

## Two Active Loads for Differential Amplifiers:

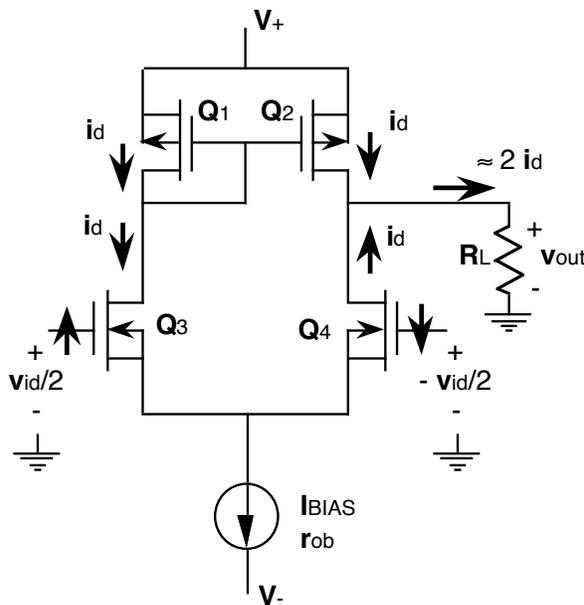
1. Current mirror load
2. Lee load

### 1. The current mirror load:

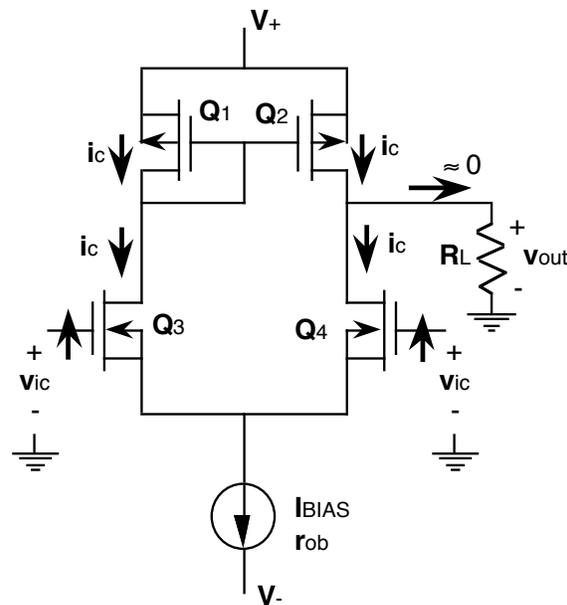
The current mirror load provides double-ended to single-ended conversion without suffering the loss of a factor of two in differential-mode gain (the common-mode gain is twice as large also, but still very small). It comes in a variety of versions (pnp, npn, n-MOS, p-MOS); the examples below use p-channel MOSFETs in the mirror loading an n-channel common-source differential gain stage.

We can begin to understand how the current mirror load functions by referring to the two figures below. The active nature of the load doubles the current delivered to the load with differential-mode inputs, and while not sending any current to the load with common-mode inputs. The results of a more detailed analysis are listed below the figures.

Difference-mode inputs:



Common-mode inputs:



A full analysis shows that with differential inputs,  $\pm v_{id}/2$ , as on the left above, the output,  $v_{out}$  is given as:

$$v_{out} \approx [2g_{m3}/(g_{o2} + g_{o4} + G_L)] v_{id}/2$$

and with common-mode inputs,  $v_{ic}$ , as on the right above, the output,  $v_{out}$  is given by:

$$v_{out} \approx [g_{ob}/2(g_{m2} + g_{o4} + G_L)] v_{ic} \approx [g_{ob}/2 g_{m2}] v_{ic}$$

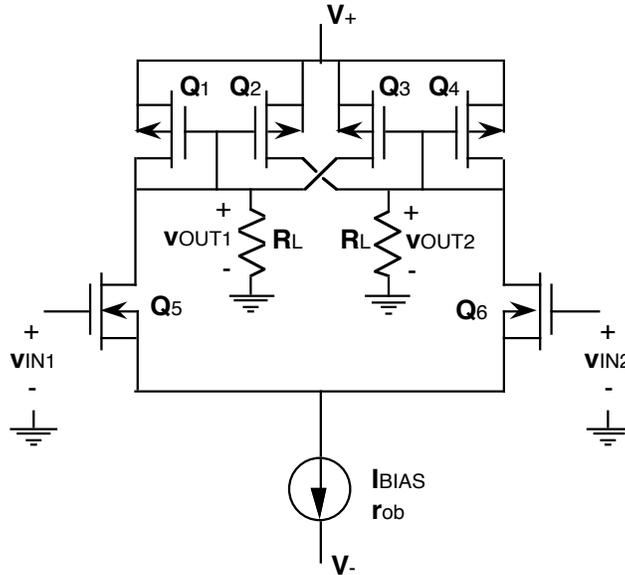
The total single-ended output for a pair of inputs to the stage is:

$$v_{out} \approx [2g_{m3}/(g_{o2} + g_{o4} + G_L)] (v_{i1} - v_{i2})/2 + [g_{ob}/2 g_{m2}] (v_{i1} + v_{i2})/2$$

