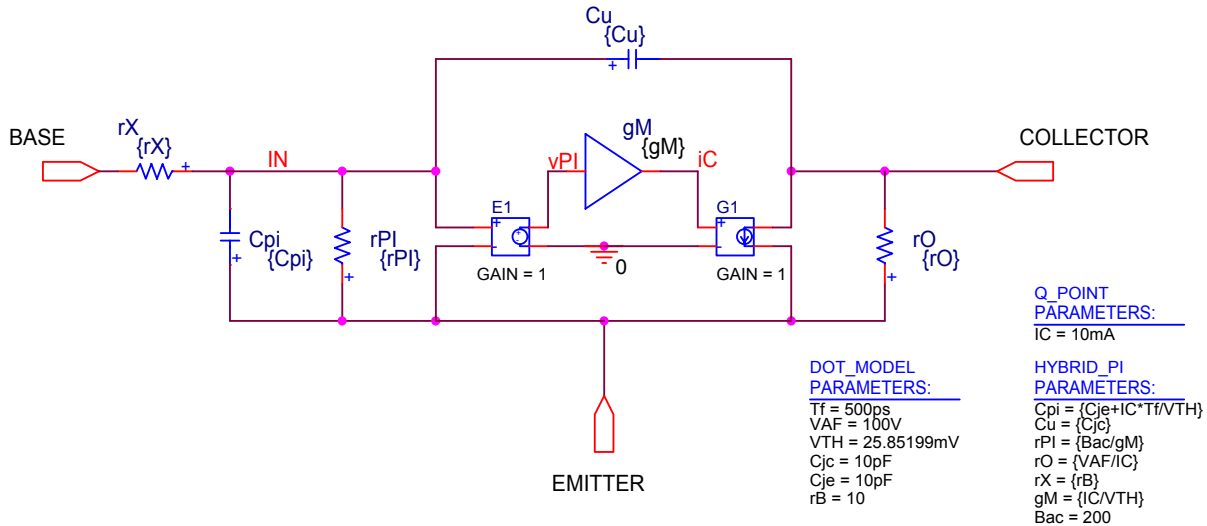# ECE 304: Making a Hybrid-π Sub-circuit

Schematic

FIGURE 1

The hybrid-π model of the bipolar transistor with g_M usable as a variable

Figure 1 is the PSPICE hybrid-π model of the bipolar transistor valid for high frequencies. The GAIN part allows use of a variable small-signal transconductance g_M[1]. Three parameter lists are added. The list HYBRID PI PARAMETERS provides the hybrid-π parameters needed to specify the circuit. Numbers can be used here, taken from the PSPICE OUTPUT file. In Figure 1, however, the hybrid-π parameters are calculated using •model parameters from the list DOT MODEL PARAMETERS. These simple formulas can be changed. The •model list and the Q-point current I_C can be omitted if numbers are used for the hybrid-π parameters.

The circuit of Figure 1 is complex, and in most circuits several transistors are used. If we make a small-signal equivalent circuit with many transistors, it is handy to convert the hybrid-π model to a PSPICE SUB-CIRCUIT. The steps outlined below are described in detail in Herniter's book[2], §7.G, pp. 458-472 with the needed menus.

1. Create the sub-circuit and make its connections attach via PORTS
2. NAME THE SUB-CIRCUIT → here it is called HYBRIDPI
3. Create a netlist as shown in Figure 2. In Figure 1, named nodes make the netlist readable.

```
* source HYBRIDPI
•SUBCKT HybridPI BASE COLLECTOR EMITTER
* Use a parameter list to set parameter values
E_gM        IC 0 VALUE {{gM} * V(VPI)}
E_E1        VPI 0 IN EMITTER 1
G_G1         COLLECTOR EMITTER IC 0 1
R_rPI        EMITTER IN {rPI}
C_Cu        IN COLLECTOR {Cu}
R_rO        EMITTER COLLECTOR {rO}
C_Cpi        EMITTER IN {Cpi}
R_rX       IN BASE {rX}
•ENDS
```

FIGURE 2

Sub-circuit netlist; a comment line (*) has been added using the NOTEPAD text editor to remind the user to add a parameter listing when this sub-circuit is used

---

[1] Parts E and G cannot use variables for their gain parameters, only numerical values.

