# DESIGN OF A HIGH-VOLTAGE CONTROLLER FOR E-BEAM AND OPTICAL MSLM

by

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## Abstract

A Microchannel Spatial Light Modulator, an optical device which is used for two-dimensional information processing, requires up to eleven high-voltage settings for its operation. This thesis will consist of the detailed design and limited subsystem testing of a controller for the MSLM which can accept digital commands from a PC or allow each line to be set manually. Minimization of the number of exotic and costly voltage sources and the adaptability of the controller to different types of MSLM are design parameters.

Thesis Supervisor: Professor Cardinal Warde
Title: Professor of Electrical Engineering and Computer Science

## Acknowledgements

I wish to thank Jim Kottas for his incalculable contributions to the design and revisions of this project, as well as his patience; Bob Dillon, for his idea of using BU205's in the crystal and grid circuits, and his explanation of their shortcomings; and Helena Aho, for her help with the typing and her moral encouragement.

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# Chapter 1

# Problem Statement

## 1.1 Description of MSLM

The use of optical technology for information processing problems offers several advantages over current computer algorithm techniques. The electron-beam-addressed microchannel spatial light modulator makes use of a combination of electronic and optical components to perform space-domain image processing operations such as contrast reversal or enhancement, edge enhancement and binary-level logic operations.

The components of the electron-beam MSLM are shown in Figure 1.[1] This device consists of an electron gun similar to those used in a cathode ray tube (CRT), a microchannel plate, a grid and an electro-optic crystal. The crystal is coated on one surface with a dielectric mirror and a transparent electrode is sputtered onto the other surface. An electron image is generated by modulating an electron beam as it executes a raster scan. This image is amplified by the microchannel plate and proximity-focused onto the dielectric mirror. The resulting charge distribution induces a spatially varying refractive index modulation in the crystal. This varying refractive index then modulates the phase and/or amplitude of a laser readout beam as it makes

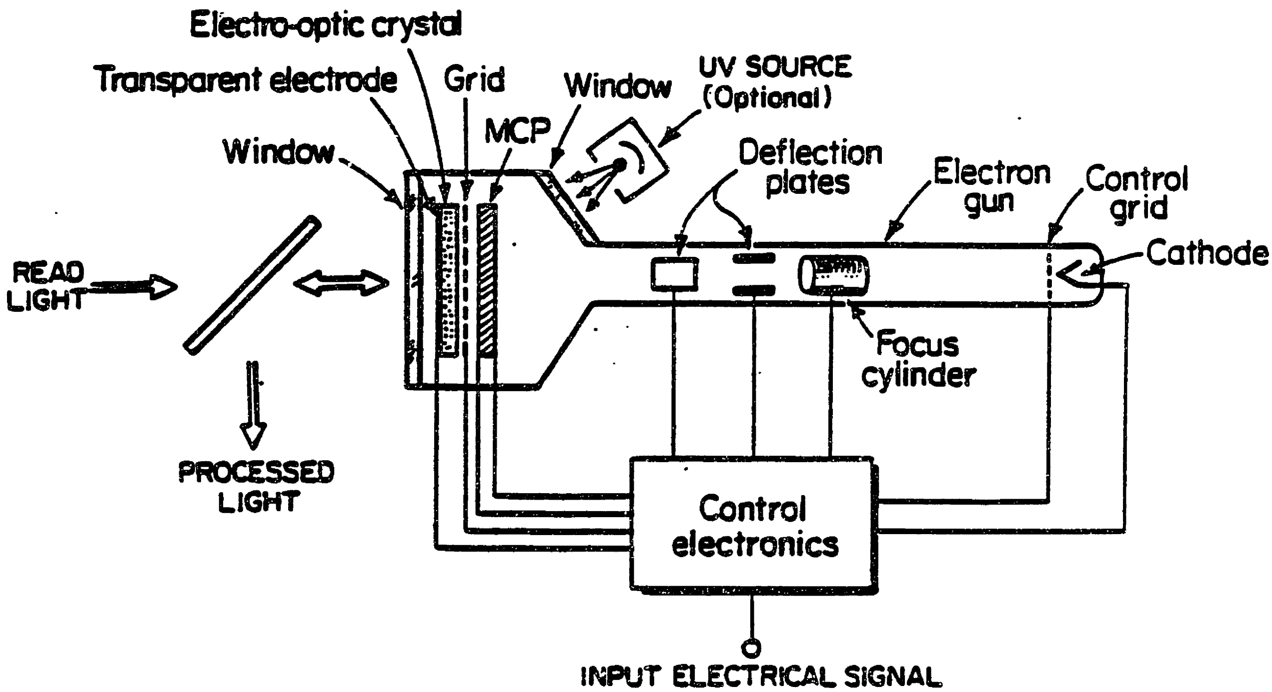



Figure 1

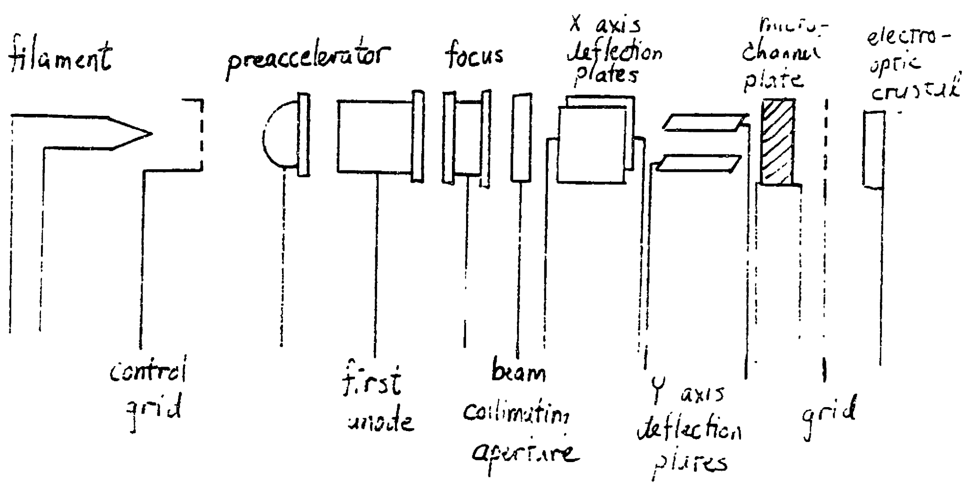



Figure 2

a double pass through the crystal. To erase the image the microchannel plate is flooded with electrons. This can be done by either defocusing the electron gun or by lighting the MCP with an ultraviolet lamp.

Although the theory and operation of the e-beam MSLM is very interesting, it is not the principal focus of this thesis. The interested reader is referred to more detailed literature on this technology.[1-4] The various components of the e-beam MSLM shall be treated as "black boxes" in order to define specifications for the controller.

Using this abstraction, the actual components that need to be controlled are pictured in Figure 2. The elements from the filament to the X and Y deflection plates comprise the electron gun. The MCP, grid and crystal are packaged with the gun in a vacuumed tube.

As an alternative to the electron gun the MCP can be driven by a photoelectron beam from an optical gun.

## 1.2 Present Methods of Control

At first, voltage and current levels were set by hand on individual power supplies. Some supplies, such as batteries, were configured for a single level and left alone, only needing to be monitored for when their output began to drop. In the case where a ramp input was desired, hand manipulation was too uneven. Some form of electronic control became necessary.

Full control by a microcomputer became the obvious goal, and it is being achieved in stages. At first, an interface box was designed and built. This box, called DASMIC, receives commands and data from a card within the PC. It can control D/AC outputs, read A/DC inputs, read an externally-attached sensor, set an erase lamp on or off, and send digital instructions to an MSLM controller over a serial line. DASMIC now controls several elements of the MSLM directly through its analog output ports; however, it is limited because it only has four such ports. It is intended instead to control up to four independent MSLMs. It runs on a cycle time of 480 kHz.

