TIA Input Z: Infinite… or Zero? What is it, really?

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What is the input impedance of a transimpedance amplifier (TIA)? Infinite? Zero? No, what is it really? Nothing is really zero or infinite, right? The answer might surprise you—worth understanding, even if you don't use TIAs. After all, an inverting amplifier is just a TIA with an input resistor, right?

The transimpedance amplifier converts an input current to a voltage and is often used to measure small currents, (figure 1). With an ideal op amp, infinite gain and bandwidth, the input impedance of a TIA is zero. Feedback of the op amp maintains V1 at *virtual ground* , creating a zero impedance. Like an ammeter, an ideal current measurement circuit should have zero impedance.

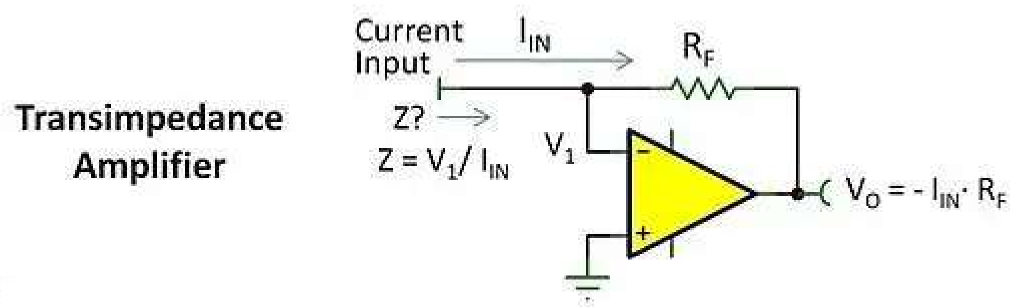

Figure 1.

We're still working on the ideal op amp, so until then, what's the input Z with finite gain-bandwidth product? Some reasoning and 8th -grade algebra reveal an interesting result.

The open-loop gain vs. frequency for the [OPA314 < http://www.datasheets.com/search/partdetail/opa314aidckt/texas-instruments>](http://www.datasheets.com/search/partdetail/opa314aidckt/texas-instruments) is shown in figure 2. As with most op amps today, the gain follows a constant -20dB/decade slope through a wide frequency range—over five decades for this general purpose device. Its gain-bandwidth is 3MHz, so the gain at any frequency along this range is fapproximately 3MHz/f.

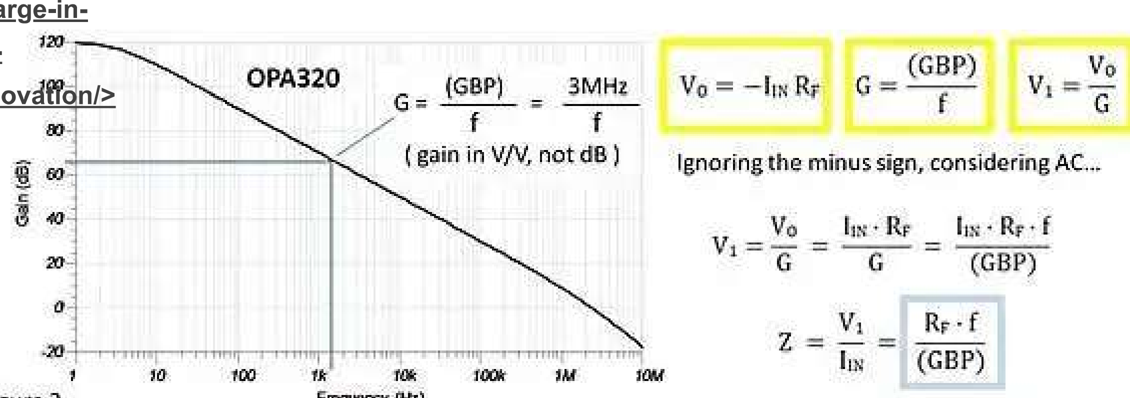

Figure 2.

