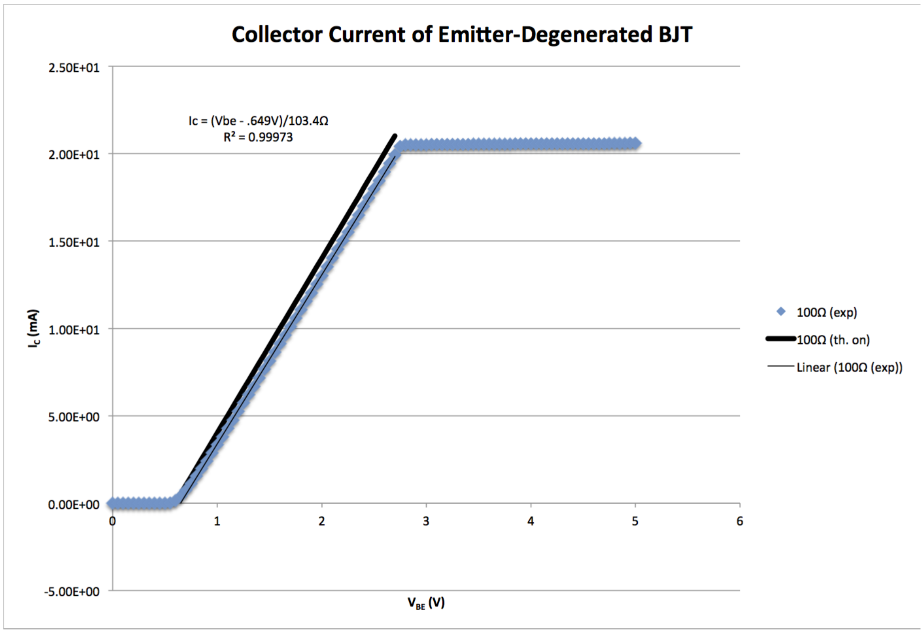

Figure 6: Collector Current of Emitter-Degenerated BJT (100Ω)

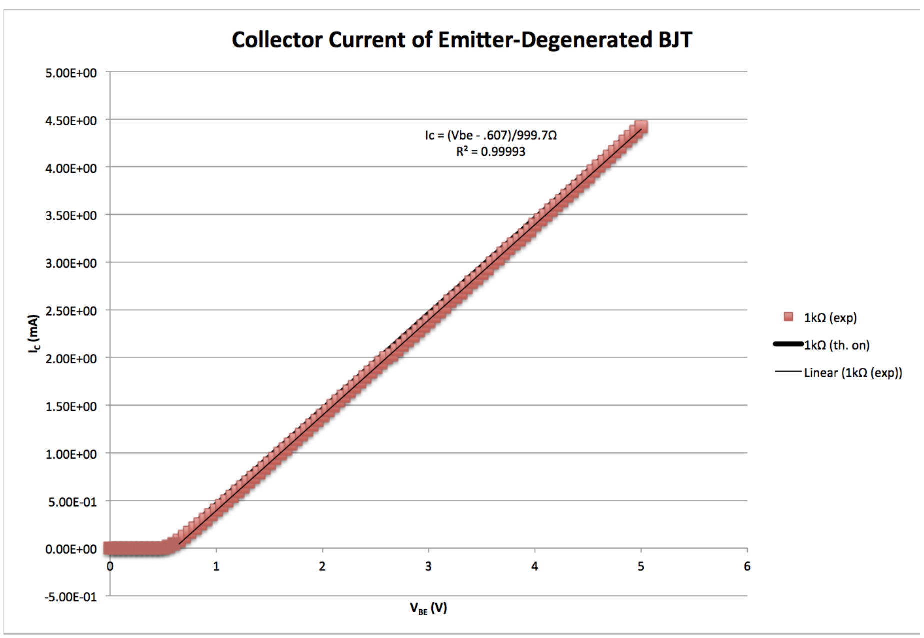

Figure 7: Collector Current of Emitter-Degenerated BJT (1kΩ)