The overall plan is illustrated in Figure 3. The controller that this thesis proposes is at the lowest "level of abstraction", in direct control of individual elements of the MSLM.

## 1.3 Desired Specifications of Controller

The overall design goals of the MSLM controller are flexibility, accuracy and low cost. It must allow for manual or computer control, it must provide for different kinds of electron or optical guns, and it must minimize the number of exotic, expensive high voltage supplies.

In Table 1, the electrical specifications are summarized for each component. The ranges for the e-beam components are standard for most types of e-beams that are likely to be used, but there is one difference. There is a bias voltage on the Anode, the Beam Collimating Aperture, and

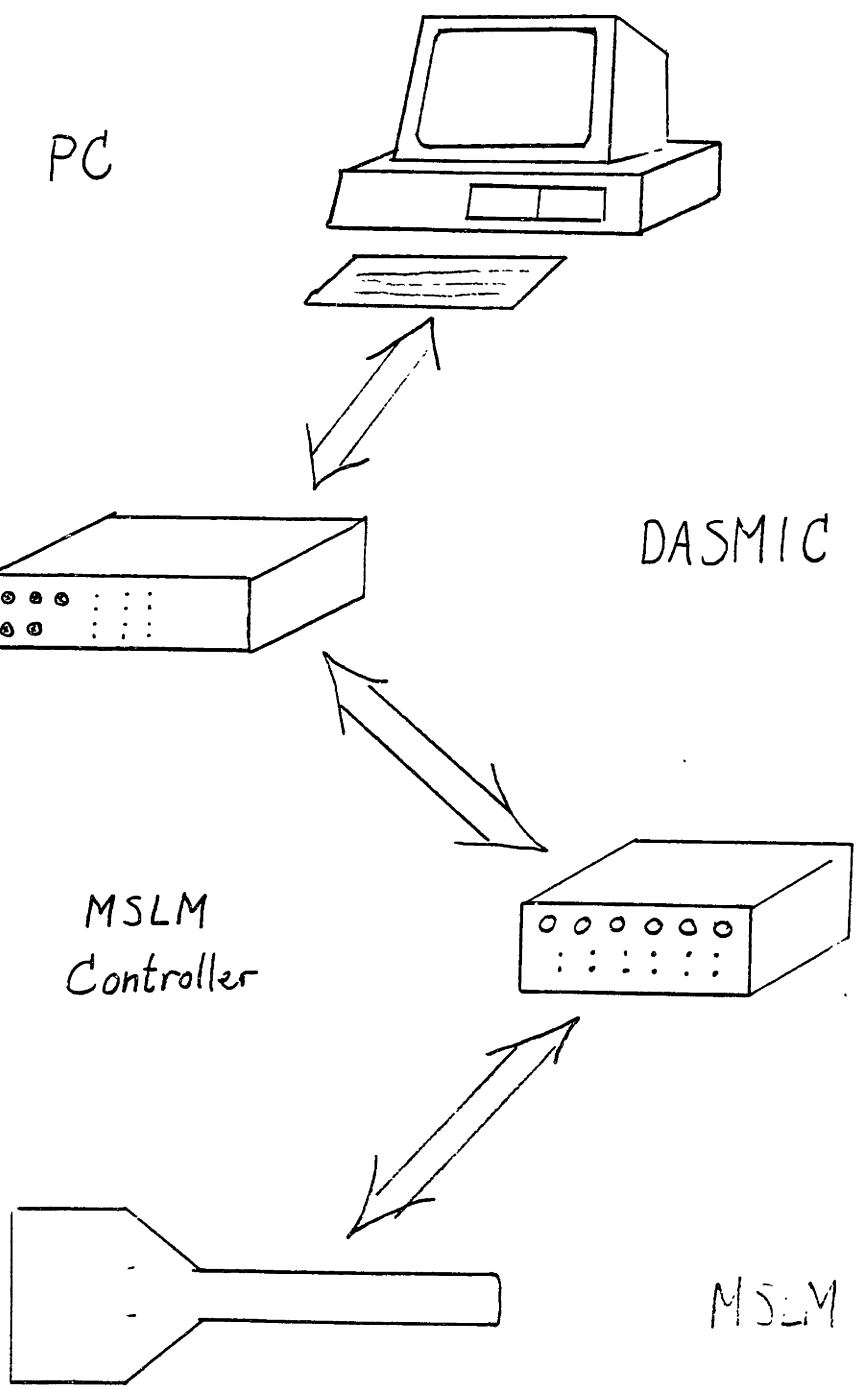



Figure 3

TABLE 1

| Element | Voltage Range | Input Current | Comments |
| --- | --- | --- | --- |
| filament | -2kv | 5A | |
| control grid | -2.1 to -2kv | nA | |
| preaccelerator | -2 to -1kv | nA | |
| anode | bias voltage | nA | |
| focus | -2 to -1.1kv | nA | |
| BCA | bias voltage | nA | |
| Y plate | ±100v | | fast rise time |
| X plate | ±100v | | fast rise time |
| MCP | 0 to 2kv | up to 1mA | |
| grid | 0 to 3kv | | slow rise time |
| crystal | -1 to 4kv | | fast rise time |
| optical beam | -3kv bias | nA | |

TABLE 2

| Element | Control Method | Status Indicator |
|---|---|---|
| filament | 3 | current on/off |
| control grid | 3 and 4 | none |
| preaccelerator | 2 | none |
| anode | 1 | none |
| focus | lower limit: 2<br>range: 3 and 4 | none |
| BCA | 1 | none |
| X and Y plates | Controlled plate: 3 and 4<br>bias plate: 1 | none |
| (optical beam) | 1 | none |
| MCP | 3 and 4 | current on/off |
| grid | 3 and 4 | none |
| crystal | 3 and 4<br>manual shift voltage switch | none |

Methods of Control

1. permanently set
2. preset by internal pot for different guns
3. variable control by external pot
4. variable control by computer

one of the two plates in the horizontal (X) and vertical (Y) deflection stage. This bias voltage, which is also asserted on the output side of the MCP, is desired in order to discourage the electron beam from being attracted to the sides of the tube.

There are essentially four levels of control required for different elements of the system. These, along with the status indicators that are to be fed back to the computer, are summarized in Table 2. As can be seen, there are six elements requiring both DAC and pot controls and two status indicator requirements.

Commands are received over a serial line in groups of twenty-four bits. Each command contains a code specifying which element is being controlled. Eight bits are reserved for DAC level data, augmented to 12 for the crystal. Each DAC input can be switched to an externally-mounted, manually-adjusted pot.

