Improved Howland Current Pump - Lillian Tucker

Monday, February 20, 2023 3:32 PM

Objectives:

1. Create an improved Howland current pump that takes in 1V and outputs 1mA
2. Test various frequencies and loads to determine which gives you the wanted gain of 1V/1mA
3. Observe which load and set up works best with the improved Howland design you created

Equations:

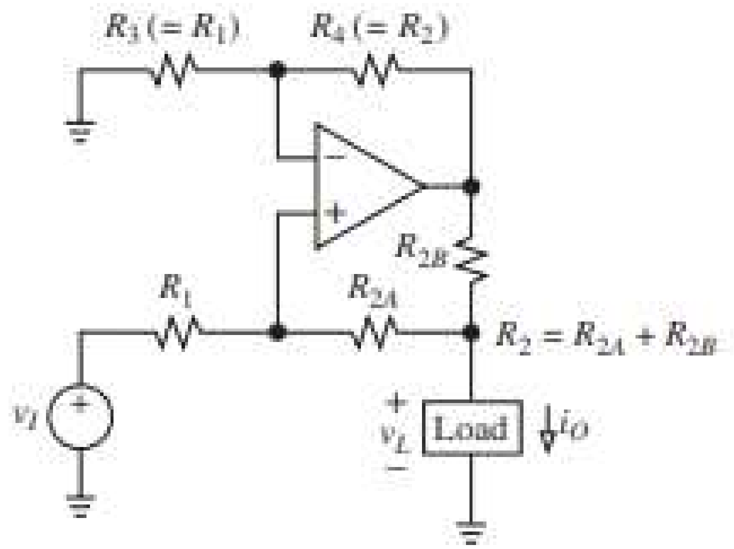


Figure 1: Improved Howland Circuit

$i_o = \frac{v_o}{RL}$ *(with load)*

$$i_o = \frac{\frac{R2}{R1}}{R2b} * v_i \ (without\ load)$$

$$\frac{R4}{R3} = \frac{R2}{R1} \ (ideal\ pump)$$

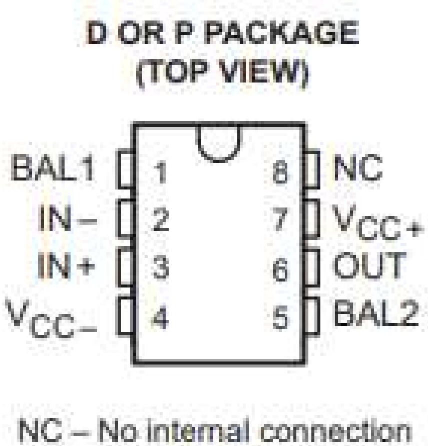
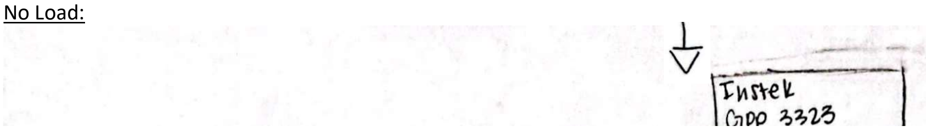


Figure 2: LF411 Op Amp diagram

Procedure:

No Load:



