MSUCL-43

Computer Compatible Servo System for Cyclotron RF

P. Sigg

CYCLOTRON LABORATORY
MICHIGAN STATE UNIVERSITY

*SUPPORTED BY THE U.S. NATIONAL SCIENCE FOUNDATION

Computer Compatible Servo System for Cyclotron RF

P. Sigg

Cyclotron Laboratory, Michigan State University
East Lansing, Michigan 48823

ABSTRACT

A new servo control system, which allows computer as well as manual setup of the RF-system of the MSU-Cyclotron has been built and tested. It features automatic switching to phase detectors when the desired positions are reached in order to fine-tune the system if the RF-drive goes on.

---

*Work supported by the National Science Foundation.

I. INTRODUCTION

The new RF-servo system allows simultaneous setup either from thumbweel switches on the console of the cyclotron or from a computer.

Since the system contains seven tunable elements, this saves a considerable amount of time, since the old system required the operator to set each element to the desired position by a manual control switch. The operator no longer is required to pay any attention to the tuning process, though it still could be done manually if so desired. Separate two-speed clocks for each servo allow a high setting speed and a matched low speed for tuning from phase detectors or position indicators. The RF-system has been described previously.[1,2]

The entire design of the control electronics is modular; the basic units are printed circuit boards which can be used in all servo loops. Since all threshold and speed adjustments are on front panels, modules of the same type can be exchanged without requiring recalibration. The basic units (PC boards) are compatible with commerically available modules,[3] which allows one to use some XDS TL-series modules and directly interface into our XDS Sigma-7 Computer. Integrated circuits in dual in-line packages are used throughout,[4] diode-transistor micrologic (DTμL) for logical functions and microamplifiers (μA) for operational amplifiers and fast discriminators. For analog and signal switching, DTμL compatbile miniature relays are used.

II. DESCRIPTION OF THE SYSTEM

Figure 1 shows the seven different servo control loops. Some loops are in the same circuit, hence not operating independently. The DC-stepping motors are controlled the following way:

<u>Automatic setup</u> (computer setup)

The program for setup checks whether the RF-voltage is off and the servos operable, then five positions (12 bits BCD) are transferred into Digital-to-Analog converters and strobed. Input buffers allow parallel setting and when the devices have reached their appropriate positions, the system automatically switches over to phase detectors for fine tuning and flags this to the computer as well as to the operator.

<u>Manual setup</u>

Thumbweel switches on the main console allow setting of three decimal digits according to a run sheet. Pushing a "manual set" button then sets up the same way as the automatic setup, however, this does not require an operable computer.

Furthermore, using a manual control switch which overrides all other signals (except limits) one can position the devices by hand and read their positions on a Digital Voltmeter (DVM).

The control panel of the servos on the main console of the cyclotron is shown in Fig. 2. All essential functions can be controlled by the experimenter, no "cyclotron operator" is required.

The secondary panel, together-with the servo logic panel is shown in Fig. 3. It displays phase-detector outputs and status information. It allows some more operating refinements as well as adjustments by qualified staff.

III. DESCRIPTION OF A TYPICAL SERVO LOOP

Figure 4 shows a block diagram of a typical servo loop. As mentioned above, setting can be done three different ways:

1. Computer
2. Thumbweel switches on console
3. Manual direction control switch on console.

The method to implement this is described now.

The manually controlable multiplexer switches inputs between computer and thumbweel switch. The output of the multiplexer is fed into a Digital-to-Analog converter (DAC) which has an output accuracy of $\pm 0.01\%$ F.S., ± 1 LSB. Strobing (transfer of input register into output) of the DAC can only be done while RF-voltage is off. This prevents erroneous detuning while the cyclotron is operating.

The ouput of the DAC is the reference voltage in an analog feedback loop and is compared with a voltage proportional to the position of the tuning element.

An absolute value of the amplified error signal is then used to determine "how far away" the real position is from the desired position and, if sufficiently small, switches the clock to low speed for fine tuning. An even smaller threshold is used to determine when the error signal is approximately zero and the input source control then switches on the phase detector and indicates this to the computer.

As soon as the computer has the confirmation that all servos are properly set, it can initiate the RF-voltage control program which turns on the RF drive and brings the RF-voltage up to the desired value.

Two voltage comparators then are used to determine the required sense of rotation of the stepping motor (Zero Detector). The subsequent encoder and control unit transforms this information into a pulse sequence suitable for the stepping motors. The encoder and control unit also contains lamp drivers for motion and limit indication lights on the main console. Furthermore, there are move and limit indication outputs available, as well as compatible inputs. With these, one system can be interconnected in a way as to inhibit another one while it is tuning. Or, there occurs another case: if one servo (with a narrow tuning range) reaches a limit it starts another servo (with a wide tuning range) to move such that the first servo gets back within it's tuning range. (Coarse and fine tuning, for example.)

