Ac equivalent circuit of bjt

Article : Andy Collinson Email : Introduction The primary function of a "model" is to predict the behaviour of a device in a particular operating region. At dc the bipolar junction transistor (BJT) and some of its biasing techniques have already been described, see these articles:BJT Biasing Transistor as a Switch The behaviour of the BJT in the sinusoidal ac domain is quite different from its dc domain. At dc the BJT usually works at in either saturation or cutoff regions. In the ac domain the transistor works in the linear region and effects of capacitance between terminals, input impedance, output conductance, etc all have to be accounted for. The small-signal ac response can be described by two common models: the hybrid model and re model. The models are equivalent circuits (or combination of circuit elements) that allow methods of circuit analysis to predict performance. Transistor Hybrid Model To demonstrate the Hybrid transistor model an ac equivalent circuit must be produced. The left hand diagram below is a single common emitter stage for analysis. At ac the reactance of coupling capacitors C1 and C2 is so low that they are virtual short circuits, as does the bypass capacitor C3. The power supply (which will have filter capacitors) is also a short circuit as far as ac signals are concerned. The equivalent circuit is shown above on the right hand diagram. The input signal generator is shown as Vs and the generators source impedance as Rs. As RB1 and RB2 are now in parallel the input impedance will be RB1 || RB2. The collector resistor RC also appears from collector to emitter (as emitter is bypassed). See below : The blue rectangle now represents the small signal ac equivalent circuit and can now start work on the hybrid equivalent circuit. The hybrid model has four h-parameters. The "h" stands for hybrid because the parameters are a mix of impedance, admittance and dimensionless units. In common emitter the parameters are: hie input impedance (Ω) hre reverse voltage ratio (dimensionless) hfe forward current transfer ratio (dimensionless) hoe output admittance (Siemen) Note that lower case suffixes indicate small signal values and the last suffix indicates the mode so hie is input impedance in common emitter, hfb would be forward current transfer ration in common base mode, etc. The hybrid model for the BJT in common emitter mode is shown below: The hybrid model is suitable for small signals at mid band and describes the action of the transistor. Two equations can be derived from the diagram, one for input voltage vbe and one for the output ic: vbe = hie ib + hre vce ic = hfe ib + hoe vce If ib is held constant (ib=0) then hre and hoe can be solved: hre = vbe / vce | ib = 0 hoe = ic / vce | ib = 0 Also if vce is held constant (vce=0) then hie and hfe can be solved: hie = vbe / ib | vce = 0 hfe = ic / ib | vce = 0 These are the four basic parameters for a BJT in common emitter. Typical values are hre = 1 x10-4, hoe typical value 20uS, hie typically 1k to 20k and hfe can be 50 - 750. The H-parameters can often be found on the transistor datasheets. The table below lists the four h-parameters for the BJT in common base and common collector (emitter follower) mode. h-parameters of Bipolar Junction Transistor Common Base Common Emitter Common Collector Definitions Input Impedance with Output Short Circuit Reverse Voltage Ratio Input Open Circuit Forward Current Gain Output Short Circuit Output Admittance Input Open Circuit H-parameters are not constant and vary with temperature, collector current and collector emitter voltage. For this reason when designing a circuit the hybrid parameters should be measured under the same conditions as the actual circuit. Below are graphs of the variation of h-parameters with temperature and collector current.Variation of h-parameters with Collector Current Variation of h-parameters with Temperature Output Characteristic Curves The graph below, shows the output characteristic curves for a 2N3904 transistor in common emitter mode. The output curves are quite useful as they show the change in collector current for a range of collector emitter voltages. Output Characteristics for 2N3904 In addition, because the base currents are also known, then two small signal parameters, hfe and hoe can be determined straight from the graph. The almost flat portion of the curves, shows that the transistor behaves as a constant current generator. However, in saturation the steepness of the curves (between 0 and 0.4 Vce) show a sharp drop in hfe. This is an important fact to consider, if using the transistor as a switch. Typical h-parameter Values h-parameters are not constant and vary with both temperature and collector current. Typical values for 1mA collector currents are: hie = 1000 Ω hre = 3 x 10-4 hoe = 3 x 10-6S hfe = 250 Examples CE Stage with RE Bypassed The h-parameter model will be applied to a single common emitter (CE) stage with the emitter resistor (RE) bypassed. The model