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Validation of Push Pull Current

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Abstract

The Impedance Measurement Box (IMB) measures impedance by exciting the battery with current that is a simultaneous sum of sine waves. On current IMB systems parallel current drivers work together to send a current that captures battery voltage response and processes that signal into impedance. While the data returned is good indication of the actual impedance measurements from the battery, the measurement quality can be improved by moving the ground of the current drivers from outside the box to in between the two current driver circuits (inside the box). This creates a floating ground (not connected to earth) and helps eliminate any noise that may accompany the current going into the battery when conducting test.

This technique of moving the ground between the current drivers is referred to as Push Pull. The name comes from what is taking place for the two current drivers. One current driver will push the current, meanwhile, the second current driver will pull the current and in between these two drivers will be the floating ground.

In order for this technique to work appropriately the current between the current drivers must match, otherwise mismatch will occur and results will suffer, achieving nothing but useless data. In order to get the currents to match, two control circuits are created: the bias current trim, and the gain trim. Bias trim will allow the use of trim pots to eliminate any bias current we do not want; meanwhile the gain trim will also use trim pots to make sure the two current driver gains are the same.

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1. Introduction

The point of this project is to modify IMB current drivers to incorporate Push Pull circuit (figure 1). Push Pull is where we have two current generators in series in order to have a floating ground node created between them. In this design we will have one current source doing the pushing while the other pulls the current. To accomplish this task one previous PCB current driver board from a 50 volt gen 3 test bed was modified to make the right half of the board a Push current source, and the left half a Pull current source.

By modifying the IMB box to incorporate push pull, noise is reduced and the need for offset power supplies is eliminated. The disadvantages of Push-Pull are that the current must be near exact or else the system will not function. If done correctly, the result will be an improved box that can give the same results as a normal box measurement but with less noise.

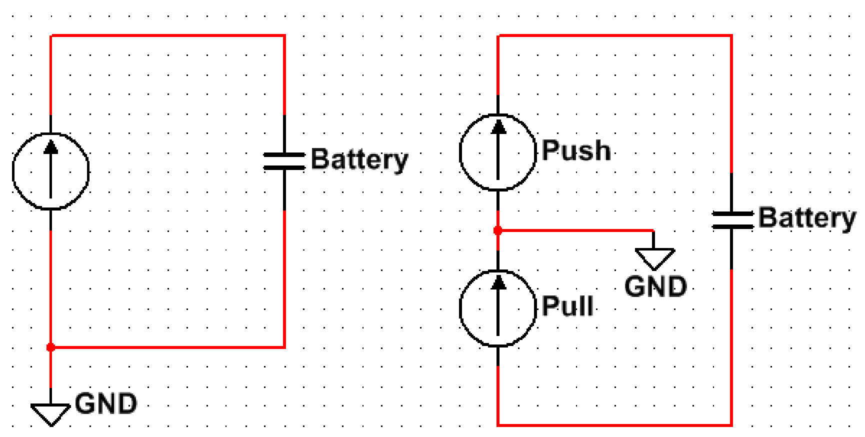

Figure 1: Left simplified version of original current driver, Right simplified new push pull

1.1 Advantages

The advantage of modifying the IMB current drivers is eliminating noise from the system. By eliminating noise, a cleaner and more accurate signal will be acquired from the measurements on batteries. The noise is eliminated by removing the ground wire from outside the box on the negative terminal of the test battery. Additionally, the need for offset power to the current drivers is eliminated.

1.2 Disadvantages

The disadvantage of Push Pull is that the current must be the same for both the push current driver and the pull current driver. This is only a minor disadvantage in the long run; as once the system is running correctly, this should no longer become a problem. The hard part is configuring the current to be matching but this can be controlled with the bias current trim circuit. Mismatch between the two current sources (push and pull) will result in system failures.

