Report 9001
Revision -
January 8, 2013

Current Amplifiers 101
And
DL Model 1211

Introduction: The purpose of this document is to provide an introduction to the Ithaco – designed and DL Instruments manufactured current amplifiers. Additionally, this paper will show the differences between the different models of current amplifiers manufactured by DL Instruments.

Discussion: From a first course in electrical engineering, the most common operational amplifier discussed is the inverting amplifier. A figure of this amplifier is as follows:

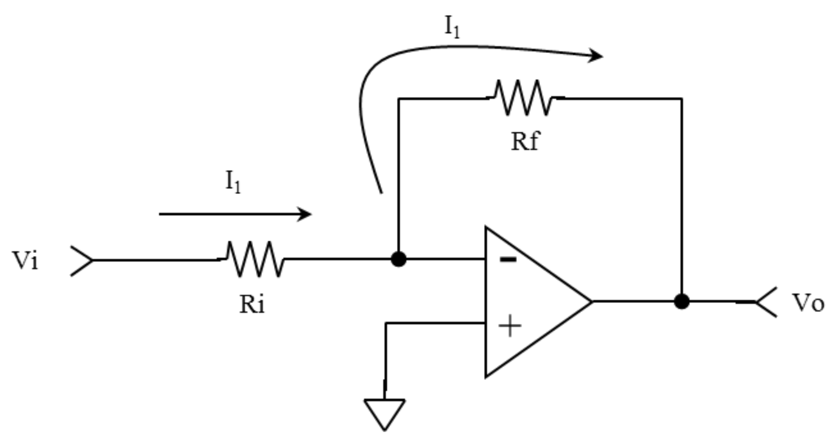

Figure 1: Inverting amplifier

In figure 1 the current that goes through the input resistor, Ri, must be the same resistor that goes through the feedback resistor (Rf) because of the extremely high input impedances of the amplifier itself. The equations of interest are:

$$I_1 = \frac{Vi - 0}{Ri} = \frac{0 - V_o}{Rf}$$

$$so$$

Equation 1

$$Vo = -Vi \cdot \frac{Rf}{Ri}$$

Now, what happens if the input resistor, Ri, is reduced to zero ohms? In this case, from Equation 1, the gain will go to infinity given any input voltage as can be seen from the following:

$$Vo = -Vi \cdot \frac{Rf}{Ri}$$
$$\text{but if } Ri = 0\Omega \qquad \text{Equation 2}$$
$$Vo = -Vi \cdot \frac{Rf}{0\Omega} = -\infty$$

However, if, instead of an input voltage there was an input current, then the circuit becomes a current amplifier. As can be seen from Figure 1, I_1 is the input current based on Vi, but if Ri is eliminated and a controlled current is applied, then the circuit will act appropriately. This is shown in the following figure:

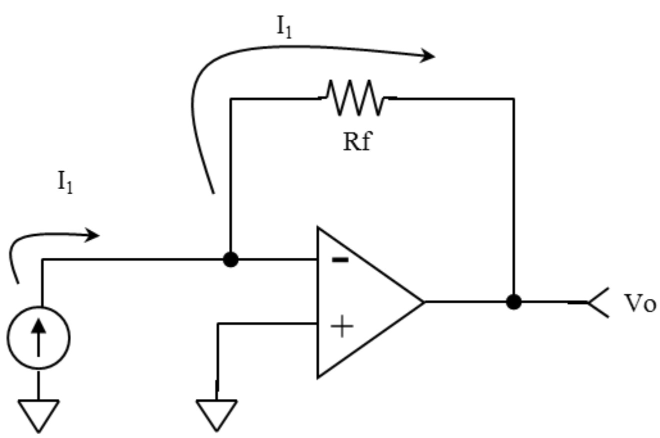

Figure 2: Current Amplifier

Essentially, the device in figure 2 is nothing more than an Ithaco – designed current amplifier. So, if an input current of 1mA is provided on the input, then the output voltage will reflect the input current. Since the amplifier output is voltage while the input is a current, this amplifier can be referred to as a trans resistance amplifier $\left(\frac{Vo}{Ii} = R\right)$.

