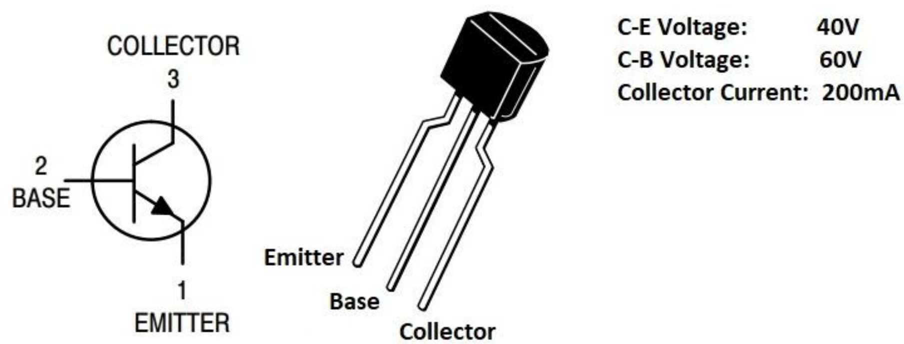
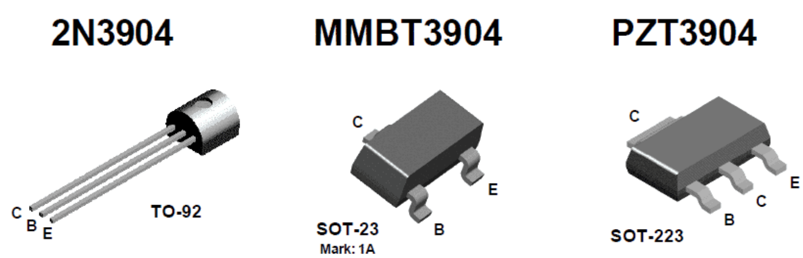
XMUT204 Electronic Design

Demo 5.1 – BJT Characteristics

In this demo, we discuss characteristics of a Bipolar Junction Transistor (BJT) based on given the manufacturer datasheet. The topics will be covered are characteristics and properties of this active device in electronics e.g. linear and non-linear behaviours of the transistor device.



2N3904 BJT transistor which is commonly used as an NPN general purpose amplifier is used as an example in this exercise. This device is designed for applications such as a general purpose amplifier and switch. The useful dynamic range of this transistor extends to 100 mA as a switch and to 100 MHz as an amplifier.



A. Parameters Data

An absolute maximum ratings for the 2N3904 NPN transistor is shown in the figure below. Notice that the maximum collector-emitter voltage (V_{CEO}) is 40 V. The CEO subscript indicates that the voltage is measured from collector (C) to emitter (E) with the base open (O). In the datasheet, we use V_{CE} (max) for this parameter.

Absolute Maximum Ratings* $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Figure 1: Absolute maximum ratings of 2N3904 BJT transistor

Also notice that the maximum collector current is 200 mA. The β_{DC} (h_{FE}) is specified for several values of I_C. As you can see, h_{FE} varies with I_C as we previously discussed. The collector-emitter saturation voltage, V_{CE} (sat) is 0.2 V maximum for I_C (sat) = 10 mA and increases with the current.

Thermal Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Characteristic	Max			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."
**Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

