Demo 6 – BJT Circuit Simulation in LTspice

XMUT204 Electronic Design

Overview

- Modelling of BJT transistor.
- Parameters of BJT transistor.
- Modelling of customised BJT transistor.
- Example of customizing BJT transistor in LTspice.

1. Modelling of BJT Transistor

The syntax for the NPN type of this model is:

```
.model ModelNameNPN (par1=a par2=b……parn=x)
```

For PNP case:

```
.model ModelNamePNP (par1=a par2=b … parn=x)
```

Where `par1, par2, … parn` are the parameters that allow to model equations of the BJT.

2. Parameters of BJT Transistor

The parameters of the BJT transistor which are essential for SPICE model:

Parameters	Description	Units	Default Value
IS	Transport saturation current	A	1e-16
XTI	IS temperature effect exponent	no unit dimension	3.0
EG	Bandgap voltage (barrier height)	eV	1.11
VAF	Forward Early voltage	V	Infinite
BF	Ideal maximum forward beta	no unit dimension	100
ISE	Base-emitter leakage saturation current	A	0
NE	Base-emitter leakage emission coefficient	no unit dimension	1.5
IKF	Corner for forward-beta high-current roll-off	A	Infinite
NK	High-current roll-off coefficient	no unit dimension	0.5
XTB	Forward and reverse beta temperature coefficient	no unit dimension	0
BR	Ideal maximum reverse beta	no unit dimension	1.0
ISC	Base-collector leakage saturation current	A	0
NC	Base-collector leakage emission coefficient	no unit dimension	2.0
IKR	Corner for reverse-beta high-current roll-off	A	Infinite

Parameters	Description	Units	Default Value
RC	Collector ohmic resistance	Ohm	0
CJC	Base-collector zero-bias p-n capacitance	F	0
MJC	Base-collector p-n grading factor	no unit dimension	0.33
VJC		V	0.75
FC	Forward-bias depletion capacitor coefficient	no unit dimension	0.5
CJE	Base-emitter zero-bias p-n capacitance	F	0
MJE	Base-emitter p-n grading factor	no unit dimension	0.33
VJE	Base-emitter built-in potential	V	0.75
TR	Ideal reverse transit time	sec	1e-8
TF	Ideal forward transit time	sec	0
ITF	Transit time dependency on Ic	A	0
XTF	Transit time bias dependence coefficient	no unit dimension	0
VTF	Transit time dependency on Vbc	V	Infinite
RB	Zero-bias (maximum) base resistance	Ohm	0

3. Modelling of BJT Transistor

Begin with the parameters that can be set to their default values without significant influence on the modelling.

Assume: `XTI=3`, `EG=1.11 eV`, `XTB=0`, `TR=10ns`, `FC=0.5`.

The only information we can use directly is essentially the maximum value of `fT` at 300 Mhz, which allows us to estimate:

`TF=1/(6.28* 300 * 10^6)=530 ps.`

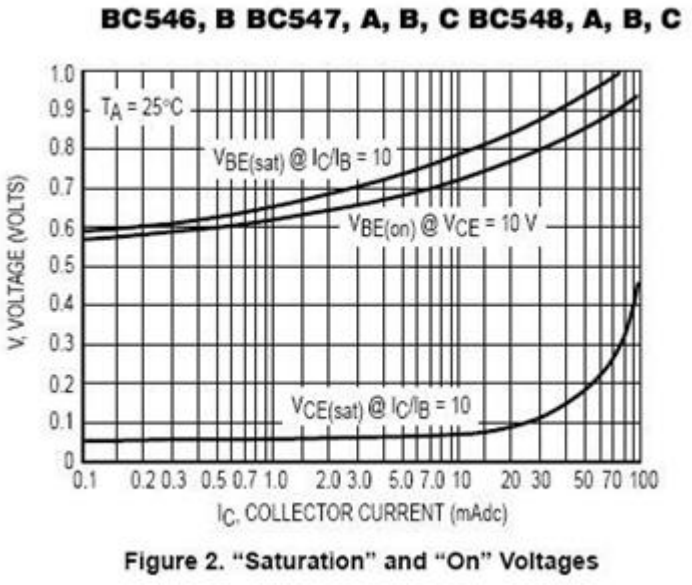


Figure 2. "Saturation" and "On" Voltages

See other parameters obtained from the graphs of the datasheet.

Observe the evolution of `Vbe(sat)/Ic`, respect to the ratio `Ic/Ib=10`, in the following chart in the datasheet.

From this first curve we find `IS` and `RB`. We obtain `IS=8.172 fA and RB=32.751`, then we set these values and continue.