will be used to build equations for voltage gain, current gain, input and output impedance. The circuit is shown below: The small signal parameter hreVce is often too small to be considered so the input resistance is just hie. Often the output resistance hoe is often large compared wi the the collector resistor RC and its effects can be ignored. The h-parameter equivalent model is now simplified and drawn below: Input Impedance Zi The input impedance is the parallel combination of bias resistors RB1 and RB2. As the power supply is considered short circuit at small signal levels then RB1 and RB2 are in parallel. RBB will represent the parallel combination: RBB = RB1 || RB2 = RB1 RB2 RB1 + RB2 As RBB is in parallel with hie then:Zi = RBB || hie Output Impedance Zo As hfeIb is an ideal current generator with infinite output impedance, then output impedance looking into the circuit is: Zo = RC Voltage Gain Av Note the − sign in the equation, this indicates phase inversion of the output waveform.Vo = -Io RC = -hfe Ib RC as Ib = Vi / hie then: Current Gain Ai The current gain is the ratio Io / Ii. At the input the current is split between the parallel branch RBB and hie. So looking at the equivalent h-parameter model again (shown below): The current divider rule can be used for Ib: At the output side, Io = hfe Ib re-arranging Io / Ib = hfe Ai = Io = Io Ib = hfe RBB Ii Ib Ii RBB + hie If RBB >> hie then, CE Stage with RE Unbypassed The h-parameter model of a common emitter stage with the emitter resistor unbypassed is now shown. The model will be used to build equations for voltage gain, current gain, input and output impedance. The circuit is shown below: As in the previous example, RB1 and RB2 are in parallel, the bias resistors are replaced by resistance RBB, but as RE is now unbypassed this resistor appears in series with the emitter terminal. The hybrid small signal model is shown below, once again effects of small signal parameters hreVce and hoe have been omitted. Input Impedance Zi The input impedance Zi is the bias resistors RBB in parallel with the impedance of the base, Zb. Zb = hie + (1 + hfe) RE Since hfe is normally much larger than 1, the equation can be reduced to: Zb = hie + hfe RE Zi = RBB || (hie + hfe RE) Output Impedance Zo With Vi set to zero, then Ib = 0 and hfeIb can be replaced by an open-circuit. The output impedance is: Zo = RC Voltage Gain Av Note the − sign in the equation, this indicates phase inversion of the output waveform. Vo = -Io RC = -hfe Ib RC As Zb = hie + hfe RE often the product hfeRE is much larger than hie, so Zb can reduced to the approximation: Zb ≈ hfeRE Current Gain Ai The current gain is the ratio Io / Ii. At the input the current is split between the parallel branch RBB and Zb. So looking at the equivalent h-parameter model again (shown below): The current divider rule can be used for Ib: At the output side, Io = hfe Ib re-arranging Io / Ib = hfe Ai = Io = Io Ib = hfe RBB Ii Ib Ii RBB + Zb Example CE Stage The hybrid parameters must be known to use the hybrid model, either from the datasheet or measured. In the above circuit, Zi, Zo, Av, and Ai will now be calculated. Note that this CE stage uses a single bias resistor RB1 which is the value RBB. Zi Zb = hie + (1 + hfe) RE = 0.56k + (1 + 120) 1.2k = 145.76k Zi = RB || Zb Zi = 270k || 145.76k = 94.66k Zo Zo ≈ 5.6k Av Av = − 4.61 Ai = 270k x 120 270k + 145.76k Ai = 77.93 Summary The hybrid model is limited to a particular set of operating conditions for accuracy. If the device is operated at a different collector current, temperature or Vce level from the manufacturers datasheet then the h parameters will have to be measured for these new conditions. The hybrid model has parameters for output impedance and reverse voltage ratio which can be important in some circuits. Free Practice With Testbook Mock Tests Answer: -1.1 - -0.9 This question was previously asked in GATE EC 2015 Official Paper: Shift 2 Solution: Download Question With Solution PDF ›› Concept: For BJT transistor when base and collector are shorted, it acts as a diode-connected load and its load value is given as: \(Load = \frac{1}{{{g_m}}}\) Where gm is the transconductance of the transistor. Also, for common source configuration gain is given as: Av = -gm Ro Where Av is voltage gain, gm is the transconductance of the input signal transistor and Ro is the output resistance. Calculation: In the given circuit, trans-conductance for both the transistors will be the same and will be equal to gm, as the transistors are identical. For the given circuit, the upper transistor acts as a diode-connected load. \(Load = \frac{1}{{{g_m}}}\) This load comes in parallel with the output resistance of the input transistor (ro). So, \({R_o} = {r_o}||\frac{1}{{{g_m}}}\) But, \({r_o} > > \frac{1}{{{g_m}}}\) Therefore, \({R_o} \approx \frac{1}{{{g_m}}}\) So, \({A_v} = - {g_m} \times \frac{1}{{{g_m}}} = - 1\) Download Question With Solution PDF ››
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