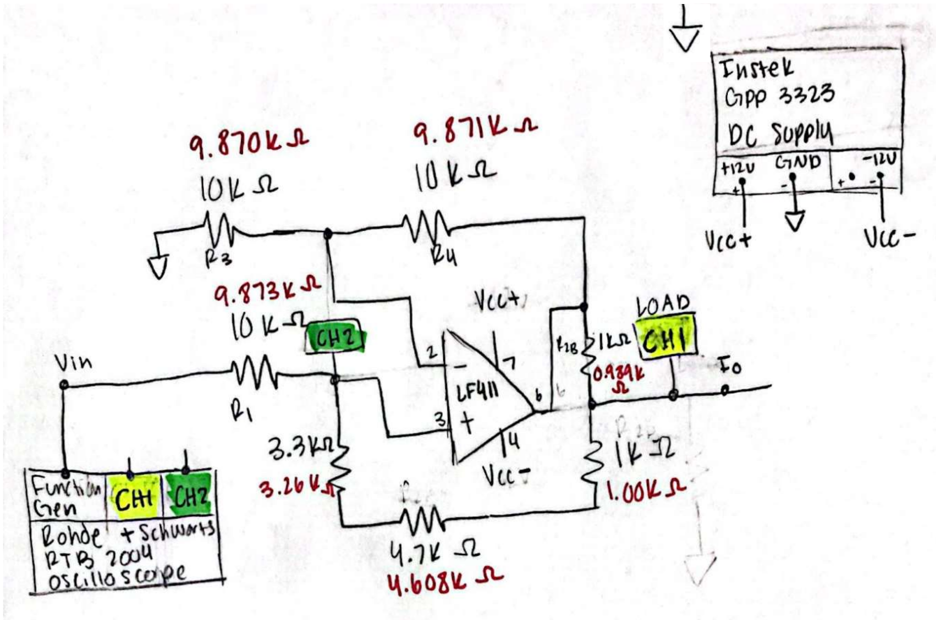


Figure 3: Improved Howland Circuit schematic with no load

Figure 4: Improved Howland Circuit scope Vin = 1V with no load

$$i_o = \frac{\frac{R2}{R1}}{R2b} * v_i = \frac{\frac{9.846k}{9.873k}}{0.989k} * 1V = 1.00835\ mA$$

Table 1: Improved Howland Circuit with no load

Vi [V]	Frequency [Hz]	Vo (ideal) [V]	Vo (real) [V]	Io (ideal) [mA]	Io (real) [mA]
1	0	10	10.25		1.01

The colors and channels in the schematic in figure 3 correspond to the channels and colors in the scope image of figure 4. Ch1(yellow) = Vo, Ch2(green) = Vi.

