

**TRIOAMP Lab Experiment**

**Physics 398 EMI / Physics 498 POM**

**The Physics of Music/Musical Instruments**

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## TRIOAMP: Triode Voltage Amplifier Experiment and Setup

In the TRIOPAR experiment, you studied the properties of dual triode tubes with DC input signals. In the TRIOAMP experiment, you will study dual triode operation as a voltage amplifier with AC input. The TRIOAMP module houses a common triode voltage amplifier circuit (Fig 1).

In the TRIOPAR experiment, the cathode was tied directly to ground. That was acceptable with a DC negative voltage on the grid. However in the Triode Voltage Amplifier circuit there are both positive and negative input voltages on the grid. If the cathode was tied to ground in this circuit, only negative grid voltages would be amplified. To amplify the full cycle, the idle anode current must be reduced. Therefore a resistance is placed on the cathode. This reduces the idle current and creates a small voltage between the cathode and the grid. This grid bias allows the full input cycle to be amplified. It should be noted that phase inversion does occur. The load resistor is tied between the HV supply and the anode. An increase in plate current increases the voltage drop across the load resistor, forcing the anode voltage to decrease.

A block diagram of the TRIOAMP experiment can be seen in figure 2. The plate high voltage is supplied by the Bertan 815 HV power supply, which is controlled by the PC+ Card. The computer uses GPIB communication to control a Wavetek Function generator. The Wavetek places a 10 mV sine wave on the grid.

We read both plate voltages with two Stanford SR830 Lock-In Amplifiers. The lock-ins allow us to study the signal in the frequency domain, even with a lot of noise surrounding the signal. The lock-in requires a reference signal from the function generator synchronized with the triode grid input. The SR830 is a dual-phase lock in, so it has outputs proportional to the cosine and sine of the phase difference between the output signal and the input. These outputs are obtained by taking the low-pass filtered product of the input signal multiplied by internal reference oscillators that are both in-phase and out-of-phase. Output 1 (X) is  $V_{sig}\cos\theta$ , representing the in-phase component of the voltage. Output 2 (Y) is  $V_{sig}\sin\theta$ , representing the out-of-phase component of the voltage. When the output is completely in-phase with the input ( $\theta = 0$ ), Output 1(X) will be the amplitude of the signal, however Output 2(Y) will be zero. We use 4 ADC's to digitize the X and Y outputs of both lock-ins.

In software we can compute the magnitude of the signal. The magnitude is equal to  $\sqrt{X^2 + Y^2}$ . We can also compute the phase shift between the input and output by  $\tan^{-1}(Y/X)$ .

The TRIOAMP experiment starts with a 10 mV peak-to-peak 10 Hz sine wave on both grids of the dual triode. We then sweep the audio frequency range, from 10 Hz to 20 KHz with a step size of 20 Hz. We take 1000 samples per point of the 4 lock-in outputs. We also record the cathode voltage at every point during the run. When resonant frequencies of the triode are reached, there are usually large phase shifts. At these large jumps, the lock-ins need extra time to stabilize. Therefore, we included code in the

software that delays stepping up to the next frequency allowing the lock-in to stabilize and provide an accurate measurement.

After building the experiment, we ran the TRIOAMP experiment for several tubes and observed a ~ 40% decrease in output signal amplitude with increasing frequency (Fig 3). Over the audio range (20 – 20 KHz) the output signal amplitude should be much flatter than this! The source of this problem is due to the intrinsically high output impedance associated with triode voltage amplifiers (typically ~ 70 K-Ohms for a 12AX7) . We use 6-ft long SMB cables (~ 32 pF/foot, or ~ 200 pF total) to connect the output(s) of the dual triode voltage amplifier to the inputs of the two SRS-830 lock-in amplifiers. The ~ 200 pF SMB cable(s) combined with the high output impedance of the triode voltage amplifier(s) had the unwanted effect of behaving like a low-pass filter between the TRIOPAR module and the lock-in amplifier inputs. In addition, the input impedance of the lock-in amplifiers is not constant, but decreases with frequency, and loads down the high-impedance output of the tubes! Thus, the voltage amplifier circuit was unable to drive the cable capacitance and input impedance of the lock-in amplifiers in the audio frequency range we were studying. To remedy this problem we simply inserted a Texas Instruments TL072 JFET Op-Amp ( $Z_{input} \sim 10^{12}$  Ohms), configured as a unity-gain buffer/cable-driver in the module, between the triode output(s) and the lock-in amplifier inputs (Fig. 4). The  $\pm 15$  V power supply powers the TL072 Op-Amp.