# Chapter 2

# Design

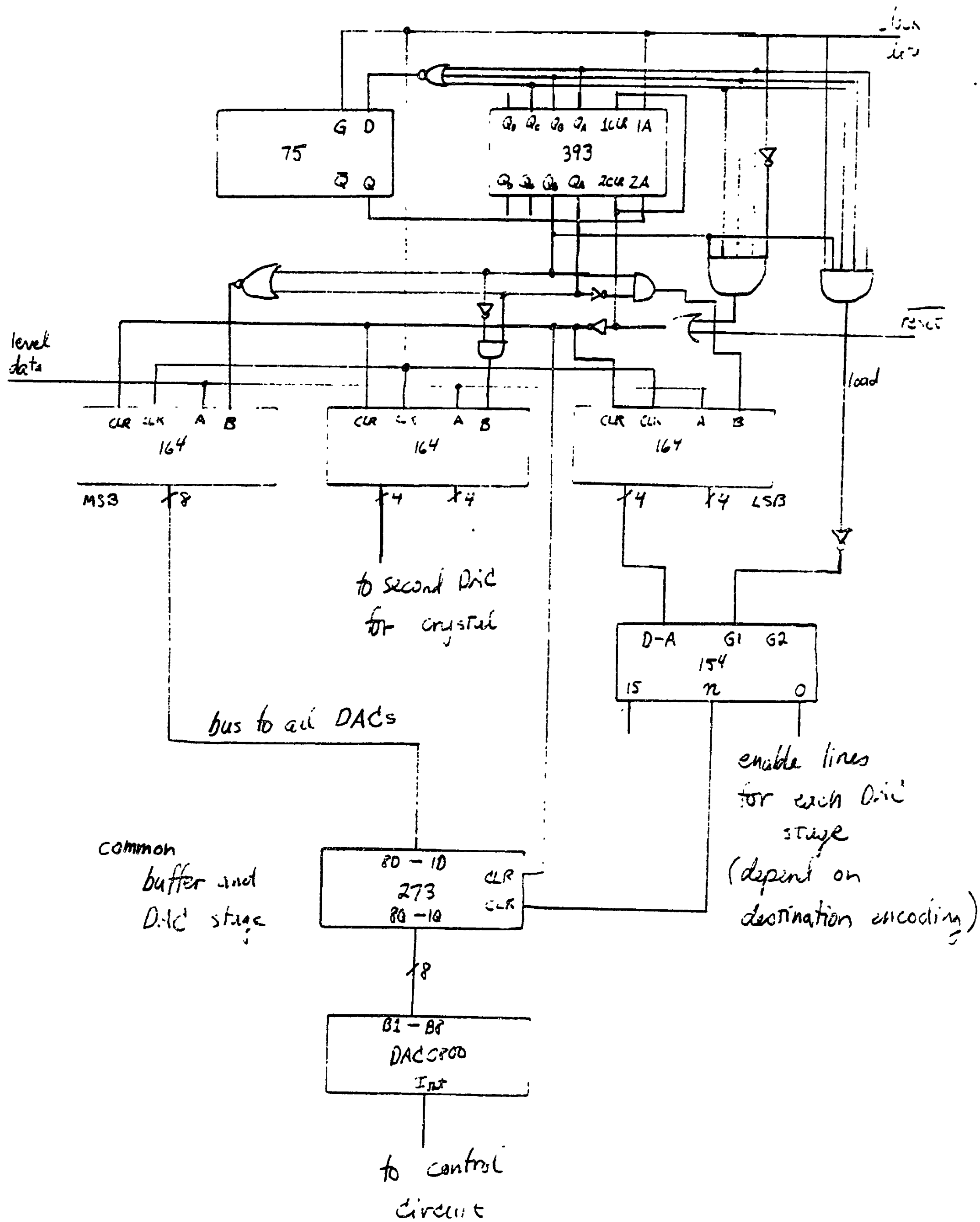
## 2.1 Overview

The MSLM controller has a number of duties to perform, so it has been broken up into a number of different sections. Commands come in serially on a data line; they are reassembled in parallel, decoded and loaded into the relevant register. D/A converters translate digital level data into analog voltage levels. These then drive the control circuits for each element. Due to the large number of different voltage ranges, many different power supplies are specified. Attempts have been made to use the smallest and cheapest supplies that meet the performance specifications.

The individual control circuits are described in detail in Section 2.3. The digital input and conversion circuitry is described in Section 2.2, and the return status information is described in Section 2.4.

## 2.2 Digital Input and Level Conversion

The primary goal of the MSLM control system is to facilitate the accurate control of individual MSLM elements by the computer. Thus the digital input and level conversion stage is key to all of the other subsystems of the design. It is illustrated in Figure 4.




Digital Input and Level Conversion
Figure 4

DASMIC is connected to the MSLM controller by six lines. They are:

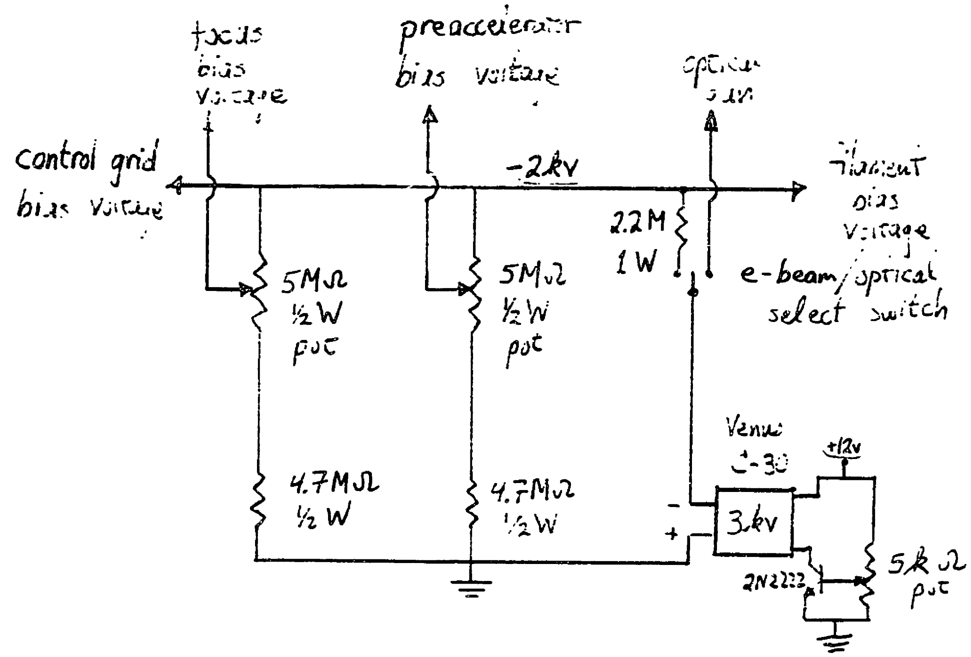
1. Clock Data
2. Command and Level Data
3. Reset
4. Ground
5. Return Status Indicator #1
6. Return Status Indicator #2

The Clock Data synchronizes the MSLM controller with the operations of DASMIC. A 393 is used to count sequences of twenty-four pulses, enabling different serial-to-parallel shift registers to capture consecutive bytes of the Command and Level Data. At the end of a twenty-four pulse group a Load command enables the storage registers for the Level Data and a 4-to-16 line demultiplexer. This decodes the destination and asserts the respective initiation line. The stored level data is processed through the DAC to present analog input voltages to the control circuits. As an alternative, a switch for each DAC can allow the input voltage to be controlled or set by an external pot.

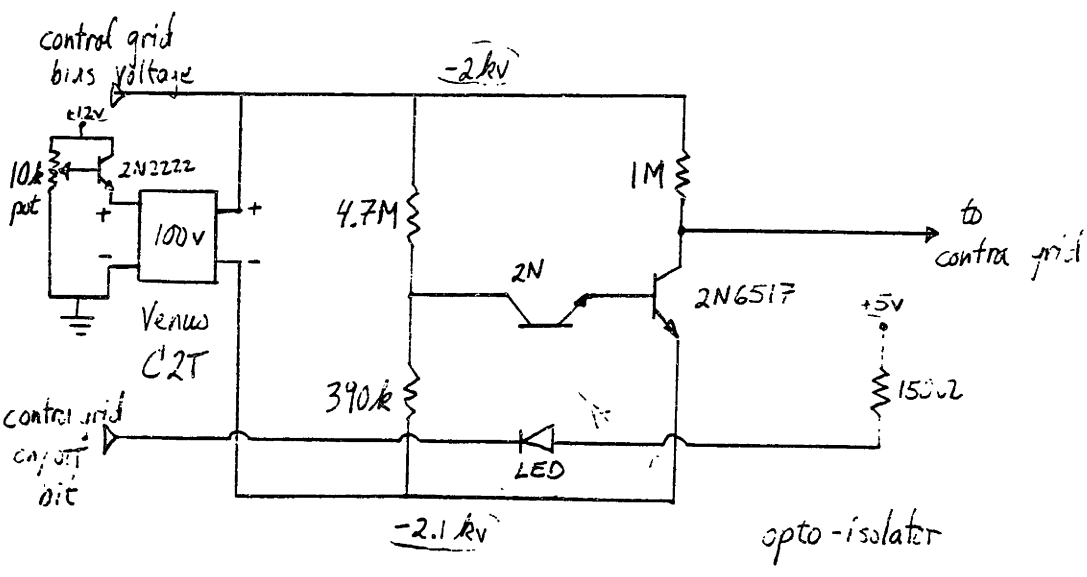
## 2.3 Output Control Stages

### 2.3.1 Main Loop

The main loop, illustrated in Figure 5, establishes the bias voltage settings for the filament, control grid, focus and preaccelerator. It is powered by a Venus C-30 3kv supply which has its positive output grounded. Thus by turning a switch a -3kv bias with up to 500uA (400uA maximum recommended) can be provided for an optical gun. Otherwise, the voltage is cut through resistors and pots to set




Main Loop
Figure 5




Control Grid
Figure 6

the required bias voltages. Each line will draw less than 1uA so no significant loading variations are anticipated. Both the preaccelerator and focus are offset between -2kv and -1kv by an internally-adjustable pot. The desired bias is set once for each different e-beam gun used.

