A DAMPED JOYSTICK:

EVALUATION AND TESTING

USING A TWO DIMENSIONAL TRACKING TASK

by

MARK HOWARD SLOAN

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Signature of Author ______________________
Department of Mechanical Engineering
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Certified by ______________________
Michael J. Rosen
Thesis Supervisor

Accepted by ______________________
Chairman, Department Thesis Committee

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Submitted to the Department of Mechanical Enginnering on May 18, 1981 in partial fulfillment of the requirements for the Degree of Bachelor of Science

ABSTRACT

The effectiveness of using a viscously damped joystick to suppress abnormal intention tremor was investigated with a two dimensional pursuit tracking task. The target, a randomly moving circle, and the response, a square controlled by the joystick, were displayed on a conventional television set. Data was recorded for off line spectral analysis by the digital computer.

One normal subject and one tremor subject were tested using two minute and ten minute tracking tasks at several frequencies. The results indicate that a damped joystick selectively reduces intention tremor more that it degrades tracking performance.

Thesis Supervisor: Dr. Michael Rosen

Title: Principal Research Scientist,
Department of Mechanical Enginnering

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In reality this project was started three years ago. Since then many people and organizations have helped and guided me through the maze that is research. They have shared in the triumphs and the setbacks, and without their assistance, I would not be writing this. I wish to thank them at this point.

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Intoduction

In the United States, there are more than 750,000 people who are hindered to some degree in their activities of daily living by pathological intention tremors (1). These tremors are caused by a variety of neuromuscular conditions, including cerebral palsy, multiple sclerosis, Freidrich's ataxia, or cerebellar injury. While the individual may still have usable levels of residual strength and voluntary control, the amount of tremor in the affected extremity makes it difficult or impossible for the person to perform a task requiring accurate positioning of the limb.

Using a joystick controller for a wheelchair would be such a task. The operation of this type of manipulator requires a high degree of positional accuracy from the user. A tremor ridden individual, who can not readily control his hand position, could follow a pattern of violent accelerations and decelerations or a wildly weaving pattern of motions as he/she tried to traverse a hallway. The resulting motions constitute a great hazard to the individual and the general population in his/her way.

Current thereputic methods, such as surgery or drug therapy have failed to adequately deal with this problem (6). Often these treatments have unwanted side effects or attentuate the individual's purposeful movements as much as, or greater than, the tremor, rendering them useless as treatment methods. These problems have motivated this study.

It is hypothesized that the application of a viscously damped load to a joint or muscle group will have a selective effect on the motor performance of tremor patients. Selective, in this sense, means that the load or damping applied to a joint or muscle group will allow the individual to make purposeful movements without the deleterious effects of tremor. Previous studies have demonstrated that the application of mechanical impedance to a joint in one-dimension (wrist flexion and extension) does reduce the level of tremor and allows voluntary movement.(1,4,5) This work intends to extend those experiments and generalize the results to the two-dimensional case by involving the larger muscle groups of the arm and shoulder.

A viscously damped manipulator, i.e. joystick, has been built that resists the rapid involuntary oscillations applied by the user in order to allow more accurate performance of his/her intended movement. This manipulator has been demonstrated to reduce intention tremor in a figure tracing experiment, where the dynamics of the subject's movements were unconstrained (6).

The goal of this project is to demonstrate the damped joystick's usefulness in suppressing tremor in a dynamic tracking task. This information is required if a damped manipulator is to be developed as an interface to a non-vocal communication device, environmental control system, or used as the controller of a moving vehicle such as a wheelchair or adapted van.

Experimental Methods

The basic experiment consists of a two-dimensional pursuit tracking task presented on a conventional television screen. The interrelationship between the human operator and the experimental apparatus is shown schematically in figure 1. Circuitry developed in part during the summer of 1980 and in part during this academic year creates the images of a circle and a square on the screen. (See appendix for a further description of the electronics involved.)

The target circle's motion is controlled by two independent noise diodes, one for the horizontal direction and one for the vertical direction. The noise diodes produce a white noise signal from .1 Hz to 100 kHz. White noise is defined as random variables containing energy distributed uniformly over all frequencies. Target driving signals were produced by filtering the noise below 1 Hz and amlifying it to the voltage level required to move the circle around on the screen. (See appendix for further details of the noise diode characteristics.) The size and width of the circle are adjustable, and were set to approximately two inches and three/sixteenth inches respectively for all trials.

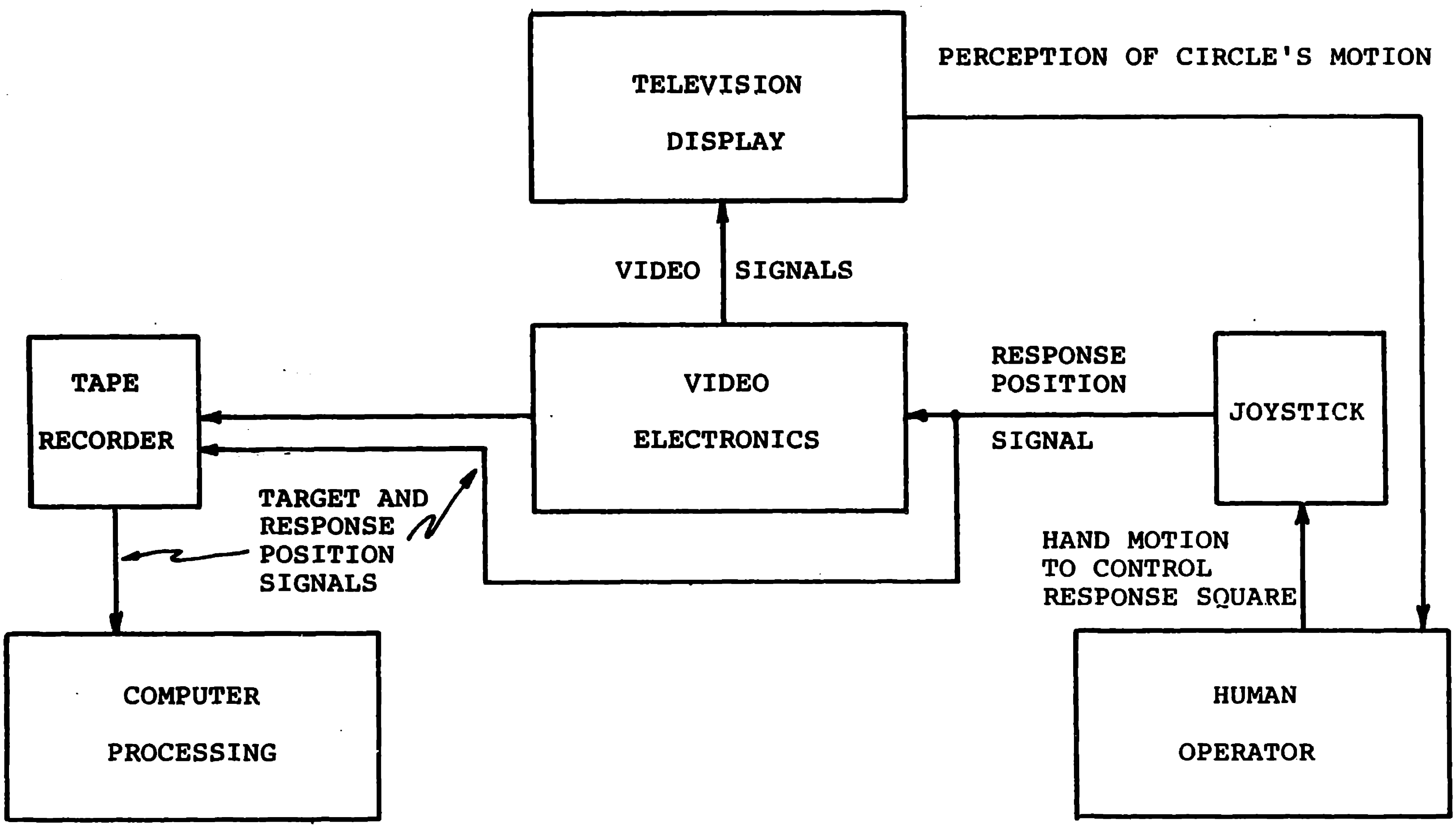


Figure 1: Schematic Diagram Depicting Ralationships Between the Subject, Joystick, and Television Display

The subjects were presented with the two-dimensional random moving target and asked to track it by keeping the square at the circle's center. The response square's position was controlled by the damped planar joystick (6). Figure 2 displays the mechanism of the joystick, dubbed Green Monster because it is housed in a 17x17x4 inch aluminum box, weighs twenty pounds, and is painted green. The joystick consists of "two double-acting hydraulic cylinders (piston rods through both ends of the cylinder) that are joined at right angles, one above the other, at their midpoints. The control handle of the device is coupled to the center of the cylinder unit and is limited to four inches of travel in either direction by the stroke of the cylinder (Clippard 9BDD4). The moving unit is supported at the ends of the piston rods by two orthogonal pairs of parallel rods via precision ball bushings (Thomson XA-81420). The damping action of each cylinder arises from the connection of the ports at each cylinder end through an external tube (0.09 in i,d,) which allows distilled water to be displaced from one side of the piston to the otner through its flow resistance"(6). (see figure 3)

When filled with water, each cylinder opposed the component of handle velocity along that cylinder's axis with a damping constant of approximately 1 lbf/(in/sec). To prevent lateral bending from damaging the piston rods and seals, a teflon and aluminum housing was machined to hold

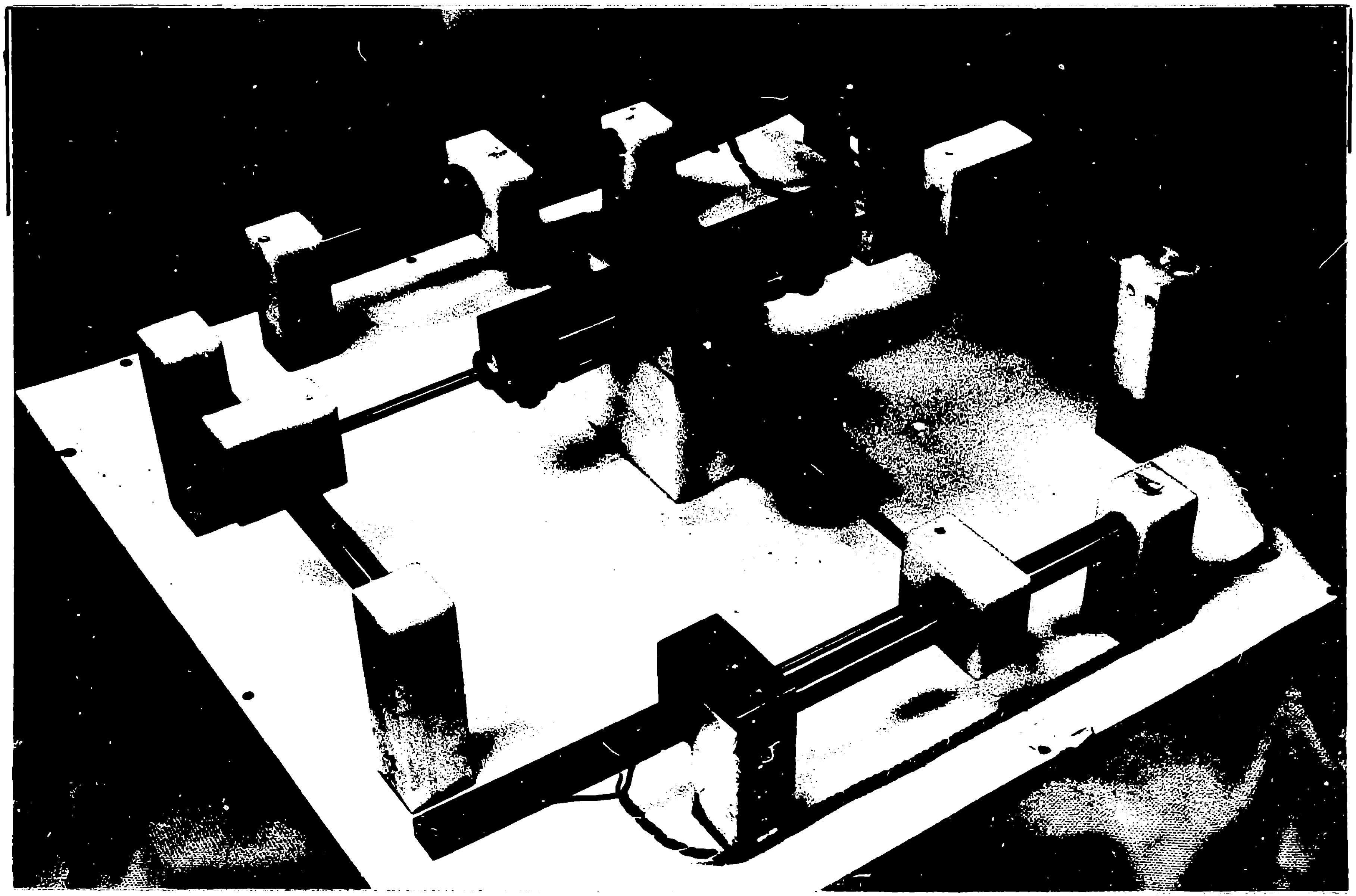


Figure 2: The mechanism of the damped planar joystick. Visible are the damping cylinders, support rods and bushings, and the signal generating potntiometers.

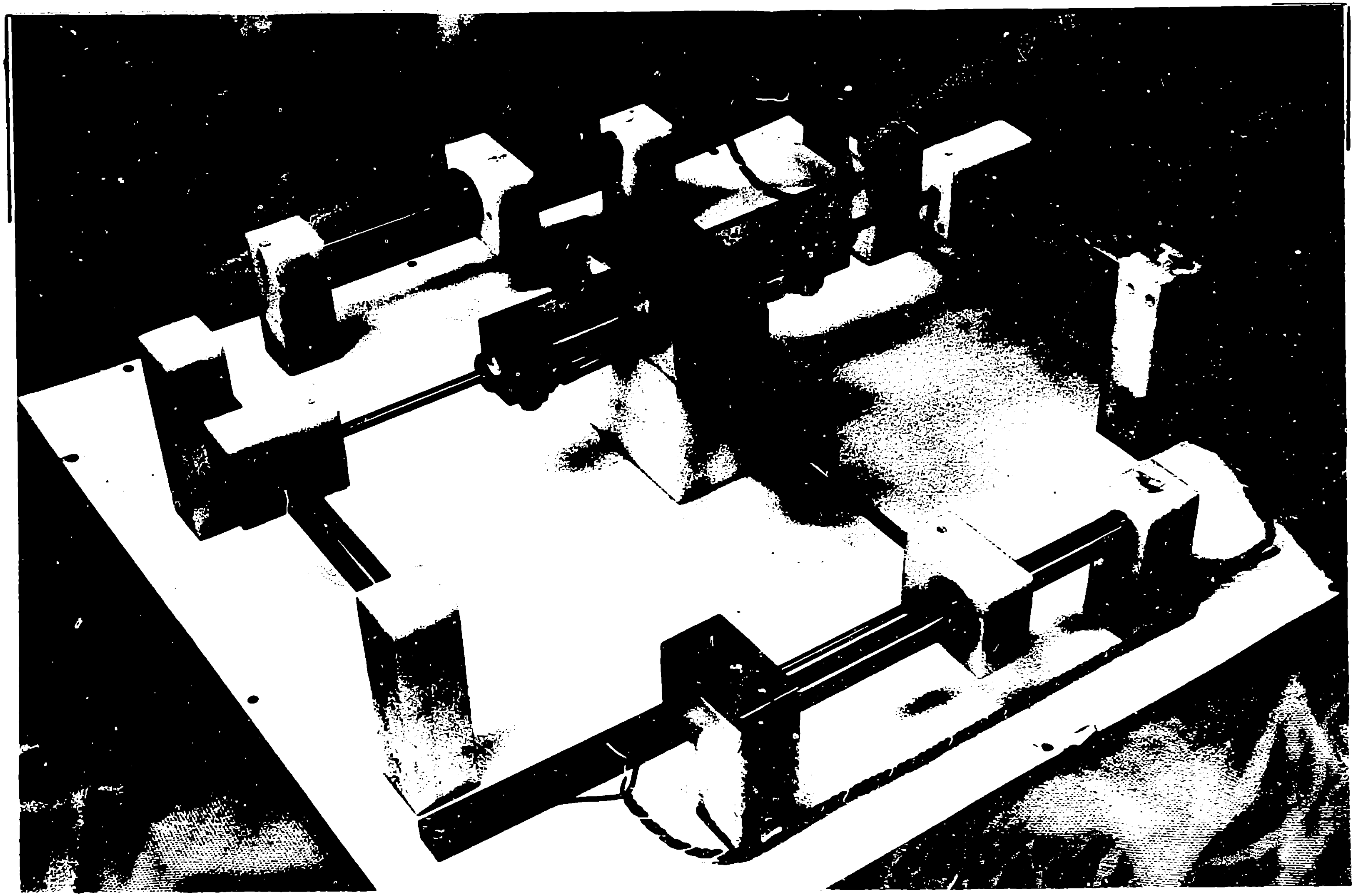


Figure 2: The mechanism of the damped planar joystick. Visible are the damping cylinders, support rods and bushings, and the signal generating potntiometers.

