

# Analog to Digital Converter

## For a Two Photon Microscope

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**Abstract--** *The output of a photomultiplier tube is an analog signal. For a computer program to be used to generate an image from the output, an analog to digital converter is needed. We chose to build a dual phase integrator as our analog to digital converter.*

**Keywords—***dual phase integrator, photomultiplier tube, adaptive optics, live imaging microscopy, Shackholm wave front sensor, deformable mirror, two-photon microscope, slew rate, noise*

### I. Introduction

The output of a photomultiplier tube is an analog signal. For a computer to generate an image from the output of a photomultiplier tube, an analog to digital converter must be used to convert the signal. Currently a two-photon microscope is being installed to replace the confocal microscope being used for live imaging microscopy. Due to this change there are many changes which are required for the new setup to work. One of these changes is using a photomultiplier tube to capture the light intensity generated by the organism being imaged. We have chosen to build a dual phase integrator, which will convert the output of the photomultiplier tube into a digital signal that a computer will be able to process to generate the final image.

### II. Background

#### A. Live Imaging Microscopy using Adaptive Optics

Live imaging is largely limited by the aberrations induced by the living tissue; correction of these aberrations can be achieved using adaptive optics. To correct for the aberrations a laser is shot into the living organism to excite fluorescent proteins within the living organism. The light emitted is then measured and

compared to a reference laser using, in this setup, a Shackholm wave front sensor. The emitted light is then corrected using a deformable mirror. This imaging process was originally used by astronomers to generate artificial guide stars, by shooting a laser into the sodium layer in the earth's atmosphere and measuring the reflected light.

#### B. Two Photon Microscope

A two photon microscope is currently being installed to be used for imaging and is replacing the confocal microscope which had previously been used. The two photon microscope uses a short high intensity pulse of light of a greater wavelength than that of the confocal microscope. Because the wavelength is longer, two photons must be absorbed by a fluorescent protein at approximately the exact same time for fluorescence to occur. Because of this the accuracy of a two photon microscope is much more precise and an open loop system can be used because there is far less ambient fluorescent light. The emitted light is measured by a Shackholm wave front sensor, which controls a deformable mirror, which corrects for the aberrations. Because it is an open loop system only one integration is needed for imaging.

#### C. Photomultiplier Tube

A photomultiplier tube is a special vacuum tube which generates a pulse equal to the current produced by the incident photons multiplied by a known constant, the constant is known and can be as high as 100 million. A photomultiplier tube is being installed into the new setup to measure the light emitted by the guide star. We have chosen to use a photomultiplier tube for live imaging microscopy due to its high gain and ultrafast response. The output of a photomultiplier tube is a voltage pulse whose amplitude is equivalent to the number of photons detected during the pixel period. For

a computer to generate an image from the output of the photomultiplier tube a fast analog to digital converter is needed.

### D. Dual Phase Integrator

A dual phase integrator is an analog digital converter which switches between two RC integrators. While channel one is integrating channel two is left open, then while channel one's capacitor is discharged channel two is used for integration and channel one is open. By switching between two channels time is not needed to hold the pixel value while the capacitor of the RC integrator is discharged. Also, by using an RC integrator: only one iteration is required per pixel, the pixel and sampling period can be changed without needing to change the resistive or capacitive value of the RC integrators, and the integrators are able to keep up with the high speed imaging of the two photon microscope. Because of these benefits we chose to build a dual phase integrator as our analog to digital integrator.

The design of our dual phase integrator is based on the dual phase integrator designed by Qouc-Thang, Jonathan Driscoll, Earl M. Dolnick, and David Klainfeld, written about in *In Vivo Optical Imaging of Brain Function, Second Edition*. We have changed the original design by designing our own RC integrator, changing the op-amps used, and creating a circuit to control the amplitude of the output.

## III. Work Completed

### A. Generating a Prototype using PSpice

Before building the physical circuit we first built a model of the final circuit using PSpice to test the effect of using different op-amps and resistive and capacitive values of the RC integrators. For each op-amp we tested different resistive and capacitive values for the RC integrators to see the effects had on the output under perfect conditions.

For each op-amp that we tested we first used Webench online at <http://webench4.ti.com> to compute the ideal resistive and capacitive values. Before selecting the op-amp we were testing we would first needed to input: the integration time, the pixel period, the minimum and maximum voltage, the power supply of the op-amp, and that the system would be run rail to rail.