2. Project Overview

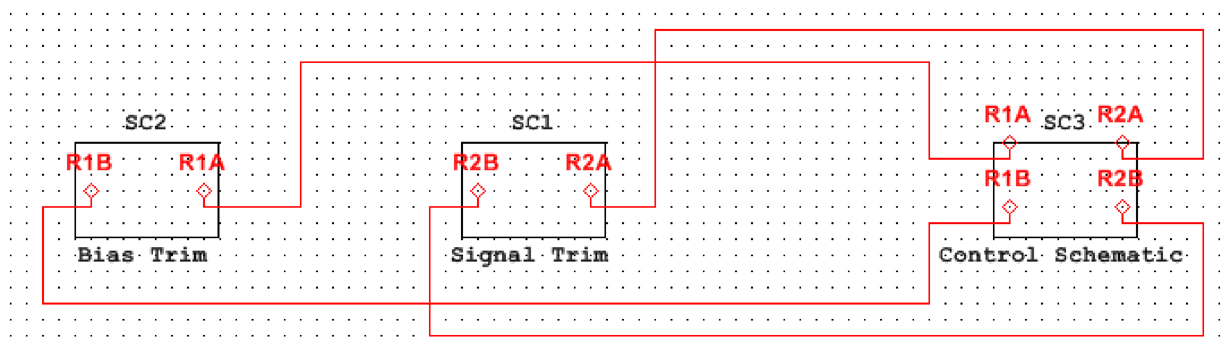

Figure 2: Basic overview of how the circuits connect

In order for this project to work correctly it relies on component matching for resistors inside the control schematic (current drivers), modifying previous current drivers, and creation of two control circuits (the bias trim and signal trim) (figure 2, above).

2.1 Component/Resistor Matching

Resistors used in the current drivers must be within .1% tolerance. The two current drivers must each have matching pairs for their input resistance and feedback loop resistance otherwise current offset will occur. A test, using a population of 26 resistors of .1% tolerance of

10kΩ, was measured using a 3458 ohm meter in order to determine matching pairs of resistors. Within this data measured, it was determine that the resistors must be within .5 Ω of each other to be considered enough of a matching pair that it does not create any significant current offset.

.5Ω was considered a matching pair by using the following equation:

$$[1] \qquad Iout = \frac{Vb}{((R1+R2)*Rs)}\sqrt{2(dR1*\frac{R2}{R1})^2+2(dR2)^2}$$

In this equation we are solving for the current out of the current drivers due to resistors. When resistors of .5Ω difference are inserted into the following equations:

$$[2] \qquad R1=\frac{(R1a+R1b)}{2}$$

$$[3] \qquad R2=\frac{(R2a+R2b)}{2}$$

$$[4] \qquad dR1=\frac{|(R1a-R1b)|}{2}$$

$$[5] \qquad dR2=\frac{|(R2a-R2b)|}{2}$$

**Note: R1a and R1b are 150k resistors actual values measured from 3458 ohm meter, R2a and R2b are 15k resistors actual values measured from 3458 ohm meter. Between these resistors is where the .5Ω difference comes into.*

the current out is equal to or less than $9.0868\text{x}10^{-5}$ A. When 1Ω difference is inserted for equations 2-5 for equation 1 values, the current out is equal to $1.8174\text{x}10^{-4}$ A. The 1Ω difference gives too much offset current, thus creating mismatch, however the .5Ω is considered okay, as this current is low enough, that current mismatch will not occur due to the resistors.

The last remaining variables are constants given by:

$$Vb = 50v$$

$$Rs = .5\Omega$$

2.2 Bias Trim Current Match

Remaining current source mismatch after resistor matching must be controlled through use of potentiometers in the bias trim circuit. During test procedures, potentiometers can be adjusted for zeroing out offset current and match gains. This process is done one time for each of the current sources.

2.3 Gain Matching

Gain matching is done by shorting the Push and Pull current sources together. This short is measured by a voltmeter and is reference to ground. Voltage in this node can be eliminated by tweaking potentiometers in the signal trim circuit. This process will need to be done twice, once for the push current driver and once more for the pull current driver.