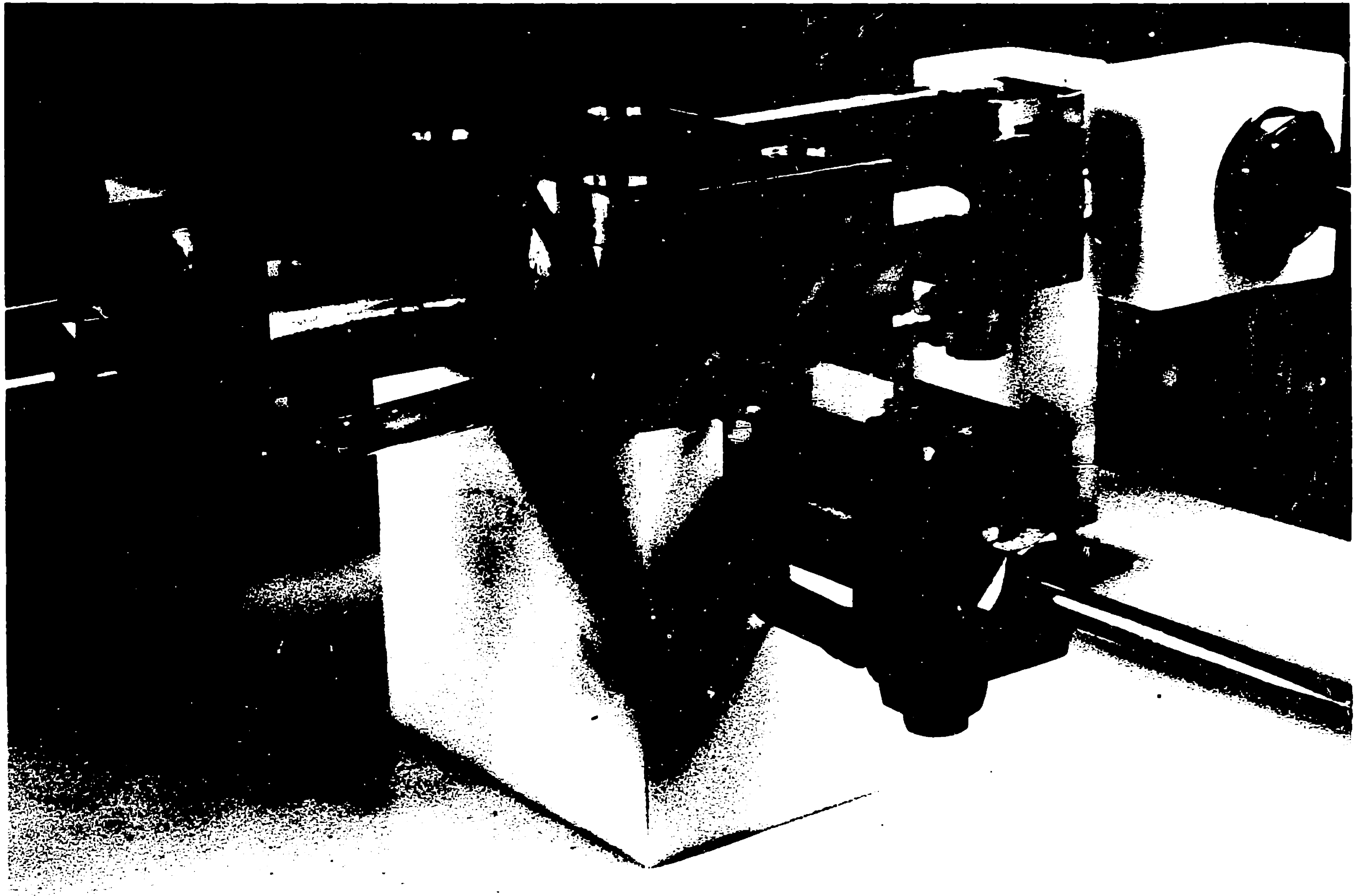


Figure 3: Detail of support housing and cylinders showing port fitting and external tube connecting the two ports.

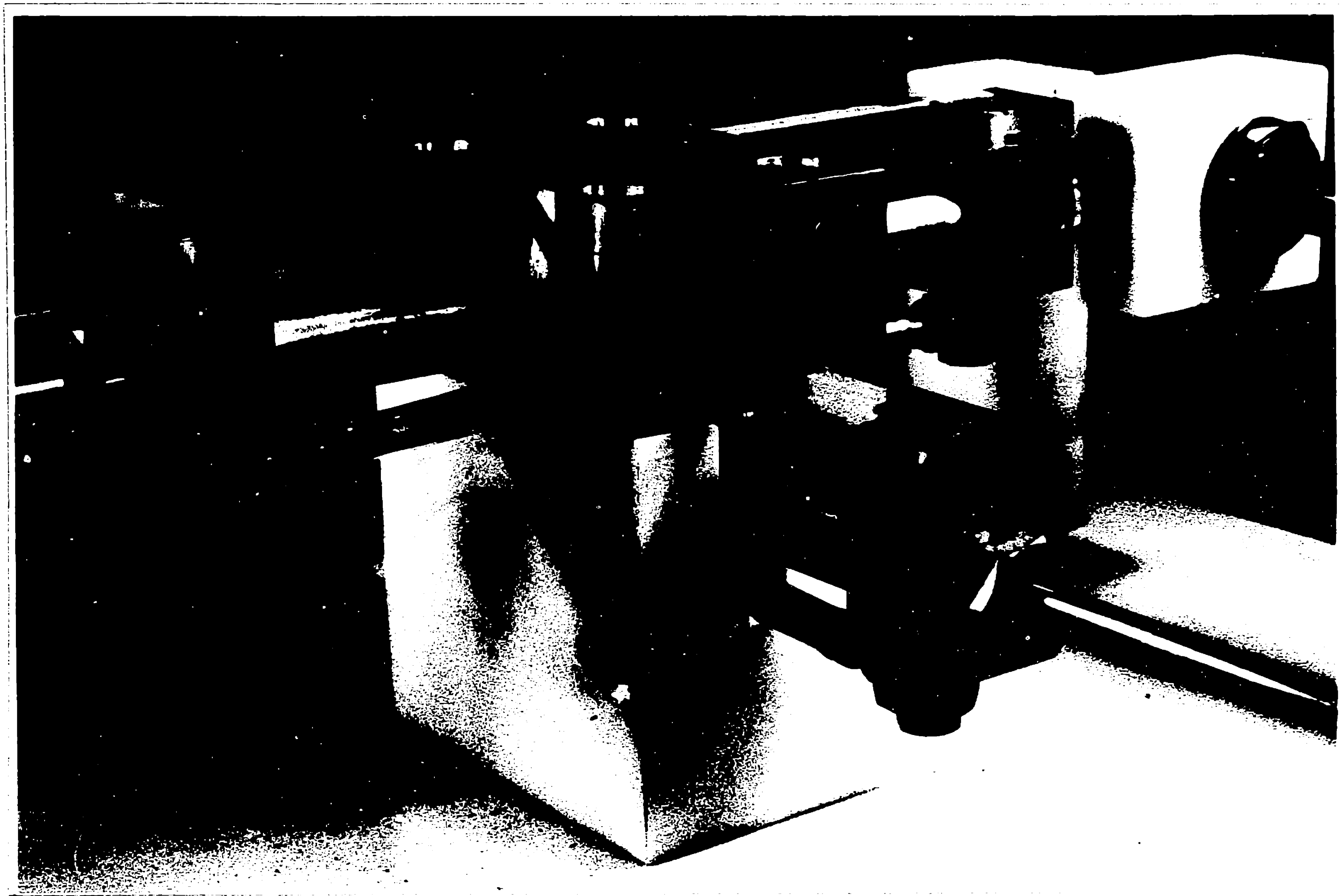


Figure 3: Detail of support housing and cylinders showing port fitting and external tube connecting the two ports.

the cylinders (see figure 3). This housing has the added advantage of keeping the cylinders perpendicularly aligned. The teflon block slides on another teflon sheet to minimize the effect of friction.

Two precision linear potentiometers (Maurey Instruments M1326-4-103) generate signals proportional to the horizontal and vertical position. A tennis ball epoxied into a pivoting metal fitting is used as a handle for the joystick (see figure 4).

The joystick was used in two modes, damped and undamped, for subject testing. For the damped mode, the cylinders were filled with distilled water, and for the undamped mode, they were drained but a piece of tubing still connected the ports on each cylinder.

Testing and evaluation was performed on two subjects, one normal subject, KC, and one tremor subject, CS. The tremor subject has had "a midbrain stroke resulting in loss of vocal speech and severe intention tremor in the one arm having residual voluntary control and strength." This subject has shown performance improvement in the one-dimension wrist-tremor tracking experiments (1,6).

The television screen was situated approximately two feet from the subject and placed about eye level for the tremor subject and chest level for for the normal subject. For the normal subject the joystick was clamped to the edge

Figure 4: The damped planar joystick closed showing the tennis ball handle.

Figure 4: The damped planar joystick closed showing the tennis ball handle.

of the table so that, when the subject was seated in front of the display and positioning the square in the center of the screen, the subject's forearm and upperarm were perpendicular to each other and the upper arm was aligned with the torso.

Since CS is confined to a wheelchair and the joystick is two cumbersome to mount stabily to his wheelchair, a free standing table was built previously to house the joystick and position the wheelchair (4). The joystick was elevated to approximately a 20 degree angle to allow ease of reach by CS. The relationship of wheelchair to table to joystick resulted in CS sitting in a slightly reclining position and centered the joystick with respect to his body. This created an elbow angle of about 150 degrees when CS positioned the square in the center of the screen. Because CS' tremor movements are sufficient to cause him to loose his grip on the tennis ball handle (6), a standard fingerless glove splint was adapted with a pivoting metal fitting and used as a joystick handle for trials with him. Figure 5 depicts the relative positions between CS, the joystick, and the television set.

Both subjects were given time to warm up and experiment with the equipment. When they felt that their performance had reached a plateau trials were begun. Twelve trials were performed on each subject, six with the joystick undamped (cylinders empty) and six with the joystick damped

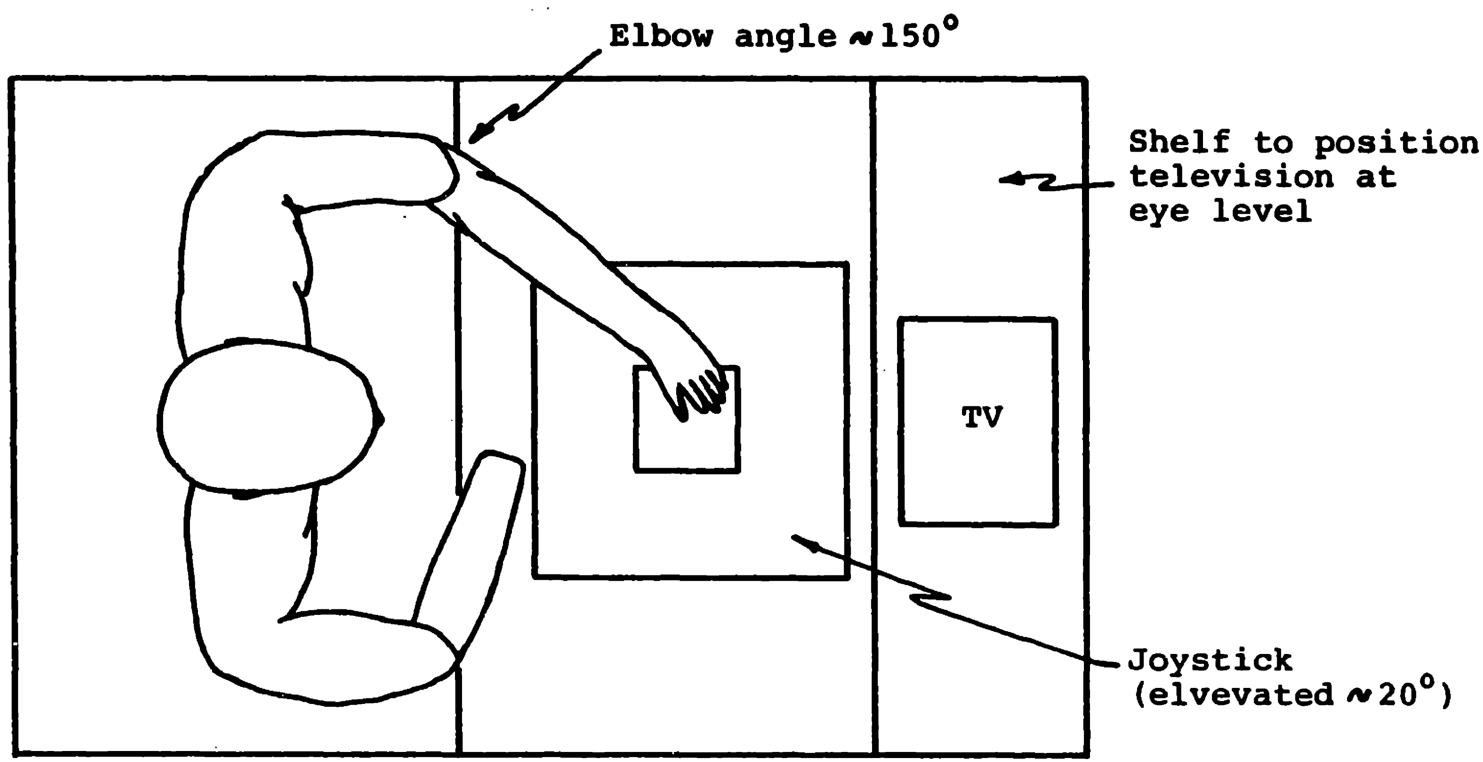


Figure 5: Diagram Showing the Position of CS in Relation to the Experimental Apparatus

(cylinders filled with water). Each subject was presented with a randomly moving target that contained frequency components in two ranges. For the normal subject, the target signals contained frequency components up to .50 Hz or up to .75 Hz, and for the tremor subject the components ranged up to .25 Hz or up to .50 Hz.

Each set of six trials was further divided into short and long trials. Four short trials, two at the lower cutoff frequency and two at the upper cutoff frequency, were performed. Each short trial lasted for two minutes. The short trials were followed by two long trials, one at the lower cutoff frequency and one at the upper cutoff frequency. The long tasks lasted for ten minutes and were designed to determine if there was any reduction in tracking performance due to fatigue or any increase due to additional learning as time progressed. Subjects were nominally given a five minute rest between short trials and ten minutes between long trials, but this was modified if the subject felt they needed more rest or wanted less rest.

<u>Data Processing</u>

The target and response signals were recorded on a Racal 14DS FM tape recorder for later reduction. The actual data analysis was performed on a DEC VAX 11/780 computer. The time domain records were sampled at a real rate of 51.2 Hz after analogue low pass filtering at 75 Hz to prevent aliasing. 4096 sets of points were gathered from each trial. One record (4096 data points) was taken from each short trial, and four records were taken from each long trial. These samples roughly divided the long trials into four equal time periods.

The auto-power and cross-power spectral densities--$G_{tr}(f)$, and $G_{tr}(f)$-- of the target (t) and response (r) time records were computed and used to evaluate the subject's performance. Separate analyses were performed for data in the horizontal direction and the vertical direction.

An assessment of the purposeful portion of the subject's response as a function of frequency--phase lag and amplitude fidelity $|H_{tr}(f)|$ -- was derived from the linear transfer function:

$$H_{tr}(f)=|H_{tr}(f)|\ e^{-\phi(f)}$$

where

$$H_{tr}(f)=G_{tr}(f)/G_{tt}(f)$$

The subject's tremor was defined as the cumulative power of the residual error spectrum: (2)

$$G(\text{tremor}) = G_{rr}(1-\gamma^2_{tr})$$

where G_{rr} = the power spectral density function of the response signal

and γ^2_{tr} = the coherence between target and response signals

In order to characterize the subject's motor performance to take into account both purposeful movement and tremor, a signal-to-noise ratio, R, was calculated for each trial:

$$R = \left[\frac{\int_0^\infty (G_{tr}/G_{tt})\,df}{G(\text{tremor})}\right]^{\frac{1}{2}} = \left[\frac{\int_0^\infty H_{tr}\,df}{G(\text{tremor})}\right]^{\frac{1}{2}}$$

where $\int G_{tr}/G_{tt}\,df$ = the average normalized power of the cross power spectrum of the target and response signals

The numerator is normalized with respect to the target power spectrum to remove any discrepancies that would occur because the amount of power in the target is not constant over the trials.