<u>100 ohm Load:</u>

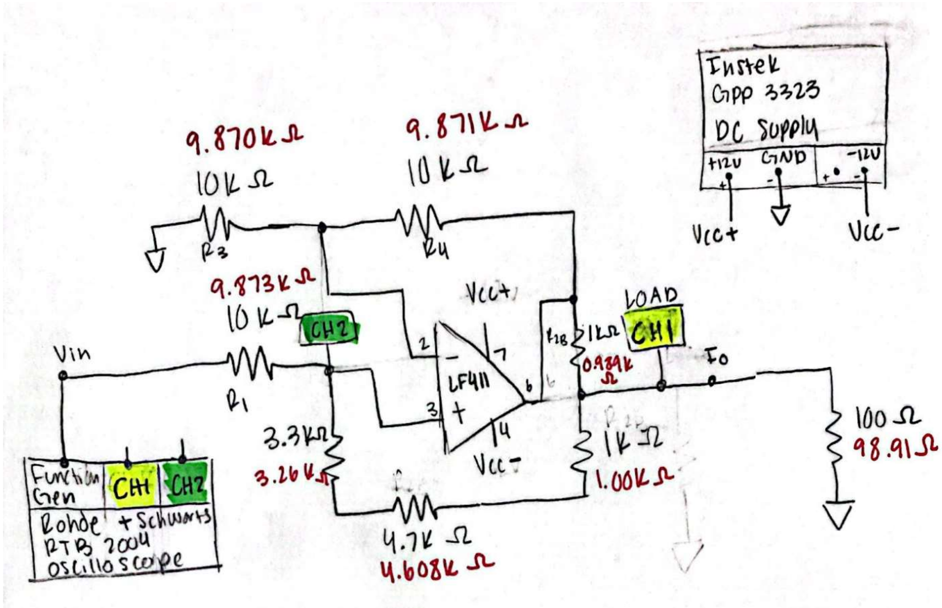


Figure 5: Improved Howland Circuit schematic with 100 ohm load

Figure 6: Improved Howland Circuit scope Vin = 1V with 100 ohm load

$$i_o = \frac{v_o}{RL} = \frac{97.66\ mV}{98.91\ ohm} = 0.987\ mA$$

Figure 7: Improved Howland Circuit scope Vin = 1Vpp 100 Hz with 100 ohm load

$$i_o = \frac{v_o}{RL} = \frac{104.5\ mVpp}{98.91\ ohm} = 1.06\ mApp$$

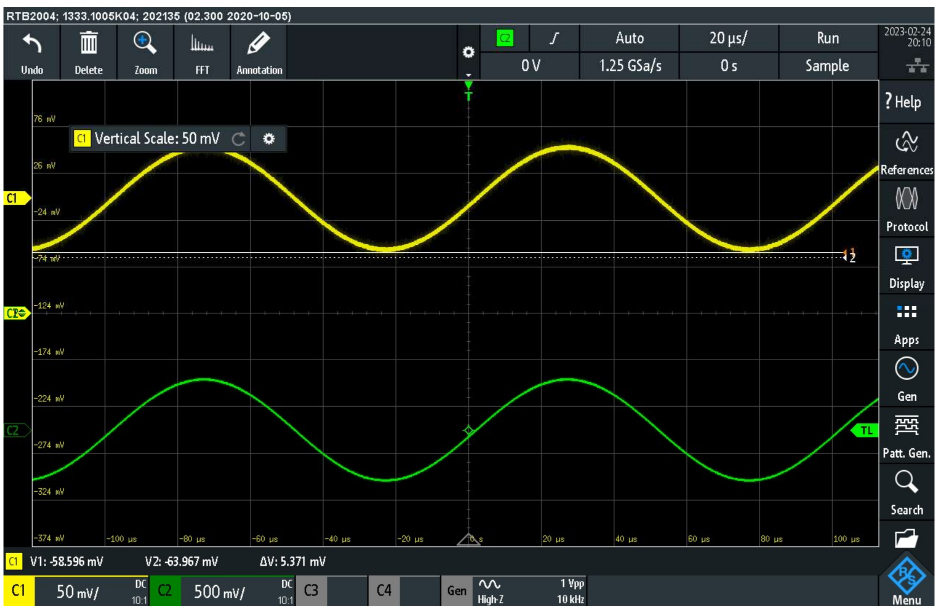


Figure 8: Improved Howland Circuit scope Vin = 1Vpp 10 kHz with 100 ohm load

$$i_o = \frac{v_o}{RL} = \frac{113.3\ mVpp}{98.91\ ohm} = 1.15\ mApp$$

Table 2: Improved Howland Circuit with 100 ohm load

Vi	Frequency [Hz]	Vo (ideal)	Vo (real)	Io (ideal)	Io (real)
1 V	0	100 mV	97.66 mV	1 mA	.987 mA
1 Vpp	100	100 mVpp	104.5 mVpp	1 mApp	1.06 mApp
1 Vpp	10k	100 mVpp	113.3 mVpp	1 mApp	1.15 mApp

The colors and channels in the schematic in figure 5 correspond to the channels and colors in the scope images of figure 6, 7, and 8. Ch1(yellow) = Vo, Ch2(green) = Vi.