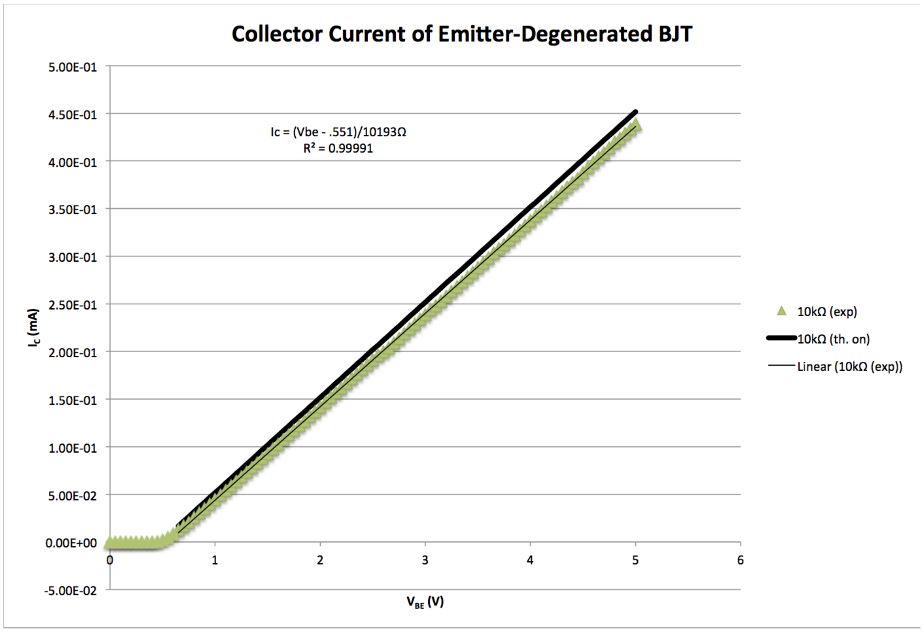

Figure 8: Collector Current of Emitter-Degenerated BJT (10kΩ)