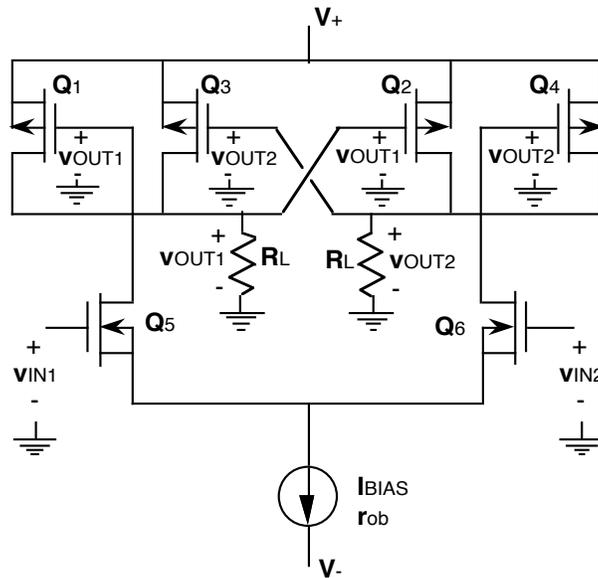
## 2. The Lee load

The Lee active load provides a typically high differential-mode gain and an unusually small common-mode gain. The conventional differential amplifier with a current-source load will have a common-mode gain of order unity, whereas the Lee Load yields a common-mode gain one to two orders of magnitude smaller [as much as something on the order of  $(V_{GS} - V_T)_{\min} / V_A$  times smaller].

The Lee Load as normally drawn is shown below, but it is somewhat easier to



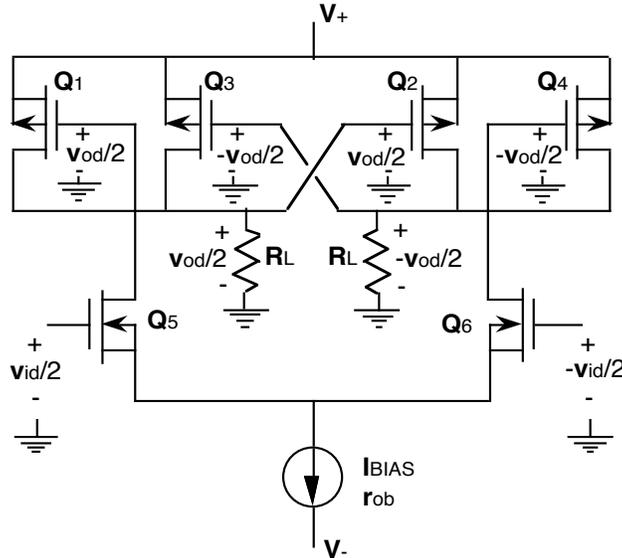
understand if it is redrawn as shown below. In this presentation it is easier to see how the two outputs are fed back to the inputs of the active loads so as to cancel each other out in difference-mode, and to re-enforce each other in common-mode.



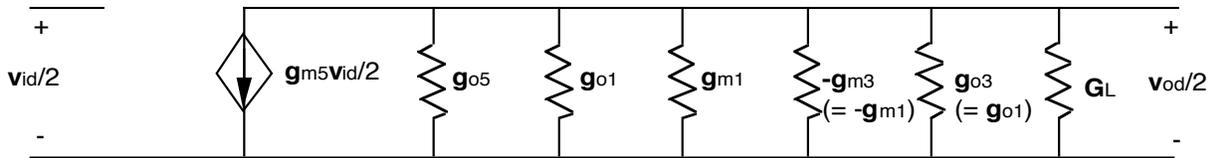
To analyze quantitatively the Lee Load performance, we can do small signal analyses using half-circuit techniques and difference-mode and common-mode inputs. We first consider difference-mode inputs, and then common-mode:

Difference-mode analysis:

The circuit drawn with difference-mode inputs is shown below:



The linear equivalent half-circuit of this amplifier with difference-mode inputs is as illustrated below. Note that the  $g_m v_{gs}$  generators for the p-channel MOSFETs are in parallel with  $v_{od}/2$ , and  $v_{gs}$  is  $+ - v_{od}/2$ , so the generators look like conductances of value  $+ - g_m$ , respectively.