[2] Marc E. Herniter, *Schematic Capture with Cadence PSPICE*, Second Edition, Prentice Hall, '03

 10/19/2002

4. Establish a sub-circuits library
5. Edit the standard symbol for the sub-circuit
6. Add the sub-circuit library to the list of GLOBAL libraries

Using the hybrid-π sub-circuit

The sub-circuit contains the hybrid-π parameters C_μ, C_π and so forth that have to be specified using a parameter box. The required parameter box is labeled HYBRID PI in Figure 1 and, if numerical values from the PROBE output file are used, this is the only parameter box needed. However, if you want to look at the parametric dependence on Q_point current I_C, or if you want to check the circuit dependence on •model parameters based upon formulas for the hybrid-π components, the extra parameter boxes are needed.

Multiple instances

It often happens that several transistors with different hybrid-π parameters are needed. This can be accomplished by pasting the sub-circuit into the schematic, highlighting it by left-clicking with the mouse, right-clicking, and selecting EDIT PSPICE MODEL. The PSPICE MODEL EDITOR menu of Figure 3 appears.
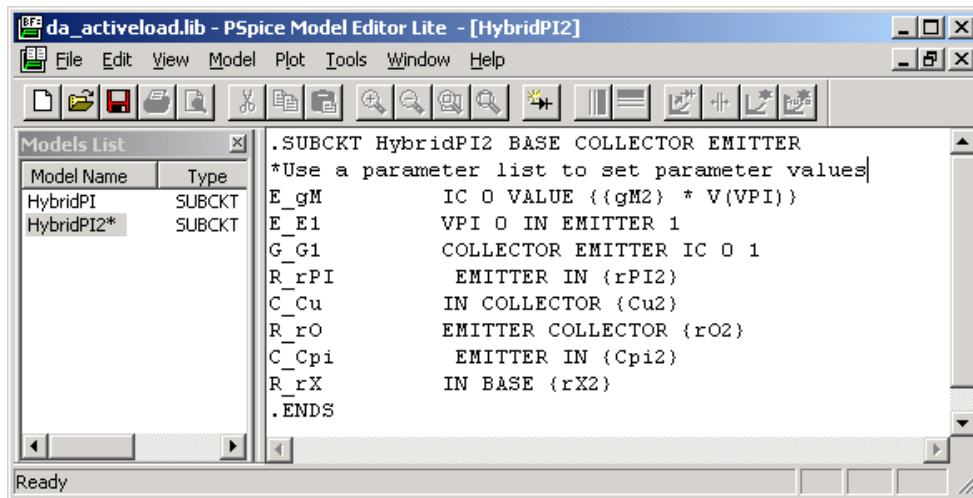

FIGURE 3

Creating a second instance of the hybrid π model called HybridPI2 with parameter names different from those in the original model called HybridPI.

The name of the model can be changed to HybridPI2, for instance, and the parameter names can be changed to gM2, rPI2 and so forth. Then the new model can be saved. To convert the pasted sub-circuit to refer to this new parameter list, right-click on the symbol of the sub-circuit to be changed and choose EDIT PROPERITES. Figure 4 shows the PROPERTY EDITOR with the VALUE and IMPLEMENTATION values changed from HYBRIDPI to HYBRIDPI2 to invoke the HYBRIDPI2 model.
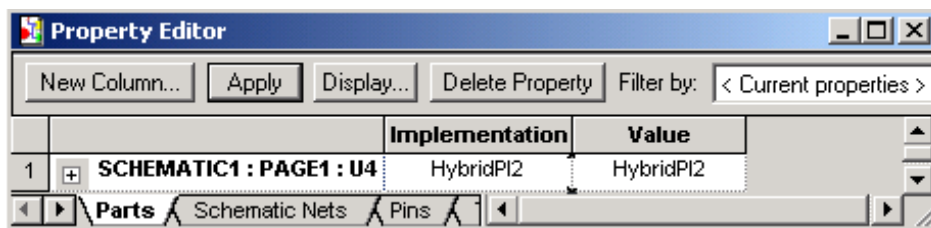

