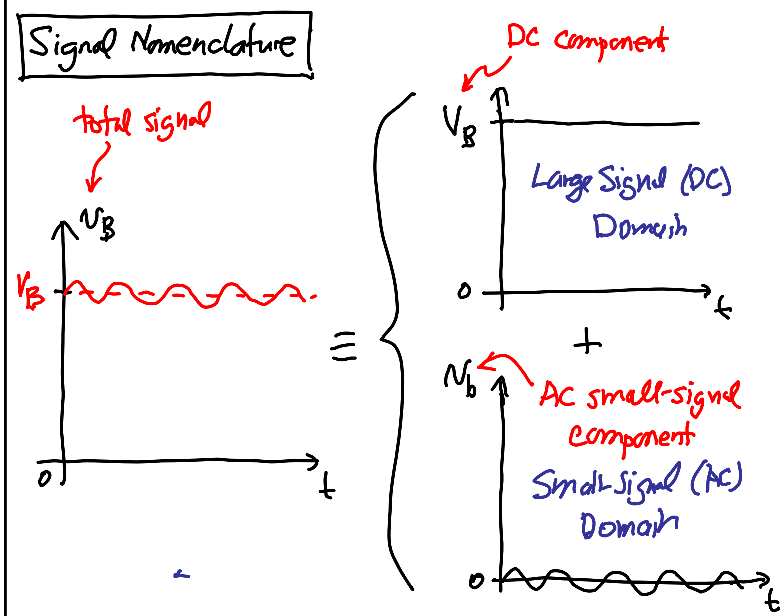
Lecture 21: Transistors As Amplifiers

- Announcements:
- HW#6 online and due Friday Oct. 12 via Gradescope
- Passed Midterm 1 Exams with solutions handed back last time
  - Remaining midterms coming back in lab section
  - Will discuss grading next time
- Lab#5 online (this is your first project)
  - Due Tuesday, Oct. 30, 5 p.m.
- ------------------------------------
- Lecture Topics:
  - Small Signal Analysis
    - —Linearizing Non-Linear Elements
    - —DC and Small-Signal AC Components
    - —Taylor Series Approximation
  - Transistors As Amplifiers
  - Small-Signal Model for the BJT
- ------------------------------------
- Last Time:
- Discussing how Taylor series leads to the small-signal method for solving nonlinear problems
- Now, continue with this …

- Need a convenient method to solve this nonlinear circuit, i.e., need some way to linearize it
- Such linearization is possible for analog circuits when the signals can break down into DC and small-signal AC components



$$v_B \triangleq V_B + v_b$$

Total Signal: lower case variable, upper case subscript; or upper case variable, lower case subscript

DC Component: upper case variable, upper case subscript

AC Small-Signal: lower case variable, lower case subscript

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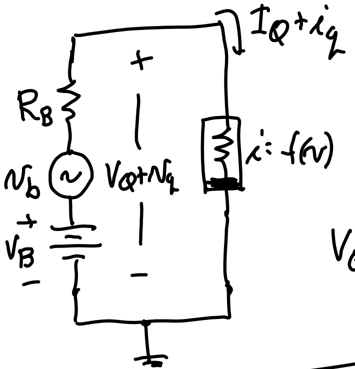
Using this notation:



$V_Q + v_q = V_B + v_b - f[V_Q + v_q] R_B$

For this: Use Taylor Series approx. for $f(v)$ around $v = V_Q$.

Review Taylor Series:

⇒ function $f(x)$ can be approximated for points near $x = a$ by:

$$f(x) = f(a) + f'(a)(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \dots + \frac{f^{(n)}(a)}{n!}(x-a)^n + \dots$$

1st derivative: $\left.\frac{df}{dv}\right|_{v=a}$ $\left\{ \left.\frac{di}{dv}\right|_{v=a} \right.$

$\approx f(a) + f'(a)(x-a)$ for $(x-a)$ = small

linear! → easy to solve!