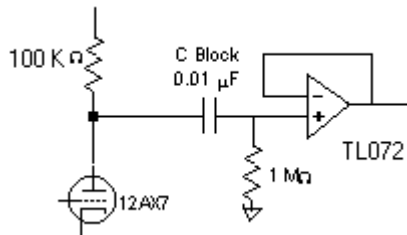


Fig 4. Addition of TL072 Op-Amp

The TL-072 JFET Op-Amp is non-inverting, and unity gain. The TL072 has a extremely high input impedance ( $\sim 10^{12}$  Ohms), but a fairly low output impedance ( $< 1$  K-Ohm). The addition of the TL-072 buffer/cable-driver op-amp(s) to the circuit completely eliminated the 40% decrease in plate signal amplitude vs. frequency (Fig 3).

The output from the triode voltage amplifiers stays about 180 degrees out of phase with the input signal for almost the whole frequency range (Fig 6). As frequency increases, the phase shift decreases a small amount from 180 degrees (fig 5 and 6). The 180 degree phase shift between input and output is expected because the phase inversion occurs in the triode voltage amplifier circuit. The Cathode voltage amplitude vs. frequency graph is also interesting in that shows the charge building up and discharging throughout the test (Fig 7).

The TRIOAMP DAQ Program's main panel can be seen in figure 8.

## **Equipment**

Bertan 815 HV Power Supply

12A\*7 Triode Voltage Amplifier (TRIOAMP) PC-based DAQ program

6.3 Vac (rms) Unregulated Filament Power Supply & Variac

White/Black 5/15 V DC Power Supply

50-pin Green Connector Board

(2) Stanford SR830 Dual-Phase Lock-Ins

Wavetek Model 81 Function Generator

## **Initial Lab Setup**

1. At the start of each TRIOAMP experiment, the Bertan Power Supply 3-pin power cable should be removed, the  $\pm 15\text{V}$  DC power supply should be off, the Wavetek 81 Function generator should be off, and the Variac and the Filament Power Supply should also both be off.
2. Plug the 50 Pin flat-cable into the green connector board. Make sure that red triangles in the right corners align with each other.
3. Ensure All SMB cables are connected correctly to TRIOAMP Module. The labels on the cable ends must correspond to the labels on the module.
4. Plug the 3 pin Molex connector (Blue, Black and Green) into the Filament Power Supply.
5. Plug the 6 pin Molex connector (Blue, Black, Green, & Red, Green, Black) into the 6.3 V AC input on the TRIOAMP module.
6. Turn on both Lock-ins and Wavetek Function generator. Ensure lock-in settings correspond with the following:

## **Stanford Research Systems SRS-630 Lock-In 1 & 2 Settings:**

TIME CONSTANT: 1 sec, 6 dB

Sensitivity: 1 volt

Signal Input: Channel A, DC coupling, GROUND referenced

Reserve: Normal

Filters: None

Channel 1: Display =X, Ratio =None, Expand = None, Output= Display, offset=off

Channel 2: Display =Y, Ratio =None, Expand = None, Output= Display, offset=off

Phase = +90 degrees

Trigger = sine

Source = unlocked w./ no signal present, = locked when signal is present.

1. Place a 9-pin miniature dual triode vacuum tube in the 9-pin tube socket, place the tube shield on the tube.
2. Turn on the variac and filament power supply, adjust the variac to get 6.3 Vac (rms) {using a Fluke DMM} and then let the tube warm up for 5 minutes.
3. Close all programs on the computer.
4. Run Labwindows/CVI by clicking on the shortcut on the desktop.
5. Go to File -> Open -> Project -> open trioamp5.prj located in c:\cvi\P398\DAQ Prog\trioamp5.prj
6. Turn the 15V power supply on. (the red LED above the +15 will light)
7. Turn on the Wavetek 81 Function Generator, connect the GPIB cable to it.
8. Plug the 3 pin power cable into the Bertan 815 HV power supply.
9. Go to Run -> Run Project. The TRIOAMP software will load.

## Running the TRIOAMP Experiment

1. Click on the **Init Daq Syst!** button to initialize the PC+ card. This clears all inputs and outputs on the LabPC+ DAQ card and also sets the Bertan HV power supply to 0 Volts.
2. Click the **START** button to begin data taking.
3. Enter the desired plate voltage, (50 V -> 250 V).
4. To stop the TRIOAMP program and disable the +HV, hit the stop button anytime during the program. Hitting the stop button will not “pause” the run, the run will end completely.
5. When data taking is complete, immediately save the data by clicking on **SAVE DATA TO FILE** in the top right corner of the screen.
6. To View Graphs, click on the **Plots** menu. You may print all graphs at once by clicking on **PRINT ALL PLOTS!**.
7. Click on the **Quit** button to Exit the TRIOAMP DAQ program.
8. Unplug the 3 pin power cord from the Bertan HV Power Supply, turn off the  $\pm 15V$  power supply, turn off the Filament Power Supply & Variac.
9. Let the tube cool before removing from TRIOAMP Module.