2.3.1.1 Control Grid

The control grid has 2 settings as shown in Figure 6: -2kv and -2.1kv. They are controlled by pinning the control grid on/off bit high and low respectively. The opto-isolator allows a 0 or 5 volt input to control a 100 volt swing on a -2kv bias. When the bit is high, no current flows through the LED, so no current flows through the phototransistor. Therefore the 2N6517 is shut off and the output is at -2kv. When the bit is low, current flows through the LED, lighting the phototransistor, which turns on the 2N6517. This shorts the output to -2.1kv. The pot on the Venus C2T supply is internally mounted; it is used to set the voltage offset to 100v. It saves me the job of calculating exact voltage divider values that are going to vary for different power transistors and supplies anyway.

2.3.1.2 Preaccelerator

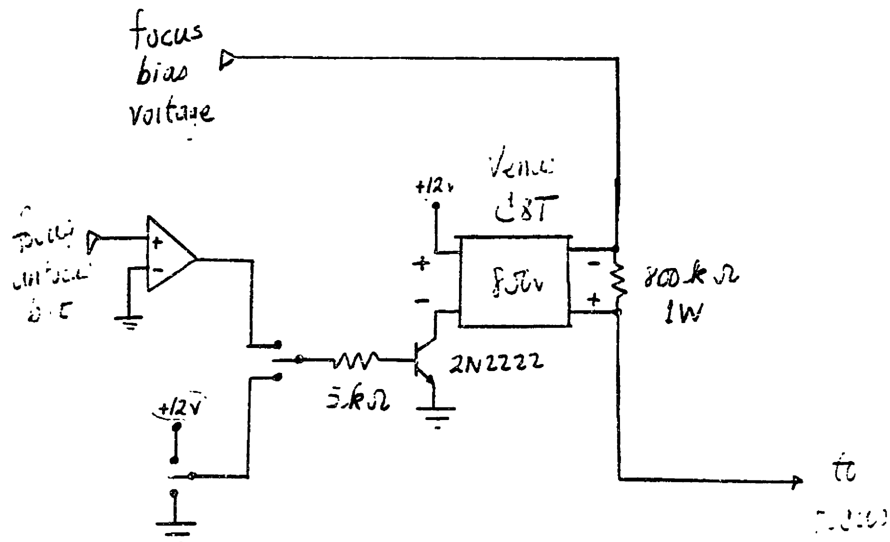
The preaccelerator line simply carries a bias voltage of between -2kv and -1.1kv. It is set internally by an adjustable pot; it is anticipated to draw less than 1uA, so it will not load the main loop or suck up current. It can be seen in the illustration of the main loop, Figure 5.

2.3.1.3 Focus

The focus control is another two-state circuit, pictured in Figure 7. Its input will depend on the particular electron gun being used but is typically between -1.9 and -1.8kv. This value is determined to give the best focus of the beam of electrons and is set on the internal pot in the main loop. As mentioned in the description above, one of the ways to clear the MCP is to defocus the beam and flood the MCP with electrons. This can be done by asserting the focus line 800 volts higher than the voltage at which it is focused. The power transistor will either be fully off or fully on, focusing or defocusing (respectively) the beam by the absense or presence of the 800 volt shift. The 1mA of current from the output of the Venus C8T will be sucked back into the input, across the resistor, resulting in no excess current along the focus line.

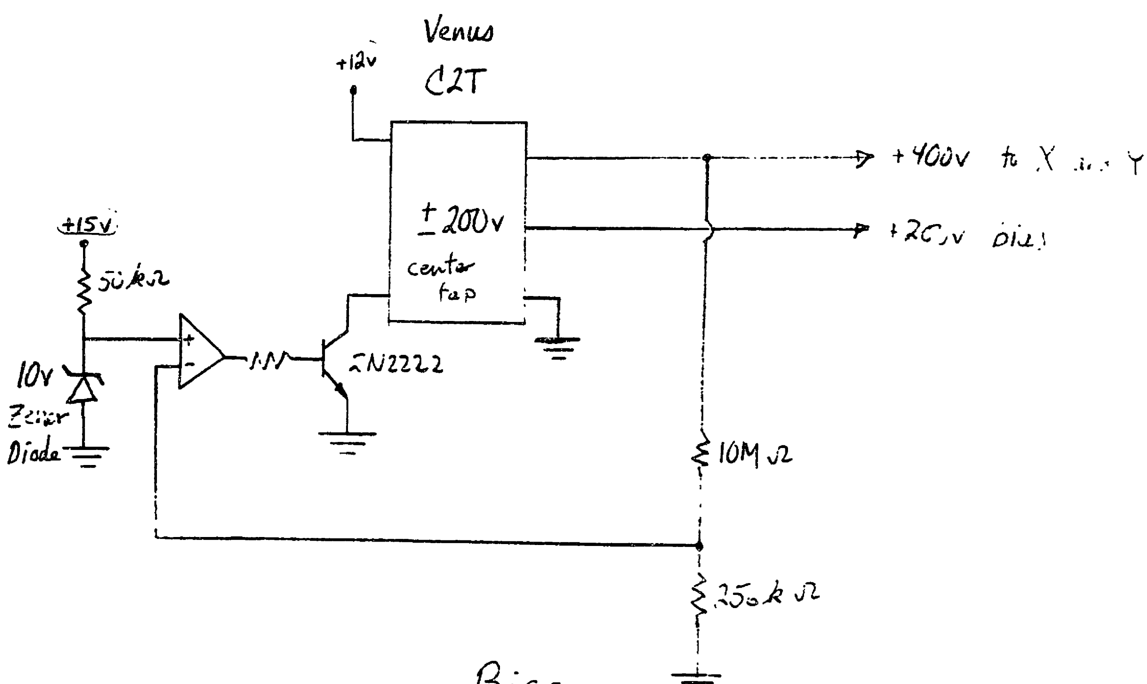
2.3.2 Bias to Anode, BCA, X, Y, and MCP

The stream of electrons is less attracted to the sides of the tube when a bias voltage of 200 volts is applied to the anode, the beam collimating aperture, the side of the X and Y deflection plates that is not used for control, and the current output side of the MCP. Figure 8 shows the supply that asserts this 200 volt bias, along with the stabilized 400 volt voltage for the X and Y deflection plates. The 400 volt output is cut by 40, which is then compared with a 10 volt Zener reference diode and used to drive the power transistor.