The data returned by the computer is presented in tables 1-4. The units in all tables are arbitrary. The system and recording parameters were held constant throughout the trials. Tables 1 and 2 contain the data for the normal subject, KC, and tables 3 and 4 contain the data for the tremor subject, CS. Tables 1 and 3 represent horizontal tracking performance and tables 2 and 4 represent vertical

Trial	Average Phase Lag	Average Normalized Power	Cumulative Tremor Power	Peak Tremor Frequency	Peak Tremor Amplitude	Signal-to-Noise Ratio
KCGMU2	-4.60	2.6381	.30844	.30	.6307	2.92
KCGMU4	-8.72	1.4436	.23998	.40	.4053	2.45
KCGMU5A	-2.20	2.7573	.42828	.30	1.0160	2.54
KCGMU5D	9.15	2.5046	.48388	.30	.8806	2.28
KCGMU6A	-2.80	1.5693	.67487	.30	1.1010	1.52
KCGMU6D	-15.54	1.2593	.32739	.30	.7477	1.96
Average .50 Hz	.78	2.6333	.40685	.30	.8424	2.58
Average .75 Hz	-9.02	1.4241	.41408	.33	.7513	1.98
Average All	-4.12	2.0287	.41047	.32	.7969	2.28
KCGML2	8.81	.68646	.030096	.60	.04073	4.78
KCGML4	22.32	.47585	.076277	.50	.12120	2.55
KCGML5A	7.07	.60925	.019224	.50	.02681	5.63
KCGML5D	8.29	.62373	.022399	.40	.02510	5.28
KCGML6A	-10.32	.51675	.054483	.40	.08131	3.08
KCGML6D	-14.85	.54421	.072952	.60	.09566	2.73
Average .50 Hz	8.06	.63981	.02391	.50	.0309	5.23
Average .75 Hz	-.95	.51277	.06790	.50	.0994	2.79
Average All	3.55	.57604	.04591	.50	.0651	4.01

Table 1: Computer Processed Data for Subject KC--Horizontal Direction

Trial	Average Phase Lag	Average Normalized Power	Cumulative Tremor Power	Peak Tremor Frequency	Peak Tremor Amplitude	Signal-to-Noise Ratio
KCGMU2	-5.26	.72120	.095248	.30	.1145	2.75
KCGMU4	-13.91	.60687	.19177	.60	.2587	1.78
KCGMU5A	-6.35	.67839	.039111	.60	.04555	2.86
KCGMU5D	-6.16	.62935	.065845	.50	.08865	3.09
KCGMU6A	-10.93	.65767	.12088	.90	.1267	2.33
KCGMU6D	-21.80	.50877	.19716	.50	.2106	2.58
Average .50 Hz	-5.92	.67631	.06673	.47	.0829	2.90
Average .75 Hz	-15.55	.59110	.16994	.67	.1987	2.23
Average All	-10.74	.63371	.11834	.57	.1408	2.57
KCGML2	-4.36	.70935	.033869	.30	.04569	4.58
KCGML4	-7.68	.68271	.083562	.30	.17070	2.86
KCGML5A	-8.03	.66723	.015942	.60	.02215	6.47
KCGML5D	-2.69	.68290	.048066	.30	.09558	3.77
KCGML6A	-8.97	.62661	.065438	.30	.07911	3.09
KCGML6D	-8.63	.69284	.069258	.30	.07888	3.16
Average .50 Hz	-5.03	.68649	.03263	.40	.0545	4.94
Average .75 Hz	-8.43	.66739	.07275	.30	.1096	3.16
Average All	-6.73	.67694	.05269	.35	.0820	3.99

Table 2: Computer Processed Data for Subject KC--Vertical Direction

Trial	Average Phase Lag	Average Normalized Power	Cumulative Tremor Power	Peak Tremor Frequency	Peak Tremor Amplitude	Signal-to-Noise Ratio
CSGMU2	6.70	1.3305	.91363	.70	1.793	1.21
CSGMU4	2.46	1.0848	1.4241	.50	3.503	.87
CSGMU5A	5.93	.76666	.86083	.60	2.005	.94
CSGMU5D	6.69	1.4126	1.3344	.50	3.665	1.03
CSGMU6A	-12.37	.99052	1.1585	.60	2.497	.92
CSGMU6D	-13.11	.87862	1.0191	.50	2.141	.93
Average .25 Hz	6.44	1.16992	1.03629	.60	2.488	1.06
Average .50 Hz	-7.67	.98465	1.20057	.53	2.714	.91
Average All	-.62	1.07728	1.11843	.57	2.601	.98
CSGML2	3.42	.58269	.28785	.50	.6063	1.42
CSGML4	-15.45	.71691	.49883	.30	1.158	1.44
CSGML5A	-10.72	.64766	.36764	.50	.7787	1.33
CSGML5D	-5.06	.62555	.42739	.40	.8143	1.21
CSGML6A	-4.48	.48213	.33842	.50	.6412	1.19
CSGML6D	-10.13	.60485	.37214	.30	.9580	1.27
Average .25 Hz	-4.12	.61863	.36096	.47	.7331	1.32
Average .50 Hz	-10.02	.60130	.40313	.37	.9191	1.30
Average All	-7.07	.60997	.38205	.42	.8261	1.31

Table 3: Computer Processed Data for Subject CS--Horizontal Direction

Trial	Average Phase Lag	Average Normalized Power	Cumulative Tremor Power	Peak Tremor Frequency	Peak Tremor Amplitude	Signal-to-Noise Ratio
CSGMU2	-1.90	.69382	.40302	.70	.5445	1.31
CSGMU4	-9.23	.37453	.48108	.70	.6824	.88
CSGMU5A	11.10	.63603	.54788	.60	.8996	1.08
CSGMU5D	-19.26	.78212	.64676	.80	.8266	1.10
CSGMU6A	-16.97	.41577	.85523	.80	1.636	.70
CSGMU6D	-24.23	.52046	.67223	.80	.9374	.88
Average .25 Hz	-3.35	.43692	.53255	.70	.7569	1.16
Average .50 Hz	-16.81	.70399	.66951	.77	1.0853	.82
Average All	-10.08	.57046	.60103	.73	.9211	.99
CSGML2	13.46	.71869	.82890	.80	2.284	.93
CSGML4	-10.51	.49151	.72733	.80	1.868	.82
CSGML5A	-.54	.58576	.99087	.80	2.487	.77
CSGML5D	-2.94	.50536	.65513	.70	1.609	.88
CSGML6A	2.00	.60514	1.3357	.80	3.132	.67
CSGML6D	25.13	.47422	.85558	.70	1.745	.74
Average .50 Hz	3.33	.60327	.82497	.77	2.127	.86
Average .75 Hz	5.54	.52362	1.17566	.77	2.248	.74
Average All	4.43	.56345	.89892	.77	2.188	.80

Table 4: Computer Processed Data for Subject CS--Vertical Direction

tracking performance. The trials are coded as follows:

<u>AAXXXYY</u>

AA = subject code: either KC or CS
XXX=joystick code: GMU=undamped joystick
GML= damped joystick
YY = trial code:
2=second short test at lower cutoff frequency (.25 Hz for CS, .50 Hz for KC)
4=second short test at upper cutoff frequency (.50 Hz for CS, .75 Hz for KC)
5A=initial 2.5 minutes of a long test at lower cutoff frequency
5D=final 2.5 minutes of a long test at lower cutoff frequency
6A=initial 2.5 minutes of a long test at upper cutoff frequency
6D=final 2.5 minutes of a long test at upper cutoff frequency

From this data two reduction factors were defined. They are a tremor reduction factor (KT) and a tracking performance reduction factor (KP). These were calculated for each trial and defined as follows:

$$KT = \frac{\text{Cumulative tremor power (joystick damped)}}{\text{Cumulative tremor power (joystick undamped)}}$$

and

$$KP = \frac{\text{Average normalized power (joystick damped)}}{\text{Average normalized power (joystick undamped)}}$$

The values for these reduction factors are presented in table 5.

Trial Pair	Horizontal Direction		Vertical Direction	
	KP	KT	KP	KT
KCGML2/U2	.26	.10	.98	.36
KCGML4/U4	.33	.32	1.12	.44
KCGML5A/U5A	.22	.04	.98	.41
KCGML5D/U5D	.25	.05	1.09	.73
KCGML6A/U6A	.33	.08	.95	.54
KCGML6D/U6D	.43	.22	1.36	.35
Average .50 Hz	.24	.06	1.02	.50
Average .75 Hz	.36	.21	1.14	.44
Average All	.30	.14	1.08	.47
CSGML2/U2	.44	.32	1.04	2.06
CSGML4/U4	.66	.35	1.31	1.51
CSGML5A/U5A	.84	.43	.92	1.81
CSGML5D/U5D	.44	.32	.65	1.01
CSGML6A/U6A	.49	.29	1.46	1.56
CSGML6D/U6D	.69	.37	.91	1.27
Average .25 Hz	.57	.36	.87	1.63
Average .50 Hz	.62	.34	1.23	1.45
Average All	.59	.35	1.05	1.54

Table 5: Reduction Factors for the Trial Pairs (Damped/Undamped)

Results and Discussion

The data shows that except for CS' trials in the vertical direction, both the amplitude of the tremor peaks and the cumulative tremor power decrease when the subject uses the damped joystick. There is also corresponding decrease in the average normalized power, which is a measure of the subject's purposeful response. However, as shown by the values for KP and KT, the subject's involuntary oscillations have been reduced more than the attenuation in intended movement. It is this selective effect, that of reducing tremor more than attenuating tracking by viscous loading, that I hoped to demonstrate. This effect is neccessary if such a device is to have clinical significance because the reduction of tremor alone is useless if purposeful movement is equally lost.

As expected, both the cumulative tremor power and the peak amplitude were lower for the normal subject than for the tremor subject. The maximum peak tremor amplitude for KC was 1.101 in the horizontal direction and .2587 in the vertical direction for the undamped joystick. For the damped joystick, the horizontal and vertical peaks were .1212 and .02215, respectively. The maximum peak tremor amplitudes for CS were, in the undamped case, 3.665 horizontally and 1.636 vertically. With the damped joystick they were 1.158 in the horizontal direction and 3.132 in the vertical direction. The average value for the cumulative tremor power and peak tremor amplitude show that the tremor in the normal subject is about an order of magnitude less than those values for the tremor subject. Some typical tremor spectra are shown in figures 6 to 9 .

The peak tremor frequencies in this experiment were on the same order as the target frequencies used. The average frequency of the tremor peak for CS in the horizontal direction was .50 Hz and in the vertical direction it was .75 Hz. These values were consistant for both the damped and the undamped trials. The normal subject did not show such uniform results. In the undamped case, the peak frequency in the horizontal direction was .32 Hz and .57 Hz in the vertical direction. However, in the damped case the horizontal and vertical peak frequencies were .50 Hz and .35 Hz, respectively.

Tests on the system with no joystick input showed spectral peaks only at 6 Hz and 15 Hz, thus ruling out the possibility that the experimental results are artifacts caused by the electronics. However, it is to early to generalize these results to the population. The reduction in peak tremor frequency from 3 Hz in the wrist-tracking experiments (4) to below 1 Hz for the whole arm experiment is explained by the fact that the whole arm is so much more massive than the wrist joint.