**To exit the TRIOAMP DAQ Program, click on the QUIT button (if you have not already done this), then on the LabWindows/CVI Project window, go to the pull-down File menu and select Exit.**

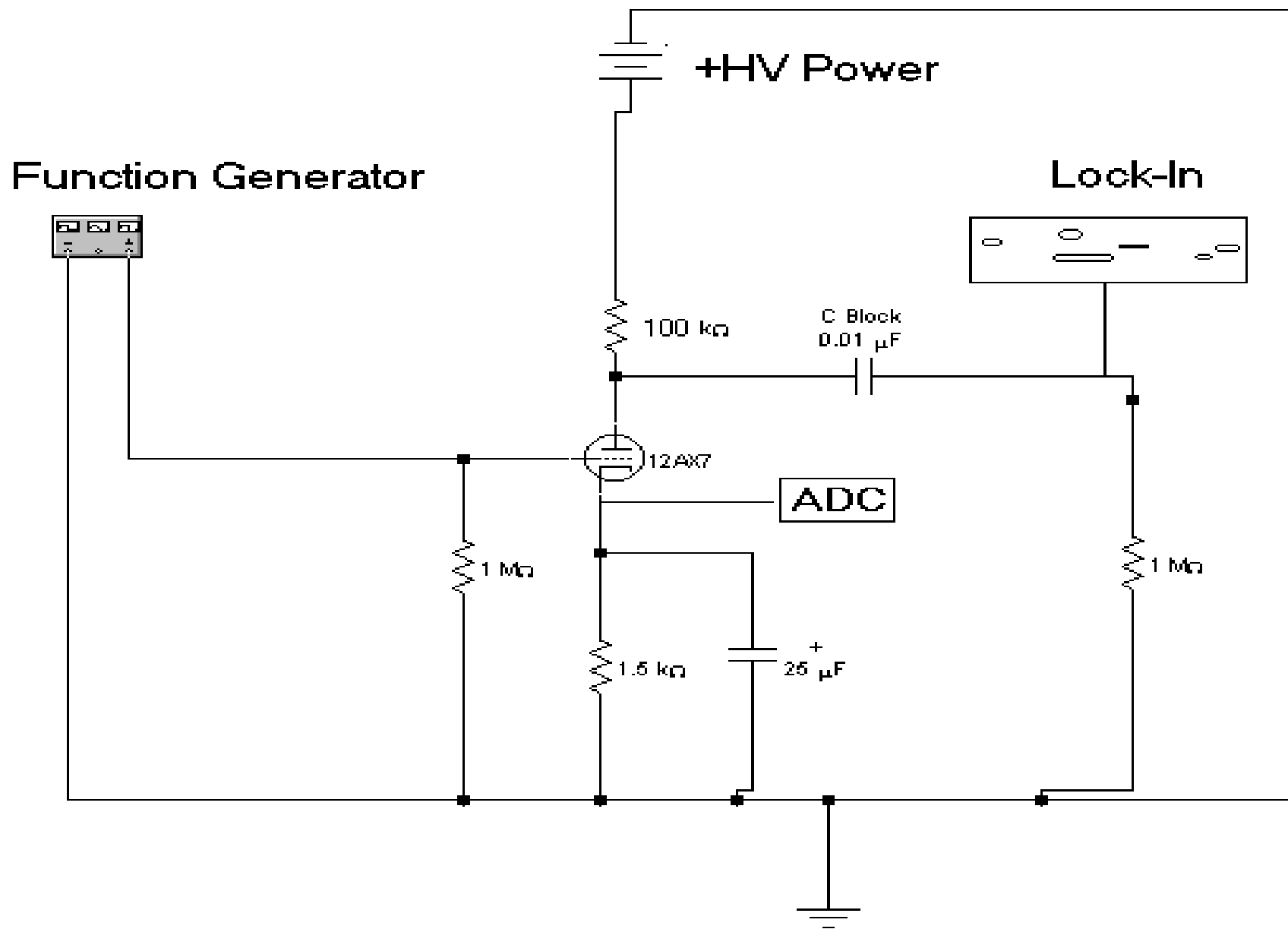
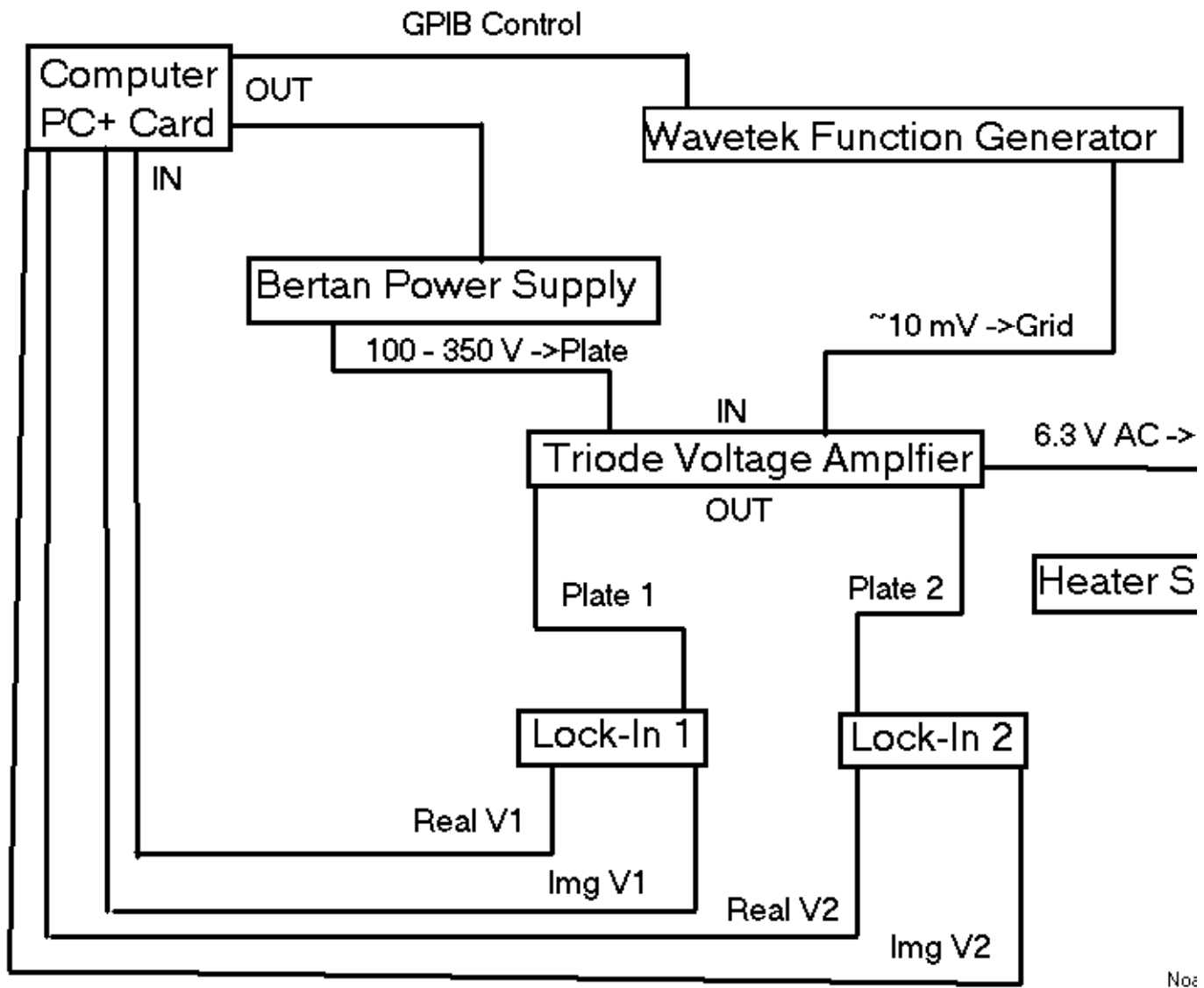