Focus

Figure 7




Bias

Figure 8

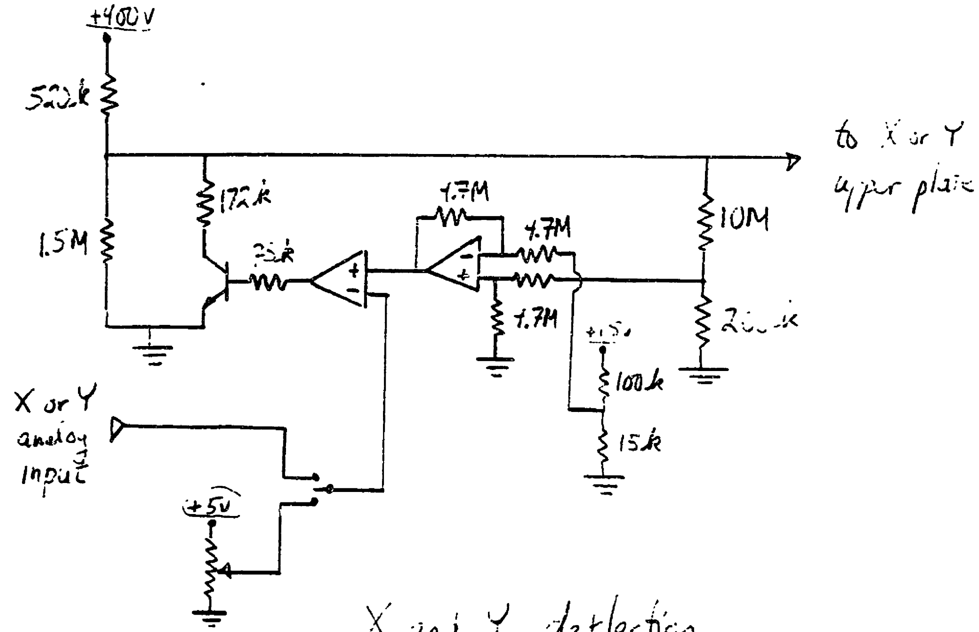
2.3.3 X and Y Deflection Plates

The X and Y deflection control circuits are identical. Since the opposite plate is assumed to be set to a +200 volt bias (this may vary, depending on the current drain of the C2T; see discussion in Section 3.4), the specifications for ±100 volts translate to a control line voltage of 100 to 300 volts. This is provided by the circuit in Figure 9. For comparison purposes, the voltage divider cuts the output down from 100-300 to 2-6. This is then shifted by 2 volts to produce a feedback voltage of 0-4 volts. When the input is high the transistor is shut off and the output is dominated by the 500k-1.5M voltage divider. When the input goes low the transistor pulls current away from the 1.5M resistor and the output is increasingly dominated by the 500k-170k voltage divider.

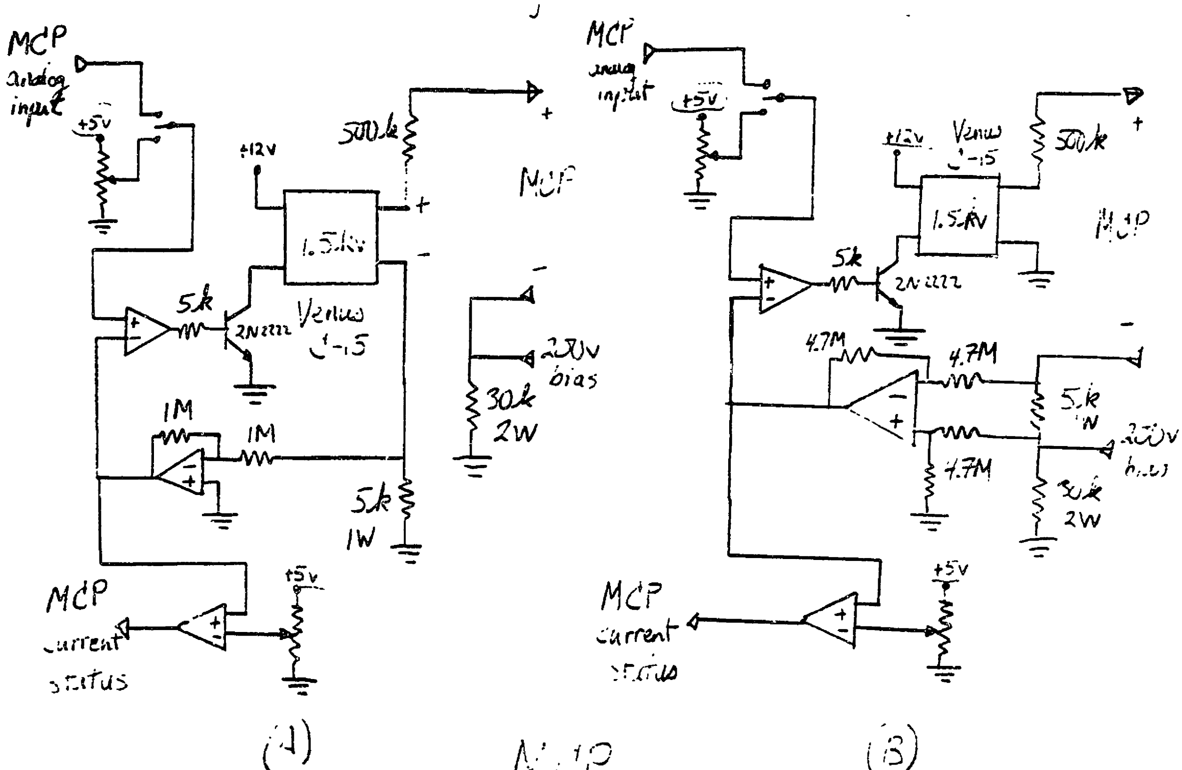
2.3.4 Micro channel Plate

There are two alternative circuits drawn in Figure 10 for controlling the MCP current. The input current sensor, (A), is favored due to its simplicity; however, problems with untraced oscillations may hamper one or both designs (see testing results, Section 3.4, and Discussion).

The intent is to control the amount of current in a feedback configuration. Thus both circuits sample the current flow across a 5k resistor and compare the resulting voltage with the input. As more current is desired from the supply, more current is drawn from it by the power transistor. The 500k resistor cuts down the applied voltage




X and Y deflection
Figure 9




MCP
Figure 10

and prevents the MCP current from running above 400uA. This cannot be exceeded by much due to the high equivalent resistance (~3M) of the MCP.

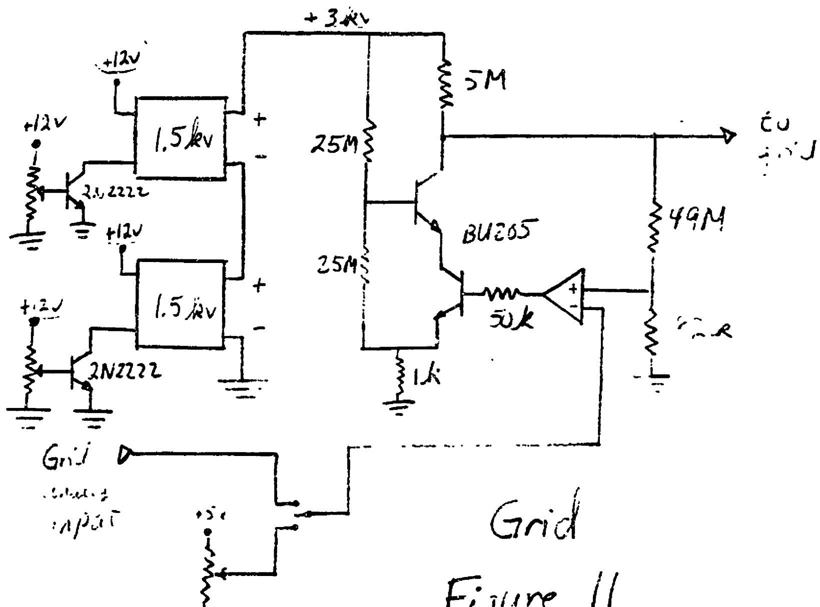
2.3.5 Grid

The control circuit for the grid uses a ladder network of high-breakdown-voltage transistors to swing across nearly 3kv, as shown in Figure 11. In fact, the breakdown voltage of 1500 volts for the BU205 is almost its only redeeming feature, since it has a current gain around 2 and takes a minimum of 0.5mA to drive appreciably. Use of less current increases the rise time of the circuit appreciably. In the interest of cost savings, the slow rise time can be tolerated for the grid, which is why a lower-current supply and higher resistor values are used here than in the crystal.