2.4 Operation Necessities

The Push Pull current drivers are power op-amp circuits that require ∓ 18 volts, and a sum of sine's control signal (or a sine signal from a function generator). The ∓ 18 volts also powers the op-amp circuits for bias current trim, and signal trim. The sum of sine's signal goes into the signal trim and allows the matching of current source gains.

3. Project Requirements

The following list is what is required of this project for this project to be considered completed and a success for validating Push Pull technique:

- Modify IMB current drivers into Push Pull configuration with system ground in-between them.
- Design and implement bias current minimization
- System Powered by ∓18 volts
- Breadboard design concept
- Gain and current offset control through PCB
- Push Pull configured into a PCB
- Validate performance by driving a Push Pull 100mA rms current to a 5Ω shunt and 12v battery

4. System Description

From a simple point of view the Push Pull System relies on three circuits: the control schematic (current drivers), bias trim and signal trim. Current drivers contains the push and pull current sources, the bias trim eliminates current and signal trim lets gains of the two current sources to match. (figure 3, below)

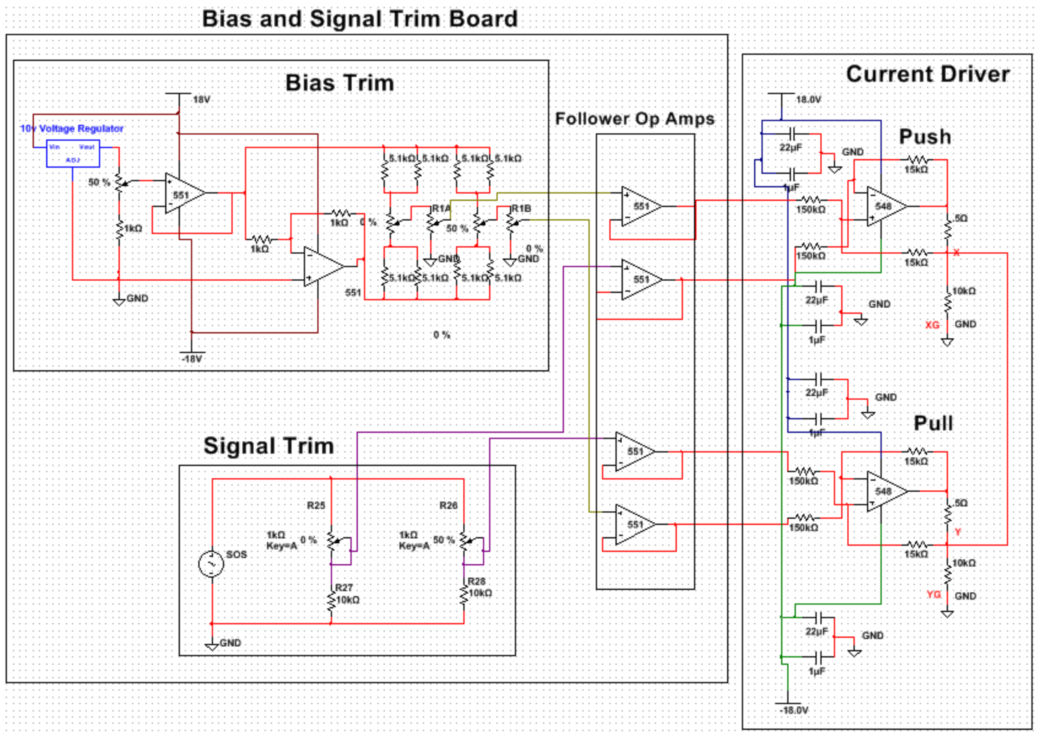

Figure 3: Full System Design

4.1 Modified Current Driver

The current driver is divided into two halves, Push current source side and Pull current source side. Note that in the PCB the Pull side is the left half and the right half is the Push side, but in the diagram, the top half is push and the lower half is pull (figure 3).