FIG. 1 The TRIOAMP Circuit



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Fig. 2 The TRIOAMP Block Diagram

Mullard 12AX7 Plate [Voltage] vs. Frequency  
Original & Buffered Output

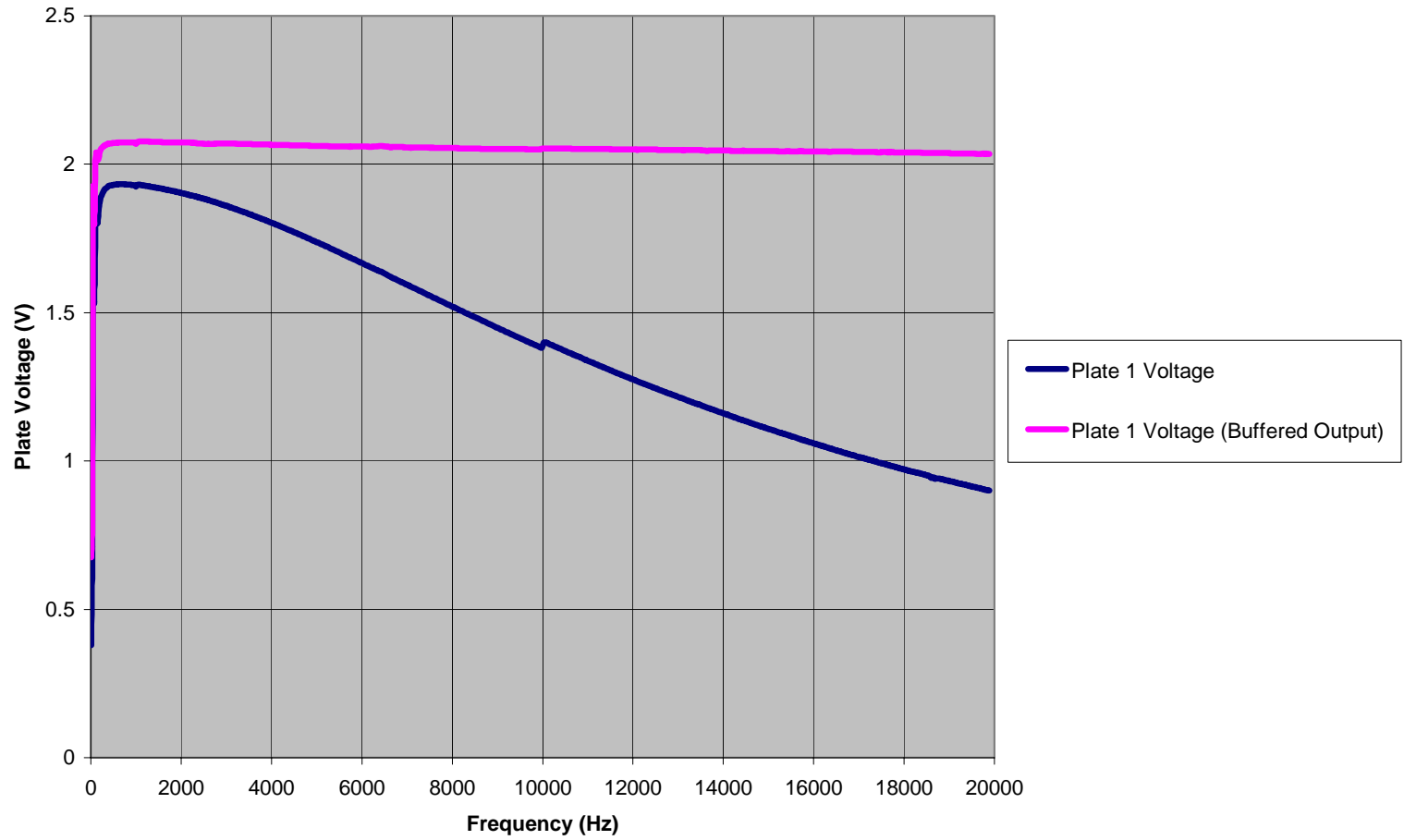