In the next graph, we must report the so-called output admittance from the datasheet.

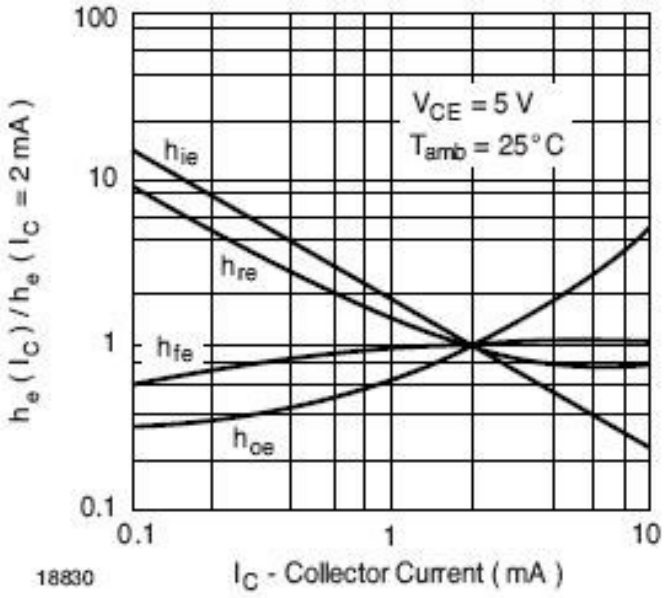


Figure 8. Relative h-Parameters vs. Collector Current

Now, we get: `VAF=139.172.`

Set the value found and continue with the next graph from the datasheet: `hfe` versus current collector.

From this curve, we can extract:

```
BF=212.95, IKF=208.44
mA, ISE=65.20fA,
NE=1.37, NK=0.839.
```

And get

```
BR=0.608, IKR=2.152,
ISC=13.68 fA, NC=1.80,
and RC=0.86 Ohm.
```

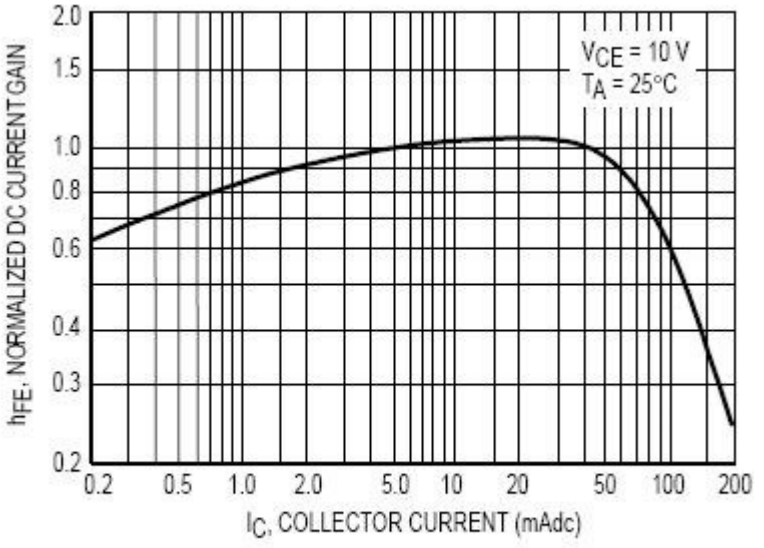


Figure 1. Normalized DC Current Gain

As usual, fix the data and see capacitances graph.

Input `Cob` data and get the curve.

Extracted data are:

```
CJC=3.968pF,
VJC=0.833V,
MJC=0.316.
```

Input data for `Cib` and we get.

From which we derive:

```
CJE=6.808pF,
VJE=1.319V,
MJE=0.477.
```

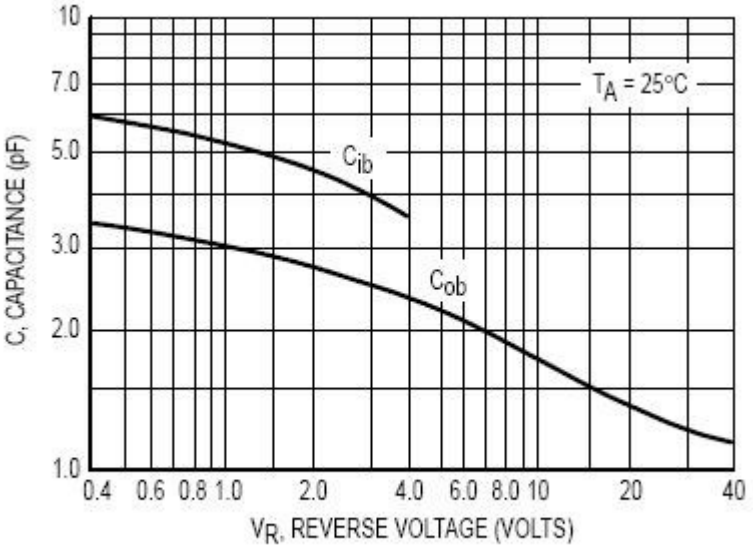


Figure 5. Capacitances

Check on Fixed to set the data. We have already estimated `TF=530ps`. Then we can enter this value and fix it.