The system is powered by ±18v, and a ground. Both current sources have matching resistors with each other, for example: 15k on push and 15k on pull for feedback, and 150k on inputs. Two op amps used here are 548s. Each op amps is powered by ±18v and has a .22mF and .01mF capacitors for elimination of noise coming from the power supply. The outputs of the 548 op amps go into the top side of a .5 resistor. The lower side of the .5 resistor is the output of the Push current source and Pull current source, respectively.

The difference between the two current sources lies in the connections going into the 548 op amps. The Push side has bias trim voltage (R1A) going into the inverting side of the op amps and the signal trim (R2A) going into the non- inverting side. Meanwhile, the Pull side is reversed, where the bias trim (R1B) now goes into the non- inverting side and the signal trim (R2B) going into the inverting side.

4.2 Bias Trim

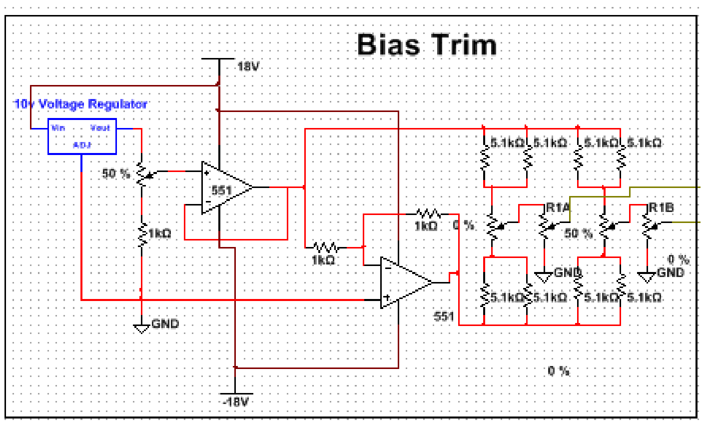

Figure 4: Bias Trim Design

The bias trim is a circuit designed to eliminate the tiny offset current of the op-amp (figure 4). Elimination of the bias current relies heavily on the trim pot in the bias trim. The circuit has +-18v input for powering the 551 op amp, and a ground. Outputs of this circuit come out of the fine trim pots (R1A and R1B). Parts used for this circuit, include three 10k 10-turn trim pots, two 1k 10-turn trim pots, three 1kΩ resistors, 5.1kΩ resistors, 10v voltage regulator, two 551 op amps.

The Bias trim consists of a voltage regulator that assures the bias trim circuit is receiving precision regulated 10v into the non-inverting side of the first 551 op amp. This voltage can be adjusted with the trim pot before the first 551 op amp, however for this test; the voltage going into the non-inverting side was left untouched so that it could be 10v.

The output of the first 551 op amp then splits off into two areas: one towards the parallel resistors for trim pot out 1A and 1B, and the other into the inverting side of our second 551 op amp. The parallel resistors resistance is combined so that is in series with the “coarse” trim pot R1a and R1b, respectively. The course trim pots (1kΩ 10-turn) are responsible for larger adjustments to voltage when measuring on the current drivers. The second 551 op amp will invert the voltage, thus creating -10v that goes into the bottom of the parallel resistors of the coarse trim pots. By having 10v go into the top of the trim pot and -10v into the lower, it allows the coarse trim pot to adjust its voltage difference anywhere between these voltages.

The coarse trim pots then deliver the voltage being received through them and send to the “fine” trim pots (10kΩ 10-turn) from its middle connection. The fine trim pots are used for smaller adjustments to voltage when measuring on the current drivers. The fine trim pots received the coarse voltage through the top side and the lower side is connected to ground. The middle connection delivers the voltage to another 551 op amp called a “follower”. The follower’s duty is to send over the exact same voltage going into it but eliminate current accompanying the original voltage.