<u>1k ohm Load:</u>

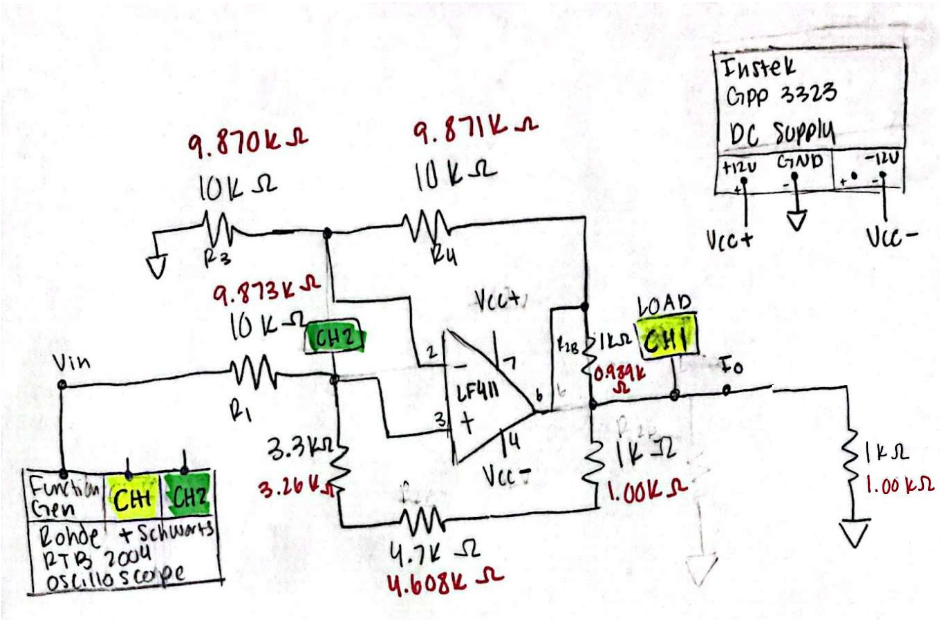


Figure 9: Improved Howland Circuit schematic with 1k ohm load

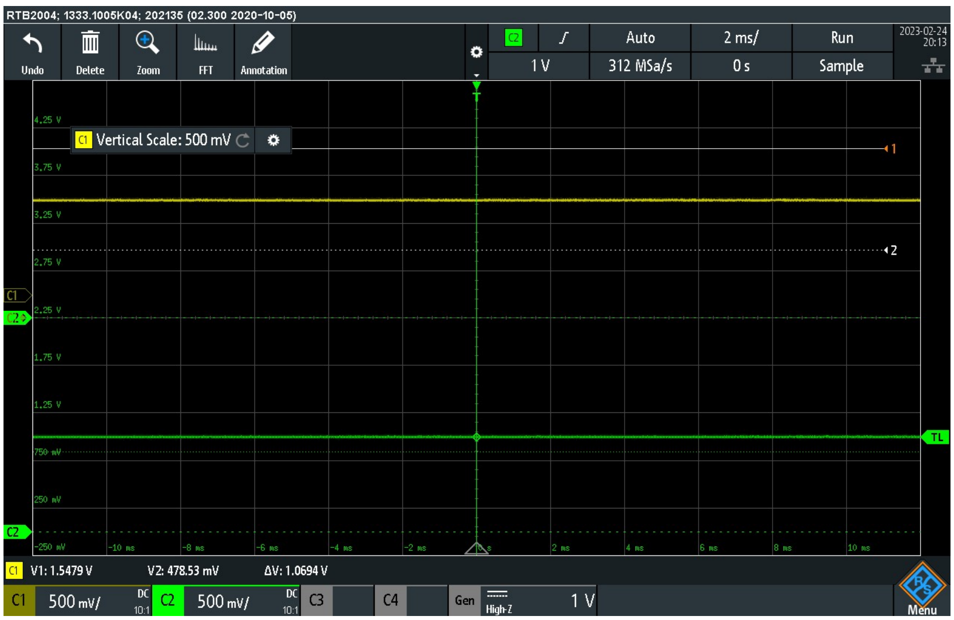


Figure 10: Improved Howland Circuit scope Vin = 1V with 1k ohm load

$$i_o = \frac{v_o}{RL} = \frac{1.02\ V}{1000\ ohm} = 1.02\ mA$$

Figure 11: Improved Howland Circuit scope Vin = 1Vpp 100 Hz with 1k ohm load

$$i_o = \frac{v_o}{RL} = \frac{1.02\ Vpp}{1000\ ohm} = 1.02\ mApp$$

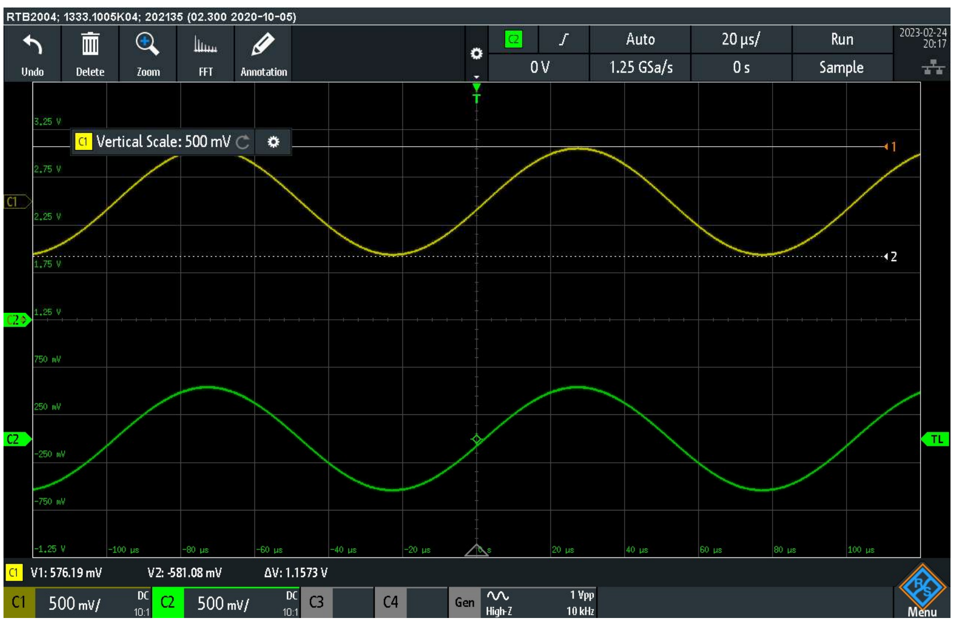


Figure 12: Improved Howland Circuit scope Vin = 1Vpp 10 kHz with 1k ohm load

$$i_o = \frac{v_o}{RL} = \frac{1.15\ Vpp}{1000\ ohm} = 1.15\ mApp$$

Table 3: Improved Howland Circuit with 1k ohm load

Vi	Frequency [Hz]	Vo (ideal)	Vo (real)	Io (ideal)	Io (real)
1 V	0	1 V	1.02 V	1 mA	1.02 mA
1 Vpp	100	1 Vpp	1.02 Vpp	1 mApp	1.02 mApp
1 Vpp	10k	1 Vpp	1.15 Vpp	1 mApp	1.15 mApp

The colors and channels in the schematic in figure 9 correspond to the channels and colors in the scope images of figure 10, 11, and 12. Ch1(yellow) = Vo, Ch2(green) = Vi.