small-signal; total signal; bias point

$$V_Q + v_q = V_B + v_b - f[V_Q] R_B - f'(V_Q) v_q R_B$$

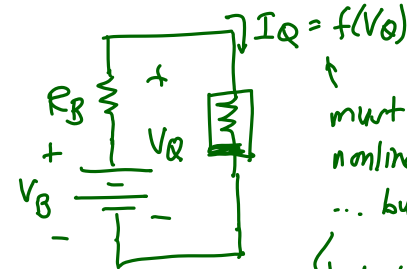
$$V_Q + v_q = V_B + v_b - I_Q R_B - \frac{R_B}{R_{ss}} v_q$$

Evaluate nonlinear fcn $I_Q = f(V_Q)$

$R_{ss} = \frac{1}{\left.\frac{\partial f}{\partial v}\right|_{V_Q}} \triangleq$ Small-signal resistance

⇒ can split this into equations → two ckts.

DC Components: $V_Q = V_B - I_Q R_B$

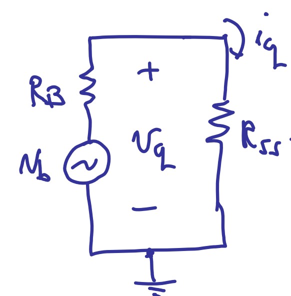


DC Circuit

↑ must deal w/ a nonlinear calculation ... but only one!

↳ Want: (V_Q, I_Q) operating pt.

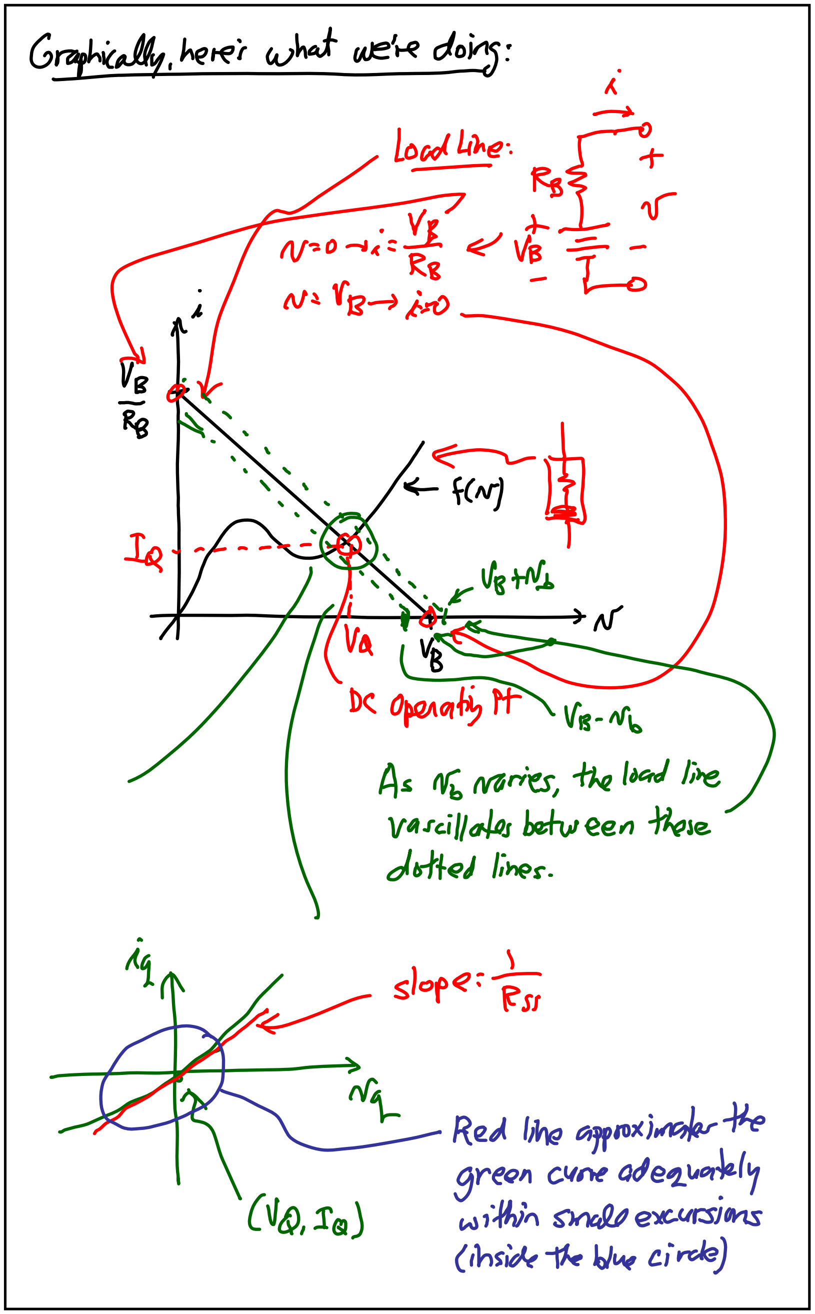
Small-Signal AC Components: $v_q = v_b - \frac{R_B}{R_{ss}} v_q$ ← linear!