Integrator - Required Parameters <a href="#">help</a>	
Integration time (DeltaT):	2.25e-3 ms
Maximum input voltage (VinMax):	0 V
Minimum input voltage (VinMin):	-5 V
Supply voltage:	<input type="radio"/> 5V <input type="radio"/> 3.3V <input checked="" type="radio"/> +/-5V <input type="radio"/> +/-3.3V <input type="radio"/> +/-12V <input type="radio"/> Other
If "Other", Positive Supply is:	5 V
If "Other", Negative Supply is:	-5 V
Integrator - Optional Parameters <a href="#">help</a>	
Is this a portable system?	<input checked="" type="radio"/> Y <input type="radio"/> N
Preferred output swing:	<input checked="" type="radio"/> Rail-to-Rail (R-R) <input type="radio"/> no preference

Figure 1 Set Up to use Webench to model an Integrator

We then selected the op-amp we wanted to simulate and the ideal resistive and capacitive values would be computed through Webench.

After using Webench we then used our model in PSpice with the capacitive and resistive values computed to test and see if the output was what we expected it to be. We expected the output of our model in PSpice to be the same as that of the output shown in the paper we based our original design off of.

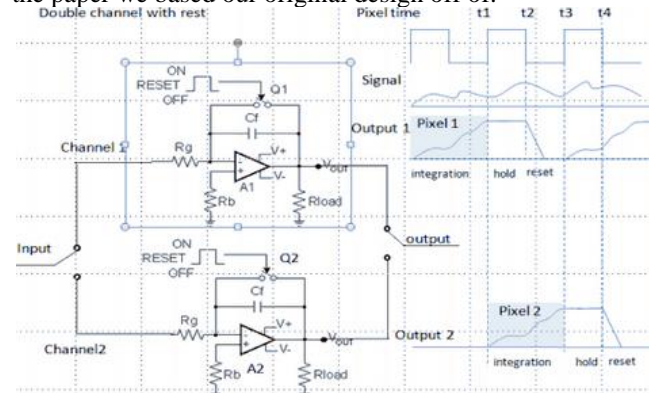


Figure 2, Original Model with expected output shown in *In Vivo Optical Imaging of Brain Function, Second Edition*

We set the input to a small period high amplitude square wave so that it would be easy to test using the same input when we finished building our prototype. We used four separate square waves to separately control the input, output, and the sample and reset of each channel.

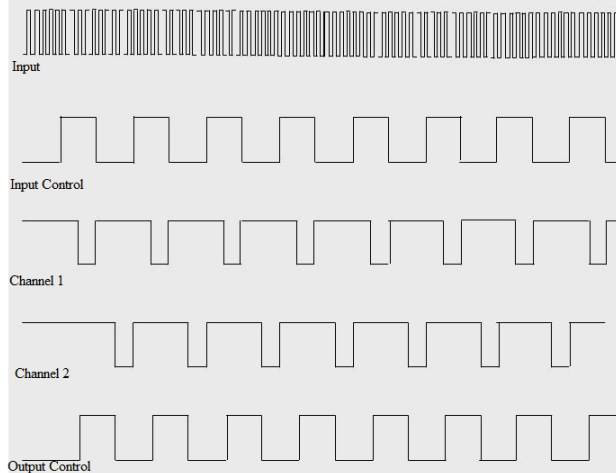


Figure 3, Timing for the Input and Controlling the Circuit

At first whenever the input or pixel (input control) period were changed the result were off for all of the op-amps, resistive, and capacitive values that we tested using the model we had created using PSpice. After some time it came to our attention that the output was only what we expected it to be when the pixel period was divisible by the input period. Since the actually input would not be a five volt square wave of a fixed period we realized that this would not affect the output of the final circuit and we could therefore move forward testing capacitive and resistive values using different op-amps.

While testing different resistive and capacitive values of the integrator we made sure to measure the power dissipation and noise in the output. We chose to use a 10 kohm resistors and 56 pF capacitors for the two RC integrators because of the low power dissipation and the fact that the time constant would be small enough for our needs.