<u>10k ohm Load:</u>

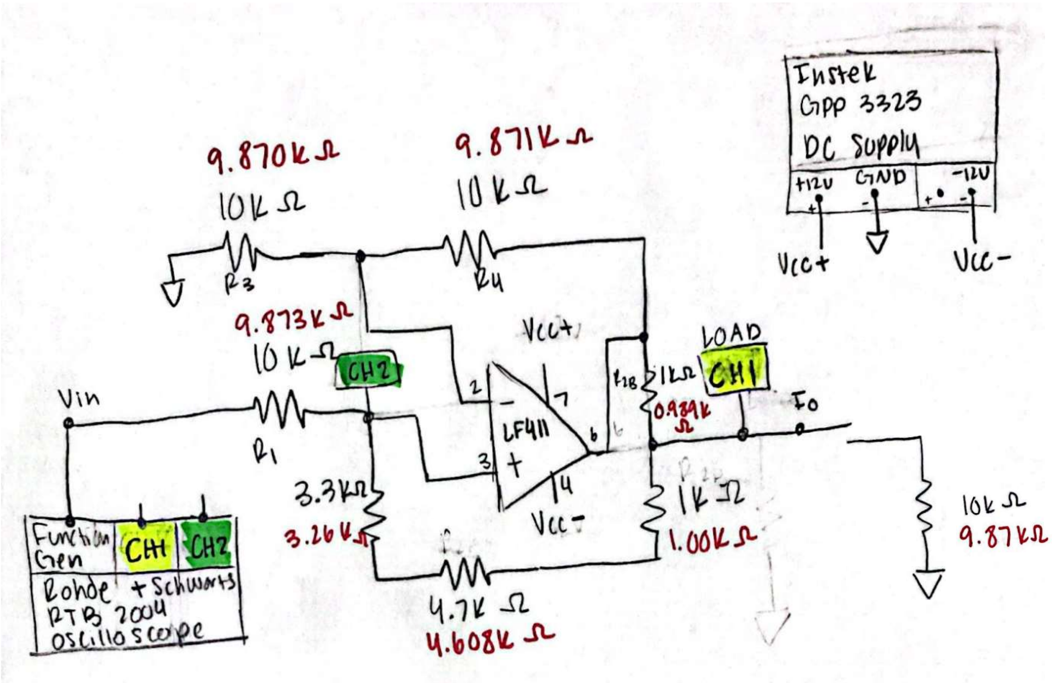


Figure 13: Improved Howland Circuit schematic with 10k ohm load

Figure 14: Improved Howland Circuit scope Vin = 1V with 10k ohm load

$$i_o = \frac{v_o}{RL} = \frac{9.3\ V}{9.87k\ ohm} = 0.94\ mA$$

Figure 15: Improved Howland Circuit scope Vin = 1Vpp 100 Hz with 10k ohm load

$$i_o = \frac{v_o}{RL} = \frac{10.74\ Vpp}{9.87k\ ohm} = 1.09\ mApp$$

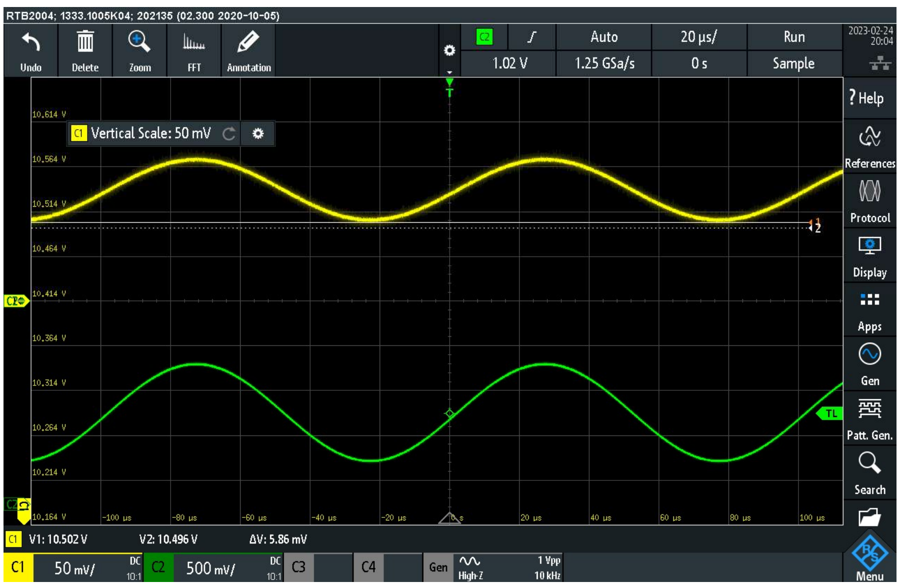


Figure 16: Improved Howland Circuit scope Vin = 1Vpp 10 kHz with 10k ohm load

$$i_o = \frac{v_o}{RL} = \frac{11.42\ Vpp}{9.87k\ ohm} = 1.16\ mApp$$

Table 4: Improved Howland Circuit with 10k ohm load

Vi	Frequency [Hz]	Vo (ideal)	Vo (real)	Io (ideal)	Io (real)
1 V	0	10 V	9.3 V	1 mA	0.94 mA
1 Vpp	100	10 Vpp	10.74 Vpp	1 mApp	1.09 mApp
1 Vpp	10k	10 Vpp	11.42 Vpp	1 mApp	1.16 mApp

The colors and channels in the schematic in figure 13 correspond to the channels and colors in the scope images of figure 14, 15, and 16. Ch1(yellow) = Vo, Ch2(green) = Vi.

Capacitive and Resistive Load (1k ohm and 10 uF):