When the input is driven high the op-amp forces the transistor to shut off, so the 3kv current divides between the 50M base-bias resistors and the 55M feedback resistors. This produces a current across the 5M resistor of around 50uA, or an output around 2700 volts. As the input is lowered, the transistors turn on, shorting the 5M resistor and with it the grid output to ground. The Venus C-15 supplies are piggy-backed in order to get more current (up to 1mA) at 3kv than with a C-30.

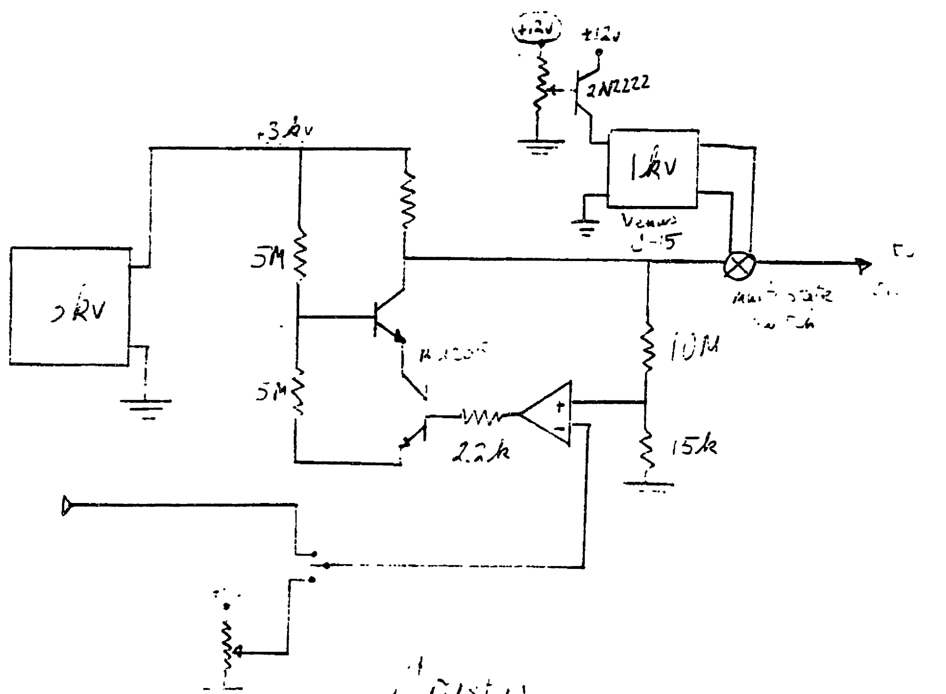
2.3.6 Crystal

The crystal control circuit uses the same transistor-short design as the grid circuit. The resistor values are lower, and a different supply with greater input current is




Grid

Figure 11




Crystal

Figure 12

specified, in order to achieve a faster rise time. I recommend the Spellman WRM3(P)10KD, which can source 3mA at +3kv, although the input voltage (28VDC) will require a separate power supply.

The full specified range of -1kv to +4 kv is not often required in a single use of the MSLM. Therefore, the circuit has been simplified by using a switch to engage an additional 1kv supply as a positive or negative output shift. When the computer is in control of the system the user must mentally keep track of the effects of engaging the offset supply. This arrangement is depicted in Figure 12.

## 2.4 Return Status Information

### 2.4.1 Filament Current

The current status indicator is an on/off bit that signals that current is flowing toward the cathode. Its circuit is illustrated in Figure 13. When current flows, the voltage drop across the small resistance (a piece of nicrome wire would work fine) activates the LED. This lights the photo transistor, which turns on the 2N3904 and the current status bit is drawn low. When there is no current, the LED doesn't light, the phototransistor does not activate and the 3904 stays open. Thus the control status line stays high.

### 2.4.2 MCP Current

An indicator that tells whether the MCP current is greater than some manually-preset value, the circuit for

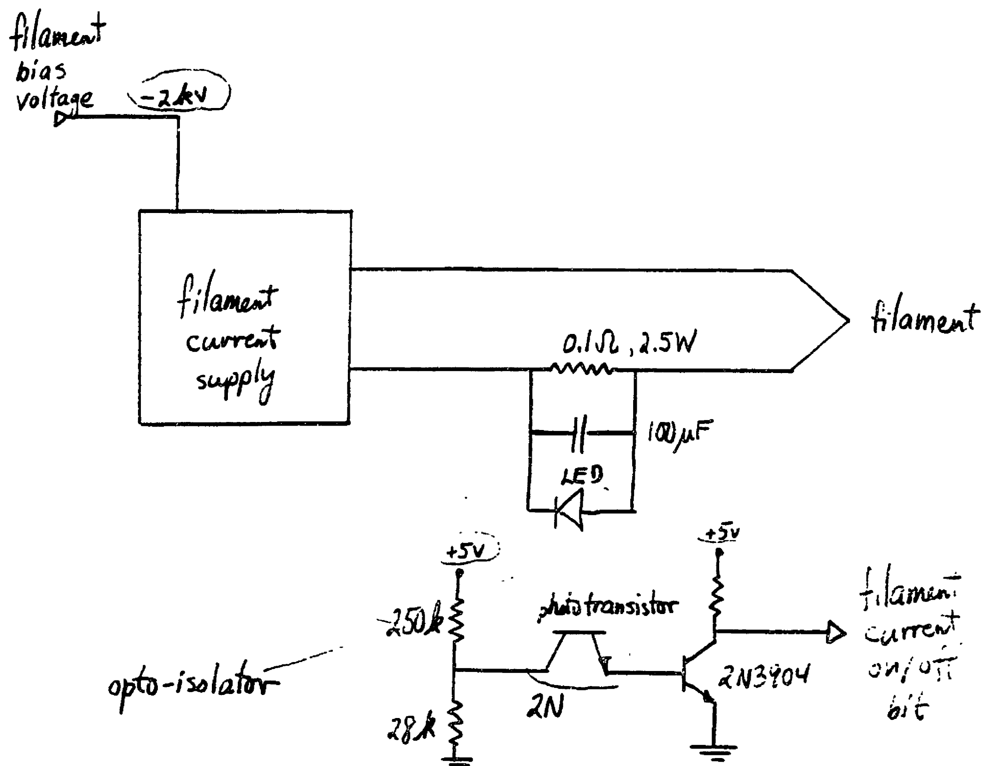

filament
bias
voltage
-2kV
filament
current
supply
filament
0.1Ω, 2.5W
100μF
LED
+5V
+5V
250k
phototransistor
filament
current
on/off
bit
opto-isolator
2N
2N3904
28k

Figure 13

the MCP current status bit is also drawn in Figure 10. When the feedback value of the current exceeds the preselected value the bit goes high; otherwise it is low.

# Chapter 3
# Testing

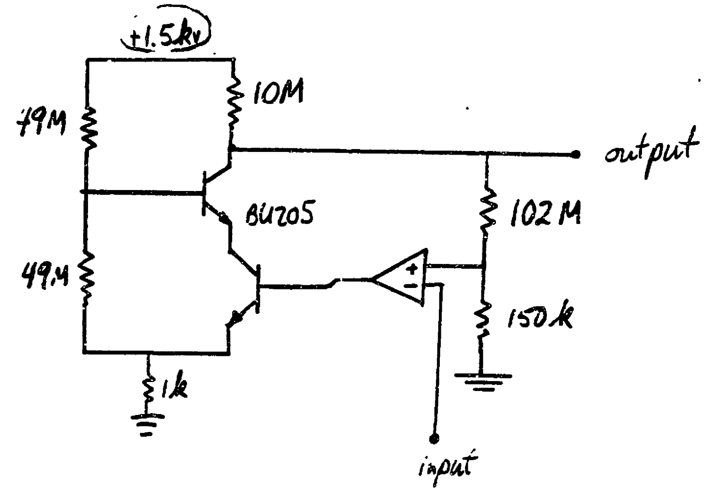
## 3.1 Operational Control Grid

The circuit for the control grid needs no testing; it is an extension of a circuit that is already working quite well in an operational system. The working circuit uses a battery to set the lower (-2.1kv) voltage level. The C2T used here is an additional expense, but allows the circuit to be more flexible.