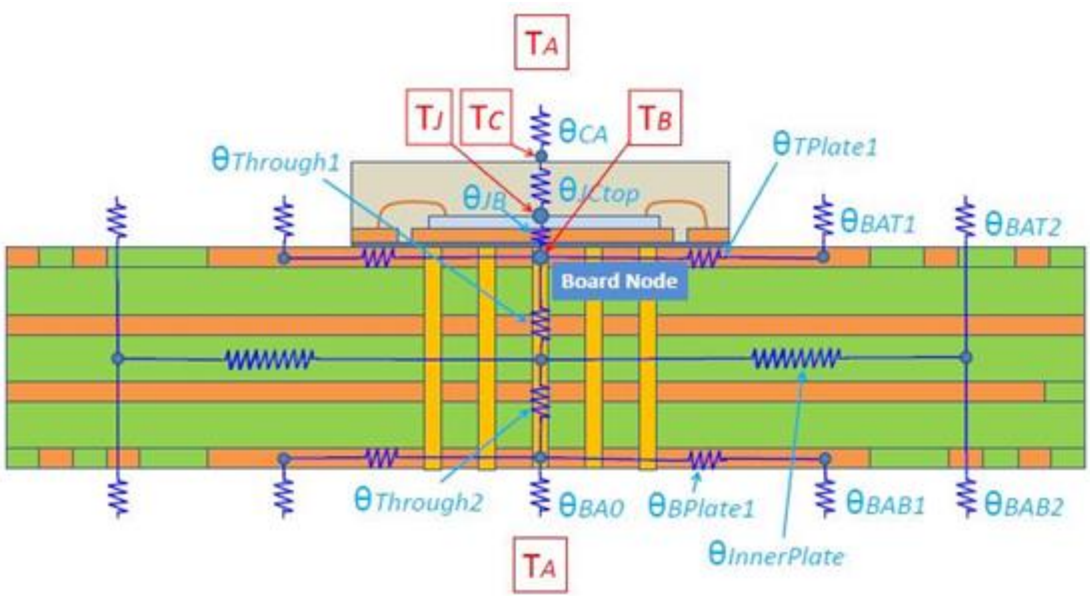


Figure 2: Thermal characteristics of 2N3904 BJT transistor

Electrical Characteristics $T_A = 25°C$ unless otherwise noted

Symbol	Parameter	Test Conditions	Min	Max	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	$I_C = 1.0$ mA, $I_B = 0$	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	$I_C = 10\,\mu A$, $I_E = 0$	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	$I_E = 10\,\mu A$, $I_C = 0$	6.0		V
I_{BL}	Base Cutoff Qurrent	$V_{CE} = 30$ V, $V_{EB} = 3V$		50	nA
I_{CEX}	Collector Cutoff Current	$V_{CE} = 30$ V, $V_{EB} = 3V$		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	$I_C = 0.1$ mA, $V_{CE} = 1.0$ V $I_C = 1.0$ mA, $V_{CE} = 1.0$ V $I_C = 10$ mA, $V_{CE} = 1.0$ V $I_C = 50$ mA, $V_{CE} = 1.0$ V $I_C = 100$ mA, $V_{CE} = 1.0$ V	40 70 100 60 30	 300 	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	$I_C = 10$ mA, $I_B = 1.0$ mA $I_C = 50$ mA, $I_B = 5.0$ mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	$I_C = 10$ mA, $I_B = 1.0$ mA $I_C = 50$ mA, $I_B = 5.0$ mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	$I_C = 10$ mA, $V_{CE} = 20$ V, f = 100 MHz	300		MHz
C_{obo}	Output Capacitance	$V_{CB} = 5.0$ V, $I_E = 0$, f = 1.0 MHz		4.0	pF
C_{ibo}	Input Capacitance	$V_{EB} = 0.5$ V, $I_C = 0$, f = 1.0 MHz		8.0	pF
NF	Noise Figure	$I_C = 100\mu A$, $V_{CE} = 5.0$ V, $R_S = 1.0k\Omega$, f=10 Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	$V_{CC} = 3.0$ V, $V_{BE} = 0.5$ V,		35	ns
t_r	Rise Time	$I_C = 10$ mA, $I_{B1} = 1.0$ mA		35	ns
t_s	Storage Time	$V_{CC} = 3.0$ V, $I_C = 10$mA		200	ns
t_f	Fall Time	$I_{B1} = I_{B2} = 1.0$ mA		50	ns

*Pulse Test: Pulse Width $\leq 300\mu s$, Duty Cycle $\leq 2.0\%$

Figure 3: Electrical characteristics of 2N3904 BJT transistor

B. Graphical Data

There are several graphical data which are of particular interest for analysis and design of BJT transistor circuits. These graphs are related closely to the properties and characteristics of the BJT transistors.

In this section, we will discuss the properties and characteristics of the BJT transistor in terms on two most common types of BJT transistor application e.g. switching and amplification.

Several properties and characteristics of BJT transistor are typically common for both switching and amplification applications such as power dissipation, on voltage, turn on time, saturations, cut-off current, output admittance, input impedance, operating frequency and noise characteristics.