Figure 6: Tremor Amplitude as a Function of Frequency for Subject KC

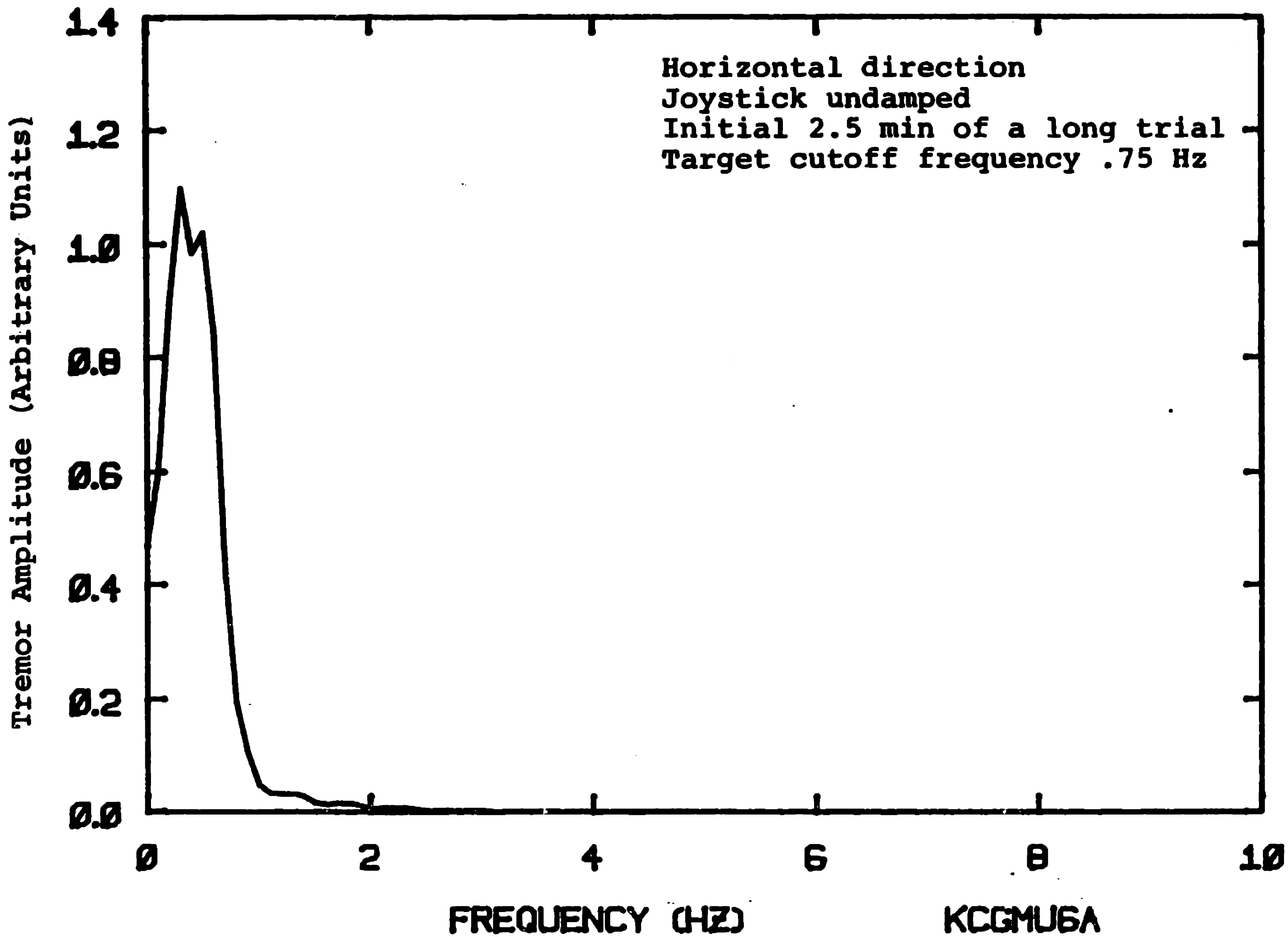


Figure 7: Tremor Amplitude as a Function of Frequency for Subject KC

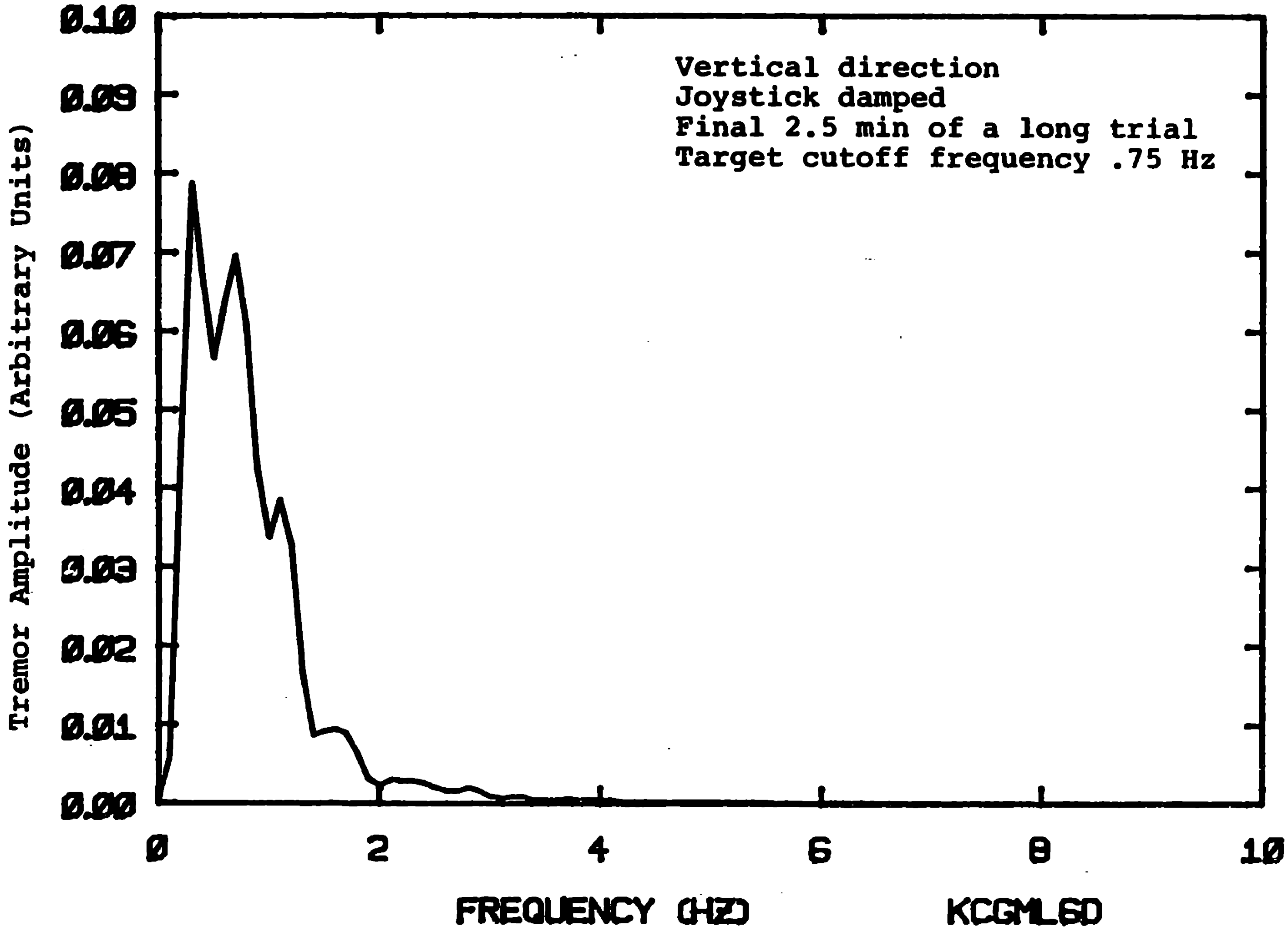


Figure 8: Tremor Amplitude as a Function of Frequency for Subject CS

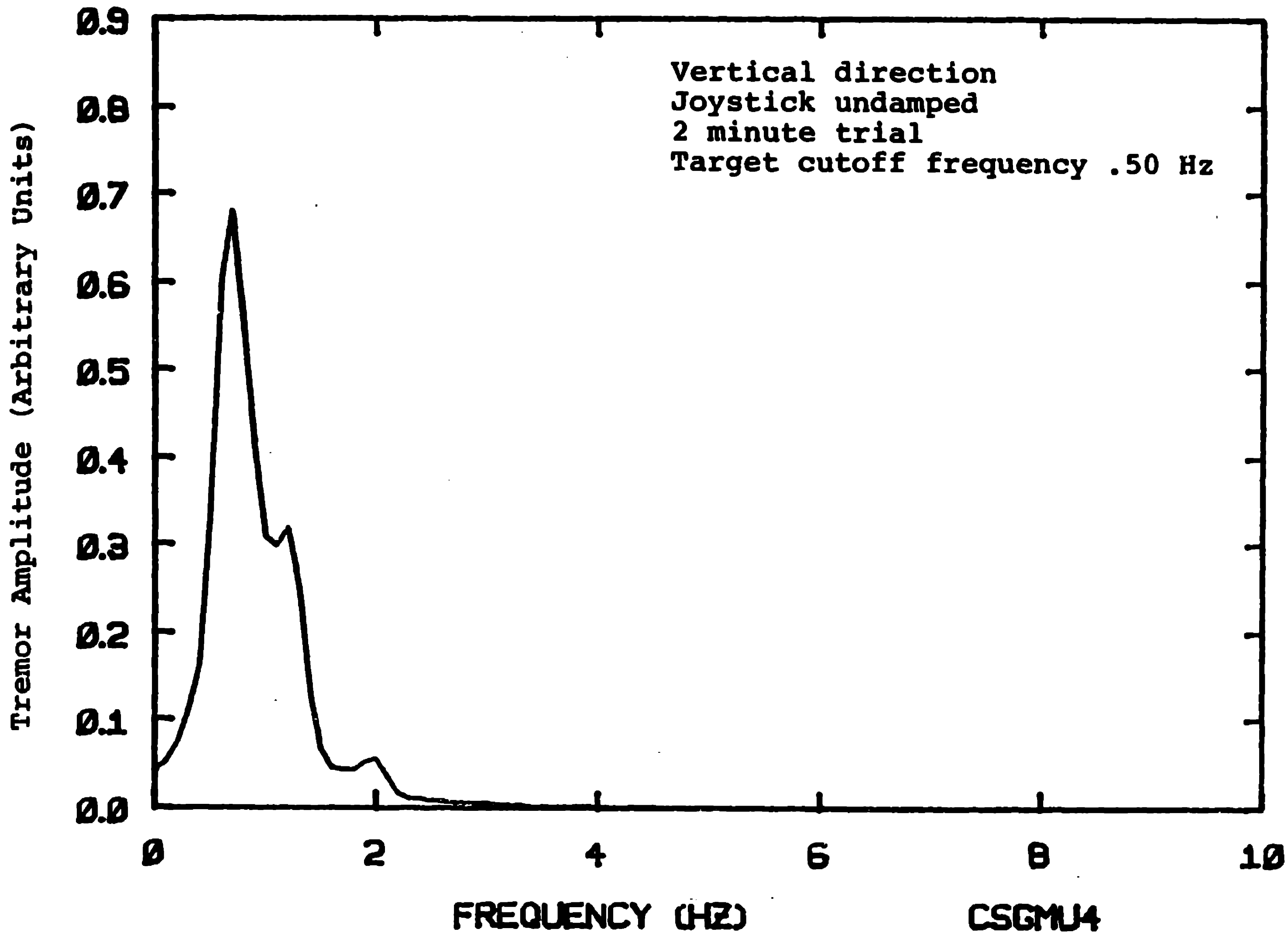
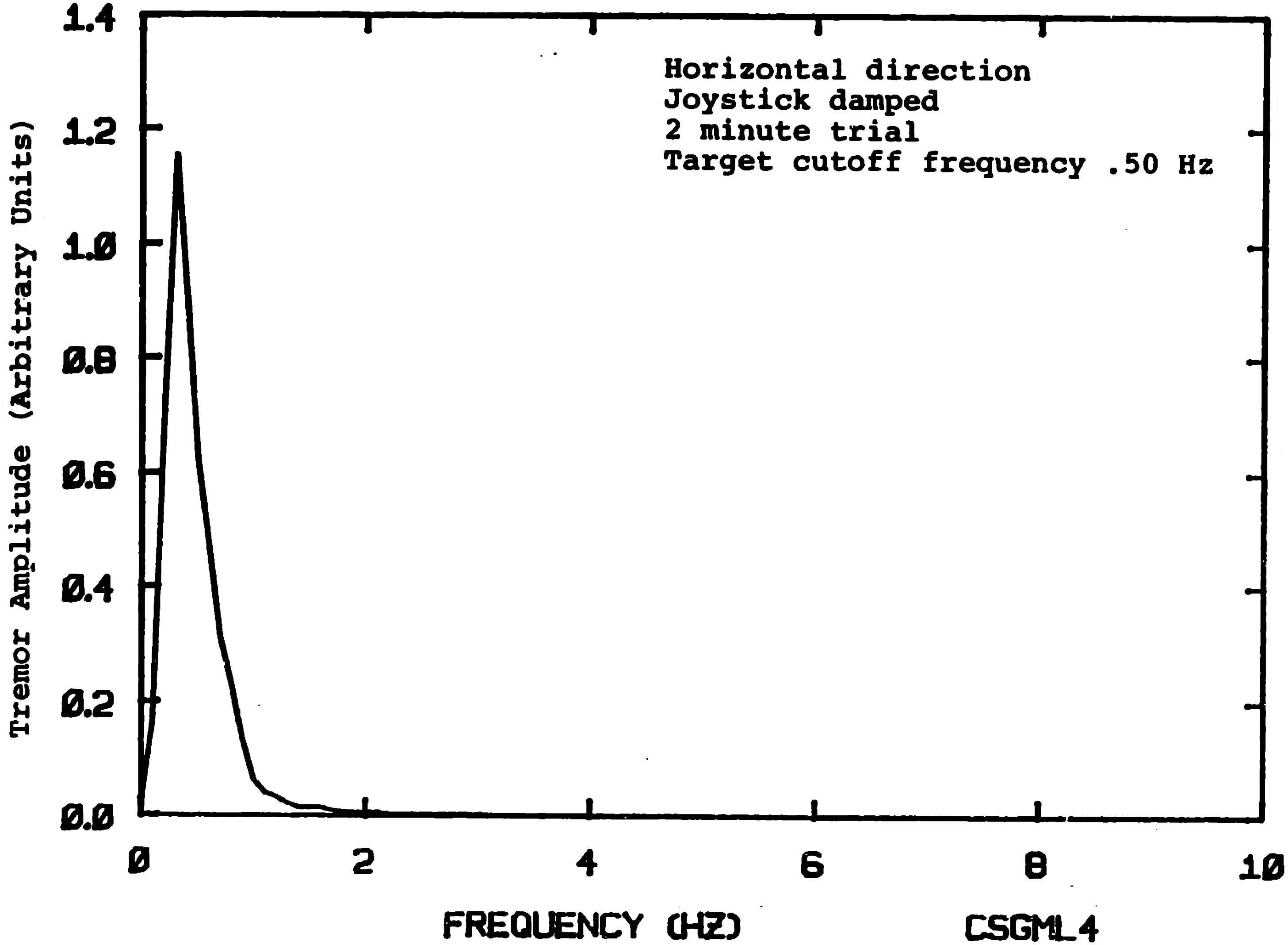


Figure 9: Tremor Amplitude as a Function of Frequency for Subject CS



Subject CS' performance in the vertical direction is very perplexing. The amplitude of his tremor peaks and cumulative tremor power both increased as the damping load was applied. This is opposite to all the other trials performed. Though observation of CS during trials suggests that his tremor manifests itself primarily when he tries to make horizontal movements, his motions in the vertical dimension, using the joystick, appear to have more of a ballistic nature to them than any sort of finer control. These could give rise to the large amplitude tremor peaks seen, but they should still be reduced when the damping load is applied. Figures 10 to 13 show CS' tracking performance for the long tests, CSGMU5A and CSGML5A.

There are several possible explanations for these unexpected results. 1)The original data was recorded onto the wrong channels of the tape recorder. This is unlikely because the subject was tested on two separate occasions and hence the same mistake would have to have been made twice. 2)The data was switched when it was entered into the computer. To check this, two sets of data (CSGMU2, CSGML2) were resampled and analyzed. The results are shown in table 6. They represent the same trends as before, though the magnitudes are diferent because a different portion of the trial was sampled. 3)The most likely explanation is that this data actually represents CS' response. No further conclusion can be drawn until additional tests can be

Figure 10: Horizontal target(solid black line) and response (dashed red line) signals for subject CS - Undamped trial 5A

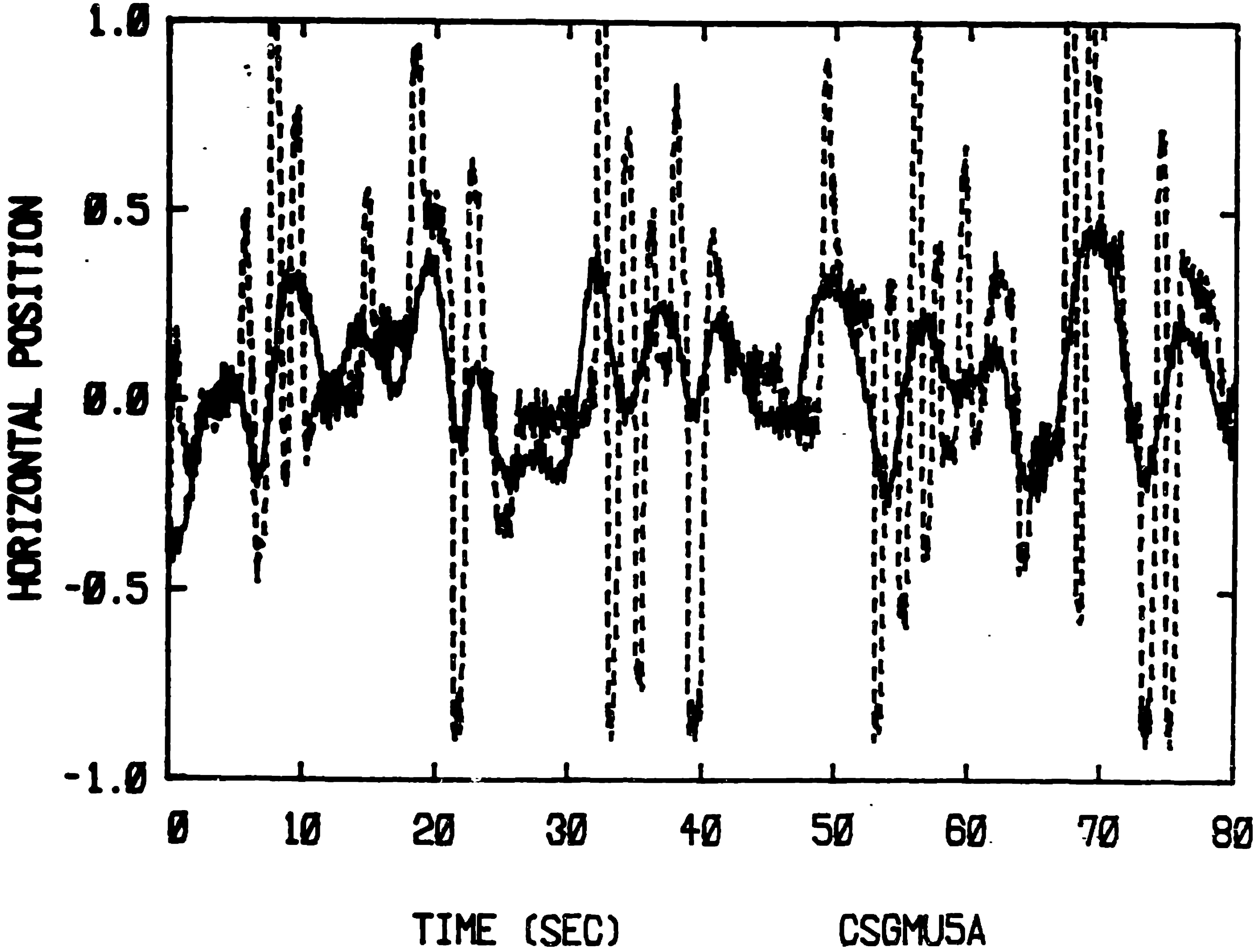


Figure 11: Horizontal target (solid black line) and response (dashed red line) signals for subject CS - Damped trial 5A. Note improvement in tracking performance over that of figure 10.

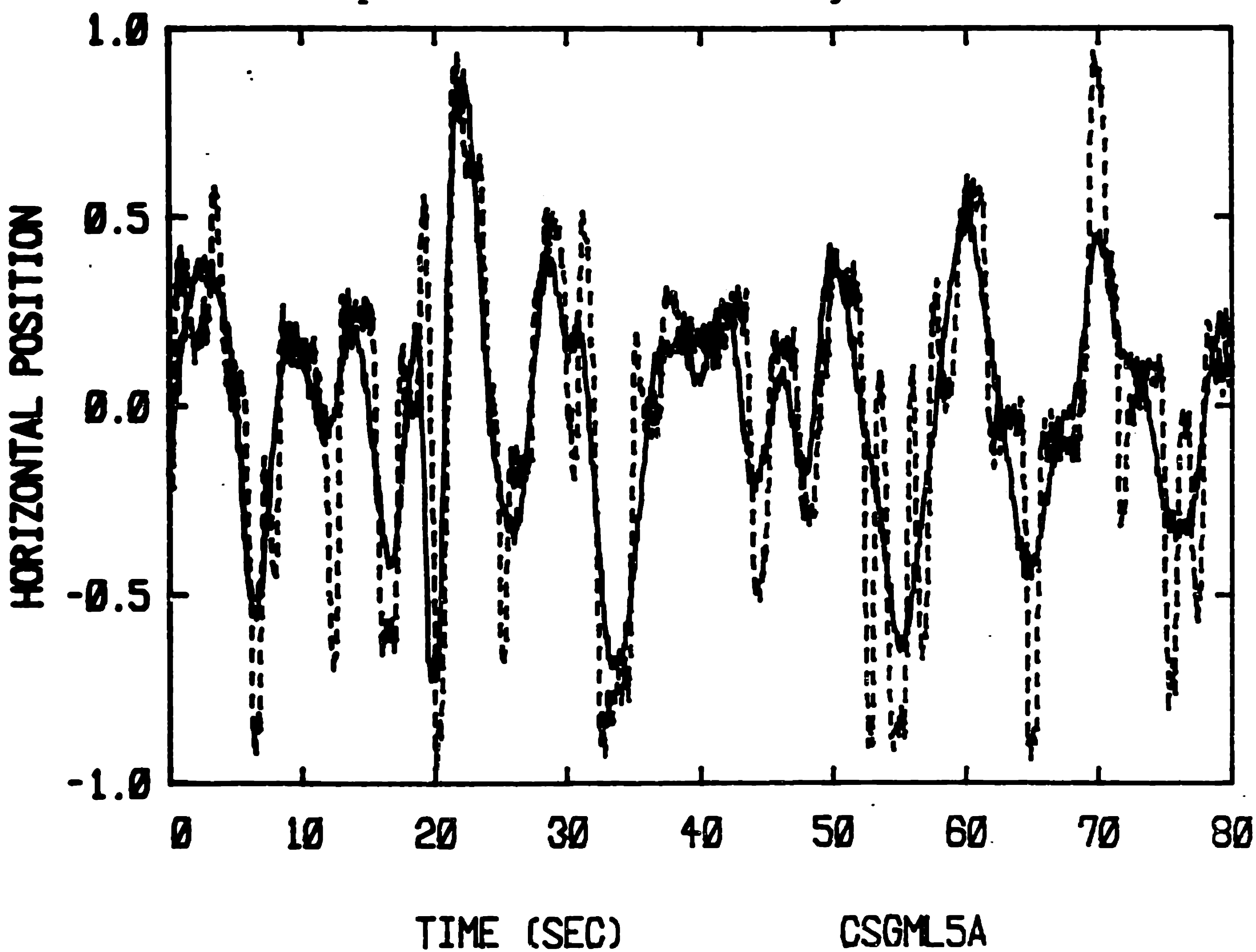


Figure 12: Vertical target (solid black line) and response (dashed red line) signals for subject CS - Undamped trial 5A.