Why would anyone want a current amplifier instead of using a common digital multi-meter (DMM)? For one thing, the output of the current amplifier is voltage which can be read into a computer with the help of an Analog – to – digital converter (ADC). If the output needs to be chart recorded, then the current amplifier would be a choice instrument.

However, most DMMs do have some form of General Purpose Interface Bus (GPIB) which convert the data to a digital word for ease of use.

The primary reason for using a current is its dynamic range. Most DMMs have a dynamic range of about 1μV. Ithaco – designed current amplifiers have a dynamic range of more than six orders of magnitude greater than 1μV. Thus, if one would want to measure currents on the order of 10pA, a DMM would not register any current where a current amplifier would provide stable voltages.

Ithaco Designed Model 1211 Current Amplifier

The front panel of the Model 1211 current amplifier has a dynamic range of 10^{-3} A/V to 10^{-11} A/V. Additionally, there is a front panel gain control that can provide an additional order of magnitude if desired (X0.1, X1, and X10).

It should be pointed out that designing an instrument like this is not a trivial because at pico ampere levels, parasitic currents, that could normally be ignored, become significant.

A block diagram of the current amplifier follows:

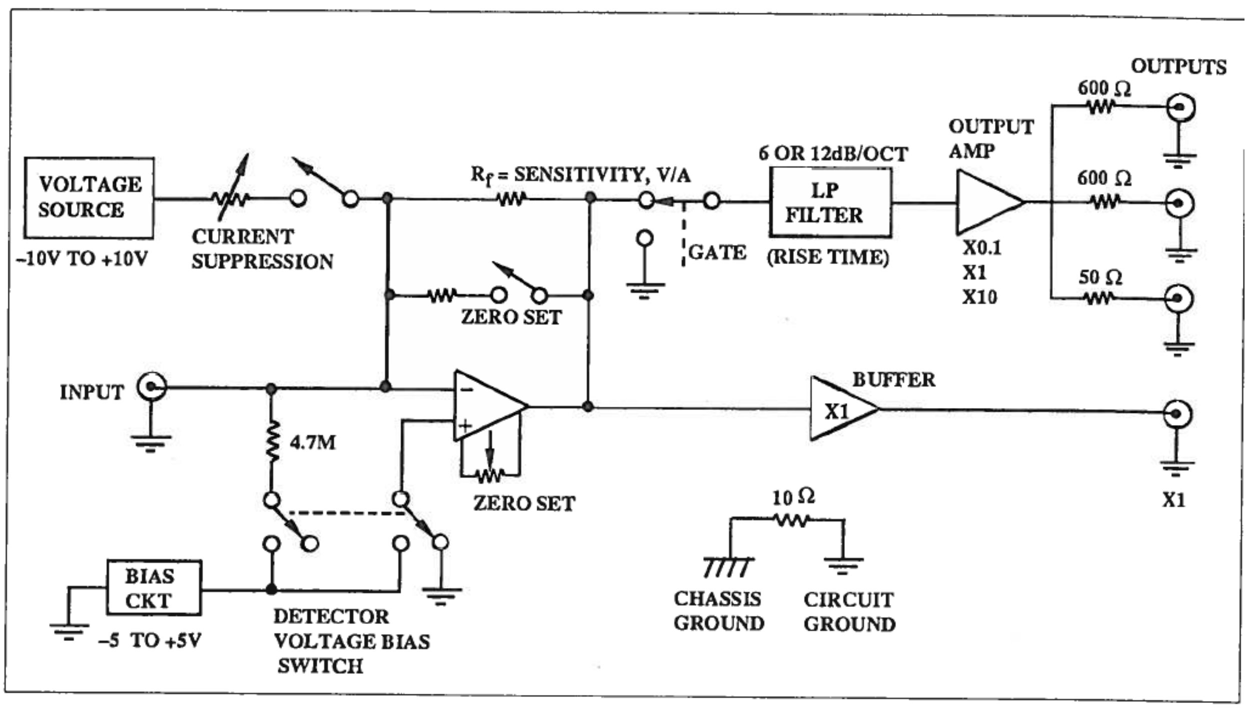

Figure 3: Model 1211 Current Amplifier

Now, if one ignores all of the additional controls, one can see zero resistance on the input and a feedback resistance for a classical current amplifier.