4.3 Signal Trim

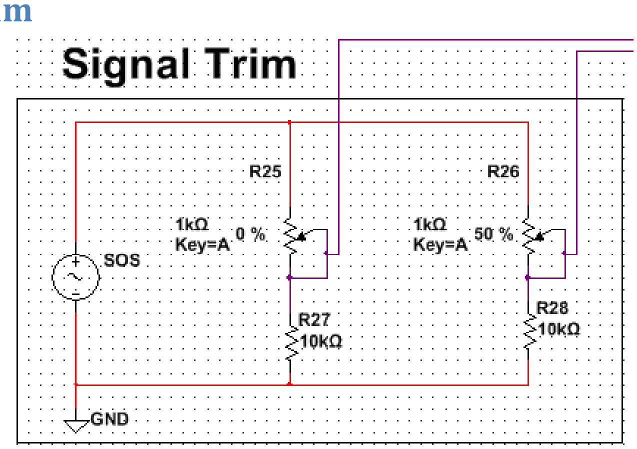

Figure 5: Signal Trim Design

The function of the signal trim is to insure that the voltage to current gains match as closely as possible. The signal for the signal trim was designed for a sum of sine signal for an input however for this test; a frequency generator set to sine wave was used to simulate the sum of sine signal (figure 5). This circuit is made up of 2 trim pots (1kΩ 10-turn) and two 10KΩ resistors.

The sine wave goes into the top side of the trim pots. The lower side is connected to a resistor that goes towards ground. The middle connection is connected to the lower side as a feedback loop. The output of this circuit is located on the bottom side of the trim pots (2A and 2B). The output is then sent to two follower op amps, (one each for 2A and 2B).Gain and bias current mismatch is accommodated by providing a 10kΩ source resistance for the push and pull current drivers.

5. PCB Design

5.1 Current Driver

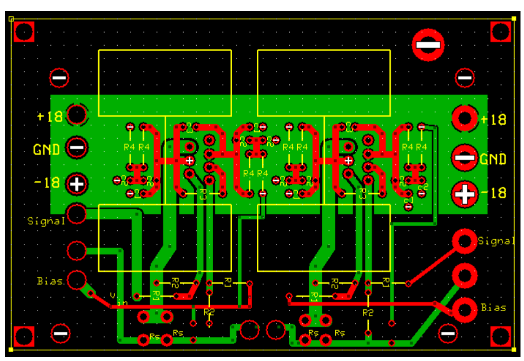

Figure 6: Modified Current driver, left Push current source, right Pull current source

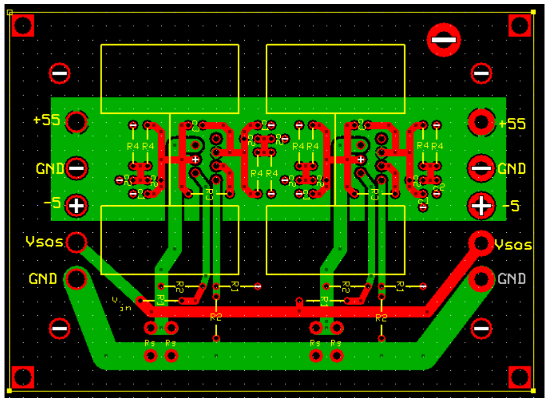

Figure 7: Original IMB Current Driver, both Push

The current driver PCB for Push Pull (Figure 6, above) is a modified version of an IMB current driver PCB (figure 7, above). The original board and the modified version are very similar, however there are indeed changes done for Push Pull. For instance R1 (resistor one) is now 150kΩ and R2 (resistor two) is now 15kΩ in the modified version compared to the original where they were 12kΩ and 15kΩ.

In the original, both current sources are Push current sources and are in parallel. The inverting side is a sum of sin signal and the non-inverting side is grounded. This PCB is also powered by +55 volts and -5 volts.