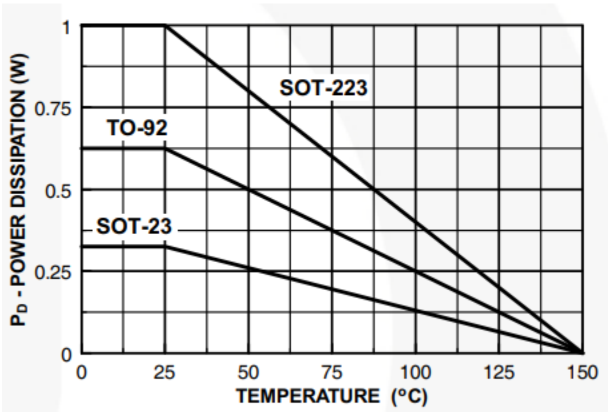


Figure 4: Power Dissipation vs. Ambient Temperature

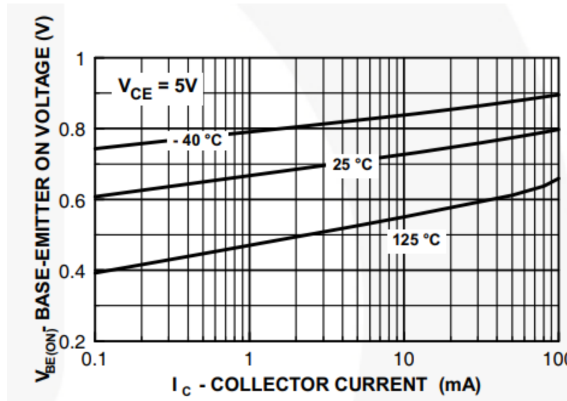


Figure 5: Base-Emitter On Voltage vs. Collector Current

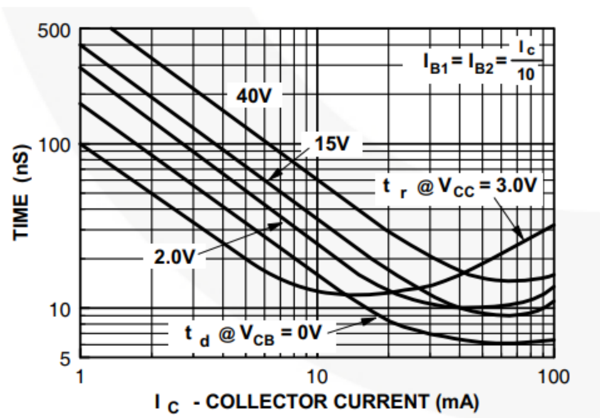


Figure 6: Turn-On Time vs. Collector Current

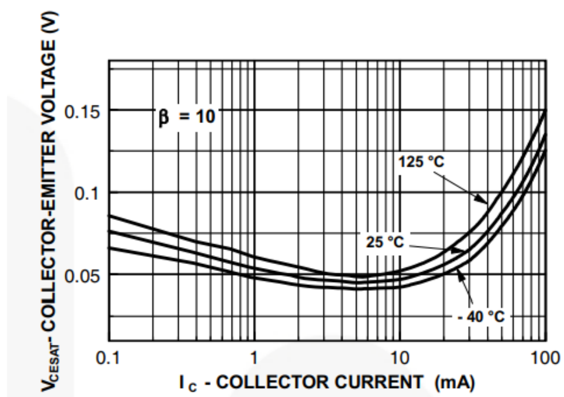


Figure 7: Collector-Emitter Saturation Voltage vs Collector Current

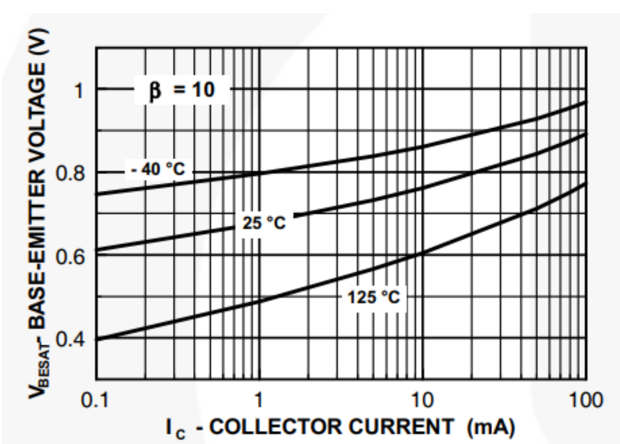


Figure 8: Base-Emitter Saturation Voltage vs. Collector Current

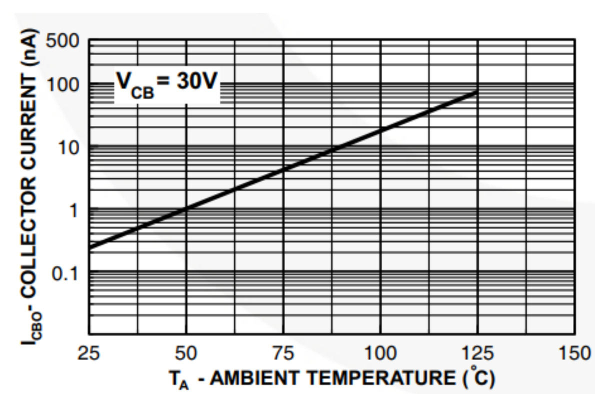


Figure 9: Collector Cut-Off Current vs. Ambient Temperature