Next, a general discussion of all of the controls on the current amplifier will be provided.

Current suppression: What is the purpose of current suppression? Current suppression is provided to eliminate DC bias currents. For example, in the following figure there is some currents of interest "riding" on top of a bias current:

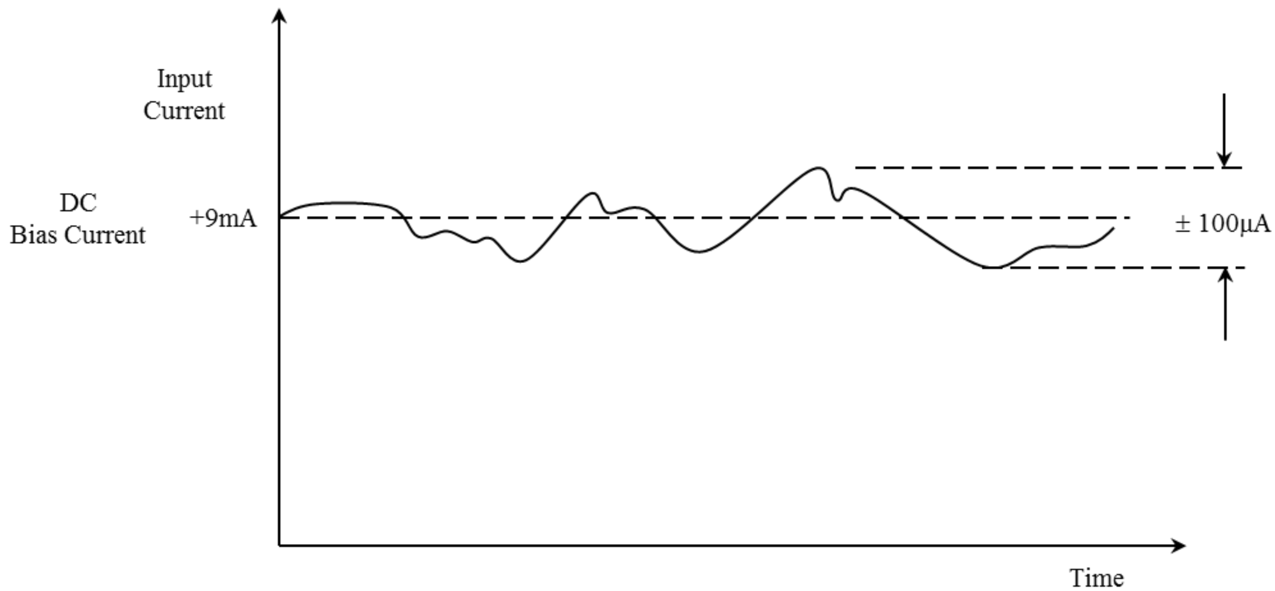

Figure 4: Current Suppression

In figure 4 above, if there is a DC bias of 9mA with a current waveform of interest of ± 100µA, a current amplifier will just show a straight line of currents between 0.00899A and 0.00901A. It would be of interest to remove this bias current so the waveform of interest could be studied more closely.

Now on oscilloscopes or multi-meters the waveform can be AC coupled. This will strip off the DC bias voltage leaving only AC components. This is generally done by putting a capacitor in series with the input amplifier. What happens if this is done to a current amplifier? The following figure shows the new topology:

