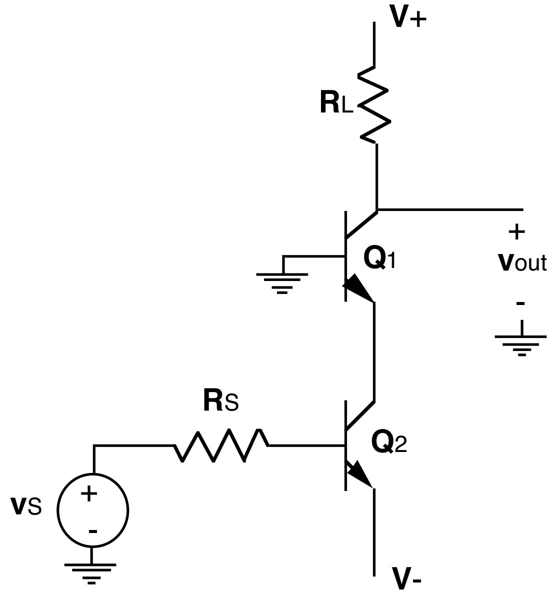
6.012 - Electronic Devices and Circuits
Fall 2003

The marvelous CASCODE:



cascode ≡ a two-transistor configuration formed of a common-emitter/ -source stage followed by a common-base/-gate stage

The cascode is a very useful two-transistor stage that provides the performance of a common-emitter/-source stage with a much smaller Miller effect and much larger output resistance. The stage was first introduced to get better high-frequency performance, and the higher output resistance was viewed as a bonus; now designers take advantage of both features in a variety of situations.

Miller Effect:

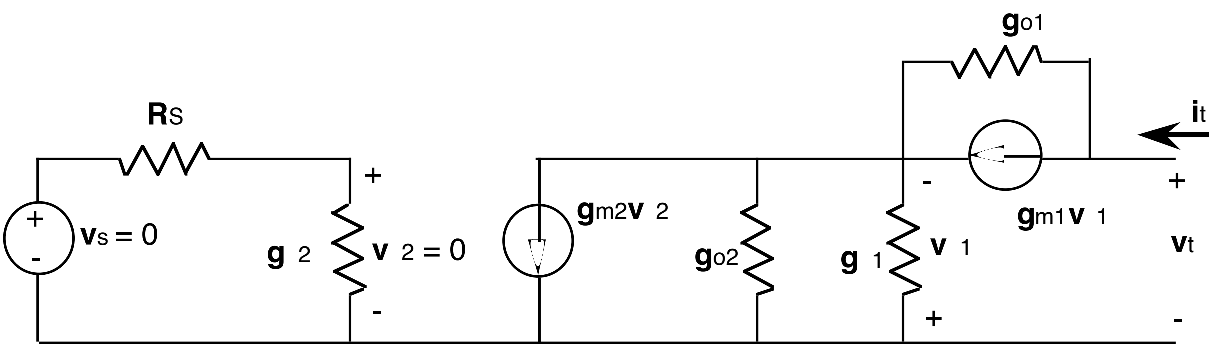
Using a common-base/-gate stage, with its low input resistance, to load a common-emitter/source stage means that the voltage gain of the latter stage will be small, and so it will have a greatly reduced Miller effect. It will still have the same high input resistance and large current gain as before, however.

The common-base/-gate member of this pair does not provide any additional current gain (i.e., its current gain is one), but it does provide voltage gain (as much as, or more than, a similarly biased common-emitter/ -source stage driving the same load). It also has a very large output resistance.

Together the cascode combination has the same overall current and voltage gains of a common-emitter/ -source stage, the same input resistance, and a larger output resistance (see below).[1]

<u>Output resistance</u>:

Consider the circuit sketched on the preceding page with zero signal input; apply a test voltage, v_t, to the output terminals and calculate the resulting current, i_t, to find the output resistance, $R_{out} \equiv v_t/i_t$. The small signal linear equivalent circuit is shown below (R_L has not been included; it is in parallel with this R_{out}):



We see immediately that $i_t = - (g_{o2} + g\ _1)\ v$, and at the one node in the circuit we can write

[1]The voltage gain is actually larger also because of the increased output resistance.

$$v \quad (g_{o2} + g \quad _1) + g_{m1}\, v \quad + g_{o1}\,(v_t + v \quad) \;=\; 0$$

We solve this for v , substitute the result into the expression for i_t, and find R_{out} to be:

$$R_{out} \;=\; \frac{g_{o1} + g_{o2} + g \quad _1 + g_{m1}}{g_{o1}\,(g_{o2} + g \quad _1)}$$

To see what this means, notice that if g_{o1} and g_{o2} are much smaller than $g \quad _1$, the numerator is approximately (+ 1) $g \quad _1$, and the denominator is approximately $g_{o1}\, g \quad _1$, so we have

$$R_{out}\ \text{(bipolar cascode)} \qquad \frac{(\quad + 1)}{g_{o1}} \;=\; (\quad + 1)\, r_{o1}$$

This result is valid for a bipolar cascode. For a MOSFET cascode the small signal model is the same as long as v_{bs} is zero on both devices,[2] however $g \quad _1$ is zero for a MOSFET so the approximation for R_{out} is different. The numerator is now approximately g_{m1}, and the denominator is $g_{o1}\, g_{o2}$, leading to

$$R_{out}\ \text{(MOSFET cascode)} \qquad \frac{g_{m1}}{g_{o1}\, g_{o2}} \;=\; \sqrt{\frac{K_2}{K_1}}\; A_{v,oc2}\, r_{o1}$$

where $A_{v,oc2}$ is the open-circuit voltage gain of Q_2. The point is that R_{out} is again much larger than r_{o1}.

Applications:

Cascode connections are often used as the gain elements in amplifier stages when the Miller effect is an issue. They are also used in current sources and as non-linear loads where the output resistance of a single

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[2] For a more general solution see the course text ("Microelectronic Devices and Circuits" by C. G. Fonstad, Jr.), Section 12.5.2.

transistor is not sufficient.[3] As devices are made smaller and smaller, to make them faster and faster, the output resistance often suffers (i.e., the Early voltage is smaller), and the cascode connection offers a way of recovering some of the lost performance.

The down side:

The "costs" of using a cascode are that you must use two transistors instead of one (not a big cost in an integrated circuit) and, more importantly, that there is a larger voltage drop across the pair of transistors in the cascode than there is in a single-transistor stage. This may reduce the ranges of voltages over which an amplifier using cascodes will operate. This is particularly important in modern circuits designed to use relatively low supply voltages and the consume minimal amounts of power (for cellular telephone applications, etc.).

[3] Examples of cascode current mirrors can be seen in Figures 12.19 and 13.20 of the course text ("Microelectronic Devices and Circuits" by C. G. Fonstad, Jr.).