Commodity IC Data: LM3900 Transresistance Amplifier

by Dennis L Feucht

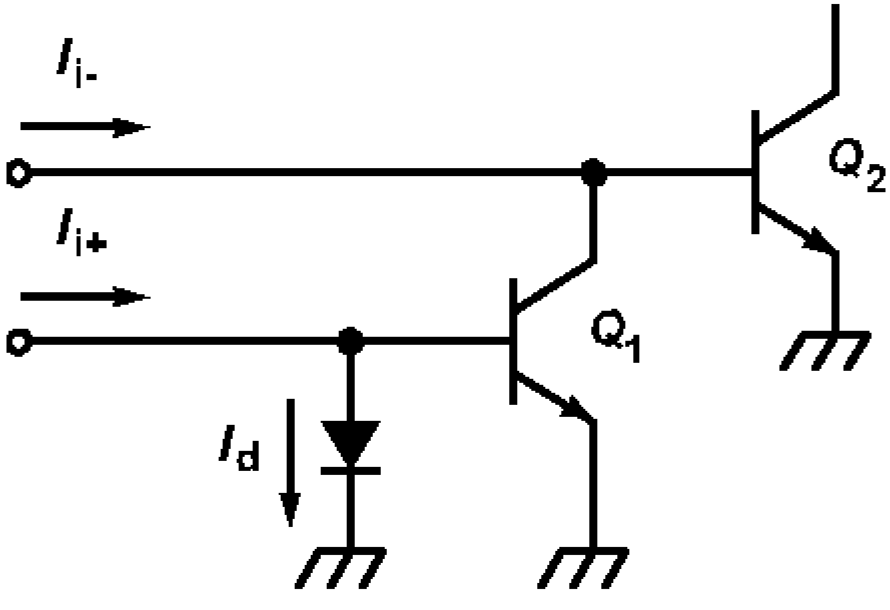
Q: I have noticed that not all the op amps offered commercially by companies such as National Semiconductor or Harris (now Intersil) are *normal*. What exactly is a *Norton* amplifier good for? And, also, why would I ever want to use a *transconductance* amplifier such as the LM13600/LM13700, or the older CA3080?

A: These components are indeed commodity ICs in that they are low in cost and are readily available. These particular parts are not voltage-in, voltage-out op amps, and they are usually not best applied where voltage amplifiers are able to be used. Most familiar op-amp circuits are best implemented with voltage-amplifying op amps or, for fast applications, with current-feedback op amps which, conceptually, have both voltage and current inputs.

These unusual parts were developed at a time when invention of new kinds of circuits was flourishing in the 1970s and 1980s. They are attractive to innovative engineers looking for new circuits ideas. Here we look at the LM3900.

LM3900

National named the LM3900 a Norton amplifier because it has a current-mirror input and is best thought of as being driven by input currents. It is a differential transresistance (current-in, voltage-out) amplifier. The input is schematized below.



The current that drives the amplifier first stage is the difference of $I_{i-} - I_{i+} = I_{B2}$. For a feedback amplifier, this is the input error quantity that is amplified. The LM3900 has two stages, the input-voltage-amplifying stage followed by a clever complementary CC (common-collector, emitter-follower) buffer stage. It is a single-supply amplifier, which means that the input and output range extend down to the negative supply voltage. Its open-loop gain is around 1000. The inaccuracy of the mirror in producing a current difference is a maximum of 5%, and is typically 2%.

The significance of this error for the circuit can be determined by beginning with voltage amplifiers. A typical op amp, such as the LM324 single-supply op amp considered in a previous article, has an input offset voltage error of typically 2 mV, with a maximum of 7 mV, and a voltage gain of typically 10^5 with a minimum of 25 k. An error, ε, added to the input, as either a current or a voltage offset error, will have an effect on the output as though it had been added to the input quantity, and is indistinguishable from the input quantity. (See the inset box for the derivation.)

The Effect on the Output of Input Error

Let the error be ε. It adds at the input to the op amp to the feedback error quantity, E. Then both are multiplied by the forward-path (op amp open-loop) gain, G, to result in output, x_o:

$$x_o = G \cdot (E + \varepsilon)$$

The feedback error is the input quantity, x_i, subtracted from the fed-back quantity:

$$E = x_i - H \cdot x_o = x_i - G \cdot H \cdot (E + \varepsilon)$$

where, H is the feedback-path gain.

Solving the above equation for E:

$$E = \frac{x_i - G \cdot H \cdot \varepsilon}{1 + G \cdot H}$$

Then eliminating E by substituting E into the expression for x_o:

$$x_o = \left(\frac{G}{1 + G \cdot H} \right) \cdot (x_i + \varepsilon)$$

Amplifier input error that adds to E is effectively added to the input, x_i.

For the voltage op amp with closed-loop gain, A_v:

$$x_o = A_v \cdot (x_i + \varepsilon)$$

Referred to the output, the typical offset error with large open-loop gain is 2 mV$\cdot A_v$ = 20 mV, for A_v =10.

With the voltage op amp for comparison, the comparable transresistance amplifier output-referred error from an input error of 2% is still 2% because the error is amplified by the same G as is E. A 2% error is equivalent to an accuracy of less than 6 bits -- not enough for some applications but sufficient for those that are not very demanding.

What benefit does a current-mirror-input amplifier have? Because the input is of relatively low resistance and has across it a *p-n* junction, or two, the voltage drop across it is relatively small: less than 1 V. This is true over the full input current range. A circuit with a very limited voltage range could benefit from this kind of input if the input currents can be controlled. In single-supply applications, the low end of the range for the v_i source can extend to less than a forward junction drop below the lower supply rail. Though a single-supply input range extends to the lower supply itself (usually ground), its upper range is limited to about 1.5 V less than the upper rail. With a current-mirror amplifier with series resistors at the input, the range is unlimited so long as the maximum input current is not exceeded. Consequently, the input quantity can be a high voltage that far exceeds the upper rail voltage. However, a one op amp differential amplifier using a voltage op amp can do this too. However, as its input voltage range is extended with closed-loop gain kept constant, its offset voltage error is also amplified. With the current-input amplifier, the current offset error remains constant.

The LM3900 current-input stage and circuit simplicity make it relatively fast for a commodity amplifier, with a gain-bandwidth of over 2 MHz. It offers another building block for circuit design and consists of fewer than a dozen transistors, making it cheap to build and high in yield. The pads occupy more silicon area than the amplifier itself.

The LM3900 can be extended by adding a diff-amp stage to it using pnp BJTs, thereby forming a complementary cascode stage with the current mirror. The LM3900 then functions as the output end of an op amp with an external, designable input stage.

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