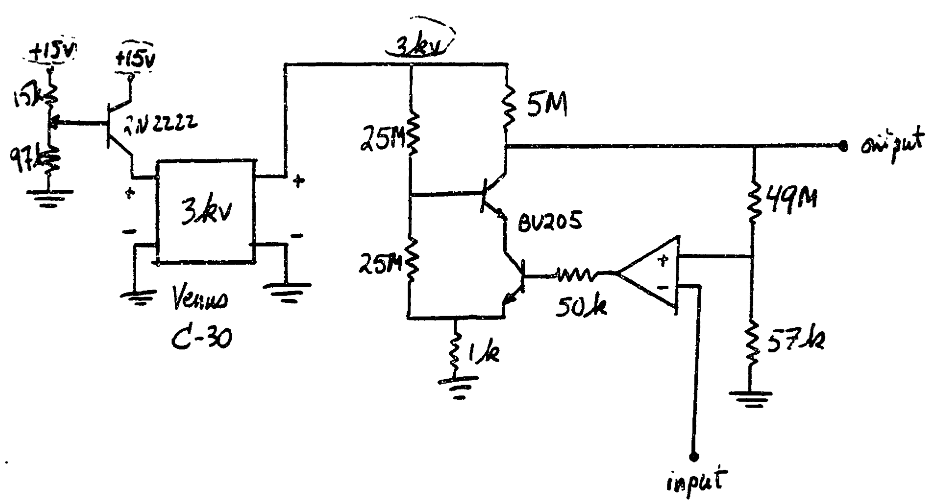
## 3.2 Grid/Crystal Circuit Test

Two models of the BU205 circuit were built and tested in the lab, as illustrated in Figure 14. In circuit (A) the resistor values were 10M, 50M, and 100M for the ladder network; in (B) the same resistors were 5M, 25M and 50M. Circuit (A) was tested using a lab power supply to set +V to 1.5kv. Circuit (B) was tested using a Venus C-30 set to 3kv; it is limited to delivering a maximum current of 500uA. In addition the circuit has been built and tested by Bob Dillon using values of 1M, 5M, and 10M.

The results of these tests are summarized in Table 3. In general, the lower resistances exhibited faster rise times but required higher currents. When higher resistances were used the current needed was less, but it did not




(A)




(B)

Grid/Crystal test circuits
Figure 14

TABLE 3

| Test | low input | | | high input | | |
|---|---|---|---|---|---|---|
| | $V_{out}$ | $i_s$ | $t_{rise}$ | $V_{out}$ | $i_s$ | $t_{rise}$ |
| R=10M +V=1500 | 640 | 86u | 3ms | 1300 | 20u | 10ms |
| R=5M +V=3000 | 0 | 600u | 1ms | 2500 | 100u | 6ms |
| R=1M +V=3000 | 0 | 3.5m | 10us | 2500 | 0.5m | 50us |

turn on the transistors very effectively. Apparently the transistor does not operate well with currents below 500uA.

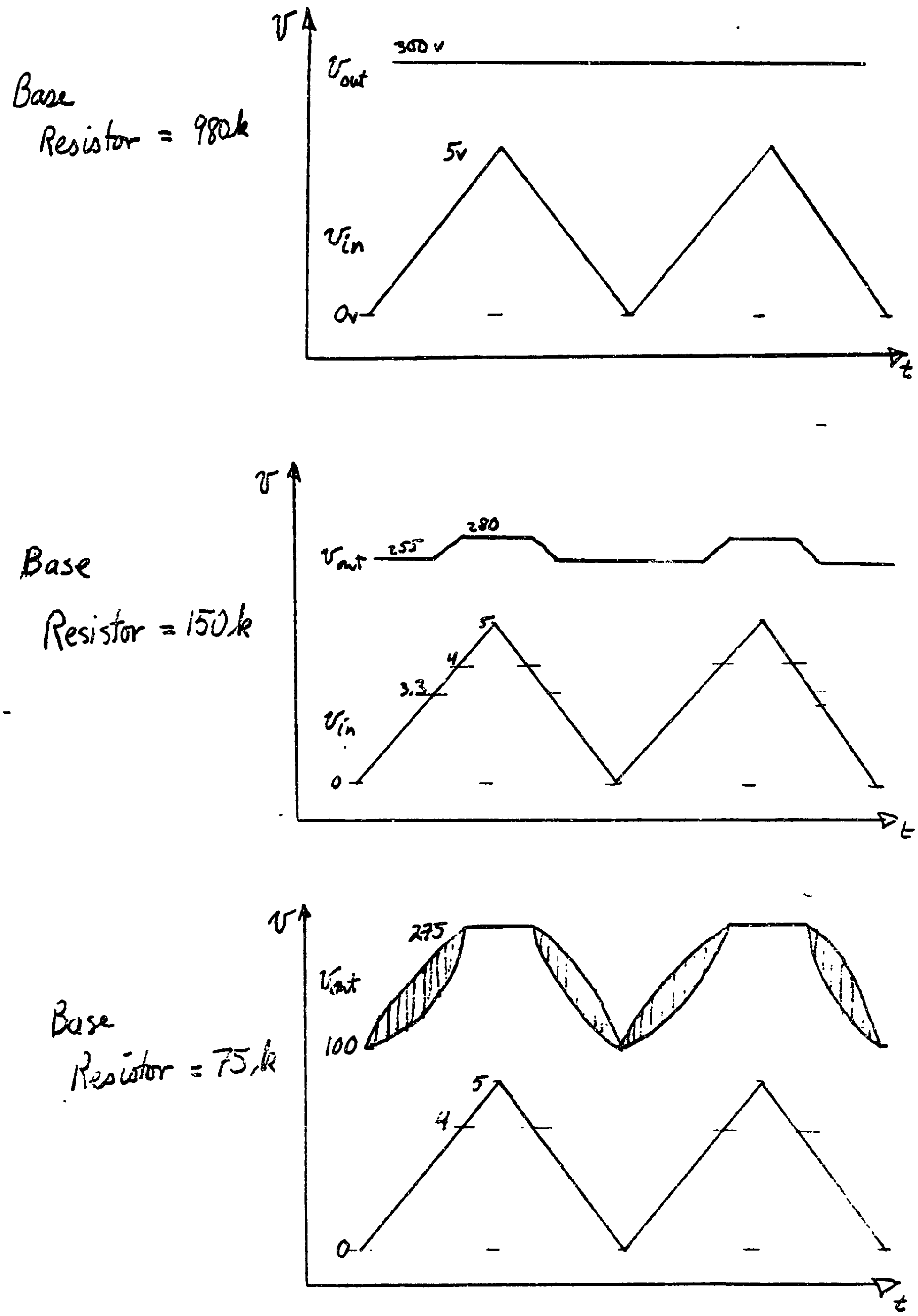
In addition to the above performance measures, a ramp input was used to estimate linearity. As expected, the first test did not even come close, the second was much better and the third was indistinquishable from the input.

3.3 X and Y Deflection Circuit Test

The X/Y deflection circuit was tested with two departures from the circuit drawn in Figure 9: a MPSA42 transistor was used instead of a 2N6517 and the resistor feeding the base junction was varied.

The original calculated value of the base resistor was 980k. Unfortunately, this value resulted in the output having a flat waveform for all input signals. When the base resistor value was decreased the output began to respond to input signals. Three iterations of this process are depicted in Figure 15.