In the modified version the right side of the board is Push and the left side is Pull. The Push side has a sum of sin signal going into the inverting side and the bias trim going into the non-inverting side. The Pull side has a bias trim going into the inverting side and sum of sins signal going into the non-inverting side. The two outputs of the current sources are no longer grounded, and are only functioning when taking measurements to the battery or shunt. An additional 10kΩ resistor was added to each output of the current sources that connects to ground. R4 (resistor four) was taken out of the circuit completely and the caps connect directly from the 548 op-amp to ground. This version is powered by ±18 volts.

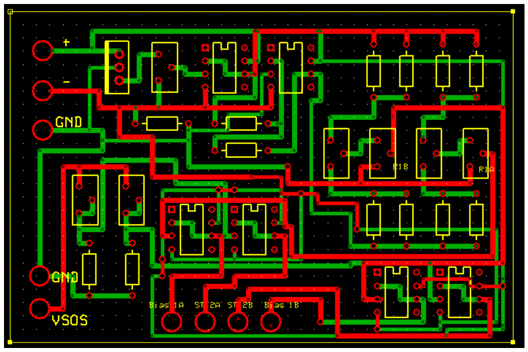

Figure 8: Bias and Signal trim

5.2 Bias Trim/Signal trim

Both the bias trim and signal trim circuits were combined onto one PCB board for saving space as well as cost (figure 8). This circuit is also powered by ±18 volts.

The bias trim takes the 18volts and has it go through a 10v voltage regulator, where it then passes it through a trim pot. From the trim pot, the 10v voltage goes into a follower 551 op amp and sends the voltage to two sets of parallel 5.1kΩ resistors and to another 551 op-amp, where the voltage is inverted to have -10v. The two sets of parallel resistors pass the voltage to the top connection of coarse trim pots (1k 10-turn), where it is then sent from the middle connection to the top of fine trim pots (10k 10-turn). The bottom of the fine trim pots connects to ground and the middle connection sends the R1a and R1b to follower 551 op amps. The inverted voltage also goes to a set of two parallel 5.1kΩ resistors where they connect to the bottom of the coarse trim pots. After R1a and R1b have been sent through follower op-amps, the bias trim connection can be sent to the current drivers, with R1a going to Pull and R1b going into Pull.

The signal gain takes the sum of sine signal and has it go through a 1kΩ trim pot that shorts its middle connection to the bottom. The bottom connection goes through 10kΩ resistor that then goes to ground. The connection between the trim pot and 10kΩ resistor is R2a and R2b and sent to follower op-amps before connecting to the current driver. R2a goes to the pull and R2b goes to Push.

6. PCB System Testing/Results

Figure 9: Physical version of the bias/signal trim

Figure 10: Physical version of the modified current driver

The system uses two separate PCB boards for implementing Push Pull current. One board holds both the bias trim and the signal trim (figure 9). The other board contains a modified current driver from gen 3 IMB (figure 10). The modification comes in the form of it holding the Push current source on the right and the Pull current source on the left.

6.1 Bias Trim Calibration

In order for the system to run the Push Pull technique, input connections must be done first then calibration must be done. Calibration includes elimination of bias current and matching signal gains. The next/final step is connecting a shunt and then removing the shunt and connecting a 12v battery instead.

Begin by connecting the system with ±18v and a ground on where it is specified on both PCBs; ground Vsos for this first step. Then take R1A and R2A and have them connect to the Push current source (right side of board). Then take R1B and R2B and connect to the Pull current source (left side).

First calibration of the Push current source is done first. Using a DMM, connect the positive side of the probe to the node above the 10k resistor on the Push side of the current driver PCB, then connect the negative side of the probe to the ground located on the underside of the 10k resistor. Now turn on the power supply.

If the reading on the DMM is not zero then you will adjust the trim pots connected to R1A (coarse and fine) until it is zero. All bias current is eliminated when the voltage drop on this resistor is zero. By using Ohms law, V=IR, we know that current is 0A when voltage is equal to zero.

These steps are then repeated for the Pull current source. The probes are disconnected from the 10K resistor on the Push side and reconnected to the Pull side 10K resistor. Then adjust the trim pots (the coarse and fine) that are connected to R1B until voltage again says zero. Turn off the system.