Fig. 3 Mullard 12AX7 Plate Voltage vs. Frequency

### Mullard 12AX7 In and Out of Phase Voltage vs. Frequency

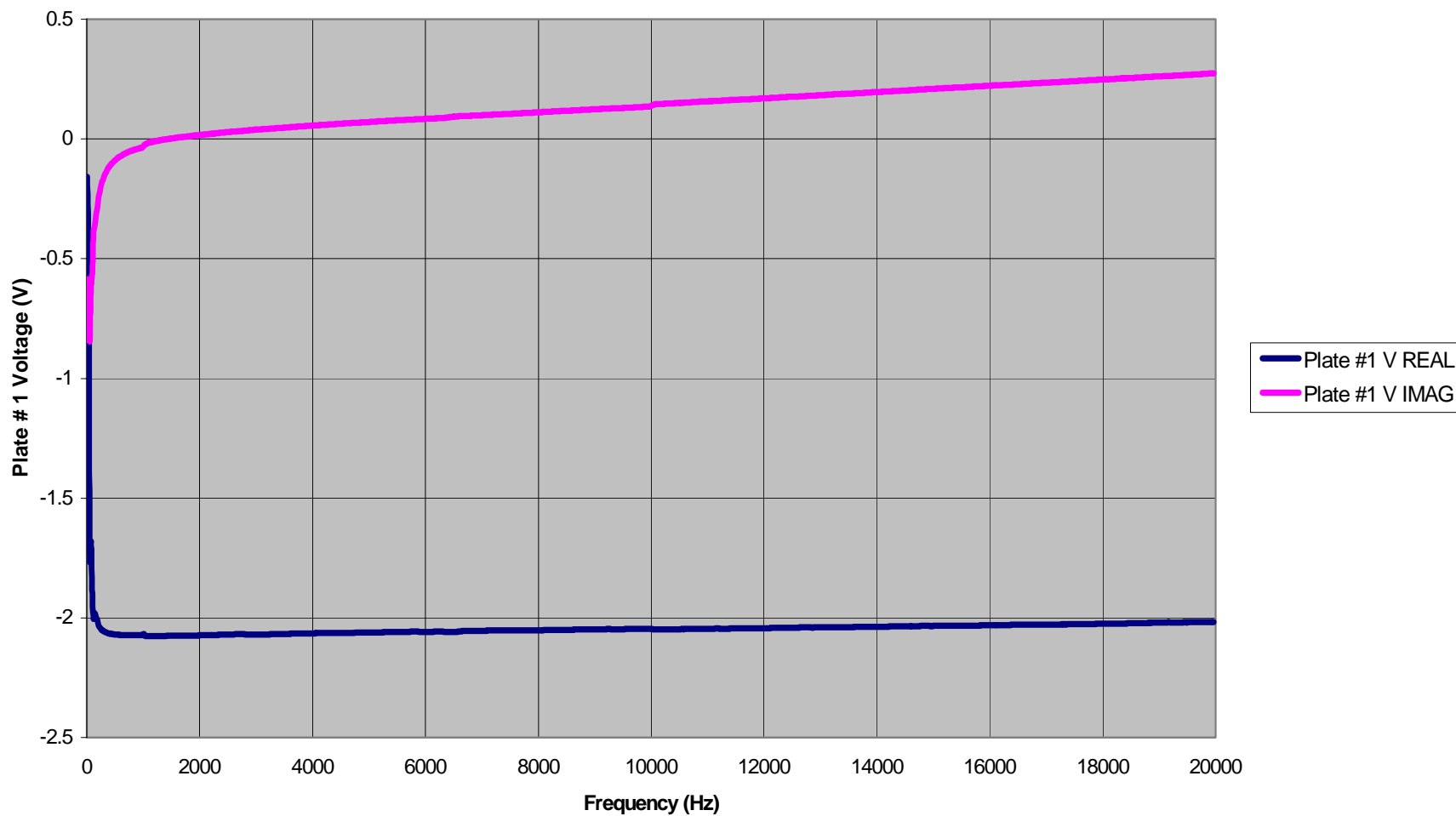


Fig. 5 Mullard 12AX7 In-Phase and Out-Of-Phase Voltage vs. Frequency