Manipulating the factors that we know (shown in yellow boxes) yields the result. Z is proportional to R_F and frequency and inversely proportional to GBP. But, hey… Z proportional to frequency? That feels much like a basic circuit element—*an inductor* . The impedance of an inductor is 2πfL, so we can calculate an equivalent input inductance of the TIA.

$$Z = 2\pi f L = \frac{R_F \cdot f}{(GBP)} \qquad L = \frac{R_F}{2\pi(GBP)}$$

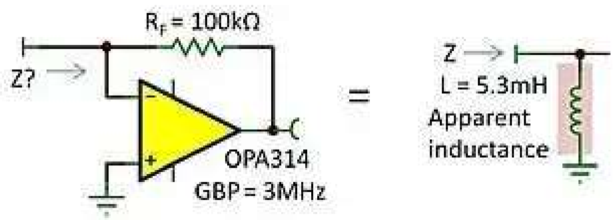

Figure 3.

Neat, huh? Or, maybe you already knew it. Over a wide frequency range the input source sees a simple inductor as a load. We want this inductance to be as low as possible in most applications. R_F is generally dictated by the transimpedance gain required, so that leaves higher op amp GBP as the only way to reduce this inductance. Put this observation to work and it might give additional insight into the behavior of photodiode or current transformer circuits (often used with TIAs).

There's nothing really new here. Various synthetic inductor circuits using amplifiers have been around a very long time but you may not have made the connection to TIAs or inverting amplifiers. Deeper understanding and creativity often come from making these connections.

Most important is the simple observation on the input voltage of an op amp. We so often want to think of the differential input voltage of an op amp as zero—the infinite gain assumption. But across a wide frequency range, it certainly is not. The simple relationship of GBP, frequency and output voltage provides an easy way to understand how the input voltage varies with frequency.

Now, a couple of provisos: This is a small-signal analysis. If you drive the op amp with enough amplitude and high enough frequency, the op amp will slew and voltage at V1 will increase. And this model assumes a simple -20dB/decade roll-off of the open-loop response of the op amp. Some op amps may have twitches in the open loop response that have a minor affect on the simple Gain = GBP/f model.

An additional thought exercise… could we refine the inductance model to include the effect of finite DC open-loop gain?

Thanks for reading and comments are most welcome.

Bruce

Index < http://www.ti.com/thesignal> to all *The Signal* blogs.

6 COMMENTS ON "TIA INPUT Z: INFINITE... OR ZERO? WHAT IS IT REALLY?"

ledlighter

October 9, 2012

Oops! There are two errors in the analysis, but they happen to cancel and the final result is cc Along the OA gain asymptote the gain magnitude is approximately as stated, but there is a 90 degree phase shift that must be taken into account. The exp

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BradWood

October 9, 2012

If the desired input impedance is to be resistive, note that a feedback capacitor will do the job the range that the open-loop gain exhibits a single-pole response. To preserve the given resis at the low-frequency corner the capacitor can have a

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Bruce Trump

October 10, 2012

BradWood and Ledlighter both have excellent comments.
BradWood observes that the input Z of a current integrator is a resistance. Very true. Readers might want to do some math to prove it. Perhaps I can scratch that blog topic off my list, now. Ledlighter

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N/A821

October 26, 2012

In the simple case where the feedback Z is resistance Rf, an all-pass network is formed with Z when a series RC is connected across the input port. The model of a single inductor is oversimplified. The more complete model is Rf in parallel with a series

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Predrag Micakovic

November 29, 2012

Hi Bruce,

low frequency equivalent impedance is zero, but at the high frequency it is limited to Rf i.e it d
not go to the infinity. At the medium frequencies it is inductive.
Border between large and medium frequency is GBW frequency.
Border between

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assadij

May 17, 2016

“2 issues here:n1st: Assumed V1 = 0V (it is only true at steady state!), then suddenly V1=Vo/(
why?n2nd: An op-amp's transfer function is not a constant. It actually exhibits an integrator fu
(1/s). Therefore, the output lags by 90 degrees.

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