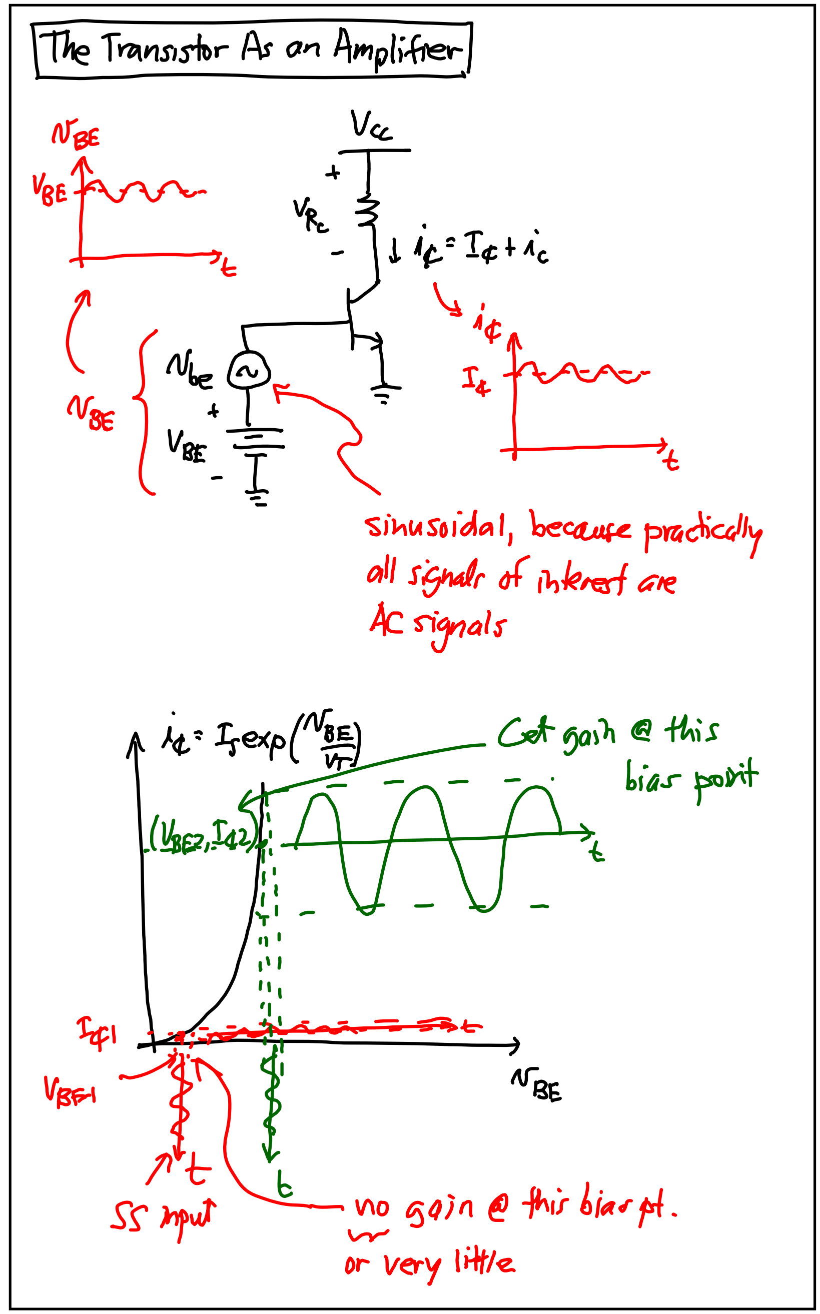


Small-Signal Ckt.