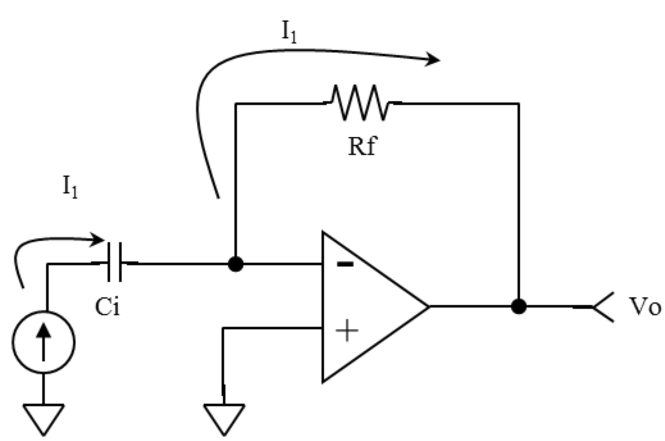

Figure 5: AC Coupled Current Amplifier

The above circuit will:
- Differentiate the input waveform
- A DC bias current from the current supply would tend to charge up Ci causing undesirable responses to the input drive circuit.

Because of the difficulties with the circuit in figure 5, another means is required to remove the DC bias. The method used is add a current suppression circuit. In the case of the waveform in figure 4, -9mA of bias current can be added to the circuit to cancel out the input bias current. Then, the input amplifier will only “see” the AC ripple on top of the DC bias current.

There is an additional benefit of the current suppression on the 1211 current amplifier; it can be used to check the overall functionality of the amplifier itself. The 1211 current amplifier with the current suppression has the following topology (in its CAL or VAR mode):

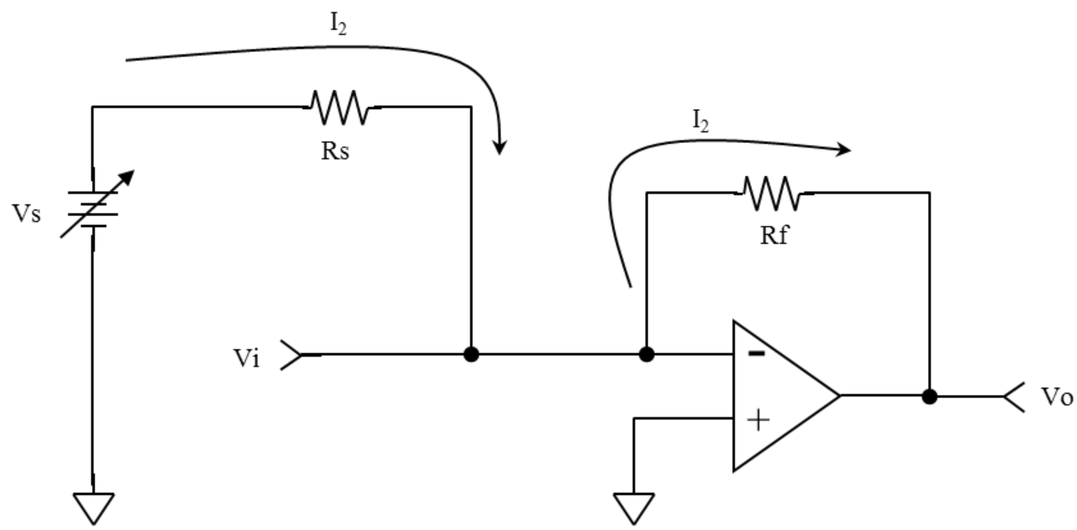

Figure 6: Current Suppression

In the above figure it can be seen that the circuit is almost identical to figure 1. This is an inverting amplifier circuit that can be used to check the functionality of the current amplifier to its highest ranges. To check the circuit do the following:

1. Put the sensitivity switch in 10^{-3} A/V
2. Put the offset switch in 10^{-3} A/V
3. Switch the Cal/Var switch to the Cal position
4. Set the gain switch to X1

5. Set the “-“ Off “+” switch into the “-“ position
6. The output voltage will be approximately +1.0V
   This effectively checks the 10^{-3} A/V position.
7. Next turn the offset switch to 10^{-4} A/V
   The output voltage will drop to 0.1V
8. Change the sensitivity switch to 10^{-4} A/V
9. The output voltage will now increase to 1.0V
   This validates the 10^{-4} A/V position
10. Continue the sequence until the entire range (except 10^{-11} A/V) is checked.
11. To check the 10^{-11} A/V range change the Cal/Var to Var.
12. Adjust the center potentiometer until the output voltage drops to 0.1V.
13. Now increase the sensitivity switch to 10^{-11} A/V.
14. The output should increase to 1V