### Mullard 12AX7 Plate 1 & 2 Voltage Phase vs. Frequency

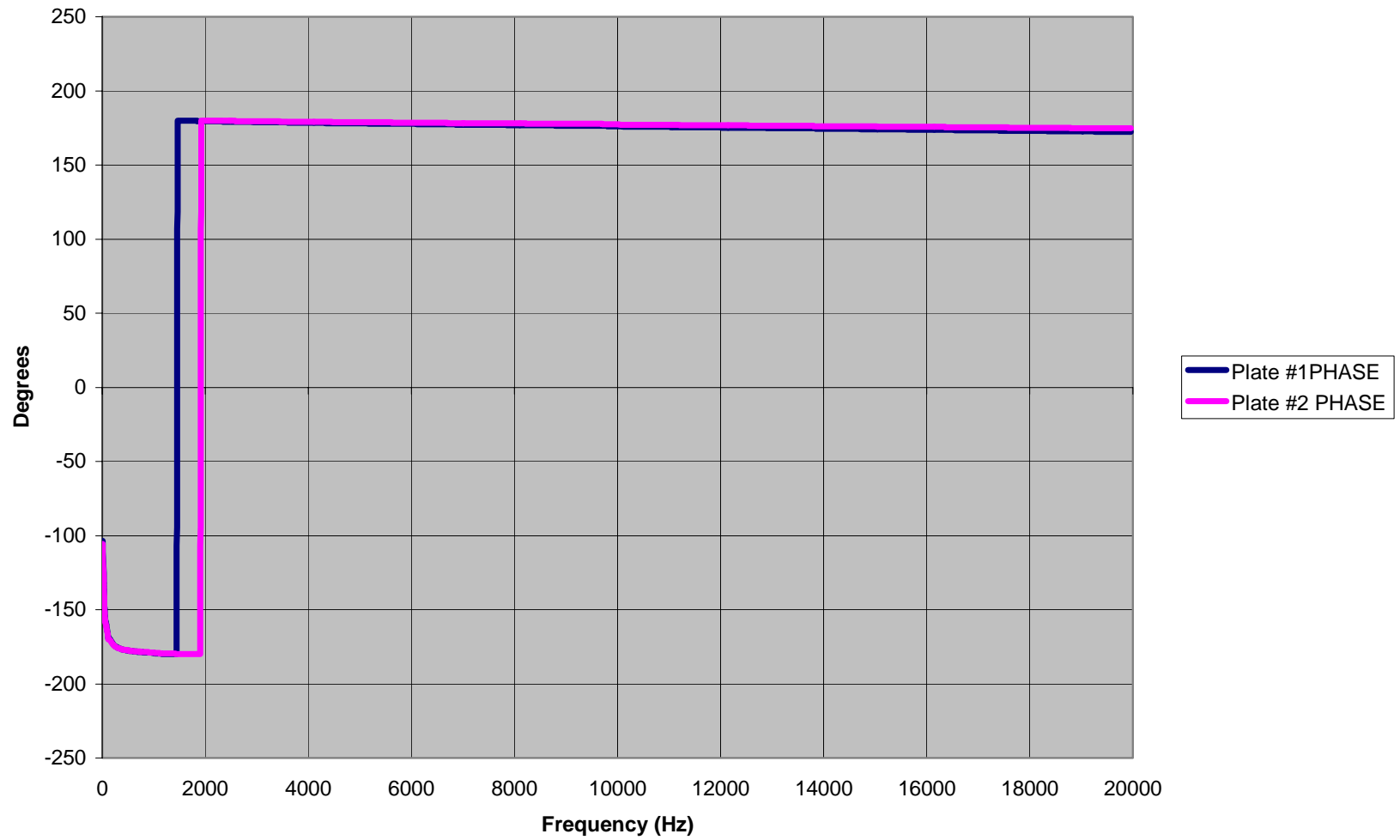


Fig. 6 Mullard 12AX7 Phase Shift vs. Frequency

Mullard 12AX7 Cathode Voltage vs. Frequency (Vplate = 150V)