All linear analysis!

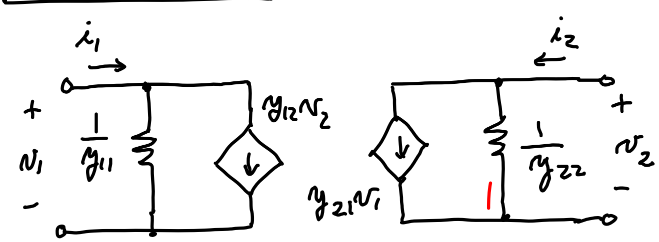
$R_{ss} = \frac{1}{\left.\frac{df}{dv}\right|_{V_Q}}$


Graphically, here's what we're doing:
Load Line:
v=0 → i = VB/RB
v = VB → i=0
f(v)
IQ
VQ
VB
DC Operating Pt
VB+vb
VB-vb
As vb varies, the load line vascillates between these dotted lines.
slope: 1/Rss
(VQ, IQ)
Red line approximates the green curve adequately within small excursions (inside the blue circle)


The Transistor As an Amplifier
VCC
vBE
VBE
vbe
sinusoidal, because practically all signals of interest are AC signals
iC
IC
Get gain @ this bias point
(VBE2, IC2)
IC1
VBE1
SS input
no gain @ this bias pt. or very little
vBE

- So far, we have shown how to obtain the small-signal circuit model for a two-terminal nonlinear resistor
- How about for three-terminal transistors?
- Look back to our general amplifier networks
- Any of the networks apply … but the most popular one is the y-parameter model:

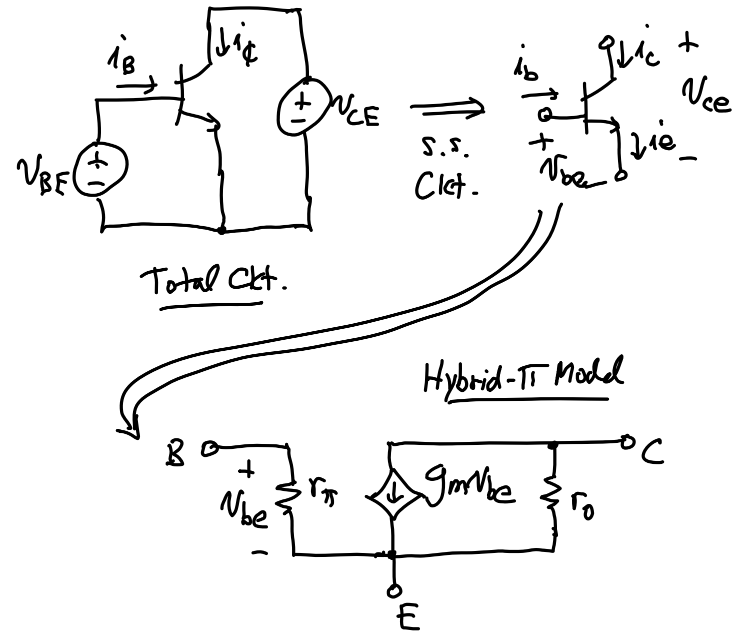
Y-Parameter Model



$$y_{11} = \frac{i_1}{v_1}\bigg|_{v_2=0} \qquad y_{21} = \frac{i_2}{v_1}\bigg|_{v_2=0}$$

$$y_{12} = \frac{i_1}{v_2}\bigg|_{v_1=0} \qquad y_{22} = \frac{i_2}{v_2}\bigg|_{v_1=0}$$

Small-Signal Models for Forward-Active BJTs



$v_{be}\uparrow \rightarrow i_b\uparrow \Rightarrow r_\pi = \frac{v_{be}}{i_b}$

$v_{be}\uparrow \rightarrow i_c\uparrow \Rightarrow g_m = \frac{i_c}{v_{be}}$

$v_{ce}\uparrow \rightarrow i_c\uparrow \Rightarrow r_o = \frac{v_{ce}}{i_c}$

Each of these determined by the bias pt.

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