FIGURE 4

Changing the IMPLEMENTATION and VALUE entries of a second part to HYBRIDPI2 to make this part refer to model HYBRIDPI2 instead of the part HYBRIDPI
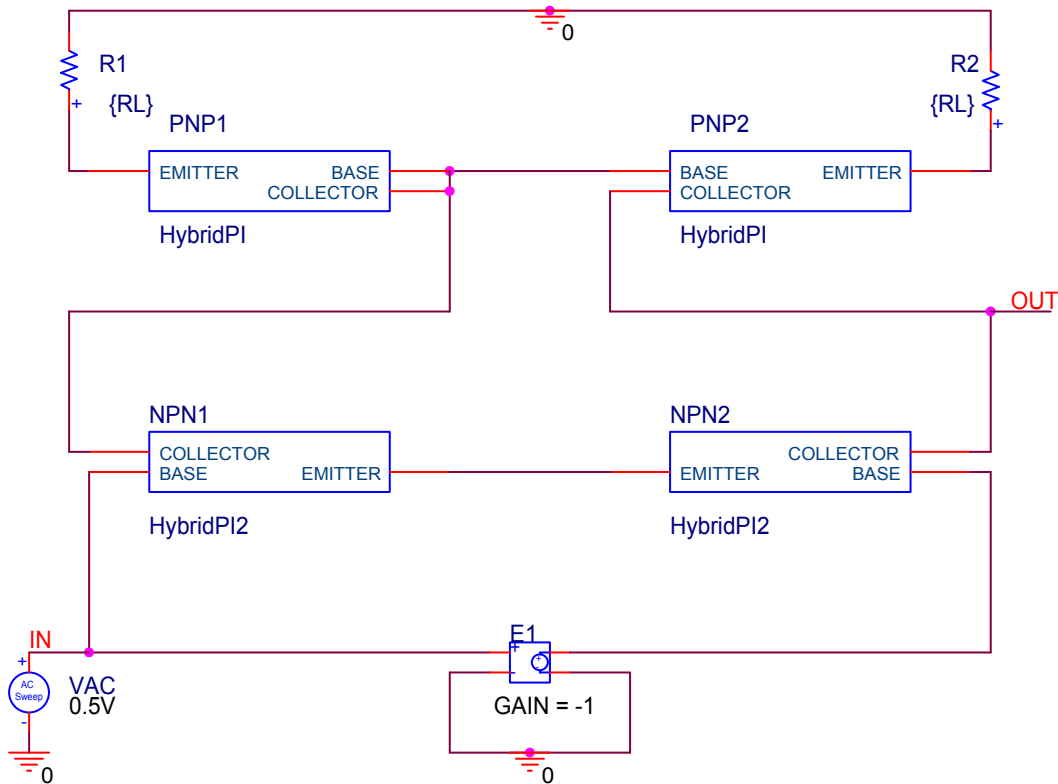
An example applying this procedure to a diff amp with active load is shown in Figure 5.

FIGURE 5

Small-signal implementation of a differential amplifier with active load and difference-mode excitation; the NPN transistors have model parameters with different names than the PNP's, which allows the NPN parameters to be varied independently from the PNP-parameters. The parameter β_{AC} can be filled in from the OUTPUT Q-point data. It is used only to calculate r_π, and is not a parameter of the sub-circuit HYBRIDPI.

