5.6.3. SPICE model

The SPICE model of a bipolar transistor includes a variety of parasitic circuit elements and some process related parameters in addition to the elements previously discussed in this chapter. The syntax of a bipolar transistor incorporates the parameters a circuit designer can change as shown below:

BJT syntax

Q<name> <collector node> <base node> <emitter node> [<substrate node>] <modelname>

+ [<area>]

.MODEL <modelname> NPN(BF=<value> BR=<value> IS=<value> CJE=<value>

+ CJC=<value> VJE=<value> VJC=<value> VAF=<value> VAR=<value>

+ NF=<value> NR=<value>)

BJT Parameters

BF	Forward active current gain	VJE	Base-emitter built-in potential
BR	Reverse active current gain	VJC	Base-collector built-in potential
IS	Transport saturation current	VAF	Forward mode Early voltage
CJE	Base-emitter zero-bias junction capacitance	VAR	Reverse mode Early voltage
		NF	Forward mode ideality factor
CJC	Base-collector zero-bias Junction capacitance	NR	Reverse mode ideality factor

Example:

Q1 3 2 1 BJTNAME

.MODEL BJTNAME NPN(BF=200 CJC=20pf CJE=20pf IS=1E-16)

where Q1 is one specific transistor in the circuit, while the transistor model "BJTNAME" uses the built-in model NPN to specify the process and technology related parameters of the BJT. The built-in model PNP is used for p-n-p bipolar transistors. A list of SPICE parameters and their relation to the parameters discussed in this text is provided in the table below.

SPICE variable	Equation
BF	BF = b_F (see section 5.3.1)
BR	BR = b_R (see section 5.3.2)

IS	$$\text{IS} = I_{s,n} = qn_i^2 A_E \left(\frac{D_{n,B}}{N_B w_B'} \right)$$
CJE	$$\text{CJE} = C_{j0,BE} = \sqrt{\frac{\varepsilon_s q}{2f_{i,BE}} \frac{N_B N_E}{N_B + N_E}}$$
CJC	$$\text{CJC} = C_{j0,BC} = \sqrt{\frac{\varepsilon_s q}{2f_{i,BC}} \frac{N_B N_C}{N_B + N_C}}$$
VJE	$$\text{VJE} = f_{i,BE} = V_t \ln \frac{N_E N_B}{n_i^2}$$
VJC	$$\text{VJC} = f_{i,BC} = V_t \ln \frac{N_C N_B}{n_i^2}$$
VAF	$$\text{VAF} = |V_{A,F}| = \frac{q N_B w_B'}{C_{j,BC}}$$
VAR	$$\text{VAR} = |V_{A,R}| = \frac{q N_B w_B'}{C_{j,BE}}$$
NF	$$\text{NF} = n_F \cong 1 + \frac{V_t}{|V_{A,F}|} \frac{C_{j,BE}}{C_{j,BC}}$$
NR	$$\text{NR} = n_R \cong 1 + \frac{V_t}{|V_{A,R}|} \frac{C_{j,BC}}{C_{j,BE}}$$

Table 5.6.1   Selected SPICE parameters of a BJT.

In addition, there are additional parameters, which can be specified to further enhance the accuracy of the model, such as:

RB   zero bias base resistance   MJE base-emitter capacitance exponent

RE   emitter resistance   MJC base-collector capacitance exponent

RC   collector resistance   EG energy gap for temperature effect on IS

The exponents NJE and MJC are used to calculate the voltage dependence of the base-emitter and base-collector junction capacitances using:

$$C_{j,BE} = \frac{C_{j,BE0}}{\left(1 - \dfrac{V_{BE}}{f_{i,BE}}\right)^m} \text{, with } m = \text{MJE} \tag{5.6.29}$$

$$C_{j,BC} = \frac{C_{j,BC0}}{\left(1 - \dfrac{V_{BC}}{f_{i,BC}}\right)^m} \text{, with } m = \text{MJC} \tag{5.6.30}$$

This exponent allows the choice between a uniformly doped junction ($m = \frac{1}{2}$), a linearly graded junction ($m = 1/3$) or an arbitrarily graded junction for which the exponent must be independently determined.

The temperature dependence of the transport saturation current is calculated from the energy bandgap, since the primary temperature dependence is due to the temperature dependence of the intrinsic carrier density, which results in:

$$I_{s,n} = qA_E \left(\frac{D_{n,B}}{N_B w_B'}\right)\sqrt{N_c N_v} \, \exp \frac{-E_g}{kT} \tag{5.6.31}$$

The corresponding equivalent circuit is provided in Figure 5.6.3. The output resistance, r_o, was added to represent the Early effect, which is included in the BJT model by specifying VAF and VAR.
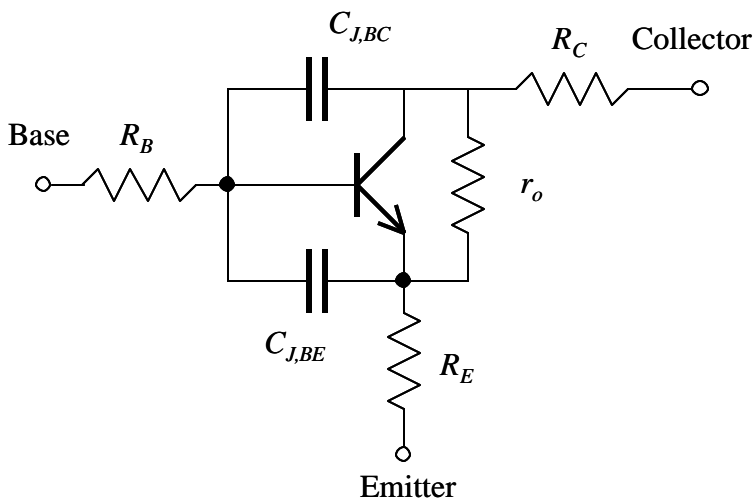

Figure 5.6.3   Large signal model of a BJT including the junction capacitances.