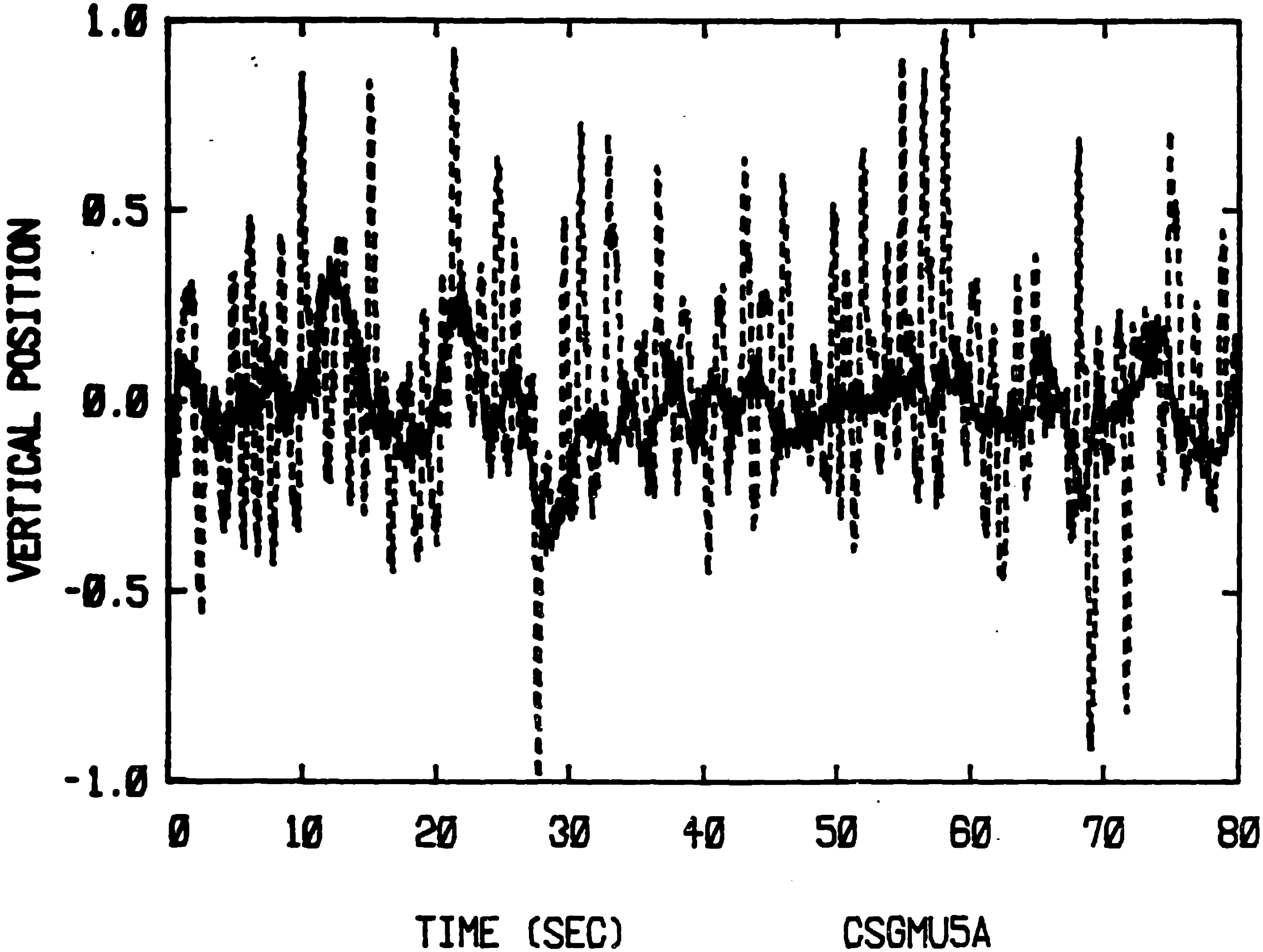
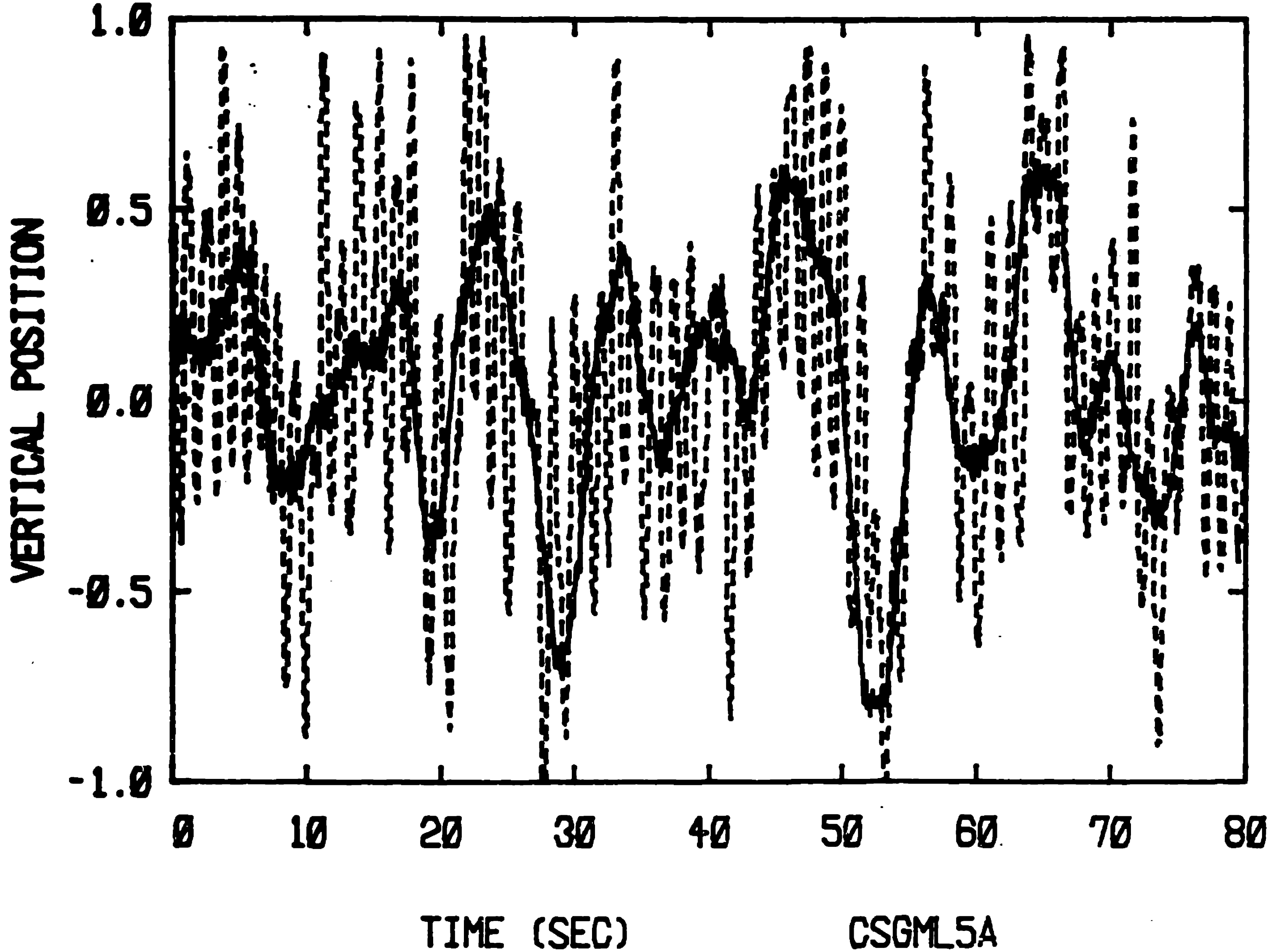


Figure 13: Vertical target (solid black line) and response (dashed red line) signal for subject CS - Damped trial 5A. Note decrease in tracking performance from that of figure 12.



Trial	Average Phase Lag	Average Normalized Power	Cumulative Tremor Power	Peak Tremor Frequency	Peak Tremor Amplitude	Signal-to-Noise Ratio
Horizontal						
Resample U2	2.49	.96752	.96402	.60	2.141	1.00
Resample L2	1.77	.77222	.26329	.50	.7495	1.71
Vertical						
Resample U2	-4.20	.70819	.39012	.60	.5694	1.35
Resample L2	-.98	.87572	.50209	.80	1.042	1.32

Trial Pair	Horizontal Direction		Vertical Direction	
	KP	KT	KP	KT
L2/U2	.80	.27	1.24	1.29

Table 6: Computer Data and Reduction Factors for Resampled Trials--CSGMU2 and CSGML2

performed with CS and other handicapped individuals.

Tables 7A and 7B show that the signal-to-noise ratio from the beginning to the end of a long trial generally increases. This finding indicates that tracking performance is not being reduced significantly due to fatigue from working against a damped load. In CS' case, this is particularly important since tremor usually increases as a muscle group becomes fatigued. This suggests that long term control with a damped manipulator is feasable, allowing for the possibility of such a controller for a wheelchair or adapted van. The possiblity also exists that such a manipulator would have applications for normal people who must work in vibration prone areas.

Subject	Direction (Damping Applied)	No: Trial Beginning	No: Trial End	Yes: Trial Beginning	Yes: Trial End
KC	Horizontal	2.54	2.28	5.63	5.28
	Vertical	2.86	3.09	6.47	3.77
CS	Horizontal	.94	1.03	1.33	1.21
	Vertical	1.08	1.10	.77	.88

Table 7A: Signal-to-Noise Ratios for Long Trials--Beginning vs End Lower Cutoff Frequency (KC= .50 Hz, CS= .25 Hz)

Subject	Direction (Damping Applied)	No: Trial Beginning	No: Trial End	Yes: Trial Beginning	Yes: Trial End
KC	Horizontal	1.52	1.96	3.08	2.73
	Vertical	2.33	2.58	3.09	3.16
CS	Horizontal	.92	.93	1.19	1.27
	Vertical	.70	.88	.67	.74

Table 7B: Signal-to-Noise Ratios for Long Trials--Beginning vs End Upper Cutoff Frequency (KC= .75 Hz, CS= .50 Hz)

<u>Suggestions for Future Work</u>

It must be emphasized that his study is preliminary in nature. Time constraints and hardware problems left only a few weeks for subject testing, data analysis, and writing. However, the findings so far indicate that a viscously damped manipulator in two-dimensions may selectively reduce intension tremor over purposeful movement. This is not to say that viscous damping is the optimal load type to be applied to a tremor hindered joint. The optimal load would probably be some combination of mass, elastic element, and damper, and would probably vary for individuals with different tremor modalities. Yet, the selective improvement in tracking performance suggests that, that with proper modification, a damped manipulator can be used to enable a handicapped individual to operate an environmental control system, or to directly position a curser in a non-vocal communication array, thereby increasing his communication speed over conventional systems.

The current damped joystick is only a prototype device. It is large and unwieldy, has a significant amount of dry (Coulomb) friction associated with it, and it is very difficult to vary the damping constant of the system. The friction problem in particular makes very fine control with the joystick almost impossible. A new joystick of more conventional size and geometry, as well as variable damping constants has been designed by India Starker (4) and should be used as a replacement for the current joystick in tracking tasks.

In addition, an isometric force joystick should be used as an input control device. This would allow a particular theory about the cause of intention tremor to be tested. The hypothesis states that the tremor is caused by a faulty feedback path in muscle spindle system (7). By using the force joystick, a subject could control the motion of the response square without making any gross movements and hence bypass the spindle system.

The electronics that generate the target and response signals have several problems that need to be resolved. There is an inherent noise in the system which causes the target circle to have a jitter on the edges. The circle also has a tendency to shrink and grow, and the set point of the circuitry drifts over the course of several trials. Some or all of these problems may be resolved when the circuitry is hardwired and encased in a portable housing. Perhaps the best solution is to redesign the equipment around a microprocessor.

The experimental protocol needs to be expanded to include more subjects, to perform tests with various degrees of damping, and to include the other joysticks mentioned. It would also be useful to have a simple method to determine when learning plateaus were reached. The fatigue tests should be lengthened to determine when a subject's performance begins to significantly decline.

The subject testing phase of this project is just beginning. If the trends demonstrated so far can be repeated by further experimentation, some practical applications may be realized. Aside from the interfaces already described, a wearable orthosis to apply mechanical loads to a tremor hindered joint could be developed. The applications of such an orthosis or manipulator are not limited to the handicapped world. Normal individuals working in high vibration areas, such as in airplanes, would also benefit from a damped control device. Whether handicapped or normal such an instrument has the potential to give the individual additional freedom to perform his daily activities.

APPENDIX

DESCRIPTION OF ELECTRONICS

Most of the electronic circuitry used for these experiments was built during the summer of 1980. This early start was made possible by the Undergraduate Research Opportunities Program at MIT. I am extremely greatful for their funding, for without it, this project would not have progressed as far as it has.

General Overview

An overall block diagram of the two-dimensional video tracking system is shown in figure A1. The basic principle underlying this system is the geometric definition of a circle:

$$X^2+Y^2=R^2$$

The ramp generator creates a horizontal and vertical ramp signal. These correspond to the motion of the electron beam in a conventional televison raster display. By squaring the signals and summing them together, a voltage equivalent to X^2+Y^2 is produced. When this voltage is equal to a voltage corresponding to R^2, a bright spot can be generated on the television screen. The locus of all the bright spots generated is the image of the circle. When a time varying offset signal (a noise voltage from a white noise diode) is added to the ramp voltage, the circle will change position on the screen. This is equivalent to the equation:

$$(X-h)^2+(Y-k)^2=R^2$$

where h and k are the coordinates of the center of the circle and are functions of time. A detailed description of each of the functional modules in the system follows. The included diagrams primarily detail the circuitry for the horizontal channel. Except as noted the vetical channel is identical to the horizontal channel.

TV Sync Circuitry (Figure A2)

This module uses a Motorola MM5321 TV camera sync generator LSI circuit driven by a 2.04545 MHz crystal oscillator to generate three signals-- a horizontal sync pulse, a vertical sync pulse, and a composite video sync pulse. The frequencies of the horizontal and vertical sync pulses are 15,750 Hz and 60 Hz, respectively. The horizontal and vertical sync pulses are used to clock the circuitry that generates the video pulses for the images of the circle and the square. When these signals are combined with the composite sync pulse and sent to the television set, the patterns appear on the screen. Included in the module is a delay circuit for the horizontal sync pulse that is built around a 74123 dual monostable. The purpose of this delay will be explained in the section on filtering.

Ramp Generator (Figure A3)

Each ramp generator consists of two 2N3906 PNP transistors acting as a constant current source that charges a capacitor. The horizontal or vertical sync pulse is used to trigger a 2N3904 NPN transistor into conduction. This shorts the capacitor to ground and discharges it. The trimpots are used to adjust the charging rate of the capacitor in order to produce a 0-10 volt ramp in the time period between sync pulses. This range was selected because of input restrictions on the multipliers.

Circle Position (Figure A4)

The elctronics in this block subtract the random noise signal, which corresponds to the coordinates of the center of the circle, from the ramp voltage. The 10K trimpot is used to center the circle on the screen when the noise input is grounded.

Noise Diodes (Figures A5-A7)

The noise diode circuitry is divided into three sections, an initial filtering and amplification stage (fig. A5), a main filtering stage (fig. A6), and a voltage clamping stage (fig. A7). The first stage was used because the noise density produced by the diodes ($\mu V/\sqrt{Hz}$) has a flat frequency response from .1 to 100 kHz and an output of approximately 500 mv over this range. However, in the frequency range of interest for these experiments, below 1 Hz, the noise output is only .1 mv. This characteristic is further complicated by the fact that a ±5 volt signal is required to move the circle across the television screen. Thus the noise output was filtered below the selected cutoff frequency, either .25 Hz, .50 Hz, or .75 Hz, and then amplified to a ±5 volt range. Since such a high amplification factor (greater than 10,000) is required, which necessarily would have introduced components of the noise signal above the cutoff frequency, the first stage low pass filters the white noise below 1000 Hz and then amplifies it by a factor of 1000. This produces about a 10 volt peak to peak waveform.