Remain to be determined `XTF`, `VTF`, `ITF`. If we input data couples of values from the graphic.

Set `XTF`, `VTF`, `ITF` to their default values (10, 10, 1), we will see that the curve starts to match datasheet curve.

With a few attempts, we can have a good correspondence with the curve of the gain with the following values:

`TF=670 ps, XTF=150, VTF=10, ITF1=1.`

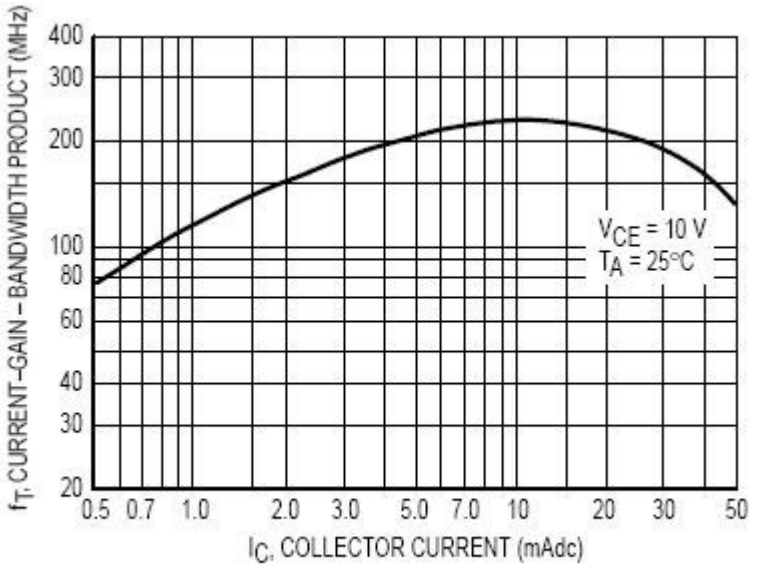


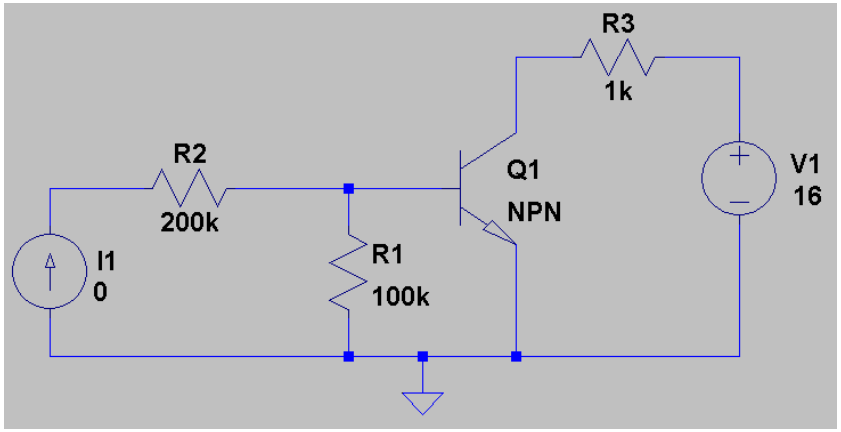
Figure 6. Current–Gain – Bandwidth Product

Finally, the model BC548A has the following expression:

```
.model BC548A NPN( Is=8.172f Xti=3 Eg=1.11 Vaf=139.172
+ Bf=212.95 Ise=62.50f Ne=1.37 Ikf=208.44m Nk=.839 Xtb=0
+ Br=0.608 Isc=13.68f Nc=1.80 Ikr=2.152 Rc=.86
+ Cjc=3.968p Mjc=.316 Vjc=.833 Fc=.5 Cje=6.808p Mje=.477
+ Vje=1.319 Tr=10n Tf=670p Itf=1 Xtf=150 Vtf=10)
```