## Examples of performance analysis plots using the hybrid-π sub-circuit
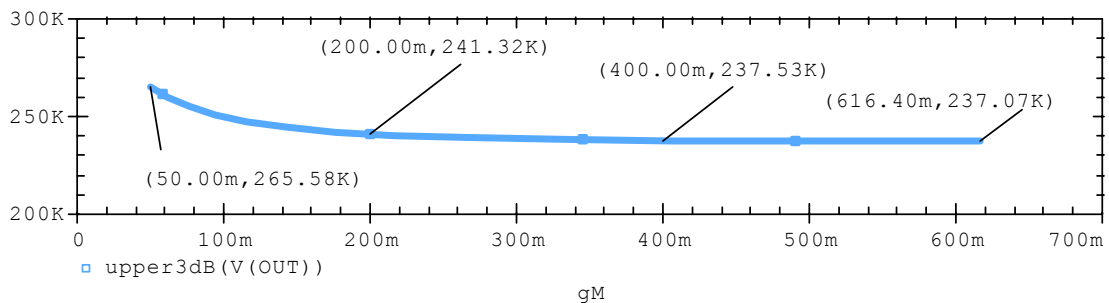
FIGURE 6

Variation of 3dB corner frequency with transconductance of mirror transistors, g_M; this plot is difficult to generate without your own hybrid-π sub-circuit

10/19/2002
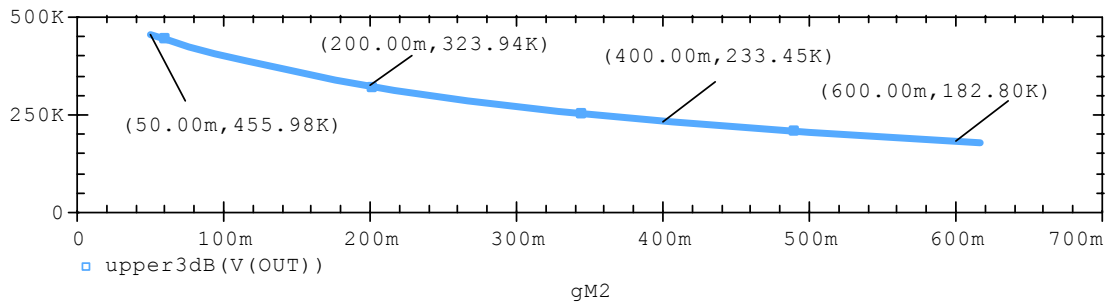
FIGURE 7
  Variation of 3dB corner frequency with the transconductance g_{M2} of the lower (output) transistors; this plot is hard to obtain without your own hybrid-π sub-circuit
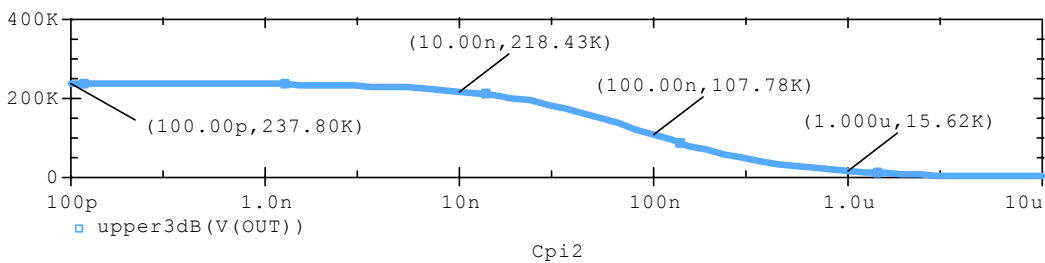
FIGURE 8
  Direct sweep of the hybrid-π model parameter C_π; until $C_\pi > 10nF$, it has little effect on the corner frequency of this amplifier; varying T_F or C_{je} in •model statement will change C_π, but neither a parametric sweep nor a performance analysis can be done
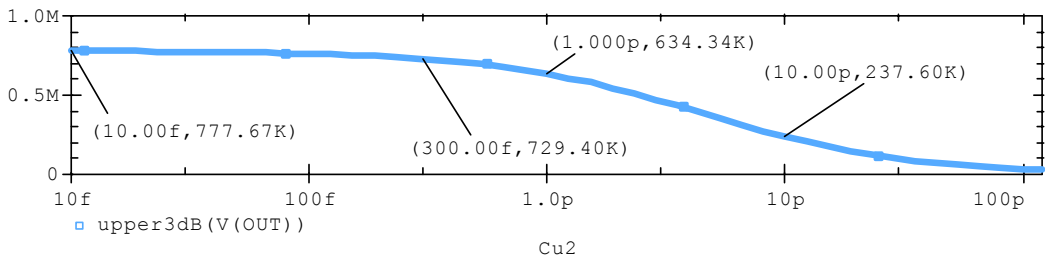
FIGURE 9
  Variation of upper 3dB frequency on C_μ of the output transistors; above C_μ = 300fF the corner frequency drops quickly with C_μ; this plot might be obtained by varying C_{jc} in •model statement, but a parametric sweep or performance analysis cannot be done