Gating: The gating function is somewhat confusing. If the current waveform has a periodic waveform that would tend to overload the amplifier, a gating signal can be applied to mask off (or blank) the signal. The following figure illustrates:

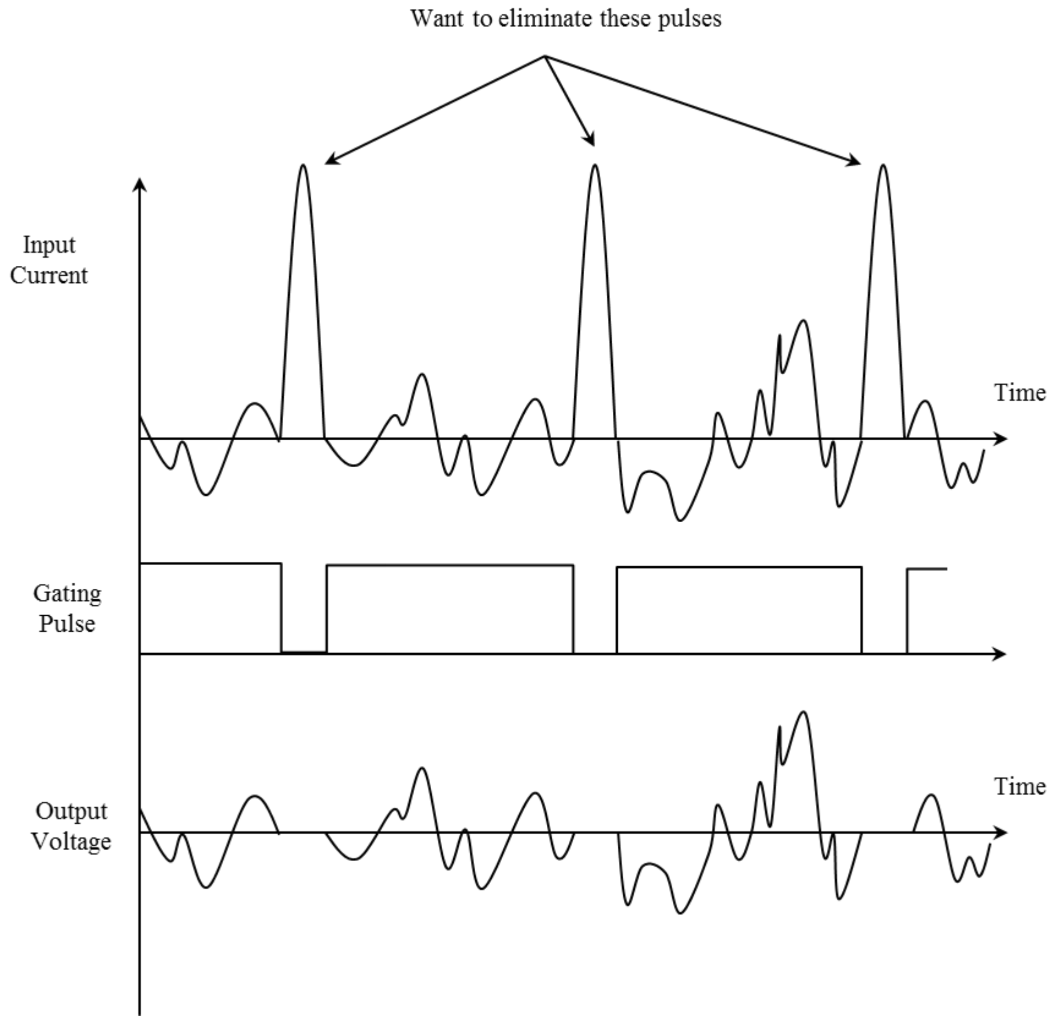

Figure 7: Gating Action

As can be seen from the above figure, the gating pulse can be used to remove periodic signals from the analog signal.