The horizontal noise section uses a ±15 volt supply and the vertical section uses a ±12 volt supply. This eliminates any coupling between the noise sources and assures that the signals in each dimension are totally random. The relevant parameter values are:

Parameter	Horizontal	Vertical
V_{ee}	±15 volts	±12 volts
R2	220K	150K
R3	75K	75K
R4	150K	150K

The main filtering stage bandpass filters the noise signals from .1 Hz to the selected cutoff frequency, and then amplifies the signals to the voltage level required to move the circle on the screen. The 1K trimpot is used to center the noise output about a dc value of zero since the diodes and associated op-amps have a dc bias in them. The resistor values for each frequency range are:

	.25 Hz	.50 Hz	.75 Hz
R5	680K	470K	330K
R6	680k	330K	220K

The voltage clamp section clips the noise output voltage so that the circle will not disappear off the edge of the screen.

Multiplier (Figure A8)

This module uses a Raytheon RC4200 analogue multiplier, wired from the maufacturer's suggestions (Product Specifications-Multiplier 4200, November 1977), to square the ramp voltages. It then sums the squared horizontal and vertical signals together.

Low Pass Filter (Figure A9)

In its present form this circuitry has a large amount of inherent noise. This noise is independent of the noise diodes and causes the circle to jitter on the TV screen. In order to remove some of this distortion a fourth order low pass filter with a cutoff frequency of 100,000 Hz was added. The filter is constructed with high performance/high slew rate op-amps (531's). Unfortunately, this cutoff frequency is sufficiently close to the horizontal scan frequency of 15,750 Hz that an appreciable phase lag is introduced into the system. This causes the circle to distort in shape when it approaches the left edge of the screen. In order to compensate for this shift, the delay circuit of fig. A2 was built. The delay introduced essentially wraps the circle around the screen once and displaces it down one raster line. The displacement is unnoticeable and allows the circle to traverse the screen from edge to edge. The amount of delay is determined by adjusting the 50K trimpot on the 74123.

Comparators (Figure A10)

The comparator circuit compares the squared and summed ramp voltage to signals corresponding to a radius plus delta and a radius minus delta. The comparator outputs are then digitally ANDed to create the circle video signal. This waveform, when combined with the composite video sync pulse, creates a circle of variable radius and thickness on the TV.

Radius and Width (Figure A11)

This module generates a radius voltage (R) and a width voltage (δ). It then adds them together (R+δ) and subtracts them (R-δ) so that they may be used by the comparators. The trimpots allow variation of the voltages.

TV Interface (Figure A12)

This circuit sums the composite sync pulses with the square and circle video signals so that the images may be displayed on the television screen.

Square Generator (Figure A13)

This module generates the video information required to create a square on the television set. A comparator monitors the ramp signal and a control voltage from the joystick. When the ramp voltage becomes greater than the control voltage, the comparator switches state and triggers a monostable. The monostable generates a pulse whose width corresponds to the size of the square. The position of the square on the screen is determined by the point along the ramp at which the comparator switches state. By synchronizing the horizontal and vertical square video pulses using a 7474 dual D-type flip-flop, a glitch that caused the first raster line of the square to trigger out of sync with the others was eliminated. The control potentiometers are adjusted to keep the square within the boundaries of the TV screen. The left edge is set first and then the right edge. The procedure is repeated until the square stays within the confines of the screen. This iterative procedure is then repeated for the top and bottom edges of the screen.

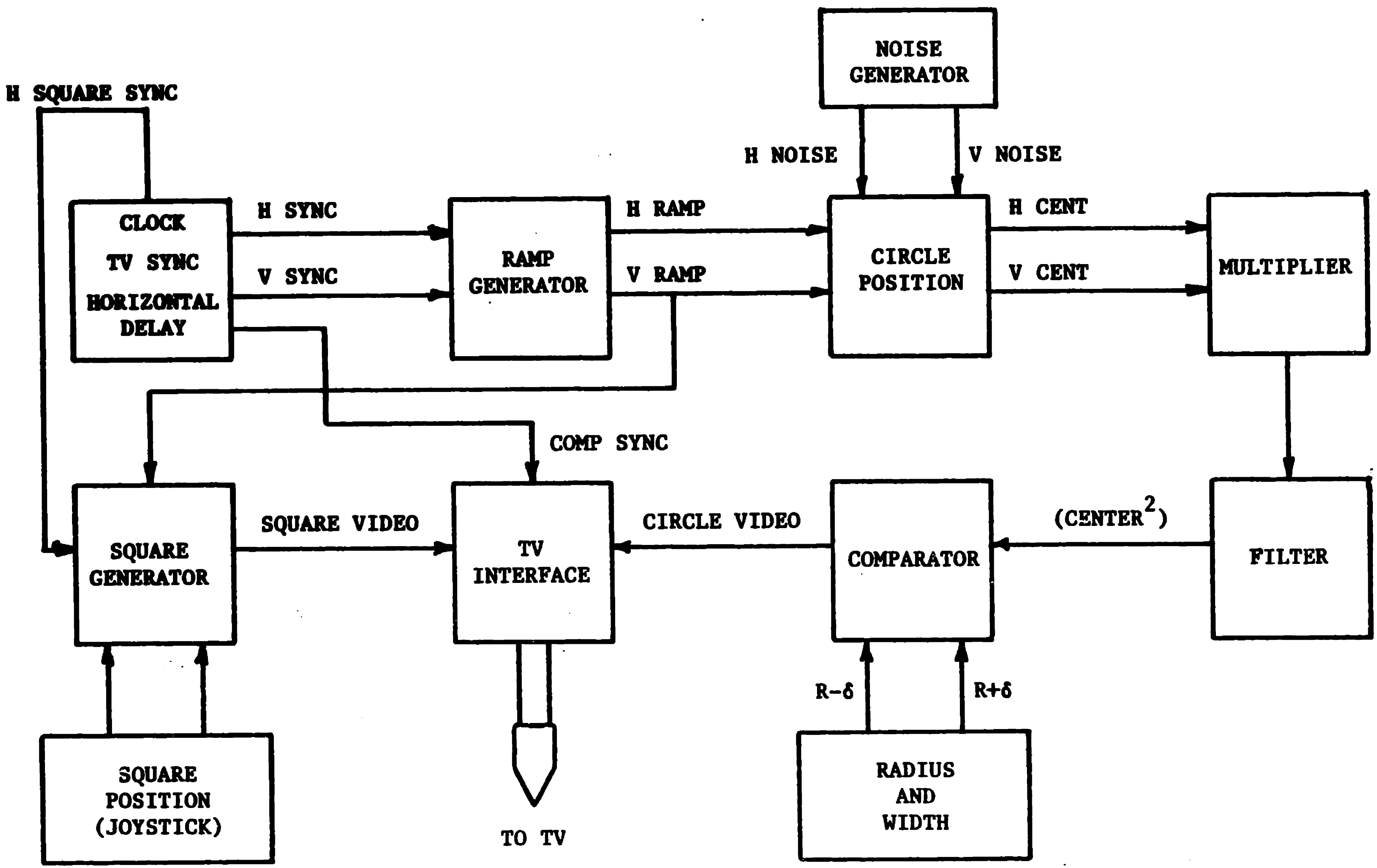


Figure A1: Block diagram of tracking electronics showing interrelations of major functional groups