The final value of the base resistor is puzzling. The MPSA42 is rated for a current gain of 40, so in order to draw down the expected current through the 500k and 170k resistors of 580uA, a base current of 15uA was predicted, yielding the initial base resistor value mentioned above. The actual working value of 75k implies that the base current is around 170uA. Apparently the transistor is having a hard time exhibiting an appreciable gain with this circuit. Its gain here is about 3.5.




Results of X/Y Deflection Circuit Test

Figure 15

In the unsaturated region of operation, an oscillation of about 100v (depending on the input voltage) bodes ill for this circuit. With a 2 volt input, the output oscillated between 140 and 230 volts with a period of 10us, resembling a right-skewed triangle function. Apparently, an AC ripple in the source current is being magnified and fed back to the transistor. After considering the results of the next section it is theorized that the lab power supply used may have an internal oscillator operating at 100kHz.

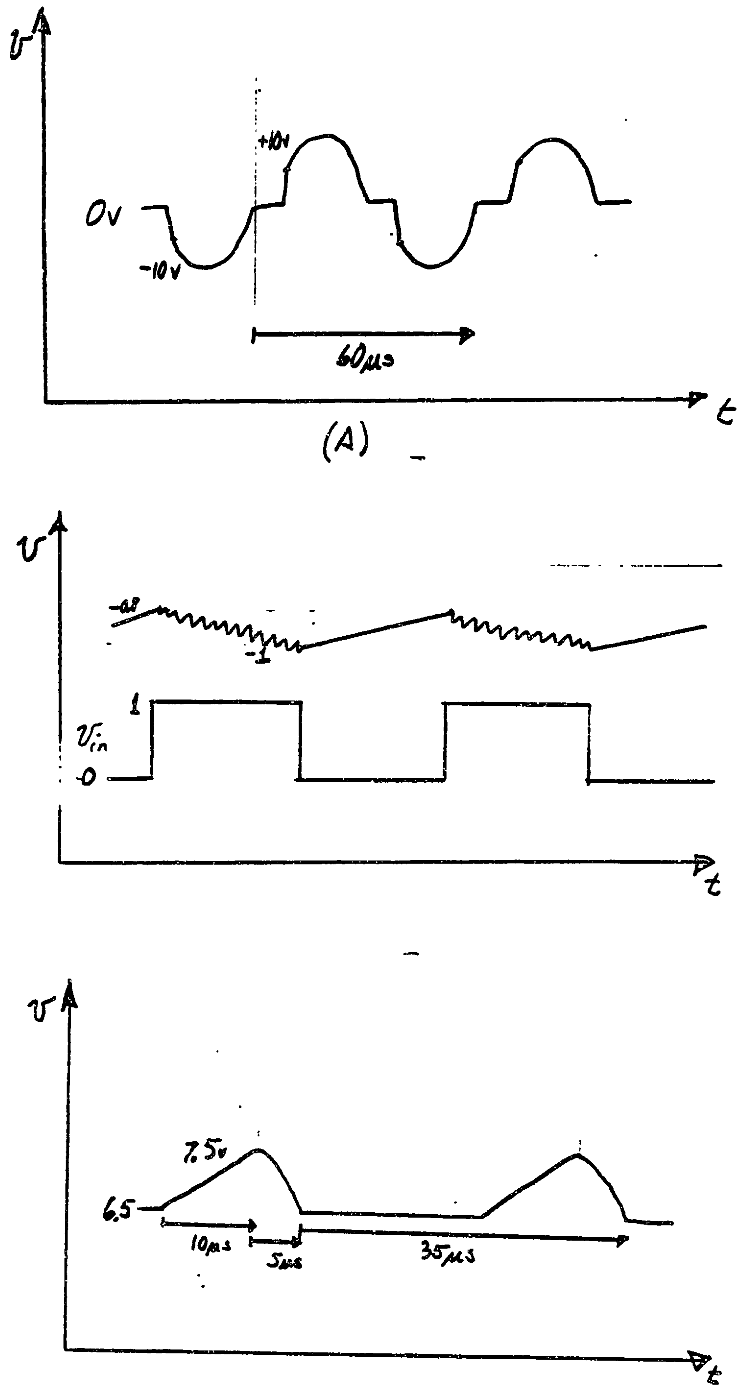
3.4 MCP Circuit Test

The MCP control circuit was dogged by oscillations in the current-sensing resistor being fed back and amplified. The circuit of Figure 10 (A) was tested first with a C-30 as the power supply and a 7.8M load resistor. Since current is being drawn by the supply through the resistor from ground, its voltage measurements are negative; they are inverted and fed back to the driving op-amp.

The actual output of this op-amp is pictured in Figure 16 (A). The 60us period is significant; it corresponds to a frequency of 16.67 kHz, which is the exact frequency of the internal oscillator the C-30 uses in transforming the input voltage to the output voltage. At first it was thought that this might be an induced effect due to stray fields, but this possibility was diminished when the supply was encased in a metal box without changing the nature of the oscillation.

An attempt was made to damp out the oscillations by paralleling the current-sensing resistor with a capacitor of 0.055uF. This did reduce the magnitude of the oscillations at the feedback input somewhat (see Figure 16 (A1); however, it also made for poor step response. Of course, where there was none before, any improvement looks good.

The circuit of Figure 10 (B) also produced an oscillation at the output of the driving op-amp; it is pictured in Figure 16 (B).




Results of MCP circuit test

Figure 16

# Chapter 4

# Discussion of Problems, Tradeoffs and Economics

## 4.1 Problems

The oscillations in the MCP control circuit and the X/Y deflection circuits are most likely caused by AC ripple in the power supplies. If this AC component is subtracted, the circuits should perform as expected. An attempt was made in the MCP circuit test to smooth the voltage being read into the feedback. A better place for this might be just before the comparison with the input.

The digital section also presented the problem of the specific destination encodings. This problem is not insurmountable; once the encodings are settled upon it is a simple job to determine which line will enable which buffer/DAC combination. The 273s and DACs may be wired exactly as the Analog Outputs that DASMIC uses.

A specific limitation on the MCP current was not addressed.

## 4.2 Tradeoffs

Simplicity was the order of the day in this design. A more predictable, better specified design could be created if the desired outputs were on tighter ranges. Circuits were designed to use the cheapest power supplies possible commensurate with the performance requirements. More expensive supplies would give wider ranges; of course, resistor values would have to be recalculated in this case. The grid and crystal circuits could have a third BU205 added to the transistor chain; this would allow voltages approaching 4.5kv but more current may be required.

4.3 Economics

Table 4 presents a summary of the principal cost parameter of this design: power supplies. The filament current source was left out of the summary; it is already available in the lab. Standard ±15 volt and +5volt supplies are needed for the op-amps and the digital section. There were nine op-amps used in the design. A +12 volt source will be needed to power the Venus supplies (with an output current of 2A), and if the WRM3 is used, a separate 28 volt supply will be required. From the cost column, it is obvious why the Venus supplies were used so much.

TABLE 4

| Use | Type | Current Required | Cost |
|---|---|---|---|
| main loop | C-30 | 200mA | $ 125 |
| control grid | C2T | 100mA | 99 |
| focus | C8T | 200mA | 115 |
| bias/X and Y | C2T | 200mA | 99 |
| MCP | C-15 | 200mA | 99 |
| grid | 2xC-15 | 400mA | 198 |
| crystal | WRM3(P)10KD | ? | 515 |
| | C-15 | 120mA | 99 |
| | | 1.42A | $1349 |

## Chapter 5

## Conclusion

This thesis was worthwhile in two respects. First, I practiced a great deal of the concepts covered in the undergraduate electrical engineering program. And secondly, I became familiar with the operations of an electron gun and an MSLM. I hope that this thesis will contribute to the research effort to better use MSLM technology.

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