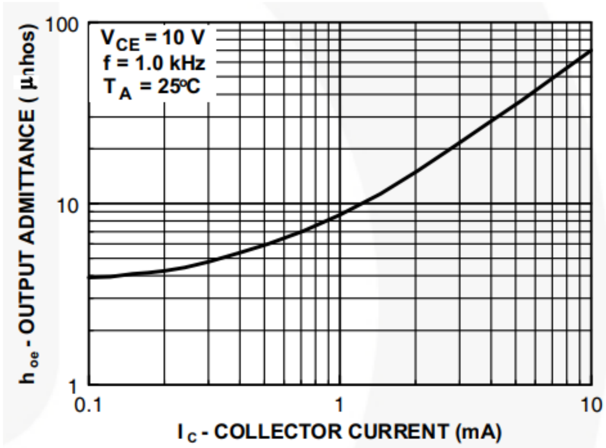


Figure 10: Output Admittance vs. Collector Current

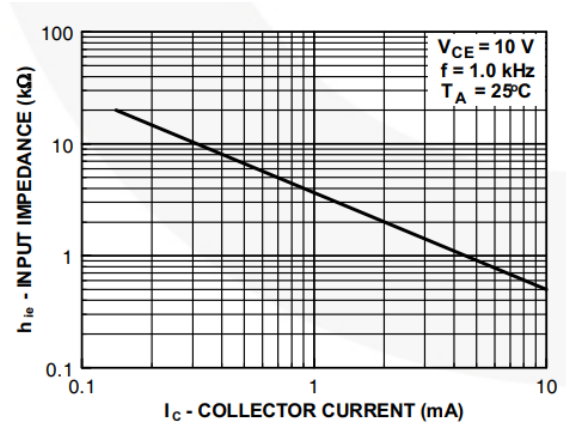


Figure 11: Input Impedance vs. Collector Current

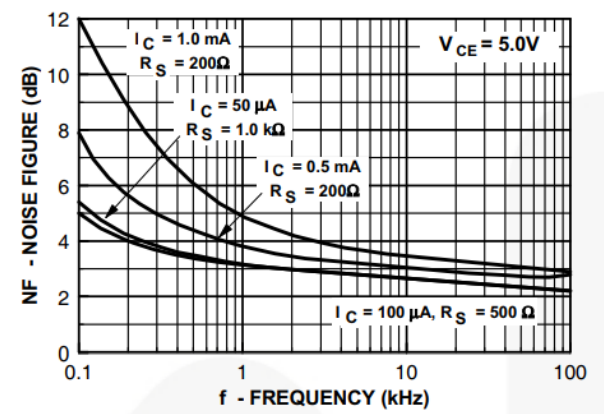


Figure 12: Noise Figure vs. Frequency

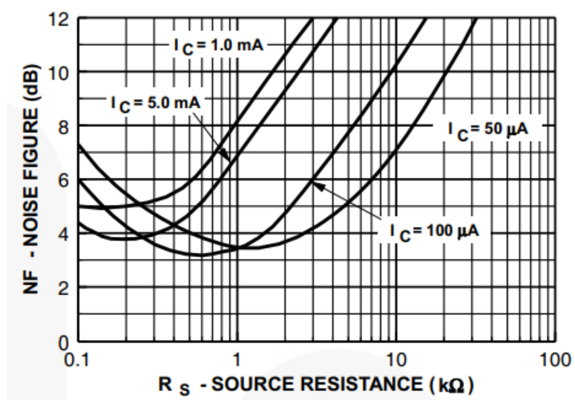


Figure 13: Noise Figure vs. Source Resistance

For switching application properties and characteristics such as rise time, storage time, fall time, and capacitance at reversed bias are important information for the design of the switching circuit.