4. Modelling of Customised BJT Transistor in LTspice

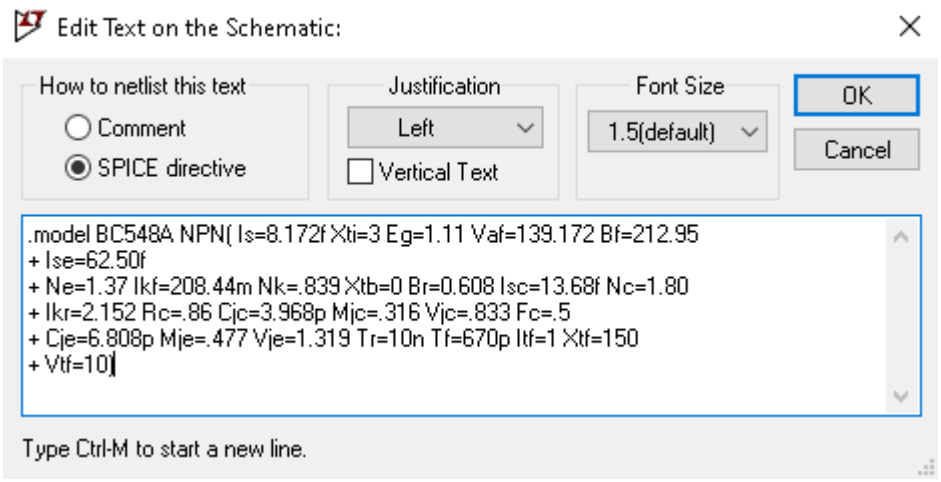
For testing the customised BJT transistor create the schematic of the circuit given below in LTspice.



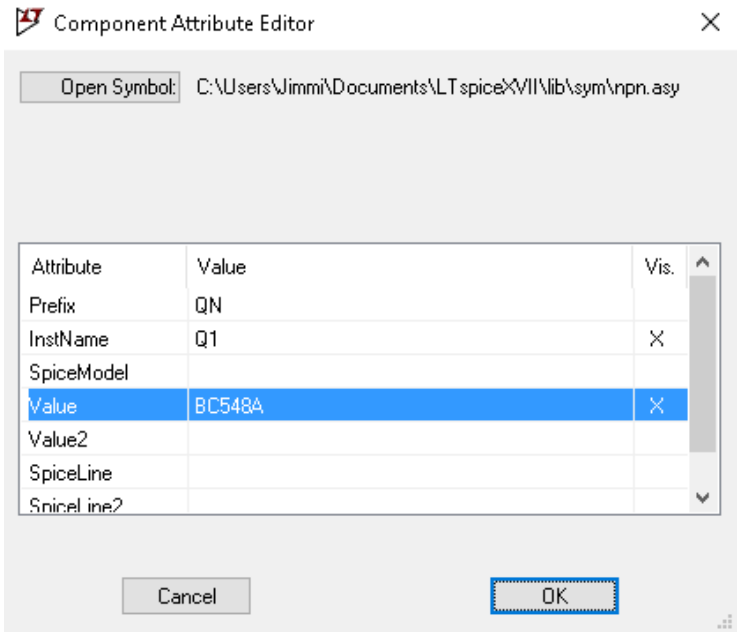
Notice in this common emtter BJT transistor circuit, at the collector there are R3 and voltage source V1 providing DC biasing of the circuit and at the base R1 and R2 resistors and a current source I1.

Create a Spice directive that include the device definition of the customised BJT transistor as shown below.

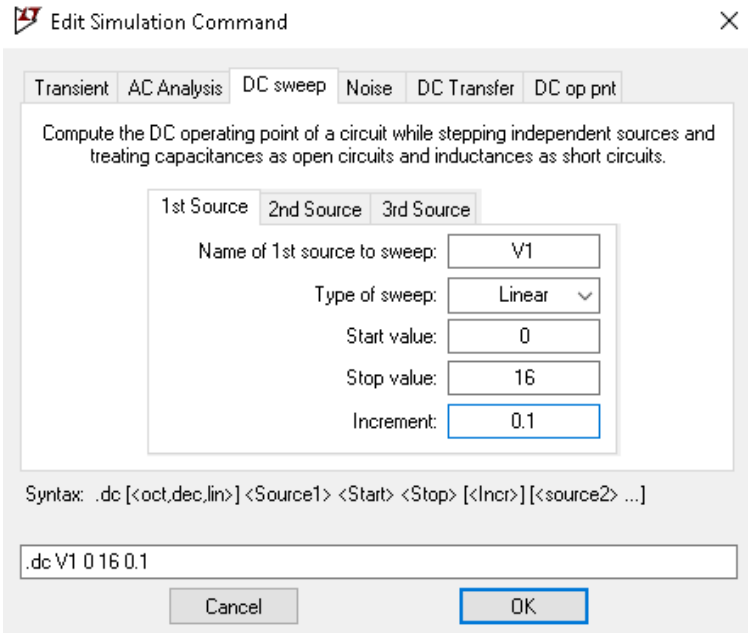
```
.model BC548A NPN( Is=8.172f Xti=3 Eg=1.11 Vaf=139.172
+ Bf=212.95 Ise=62.50f Ne=1.37 Ikf=208.44m Nk=.839 Xtb=0
+ Br=0.608 Isc=13.68f Nc=1.80 Ikr=2.152 Rc=.86 Cjc=3.968p
+ Mjc=.316 Vjc=.833 Fc=.5 Cje=6.808p Mje=.477 Vje=1.319
+ Tr=10n Tf=670p Itf=1 Xtf=150 Vtf=10)
```