<u>Low Pass filter</u>: As one would expect, the low pass filter is just that, it takes the output signal from the amplifier (see figure 3) and applies a low pass filter to the signal. So, if one wants the highest possible bandwidth signal the filter should put in the lowest position. There are a series of several different filters that can be applied, from less than 10μs up to 1 second. The 1211 is shipped with the filters set for -12dB/Octave (-40dB/decade), but there is an internal slide switch that can be switched to put it into -6dB/Octave (-20dB/decade). The low pass filter does not provide for the -3dB frequency, but the rise time (2.2τ).

Output Amplifier: After the low pass filter there is an adjustable gain block. The block can be set to 0.1V/V, 1.0V/V, or 10V/V. The front panel is a little confusing because the 0.1 setting actually provides a gain of 10V/V.

X1 Output Amplifier: If one chooses to totally bypass the low pass filter (and the gating) then the X1 output can be used. This output is on the rear panel and has the least signal processing applied.

Zero Set: This function is to zero out the instrument to ensure that with zero input current the output is also at zero

Voltage Offset: On the rear panel there is a voltage bias switch and variable adjust. The purpose of this switch is to apply a voltage to the front end of the amplifier other than zero. For example, assume that the noise current of a solar cell is to be investigated. A input series resistance is provided some limitations of the voltage transients. The following circuit illustrates:

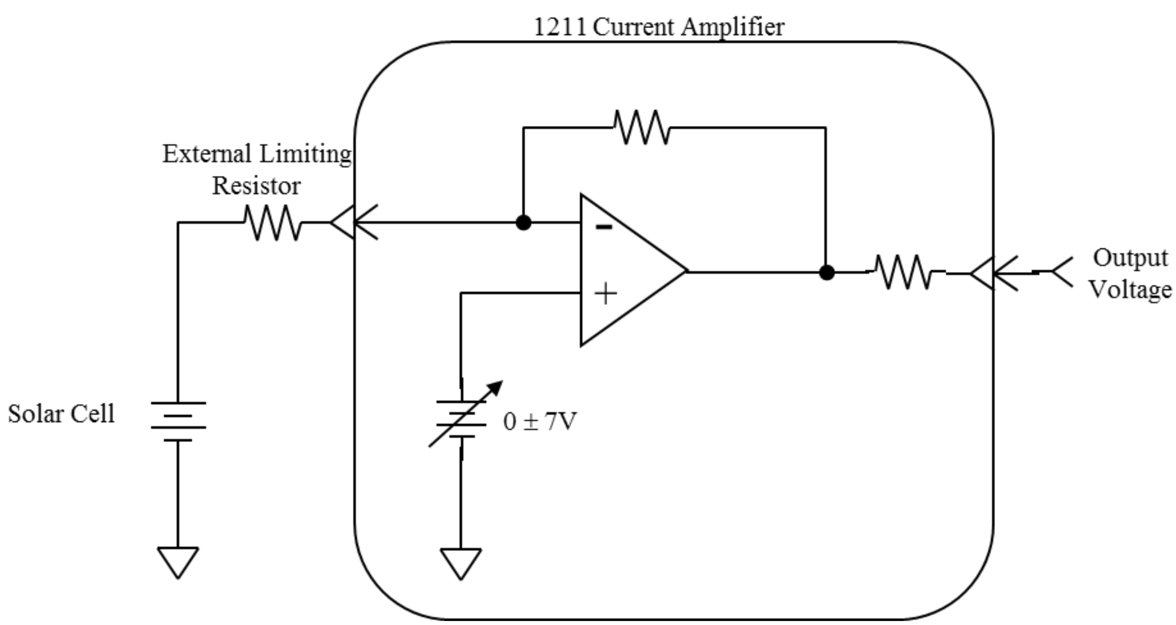

Figure 8: Bias Voltage

In the above figure the internal bias voltage would be adjusted to the solar cell voltage such that the bias voltage would exactly equal the solar cell voltage. The voltage on the "+" side of the amplifier will be reflected to the "-" side of the amplifier. As such, the differential voltage across the external limiting resistor would be zero and no current will flow except for the noise current that is of interest.