How fast switching operation can be performed depends on the nature of the timing (rise time and fall time) of the signal pulses. How fast the transistor can recover depends on the value of capacitance of the transistor and hence the storage time. As capacitance in the transistor limits the amount of time for the transistor to be ready for the next cycle of pulses.

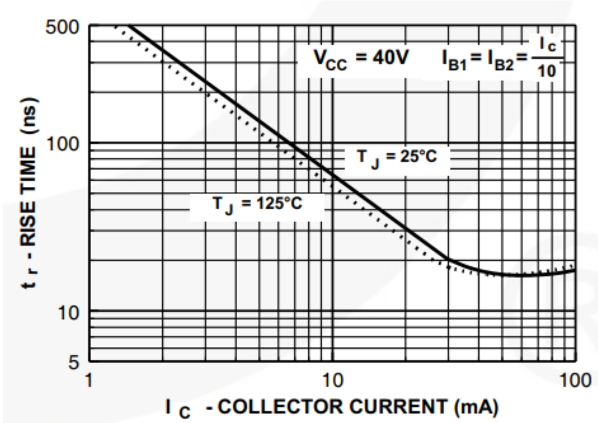


Figure 14: Rise Time vs Collector Current

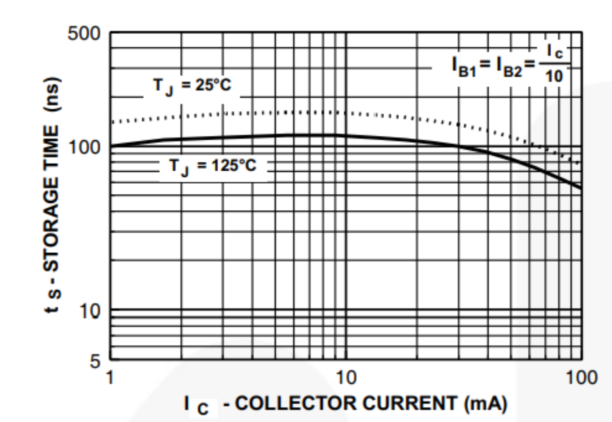


Figure 15: Storage Time vs. Collector Current

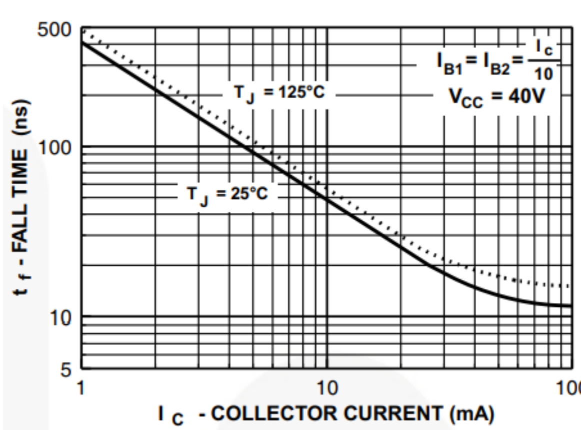


Figure 16: Fall Time vs. Collector Current

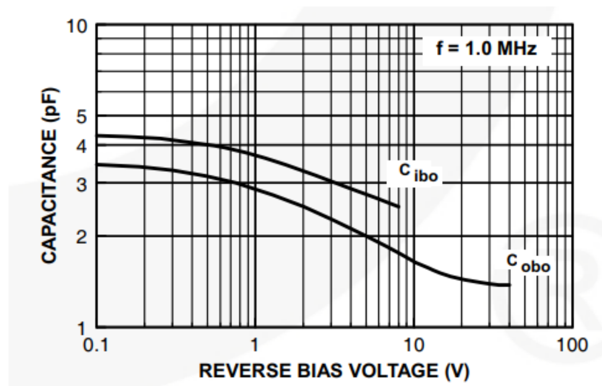


Figure 17: Capacitance vs. Reverse Bias Voltage

Properties and characteristics of BJT transistor such as voltage and current gain, frequency bandwidth and voltage feedback characteristics are essential to know for amplification application.

