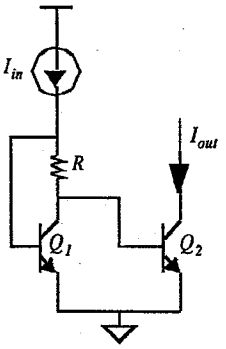
Name: Tom Lee **Solutions** Ph.D. Qualifying Examination 2007

STANFORD UNIVERSITY
Department of Electrical Engineering

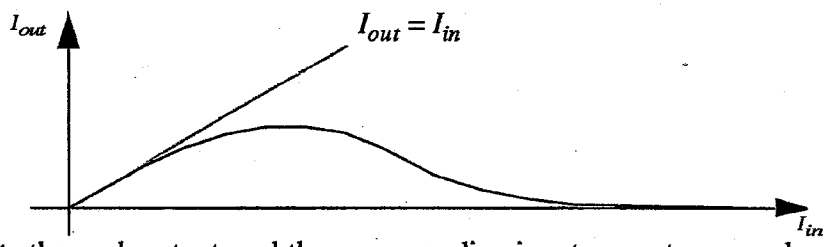
Bob Widlar is often considered to be the father of analog IC design. The following current source is but one of his many ingenious circuits (from the LM101A op-amp):

Assume that all components are ideal.



Plot the output current as a function of input current. Label any features of relevance.

Ans: A couple of quick observations enable a rough sketch. First, $V_{BE2} < V_{BE1}$ for any nonzero I_{in}. So, $I_{out} < I_{in}$ for all $I_{in} > 0$. There is a range of I_{in} (to be defined later) over which the drop across R is negligible, and thus over which I_{out} is approximately equal to I_{in}. But, the drop across R grows linearly, while V_{BE1} grows only logarithmically. So, V_{BE2} eventually decreases. At very high I_{in} the drop across R is large enough that V_{BE2} is essentially zero (V_{CEsat1} could be taken as ideally zero), and the output current heads to zero. The corresponding plot therefore looks roughly like this:



To compute the peak output, and the corresponding input current, we need an equation or two:

$$\left(I_{in}R = V_{BE1} - V_{BE2} = V_T \ln\frac{I_{in}}{I_{out}}\right) \Rightarrow I_{out} = I_{in}\exp\left(-\frac{I_{in}R}{V_T}\right). \qquad \text{(EQ 1)}$$

This equation is readily solved for the coordinates of the peak: $I_{in} = V_T/R$, $I_{out} = V_T/eR$. This circuit, known as a *peaking current source*, is useful because its output current is independent of input current (to first order), provided that the nominal input current is set to V_T/R. The circuit then produces an output current that is a factor of e smaller than that nominal value, even if the input current should deviate a bit from the nominal. Several may be combined to broaden the flatness, in a manner similar to filter design. Finally, the same topology functions for MOS implementations, although the numbers differ.