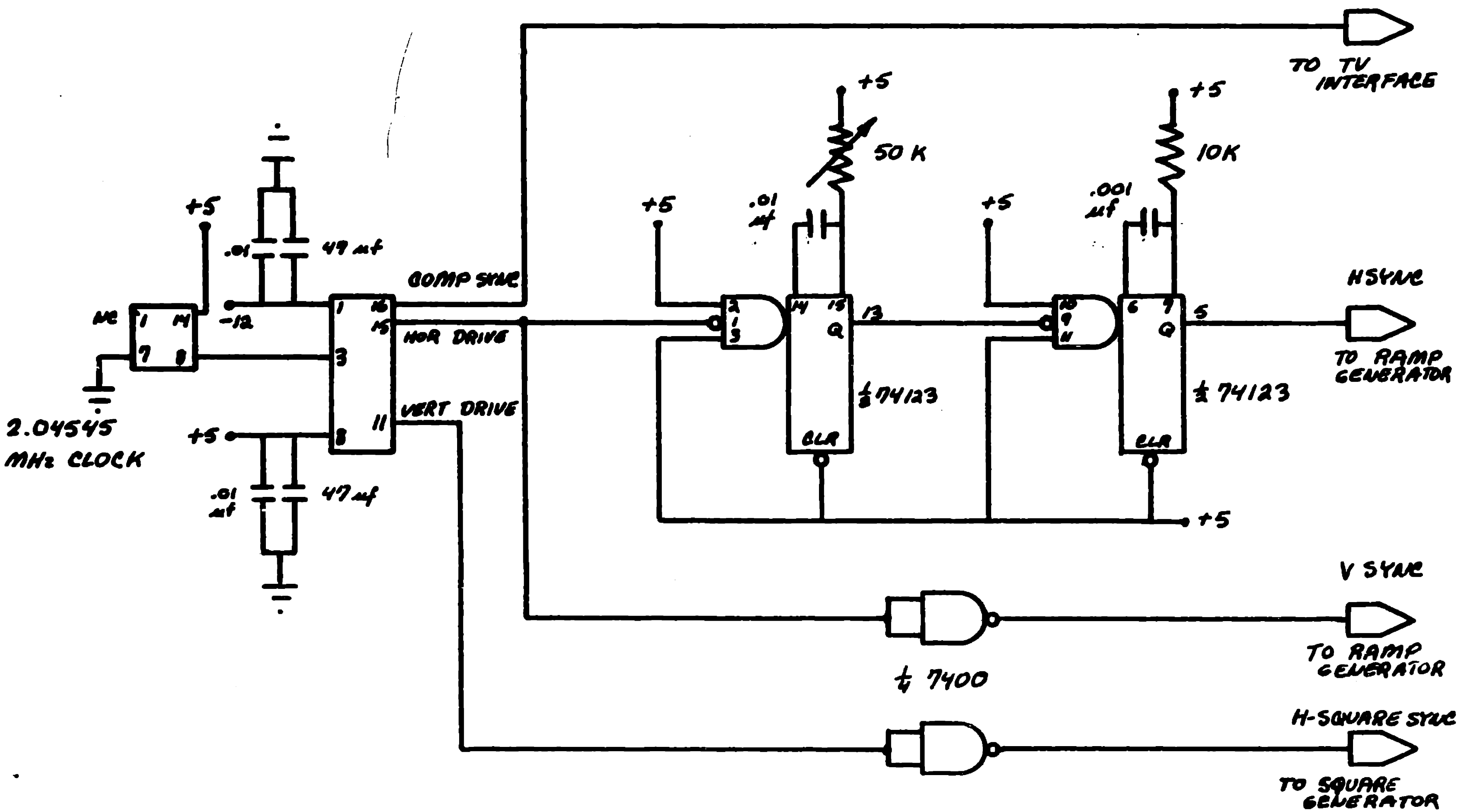


Figure A2: Clocking, TV sync, and horizontal delay cicuitry

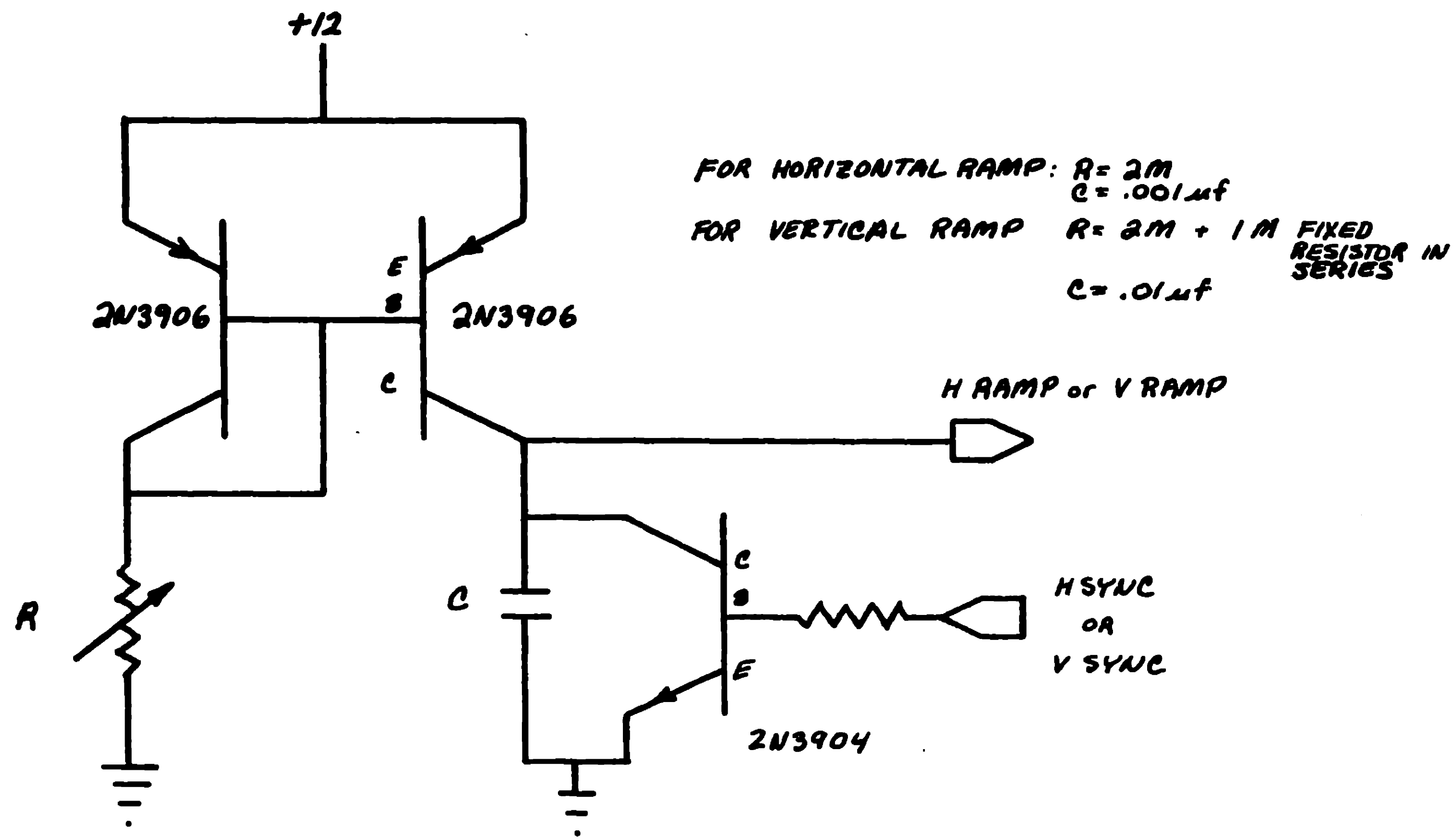


Figure A3: Ramp generator cicuitry

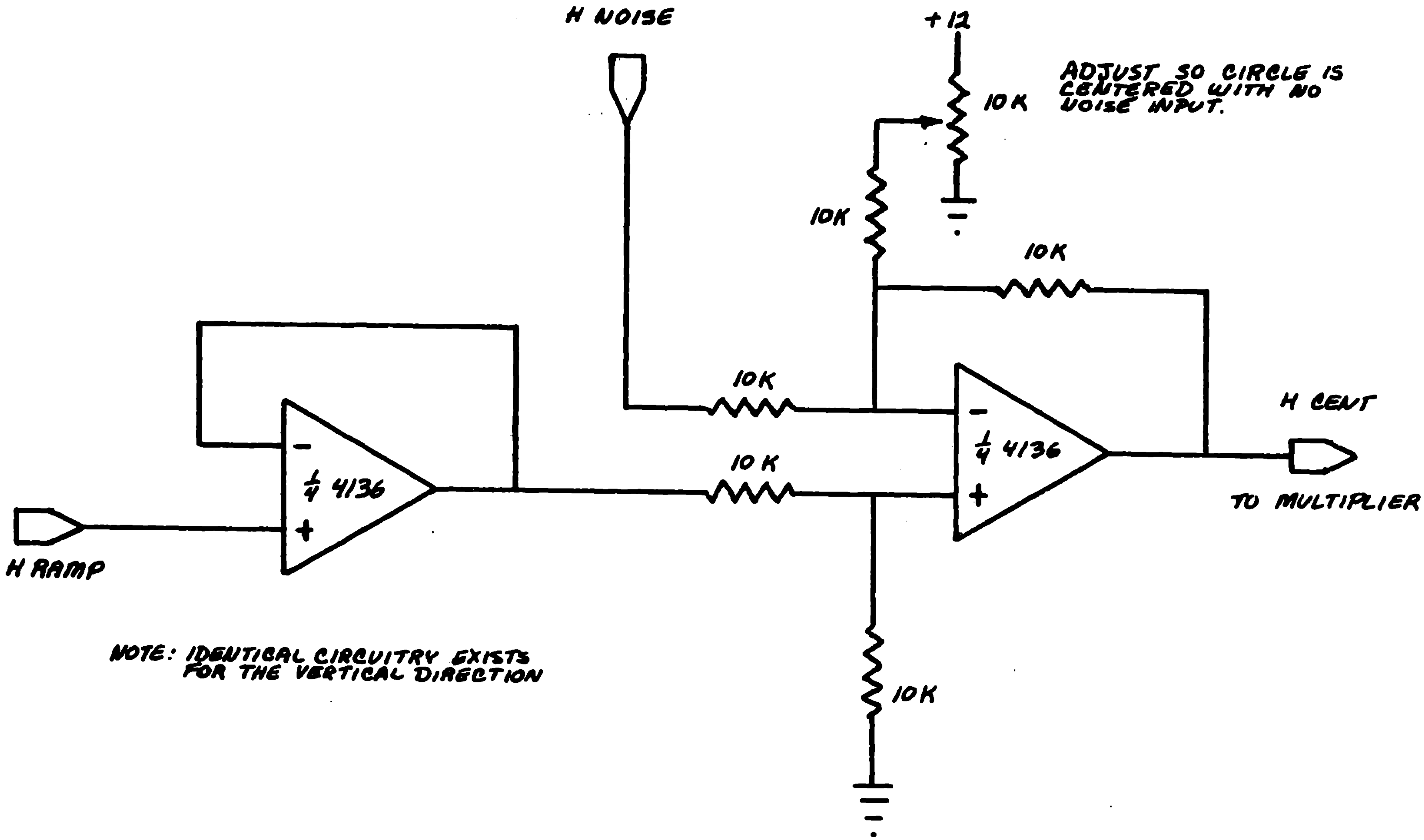


Figure A4: Circle position circuitry

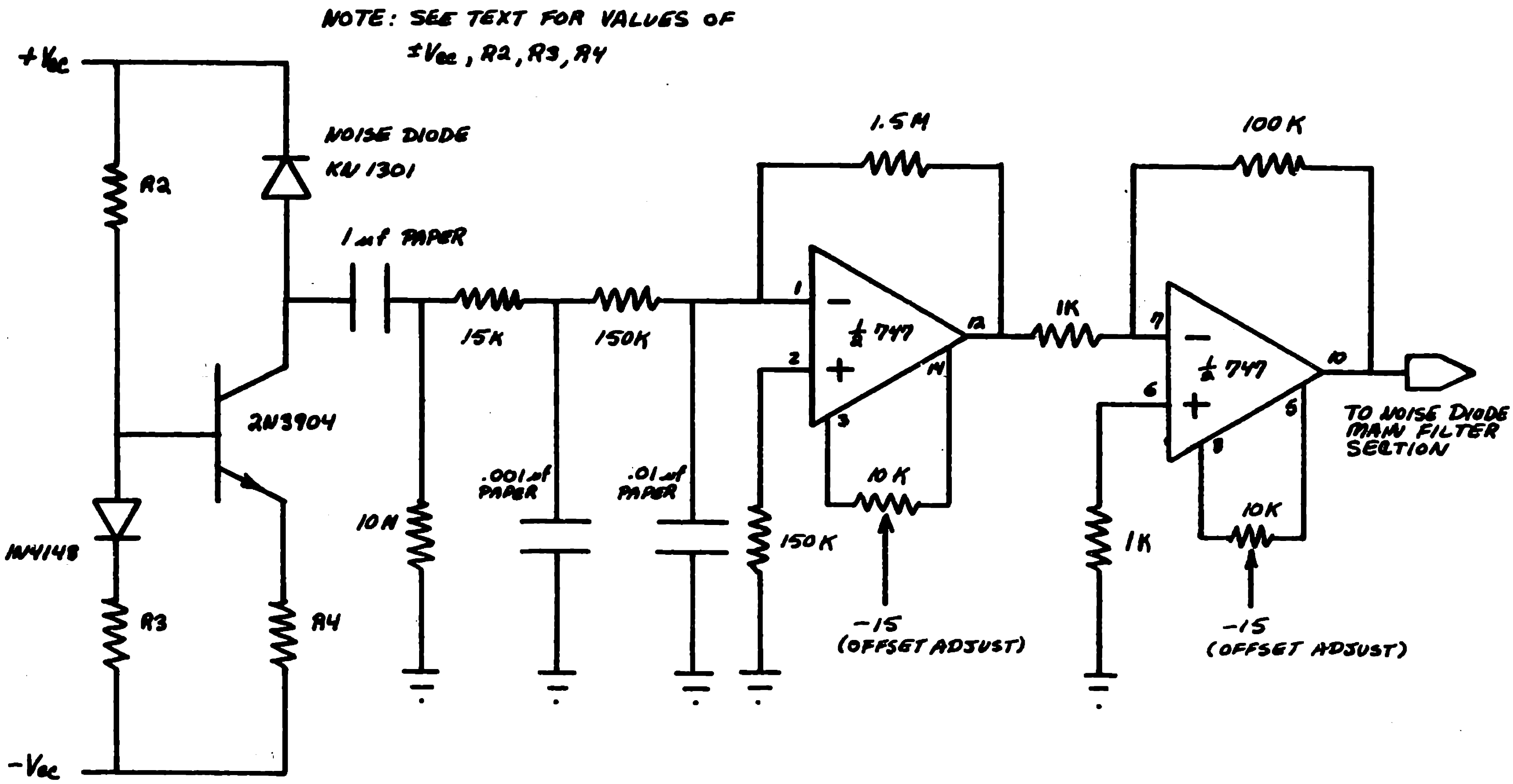


Figure A5: Noise diode-initial filtering and amplification stage

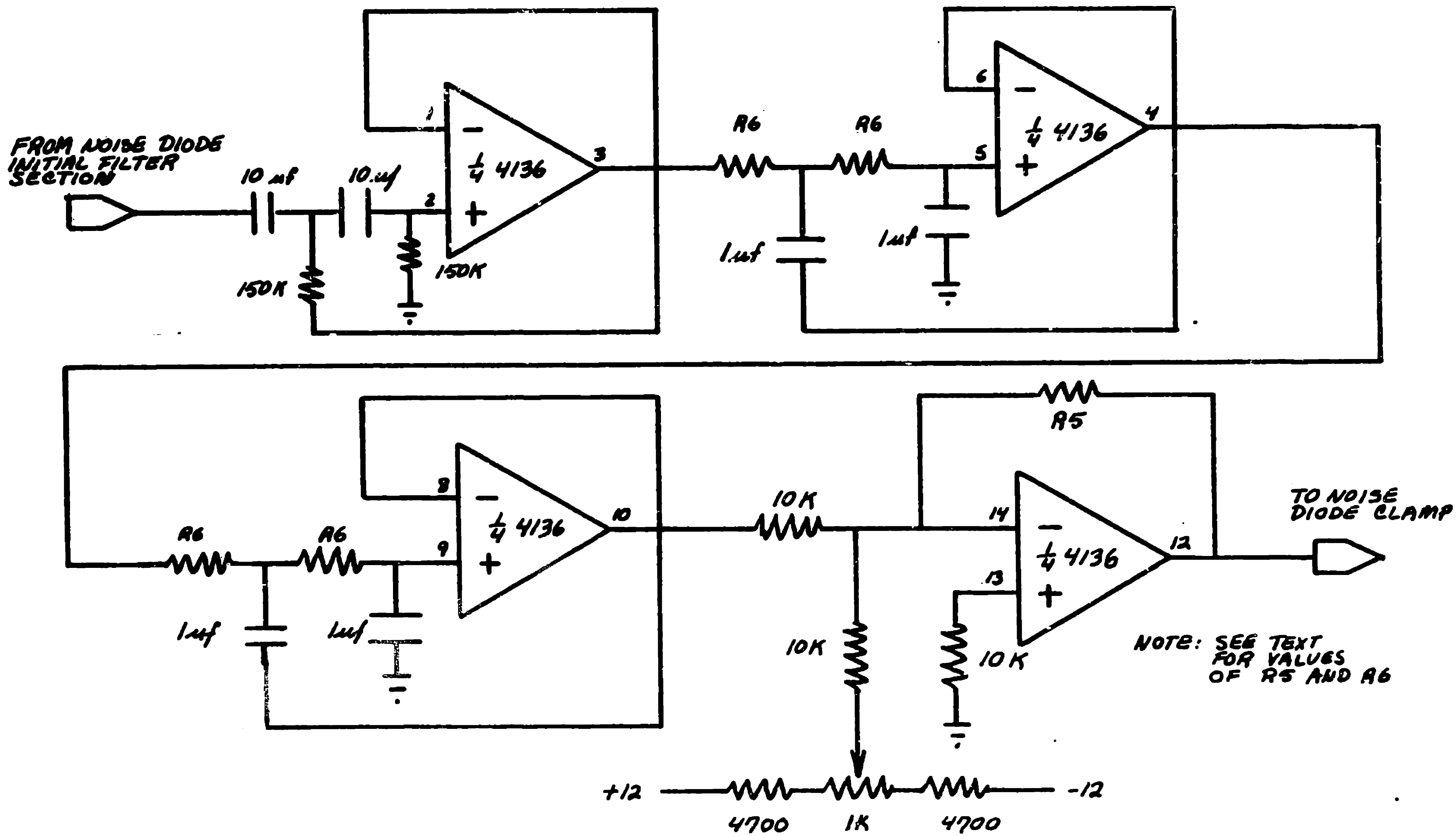


Figure A6: Noise diode-bandpass filter section

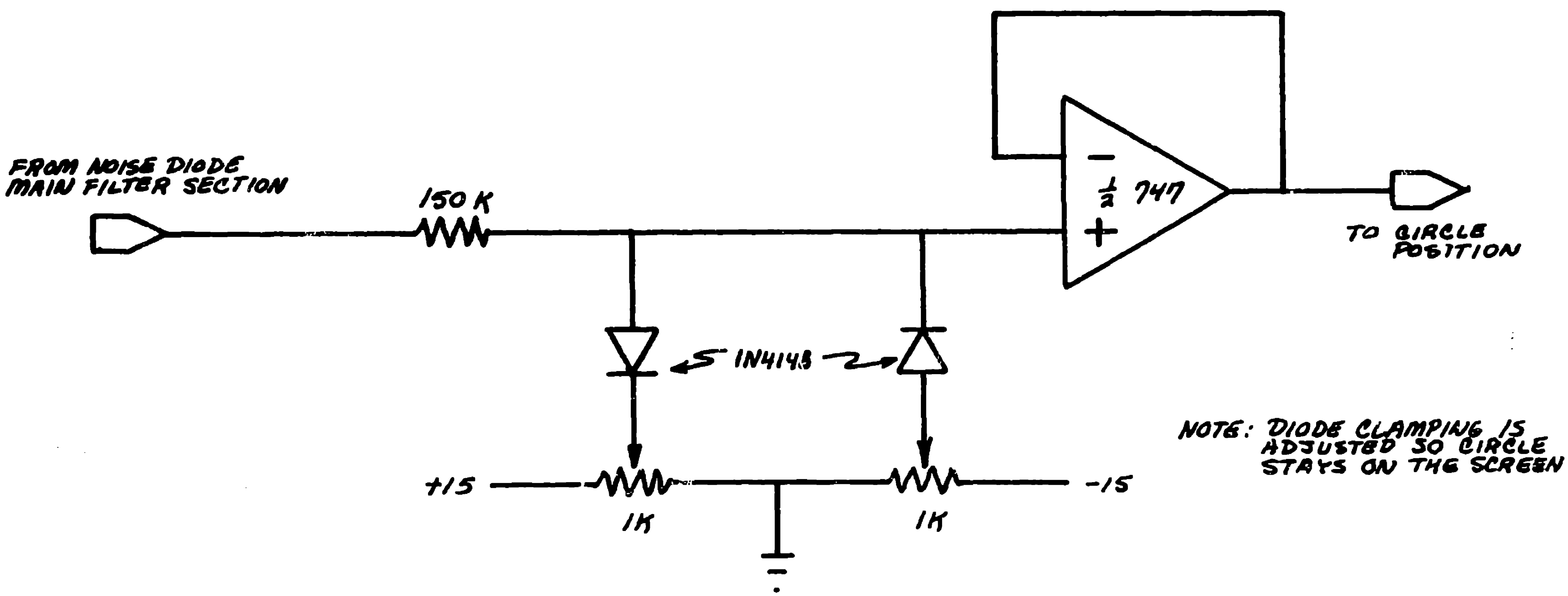


Figure A7: Noise diode-voltage clamp section