How much signal can be amplified depends on the gain of the transistor. What frequency of operation (e.g. maximum and minimum frequencies) can be safely amplified in the circuit depends on the bandwidth of the transistor. Voltage feedback characteristics will determine the ability of the transistor to be put into feedback arrangement, typical set up for amplifier circuit design.

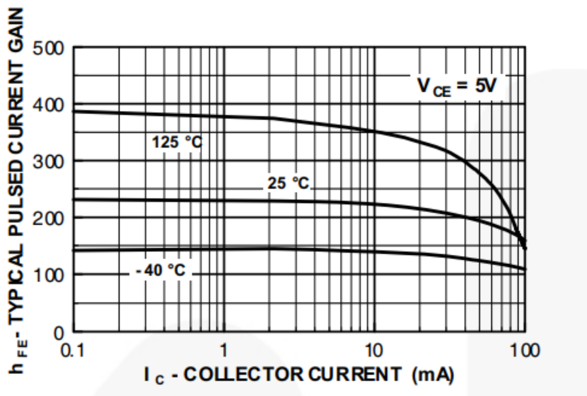


Figure 18: Typical Pulsed Current Gain vs Collector Current

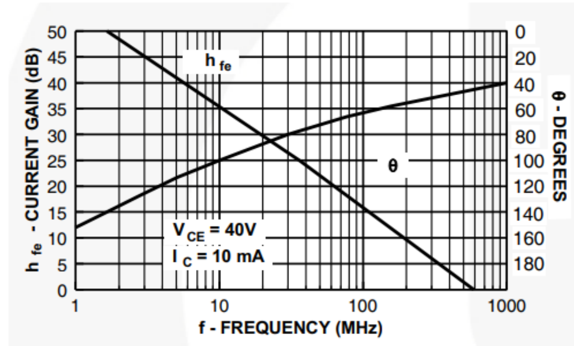


Figure 19: Current Gain and Phase Angle vs. Frequency

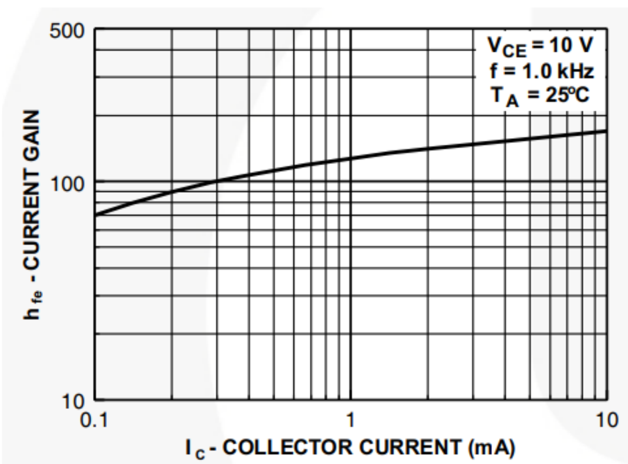


Figure 20: Current Gain vs. Collector Current

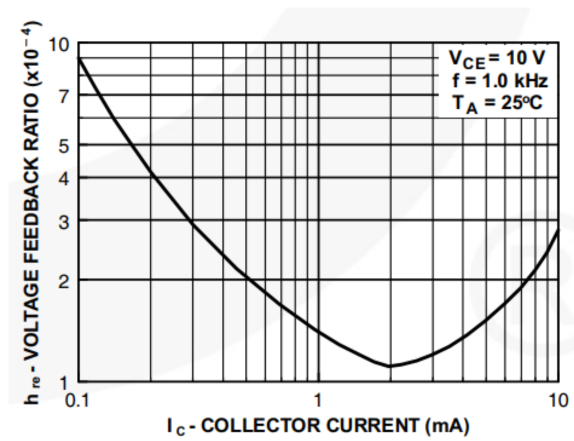


Figure 21: Voltage Feedback Ratio vs. Collector Current