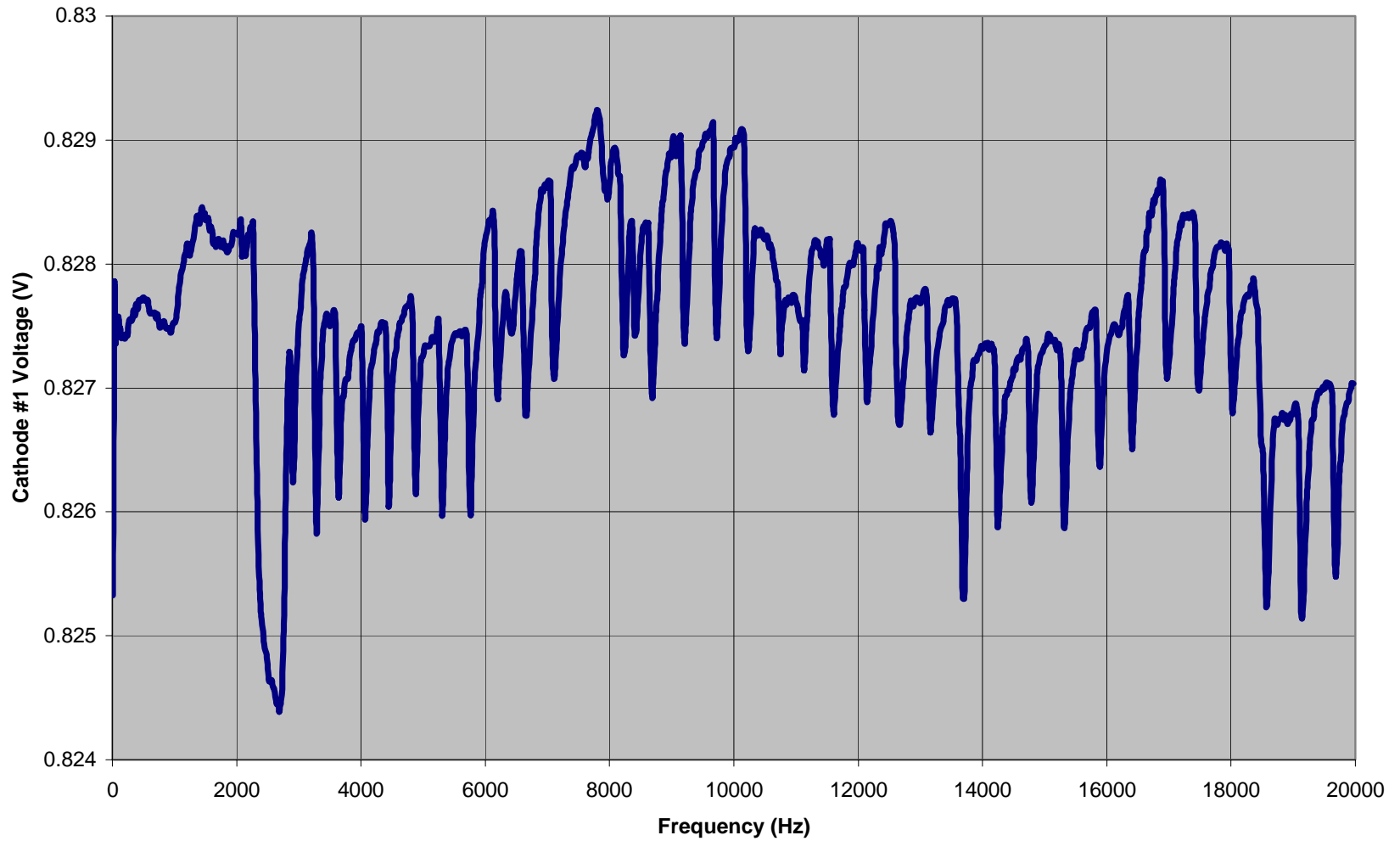


Fig. 7 Mullard 12AX7 Cathode Voltage vs. Frequency

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HELP Change Wavetek Amplitude! Change Wavetek Freq Range! Change Lock In Wait/Delay Time Plots Save Data to File

Init DAQ Syst!
START
STOP

**Wavetek Function Generator**

Frequency	F_Min (Hz)	F_Max (Hz)	F_Step (Hz)	Amplitude(V)
0.000000	0.000000	0.000000	0.000000	0.000000

**General Information**

Sample #	Time Begin	Date
0	hh:mm:ss	dd-mm-yy
# SmpIs/Pt	Time End	Duration (s)
0	hh:mm:ss	0.00

**PLATE 1 VOLTAGE** Lock-In Amplifier **If change L.I. Sensitivity**

Lock In Sensitivity (mV) 5.0 **MUST change here too!!**

<ADC 4>  **OVLD !** Stabilize LI  <ADC 5>  **OVLD !**

0.00

<ADC 4>

0.000000

<PED 4>

0.000000

Re V1 (mV)

0.000000

dRe V1 (mV)

0.000000

<ADC 2>

0.000000

LI Tdelay (s)

0.00

**PLATE 1 VOLTAGE**

Phase (deg)

0.000000

|V1| (mV)

0.000000

d|V1| (mV)

0.000000

<V\_K1> (V)

0.000000

0.00

<ADC 5>

0.000000

<PED 5>

0.000000

Im V1 (mV)

0.000000

dIm V1 (mV)

0.000000

<I\_K1> (mA)

0.000000

**PLATE 2 VOLTAGE** Lock-In Amplifier **If change L.I. Sensitivity**

Lock In Sensitivity (mV) 5.0 **MUST change here too!!**

<ADC 6>  **OVLD !** Stabilize LI  <ADC 7>  **OVLD !**

0.00

<ADC 6>

0.000000

<PED 6>

0.000000

Re V2 (mV)

0.000000

dRe V2 (mV)

0.000000

<ADC 3>

0.000000

LI Tdelay (s)

0.00

**PLATE 2 VOLTAGE**

Phase (deg)

0.000000

|V2| (mV)

0.000000

d|V2| (mV)

0.000000

<V\_K2> (V)

0.000000

0.00

<ADC 7>

0.000000

<PED 7>

0.000000

Im V2 (mV)

0.000000

dIm V2 (mV)

0.000000

<I\_K2> (mA)

0.000000

**Bertan 815 Power Supply**

ON/OFF  Constant Voltage  Constant Current

Desired Output Voltage (V) 0.000000 DAC0 Volts 0.000000 <ADC 0> 0.000000

Desired Output Current (mA) 0.000000 DAC1 Volts 0.000000 <ADC 1> 0.000000

Readback Output Voltage (V) 0.000000 Readback Output Current (mA) 0.000000

**IMPEDANCE**

Phase (deg) 0.000000

Re Z (Ohm) 0.000000 |Z| (Ohm) 0.000000 Im Z (Ohm) 0.000000

dRe Z (Ohm) 0.000000 d|Z| (Ohm) 0.000000 dIm Z (Ohm) 0.000000

PRINT

QUIT

Fig. 8 The TRIOAMP PC-based DAQ Program