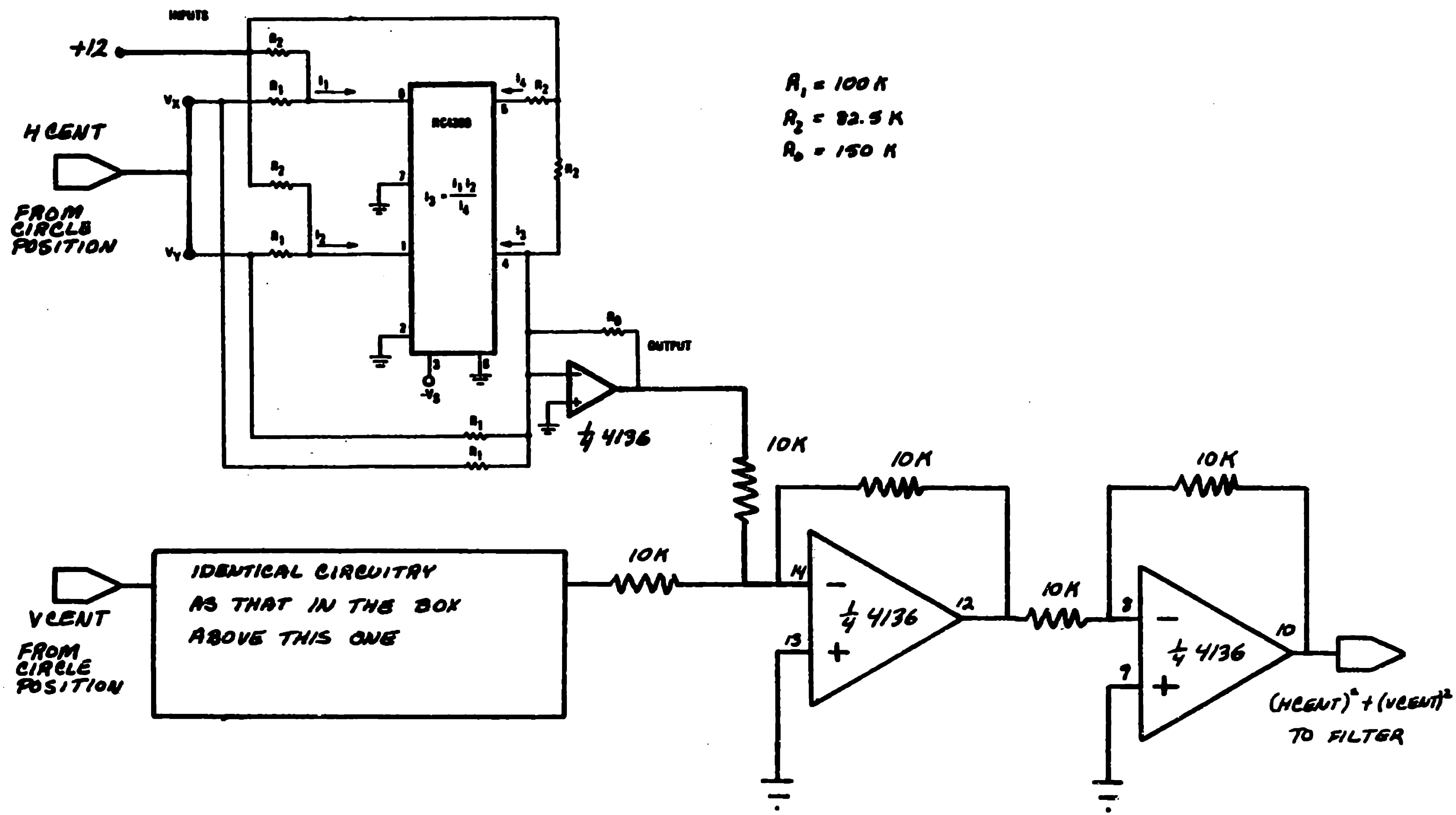


Figure A8: Multiplier circuitry

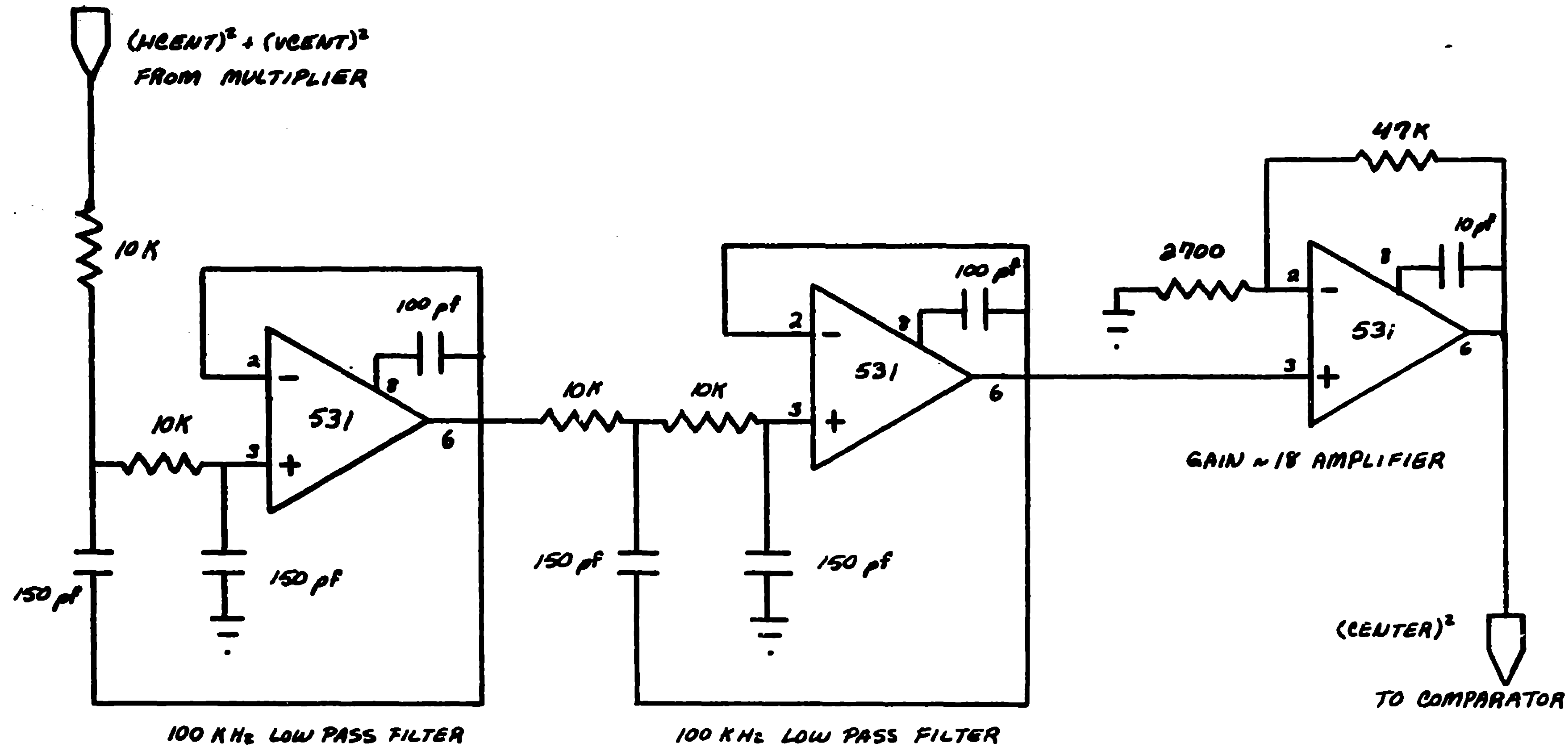


Figure A9: Low pass filter section to improve circle appearance

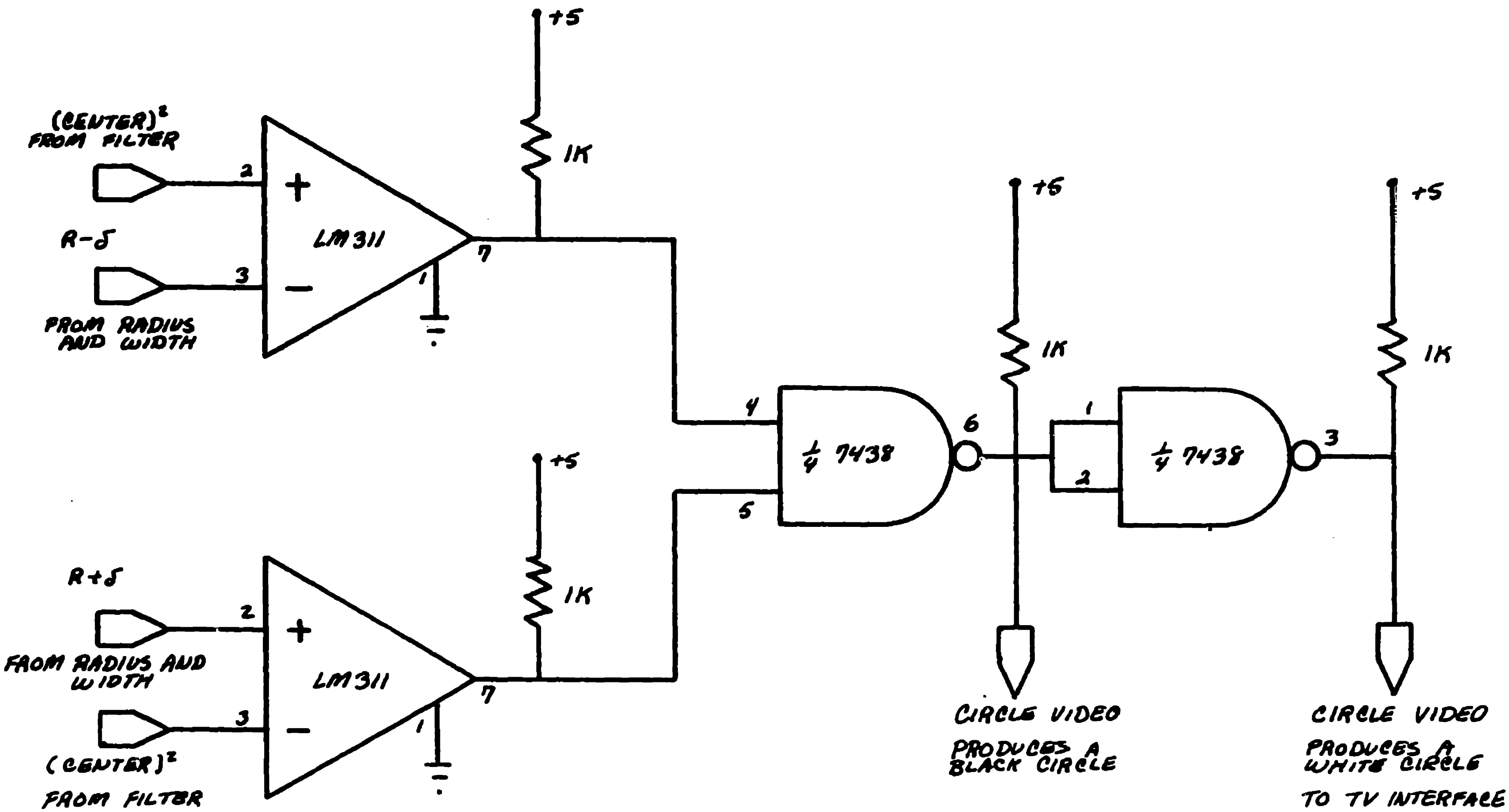


Figure A10: Comparator circuitry

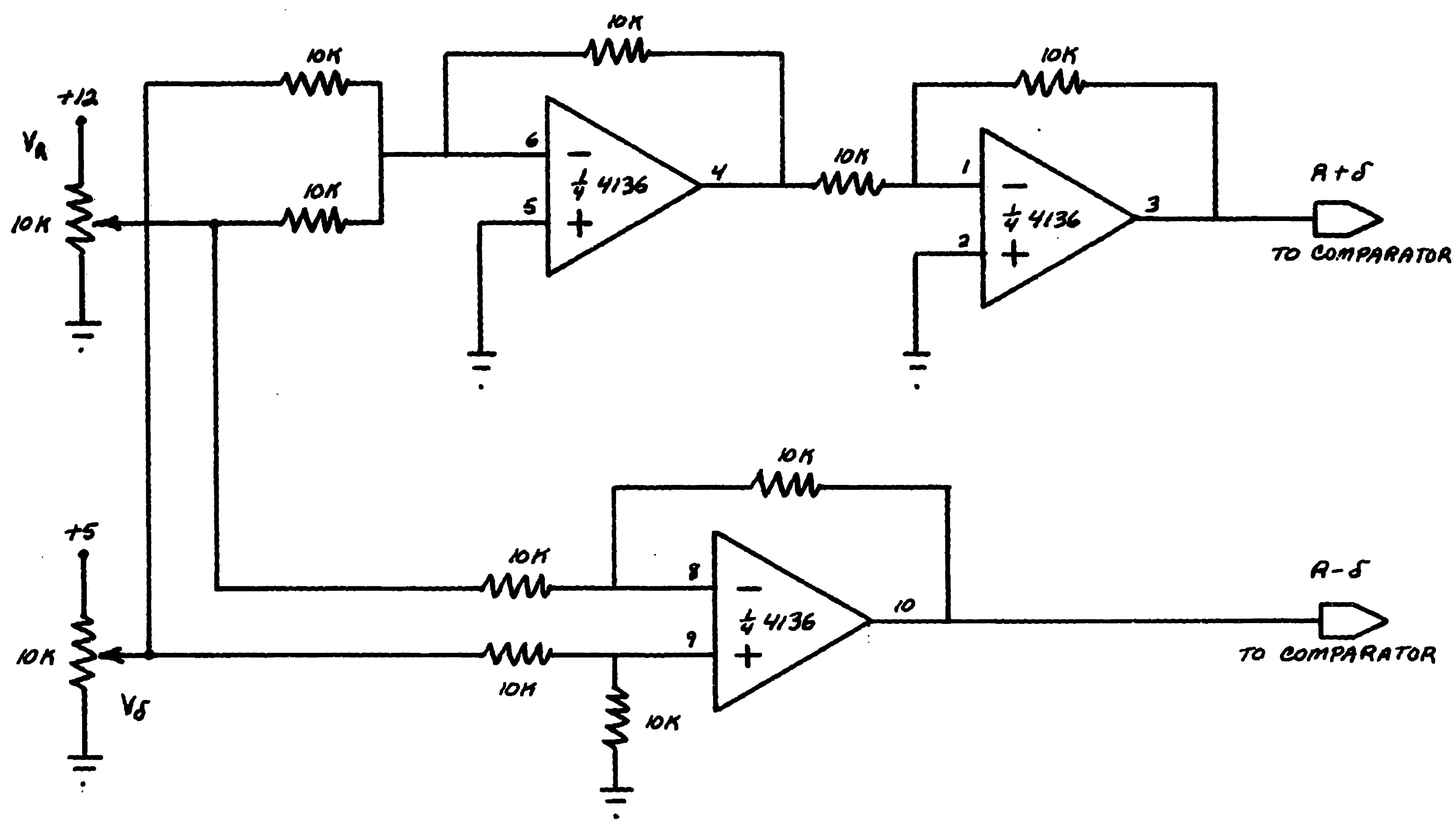


Figure All: Radius and width circuitry

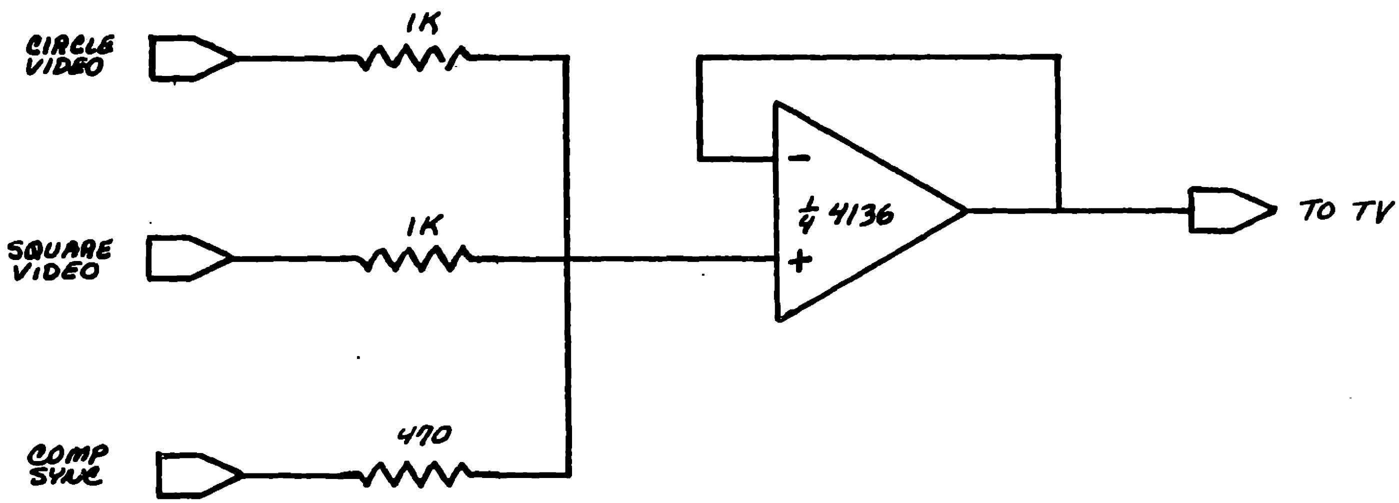


Figure A12: TV interface circuitry

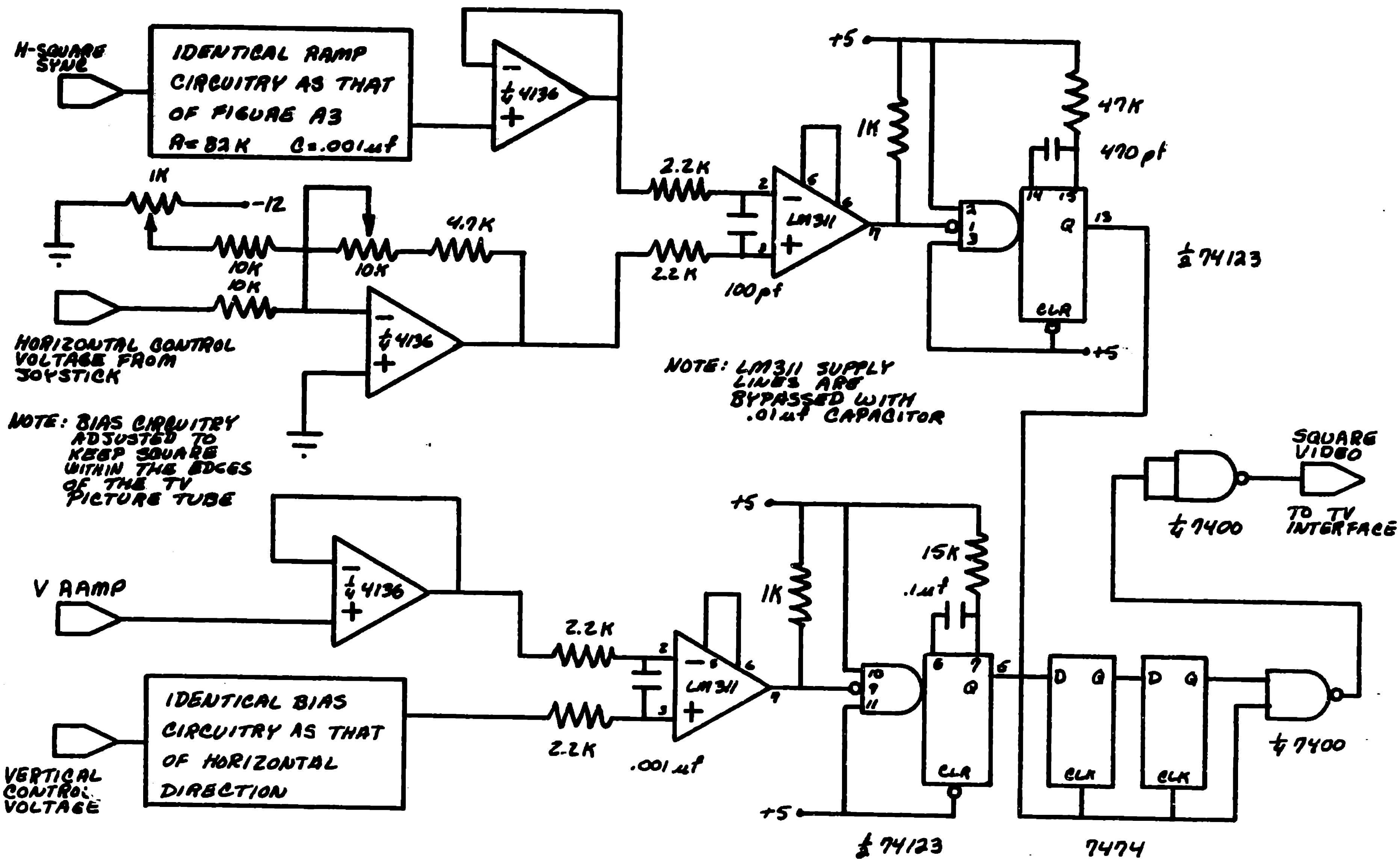


Figure A13: Square generator circuitry

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