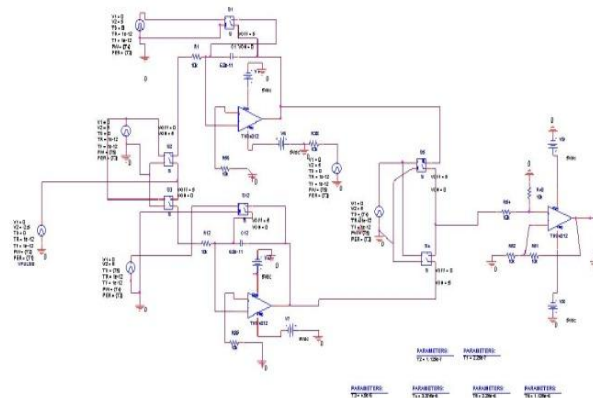


Figure 4, Final PSpice Schematic of the Dual Phase Integrator

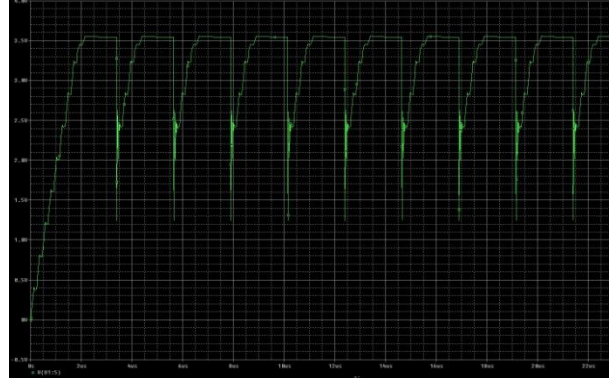


Figure 5, Final and Expected Output of the Dual Phase Integrator PSpice Model

### B. Testing Op-amps and Switches

Next came the task of choosing the switches and op-amps that would work fast enough, with a small amount of power dissipation whilst being able to handle a high amplitude and low period input. We first went through all of the op-amps and switches available through Texas Instruments, Analog Devices, and Vishay online. By looking at their data sheets we were able to select op-amps that was able to handle an input voltage of at least -5 to +5 volts, had a small amount of input noise, a large bandwidth, and a slew rate of at least  $6 V/\mu\text{sec}$ . In the same way we were able to select potential switches that could handle an input voltage of at least -5 to +5 volts, switching times that were at least under 300 nsec, and were either single pole single throw (SPST) or single pole double throw (SPDT).

The op-amps that we chose to test in the prototype were the LT1357, LT1358, LM1358, THS4012, LMH6657, LMH6645, THS4012, LT1357, LF412, LM833 and the LMH6645. The switches that we chose to test were the ADG1236, ADG752, ADG719BRTZ, DG417, DG201, and the ADG636. Multiples of each op-amp and switches were tested to make sure that any errors were not the result of manufacture error or an open or short created whilst soldering the parts onto their adapters.

To test the op-amps we created a simple RC integration circuit with the resistive and capacitive values that we would be using in the final circuit. We used a SCB-68 to generate a sine wave with a period twice the period of the pixel period,  $4.5 \times 10^{-6}$  seconds, and measured the output using an oscilloscope.

To test each switch we created a simple circuit with the input voltage being run through a voltage divider to lower the amount of current flowing through the switches and measured the output voltage by measuring the voltage difference across a 10 kohm resistor placed between the output of the switch and ground. When testing the switches we tested at  $1/10$ th the speed that the final circuit will be run at to gain a better understanding of the noise generated by the input when

the switch was turned off. To generate the square waves that controlled the switches when testing we used the same SCB-68 as we had used to generate the sine wave when testing the op-amps.

Below is a comparison of the DG201 versus the ADG1236, both of which were SPDT CMOS switches with relatively similar data sheets, yet as we saw the ADG1236 performed much better than the DG201.

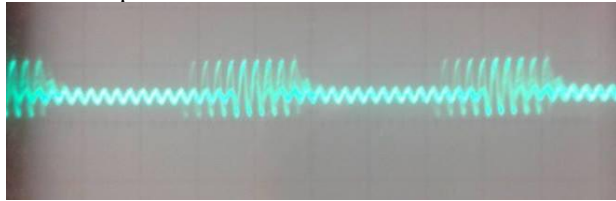


Figure 6, Output of the NS201 when the input was a square wave.

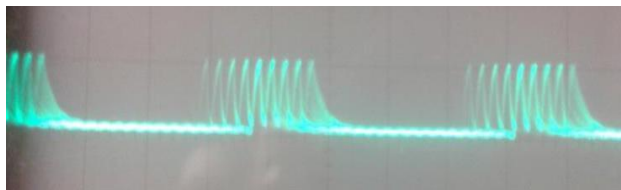


Figure 7, Output of the ADG1236 when the input was a square wave.

The final op-amps that were chosen to be tested in our Dual-Phase Integrator prototype were the LF412, LM833, and the LM1358 because of their high slew rate and low output noise. The switch chosen to control input and output was the ADG636 and the switch chosen to control the integrate and reset of each channel was the ADG1236. Two switches were chosen because the switch controlling the input and output only needs to be a SPST whilst the switch controlling the channel's integrate and reset needs to be an SPDT.

### C. Creating a Prototype of the Dual Phase Integrator

After selecting the op-amps and switches we began work on the prototype to test the circuit and to test each op-amp and select the op-amp which created the least amount of noise and had the least amount of power dissipation. The switches used in the circuit were controlled by square waves generated by the SCB-68. We first tested each channel and used the SCB-68 to generate the input as well. The input was 5 volt square wave with a period  $\frac{1}{10}$ th of the pixel period. When testing the prototype we tested at  $\frac{1}{10}$ th the speed which the final circuit will be running to more easily test the op-amps and to more easily find errors in the prototype.