Referring to the linear equivalent half-circuit, we see that

$$v_{od}/2 = [g_{m5}/(g_{o5} + g_{o1} + g_{o3} + g_{m1} - g_{m3} + G_L)] v_{id}/2 = [g_{m5}/(g_{o5} + 2 g_{o1} + G_L)] v_{id}/2$$

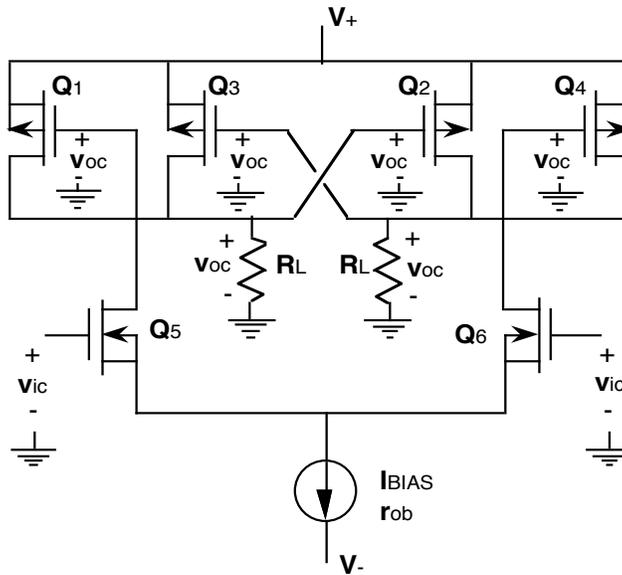
Thus the difference-mode voltage gain,  $A_{vd}$  is

$$A_{vd} = g_{m5}/(g_{o5} + 2 g_{o1} + G_L)$$

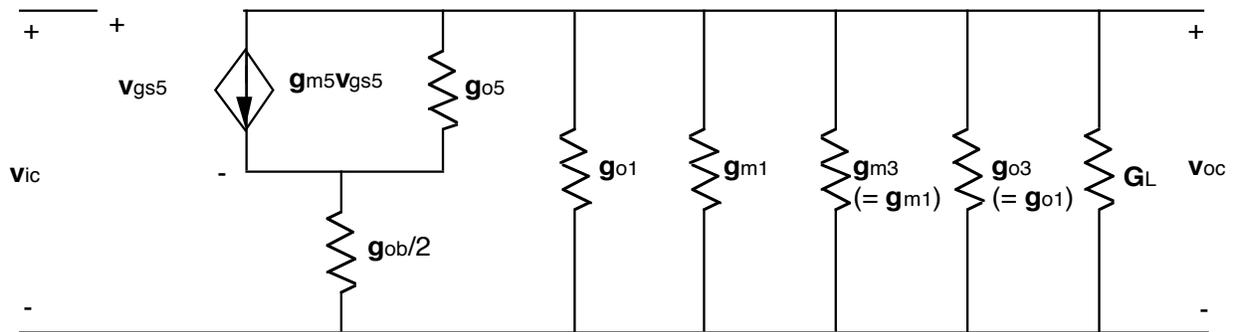
We see that the  $g_m$  factors in the denominator, which are the biggest factors there, are of equal magnitude, but of opposite sign, and thus cancel, resulting in a large difference-mode gain.

Common-mode analysis:

The circuit drawn with common-mode inputs is shown below:



The linear equivalent half-circuit of this amplifier with common-mode inputs is as illustrated below:



Referring to the linear equivalent half-circuit, we see that

$$v_{oc} \approx [g_{ob}/2(g_{o1} + g_{o3} + g_{m1} + g_{m3} + G_L)] v_{ic}$$

It is clear that this time the  $g_m$  terms are not going to cancel. Continuing we find that they in fact dominate the denominator:

$$v_{oc} \approx [g_{ob}/2(2g_{o1} + 2g_{m1} + G_L)] v_{ic} \approx [g_{ob}/4g_{m1}] v_{ic}$$

Thus the common-mode voltage gain,  $A_{vc}$  is approximately

$$A_{vc} \approx g_{ob}/4g_{m1}$$

$A_{vc}$  is typically quite small because  $g_{ob}$  will be very small, and  $g_{m1}$  will be much larger.

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