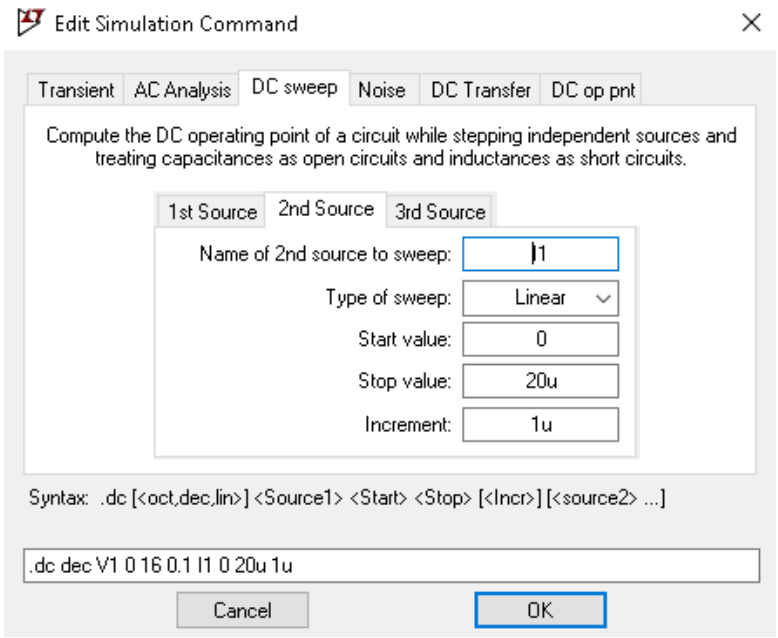


Assign the NPN transistor in the circuit for this customised BJT transistor.



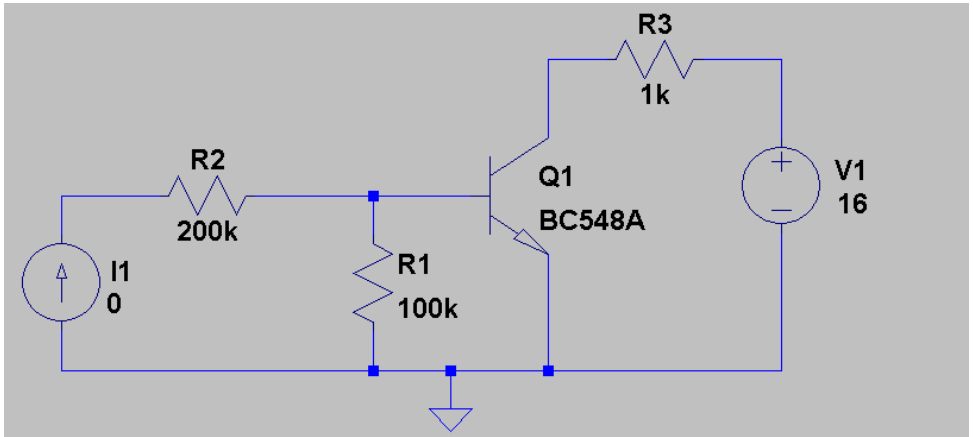
Test the circuit with the customised BJT transistor by plotting the current to voltage curve characteristics of the given BJT transistor.





.dc dec V1 0 16 0.1 I1 0 20u 1u

The final schematic of the customised BJT transistor circuit is shown in the following figure.



For plotting the current to voltage curve characteristics of the customised BJT transistor, probe the current on the leg where the 1 kΩ line goes into the transistor (the collector).

A special symbol (i.e. a magnifying glass symbol) will show up if one hovers over the leg.

The plot given in the figure below is the voltage-to-current characteristics of the customised BJT.