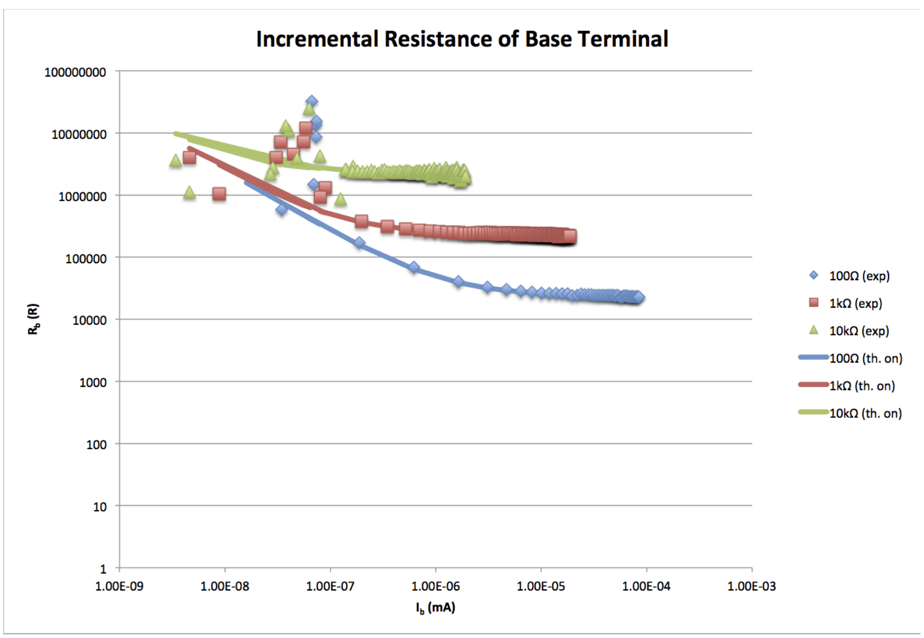

Figure 9: Incremental Resistance of Base Terminal

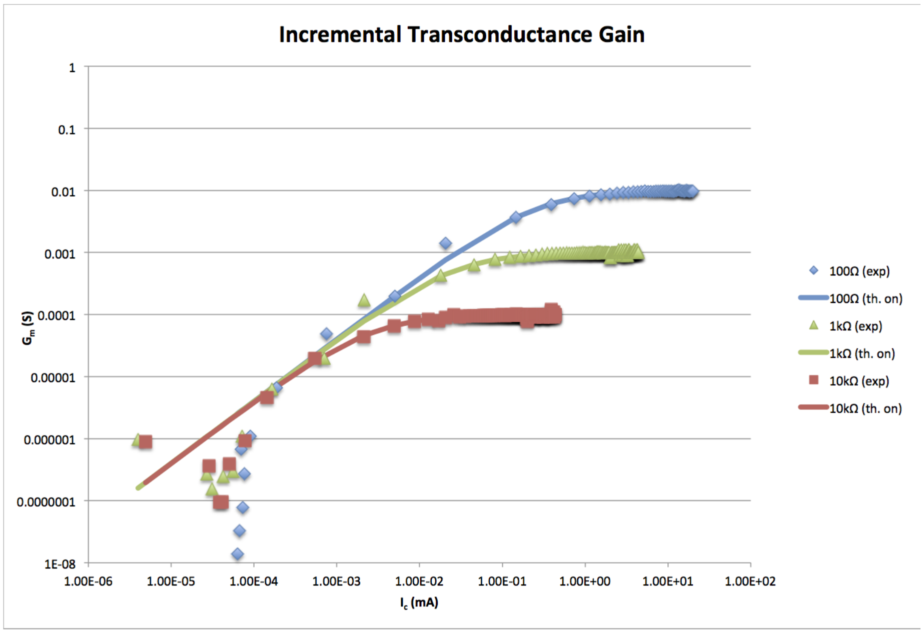

Figure 10: Incremental Transconductance Gain

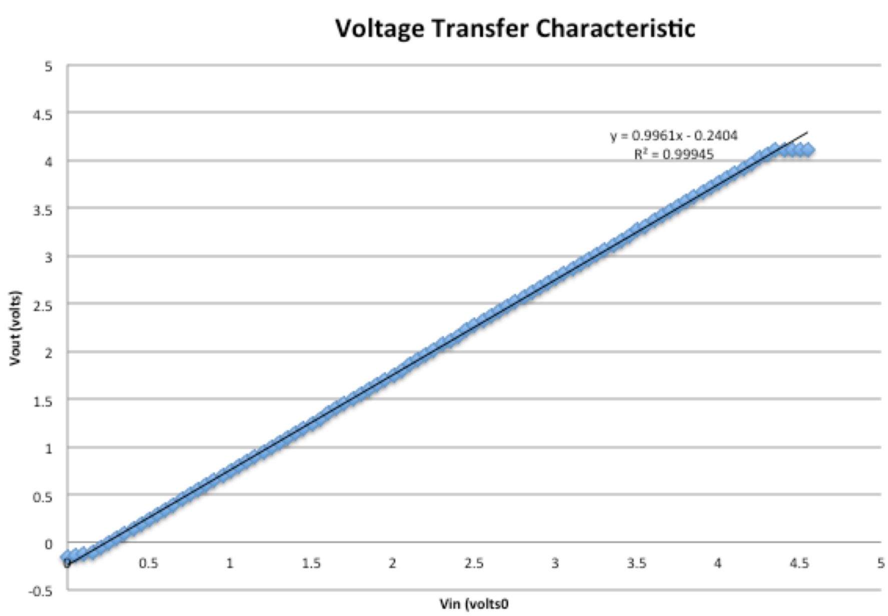

Figure 11: A plot of an emitter-follower's voltage transfer characteristic

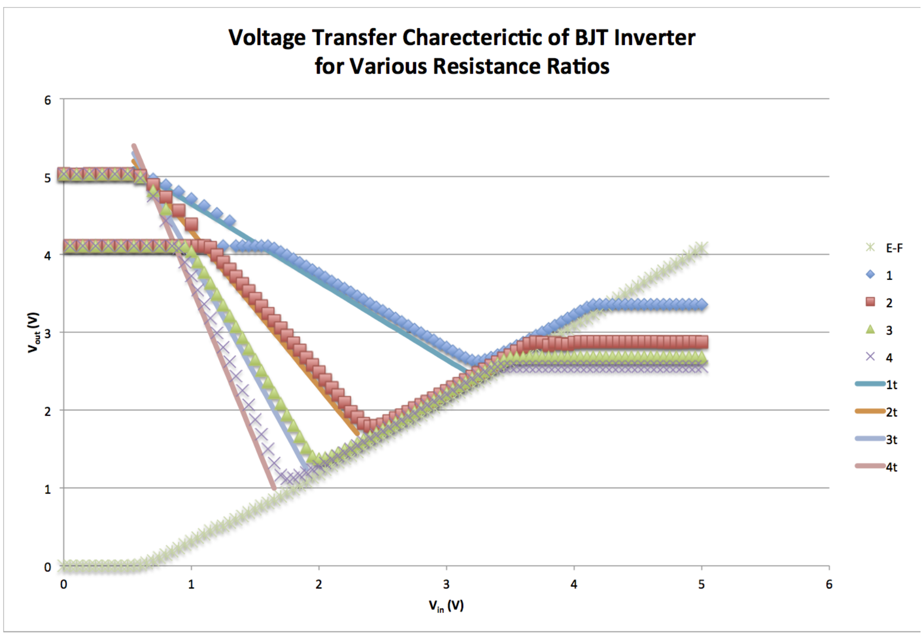

Figure 12: VTS of BJT inverter with 4 different mR values (m=1,2,3,4)