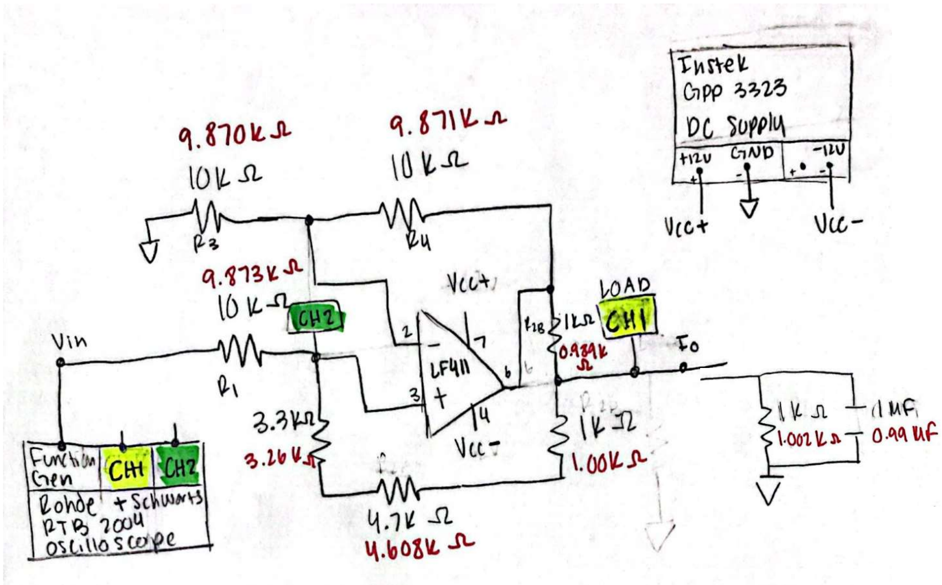


Figure 17: Improved Howland Circuit schematic with 10k ohm load

Figure 18: Improved Howland Circuit scope Vin = 1V with 1k ohm and 10 uF load

$$i_o = \frac{v_o}{RL} = \frac{9.45\ V}{1k\ ohm} = 0.95\ mA$$

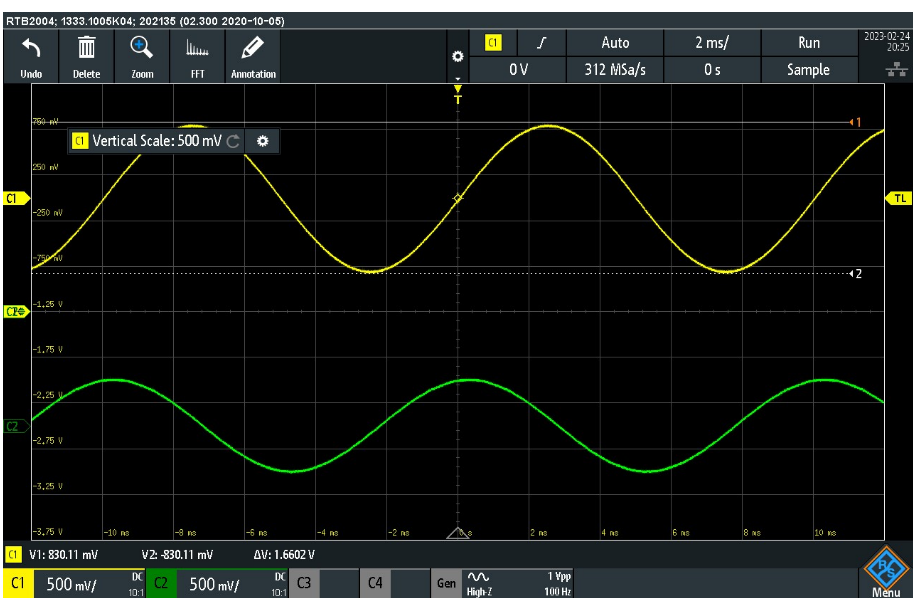


Figure 19: Improved Howland Circuit scope Vin = 1Vpp 100 Hz with 1k ohm and 10 uF load

$$i_o = \frac{v_o}{RL} = \frac{1.62\ Vpp}{1002 - j1010\ ohm} = 1.14 < 45.2°\ mApp$$