6.2 Signal Calibration

Signal calibration is done by connecting the Vsos from ground to either a frequency generator or a sum of sine signal. Then short together R1A and R1B. Now turn on both the power supply and frequency generator. If you are measuring this shorted line, you will want to see a voltage at or near zero. Adjust trim pots (connections toR2A and R2B) until the voltage of the shorted line is at or near 0v.

For my test I wanted a goal of 100mA. In order to achieve this I had to use the equation:

$$\textbf{[6]} \qquad \boldsymbol{I = Gm(\Delta V)}$$

Where *I* is the current I want, *Gm* is the gain through all op amps (constant .2), $\boldsymbol{\Delta V}$ is voltage.

$$\boldsymbol{100mA = .2(\Delta V)}$$

$$\boldsymbol{\Delta V = .50v}$$

Therefore I needed 500mV to achieve this.

6.3 Connecting Shunt and Battery

Connect the Output of the Push current side to the one of the outside connections of the shunt and the Pull current source to the other outside connection. Connect a current probe and see if the current is still 100mA. Once verified it is indeed 100mA, you may not connect to a battery. Note the system must be running before connecting a battery.

6.4 Results

The goal when eliminating bias current is to have 0A running through the system, and to do that aim for having 0v drop through the 10k resistors of the current drivers. Due to the nature of the system, the current drivers drop over this resistor would bounce, and therefore would not settle properly on exactly 0v. Therefore, I created an acceptable range for this voltage to bounce that would lead to small enough current running through the current sources that would not create mismatch. This range was 0v-300mV, and the current produced from this was 0-30µA.

The signal trim did not have to be adjusted much as the voltage, when current sources were shorted together, was near 0v. To simulate a sum of sin signal, a frequency generator was used and adjusted to 1v at 100Hz, where it went through a voltage divider to get 500mV.

When a 12v battery is connected, each current source should see 6v across. The Push current source voltage measurement is obtained by measuring the positive side of the battery (with a DMM), that is connected to the Push current source, to the ground connected through the 10kΩ resistor of the Push current driver. The process is then done once again for the pull side, with the exception that the negative side of the battery is measured against the 10kΩ resistor of the Pull current source. The actual measured voltage over this area for push current source was 6.11v, and the pull current source was 5.94v.

When done properly the current running through the battery and shunt will be 100mA when 500mA is ran through the sum of sin connection (figure 11 and 12).

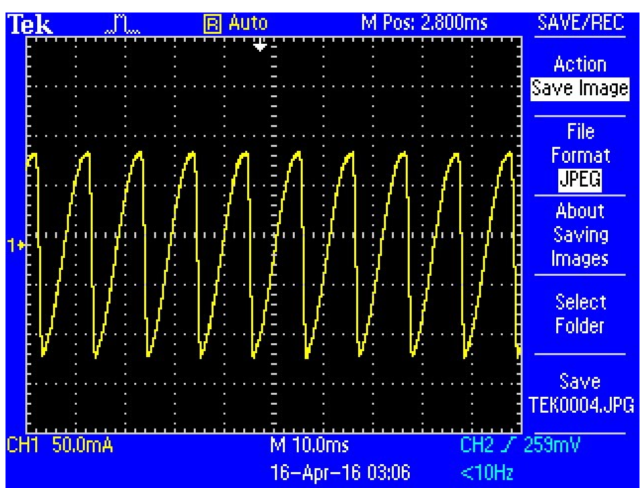

Figure 11: 100mA current running through battery

Figure 12: Voltage of the signal after going through voltage divider, in RMS

7 Lessons Learned and Conclusion

From this project I learned quite a bit. I learned to not leave things until the last moment to get them done. For instance, if you need parts, order them early or else you will miss due dates. Doing things early also allows you to have time to do an audible and fix things if errors occur when building the system.