After testing multiple op-amps we have chosen that we will use the LM833 because the lack of noise generated by the LM833.

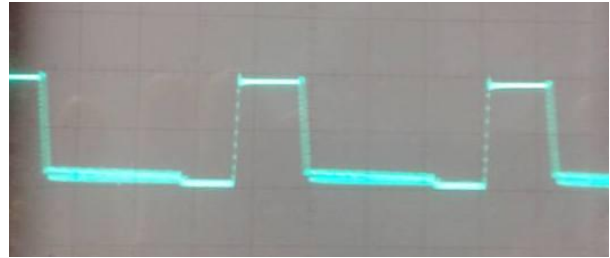


Figure 8, Output of a single Channel of the Dual Phase Integrator Using the LM833

The LF412 was not chosen because the power the power dissipation and the noise generated when the switch was turned on was too high.

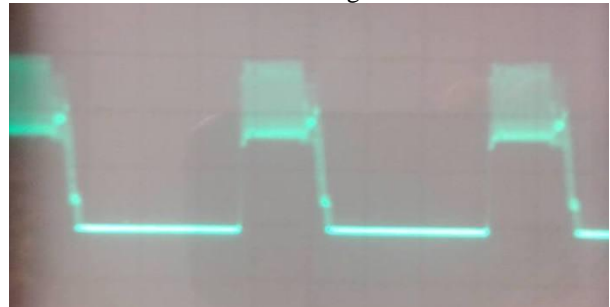


Figure 9, Output of a single Channel of the Dual Phase Integrator Using the LF412

The LM1358 had less power dissipation than the LM833 and the LF412 but generated significantly much more noise in the output than either op-amp as well.

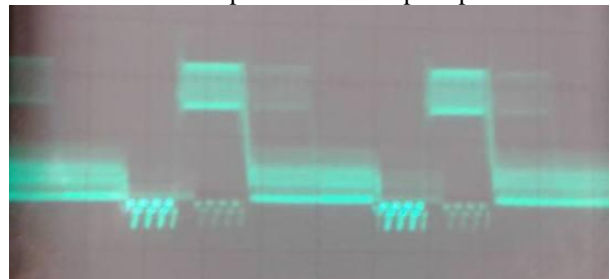


Figure 10, Output of a single Channel of the Dual Phase Integrator Using the LM1358

After choosing the op-amp that would be selected for the final circuit we then connected the input to the voltage source and connected another ADG1236 to the output and used the SCB-68 to control the output. We chose to use the LM833 for the output as well and connected the output of the ADG1236 controlling the output to a voltage divider followed by a non-inverting operational amplifier configuration. We chose this configuration so as to be able to control the amplitude of the output to fit our needs.



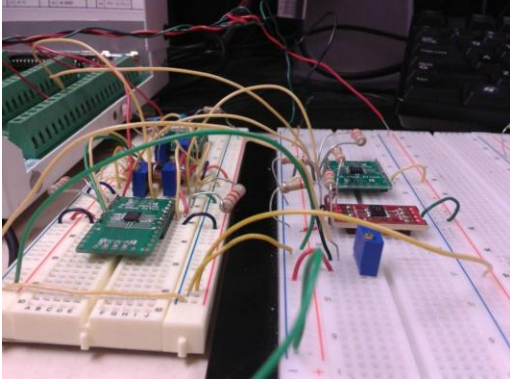


Figure 11, Final Prototype of the Dual Phase Integrator

#### IV. Future Work

Currently work is under way to build the final Dual Phase Integrator which will be used as the analog to digital converter between the PMT and the computer. To create the final circuit we will be soldering the selected parts onto a PCB board to drastically cut down the amount of wire and limit the amount of noise generated. The square waves used to control the switches in the final circuit will continue to be generated by a SCB-68. After soldering the parts onto a PCB board we are planning on also placing the final circuit into a metal container to limit the amount of noise picked up by the circuit from the imaging system itself. We will need to find a way to reliably supply the input and control square waves to the circuit if we do this which will require a bit more engineering. Once the final circuit is built it will be attached to the PMT and used for imaging.

#### V. Conclusion

We have finally created a prototype of the dual phase integrator, which will be used as the digital to analog converter for the two-photon microscopy being used for live imaging microscopy. The Dual Phase Integrator is fast enough and resilient enough against noise that it will work well as the analog digital converter. Though the final circuit has yet to be built we have had great progress and the results are what we wanted for the finished product.