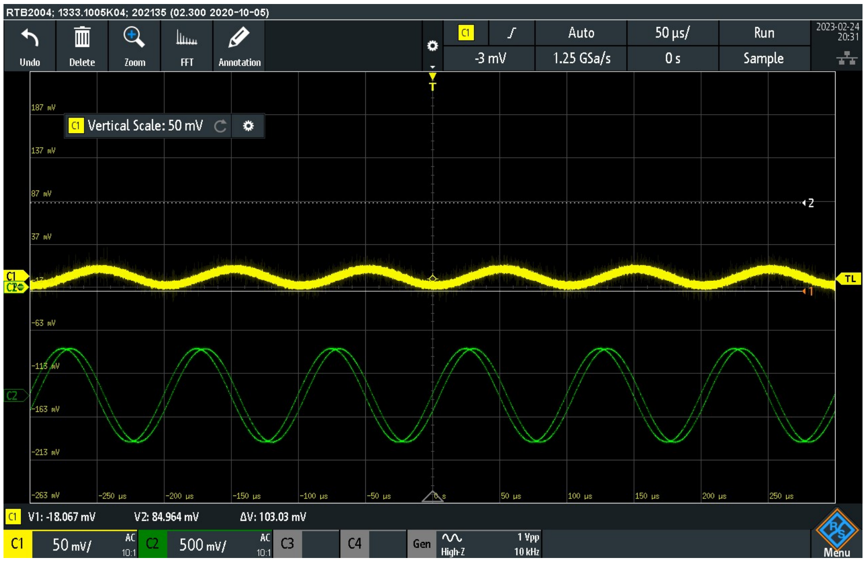


Figure 20: Improved Howland Circuit scope Vin = 1Vpp 10 kHz with 1k ohm and 10 uF load

$$i_o = \frac{v_o}{RL} = \frac{27.4\ mVpp}{1002 - j1010\ ohm} = 0.0193 < 45.2°\ mA$$

Table 5: Improved Howland Circuit with 1k ohm and 10 uF load

Vi	Frequency [Hz]	Vo (ideal)	Vo (real)	Io (ideal)	Io (real)	Phase Shift [degrees]
1 V	0	1 V	9.45 V	1 mA	0.95 mA	0
1 Vpp	100	1 Vpp	1.6 Vpp	1 mApp	1.14 mApp	45.3
1 Vpp	10k	1 Vpp	0.0274 Vpp	1 mApp	0.0193 mApp	45.2

The colors and channels in the schematic in figure 17 correspond to the channels and colors in the scope images of figure 18, 19, and 20. Ch1(yellow) = Vo, Ch2(green) = Vi.

Conclusion:

Table 6: Variability Percentage from expected value

Figure	Load	DC variability [%]	AC variability (100 Hz) [%]	AC variability (10 kHz) [%]	Variability Range (absolute value) [%]
5	100 ohm	-0.23	+4.5	+23	27.73
9	1k ohm	+2	+2	+15	19
13	10k ohm	-7.0	+7.4	+14.2	28.6
17	1k ohm + 10 uF	-5.5	+64	-97.3	166.8

Table 6 shows the variability of the output signals of our circuit when we vary load and frequency. From this table, we can see the circuit that has the most variability is the circuit in figure 17 which has a 1k ohm resistor and 10 uF capacitor as the load. The combined percentage variation of the absolute value of each frequency variation is 166.8% difference/variation. The circuit that has the least variability is the circuit from figure 9 which has a 1k ohm resistor as the load. The combined percentage variation of the absolute value for each frequency variation is 19% difference. Note that the resistance of the load is the same as the resistance of resistor R2B. This could be the factor for determining the best circuit design and load for an improved Howland current pump for other circuit variations.

Another thing to note is that as the frequency increases, the higher the percentage error from the ideal output. Although the circuit from figure 9 has the lowest overall percentage error, the difference between frequencies isn't the lowest. The circuit in figure 9 has a difference of 7% between varying frequencies while the circuit from figure 13 has a difference of 6.8% through varying frequencies.

The figure with the lowest variability for an individual case is the circuit from figure 5 with a 100 ohm resistor as the load at 1 V with -0.23 % difference.

In conclusion, from the data in table 6, there are 3 cases and 3 corresponding circuits you would want to use based on this specific design of the Improved Howland Circuit:

1. DC only signal(s): 100 ohm load (the smaller the load the better)
2. AC only signal(s): 10k ohm load (it seems like there is less variability from frequency to frequency but more evidence is needed to determine if this variability is negligible or not compared to other designs.
3. AC and DC signals: 1k ohm load (has the closest output to ideal in AC and DC and still has minimal variability for various frequencies)