I learned that sometimes it's better to trust yourself over others. When I couldn't figure out why my circuit was shorting, I asked others what they thought, the reply I got was along the lines of, you either screwed up your PCB design or you messed up soldering. I did not feel I screwed up either, but I redid entire work on PCB, looking at nodes and redoing solder. What occurred was I was misinformed about the original current driver PCB. The connections I thought were GND, negative voltage, and positive voltage (on original current driver PCB, the labels were not there and were later added by me); they were actually positive voltage, ground, and negative voltage.

The last thing I learned is that things will go wrong. When things go wrong you can either give up or you can go back to the drawing board and figure out where things went wrong, why and what I can do to fix it.

7.1 Conclusion

In Conclusion, the goal of this project was to validate that Push Pull technique is viable for moving a ground from the negative side of a battery to in between two current sources. The reason for doing this is so that in future versions of the IMB, more precise results of the battery can be recorded.

The Push Pull technique was considered viable after this experiment because the ground was indeed moved from the negative side of the battery to in between the two current sources. The results of achieving the 100mA through the battery at the end support this because of the changes made to the system. The changes made were creating: a Push and Pull current source, bias trim and signal trim circuits. If any of these changes did not work correctly then mismatch of current would occur between the two current sources. When mismatch occurs between two current sources in series, rather than moving the ground in between the current sources, the mismatch causes system failure as two current sources cannot be put into series with each other unless they are matching current.

Since the system did not "blow up" or any other massive failure occur when running the system, and we received the results that were expected through the battery, we can say that Push Pull technique does indeed work for moving the ground from the negative end of the battery to in between the current sources.

8 System Cost Summary

# Amount Needed	Part	Unit Price
25	15kΩ .1%	$.51

25	150kΩ .1%	$0.60
13	1k 10-T Trim pot	$1.46
10	10k 10-T Trim Pot	$2.86
8	22uF	$0.39
8	.1µF	$0.10
5	548 op amp(KZN)	$15.00
5	548 op amp(T)	$15.00
10	551 op amp	$4.00
1	Current Driver PCB	$95.05
1	Bias/Signal Trim PCB	$75.05
4	10V Voltage regulator	$0.78

The table above shows the cost per unit for the entire project with the exception of the PCB boards. The PCB cost is correct as total cost of the boards, I say this because the company I purchase the boards from (ExpressPCB) would ship with 3 boards for the price given, and there is not option to order less amount of boards. It is also important to note that the PCB size was 3.8'x2.5', once the size is outside of these parameters the cost increases by $100-$200. The two different 548 op amps are due to different chip packaging, where one was used for breadboard prototype (T) and the other was used for PCB (KZN).

They the amount ordered for this project was created with the knowledge of having to build two current drivers PCB and two bias/signal PCB. While this was the original thinking, I actually went a different direction and created two current drivers PCB, and one bias/signal trim PCB. The extra current driver became a backup, and the remaining parts are also backups.

The total cost of this project, including the shipping, was $423.91 and without the cost of shipping was $409.93. Where shipping was $6.99 for each time I ordered parts from mouser, which was two times.

9 Matlab Code

```
%Randy Ford
%Senior Project
clc;
clear;
close all;

%found it to increase by about .0018mA, for every increase in .0005
%used to test actual resistor values
r2a= 10;
r2b= 10.0024e3;
r1a= r2a*10;
r1b= r2b*10;
%simulates resistor values and test ohms
rs= .5;
r1=100e3;
r2=10e3;
r1=abs((r1a+r1b)/2);
r2=abs((r2a+r2b)/2);
dr2= 5;
dr1= 10*dr2
dr1=abs((r1a-r1b)/2);
dr2=abs((r2a-r2b)/2)
vb= 10;
```

10 References

Equations 1-5 were from:

Matt Egloff, J.L. Morrison, "Critical Analysis of an Instrumentation Current Source", 15A 59TH IIS Conference, Cleveland OH, May 2013