Utility of the hybrid-π sub-circuit

It is possible to run the full blown transistor model of a circuit in an AC simulation with various PSPICE •model parameters, so why not do that instead of inventing your own small-signal model? Mainly the advantages are in exploring how the circuit works, as part of the design process. There are some minor conveniences as well, due to the way PROBE works for AC simulations.

1.   Your own hybrid-π model allows you to change the hybrid-π circuit parameters directly, as shown in Figure 6-Figure 8. If you use the full-blown circuit you have access to the PSPICE •model parameters, but not the hybrid-π model parameters. Hence, you have to guess what changes in the •model parameters will cause the changes you want in the hybrid-π parameters. For some parameters, like rX, it is easy to change rB to get the rX you want. But

10/19/2002

for others, like g_M, it may be difficult, and there may be no •model parameter that changes only the one hybrid-π parameter you want to look at.

2. Following up on Point 1, if you want to make an AC analysis for several values of a hybrid-π model parameter, you can't do it directly in the full-blown circuit because you don't have access to these parameters. But, you also can't do this AC analysis using a PARAMETER SWEEP with a VALUE LIST of a •model parameter, even though you have access! (It will run, but only the first value on the list is used, and the successive sweeps keep using this value). You <u>can</u> run a separate AC analysis for each selected value of •model parameter (say, by introducing separate simulation profiles), and then assemble the results on one plot by using the menu FILE/APPEND WAVEFORM. However, for either hybrid-π model parameters or •model parameters, with your own hybrid-π model you can run AC analyses using the PARAMETER SWEEP option directly and get all the curves on the same plot with no hassle.

3. As an extension of Point 2, because PSPICE will not allow you to use the PARAMETRIC SWEEP option for a •model parameter in an AC analysis, you also cannot run a PERFORMANCE ANALYSIS. But, using your own hybrid-π model, you <u>can</u> use the parametric sweep option for both •model parameters and hybrid-π parameters to do performance analysis (for example, Figure 7 − Figure 9).

4. If you are interested in midband, with the hybrid-π model you can use a DC simulation instead of an AC simulation. (Of course, the full-blown circuit cannot do this even at midband, because it needs an AC analysis to construct a small-signal model to work with). PROBE has more flexibility for DC than for AC analysis, making parameter sweeps and performance analysis based on these sweeps a lot more convenient using DC rather than AC[3]. Using your own hybrid-π model at midband can be handy.

---

[3] At midband, there are no capacitors. The hybrid-π model contains only high frequency capacitors, and at midband these capacitors should be treated as open circuits. Using a DC analysis automatically treats these capacitors as open circuits, so the hybrid-π model works well, and you don't need a new sub-circuit that has no capacitors.