This shows why adjustable, independent tuning speeds are essential, because the two tuning speeds of two servo loops have to be adjusted such that the system always stays tuned during such a process.

IV. DESCRIPTION OF INDIVIDUAL MODULES

1. Dual input multiplexer

XDS T-series model BT-33 is used and the selection of the input is done by a switch on the main console ("Computer-Manual Positioning Mode"). Status of this switch is monitored by the computer.

2. Digitial to Analog Converter (DAC)

The DAC is a minimodular device made by Varadyne which has a 12 bit input storage register and an output range of 0 to +10 V with 2 μs setting time. A strobe input which enables transfer of contents of the input register to the analog output can be applied either manually (if thumbweel switches are used) or by the computer (automatic setup). The strobe input is gated in such a way as to inhibit setting of the output to a different value if the RF-drive is on.

3. Setting Amplifier and Level Detector

A simplified schematic of the setting amplifier and level detector is shown in Fig. 5.

It contains a summing amplifier to create the error signal $E=(V_{position}-V_{DAC})$ which is used in the zero detector (see following section). An absolute value amplifier ($|V_{position}-V_{DAC}|=|e|$) is then used in connection with two fast discriminators (Fairchild μA710) to determine:

a) the level at which the clock speed changes and

b) the switching point for the phase detector.

These levels can be adjusted by potentiometers on the front panel. Both outputs are gated with "RF-on" signals such that the clock speed cannot go high and the phase detector cannot be disconnected while the RF drive is on.

4. Zero Detector

As shown in Fig. 6, the error signal from the setting amplifier is then fed through a (miniature) relay controlled by the discriminator of section b) above. Either phase detector or error signal then are fed into an amplifier which is output voltage-limited to prevent saturation. This amplifer drives two fast discriminators, one for positive and one for negative level for sense of rotation detection. The dead band during which no rotation occurs is also adjustable.

A second relay, controlled by a "mode" switch on the main console, allows one to disconnect both inputs and grounds the amplifier input. This is used for manual operation, calibration and trouble shooting. (The status of this relay is also monitored by the computer.)

The band width of the feedback amplifier is about 5 kHz, which is far higher than the motor speed, to allow fast step response and get stable operation of the loop.

5. Encoder and Control

As shown in Fig. 7, the encoder and control unit consists of two clock-controlled J-K flip-flops, of which two of the four outputs are inversed or noninversed, corresponding to the two senses of rotation of the stepping motor. The clock input is gated and clock pulses are applied to the flip-flops only if a "clockwise" or "counterclockwise" signal is present. Three different motion control input pairs are provided, with different override capabilities.

The manual control switch has the highest priority. it overrides everything but the limits.

Auxiliary "move" can be used in connection with a narrow range tuning element in the same circuit.

The phase detector input (lowest priority).

Furthermore an inhibit input is provided, which affects each one but the manual input. Limit switch inputs interrupt motion only into direction of limit so that the servo can get itself off the limit all the time. Should this limit fail, there is a second (emergency) switch at each end of the tuning range which, if tripped, interrupts the power to the motor. The status of the limit switches is also fed into the computer.

6. Logic Output Amplifiers

This module contains four ditial amplifiers, each capable of switching .70 A @ 20V. This suffices for smaller motors, up to Slo-Syn (Superior electric) SS150 with a torque of 150 oz. in. without gears.

For larger motors an additional stage is needed. This requires larger heat sinks and different transistors and therefore cannot be made in the same modular design.

7. Two-speed Clock

Speeds are adjustable within the following ranges:

(Cycle Length)

Clock type 1	low speed:	t=40ms...500 ms
	high speed:	t= 8ms... 80 ms
Clock type 2	low speed:	t=15ms...240 ms
	high speed:	t= 3ms... 70 ms

The two clock types are identical except for two additional capacitors in type 1. The clock is a conventional multivibrator using low drift components and an output buffer stage.

Auxiliary Modules

8. Auxiliary Panel Control

This unit connects a fine and coarse tuning servo in the same circuit such that the fine tuning element always stays within its range. This arrangement requires the tuning speed of the coarse tuning servo to be slower than the speed of the fine tuning servo in order to keep the whole circuit tuned all the time. The fine tuning servo requires a center position sensor to indicate to the auxiliary panel control when to stop coarse tuning. Bistable flip-flops are used to achieve this function.

9. Special Zero-Detector

This Zero Detector is used to achieve the mode indicator lights on the main console. (0°, 180° mode of the dees) The output is also fed into the computer.

10. RF-Mode Control

This unit serves to reverse the sense of tuning of the one dee if 0° instead of 180° RF Mode is used, it's status is fed into the computer.

11. Interface

Cable Receivers:

XDS T-series module AT10 with 14 independent receivers is used.

Cable Drivers:

XDS T-series module AT12 with 14 independent drivers is used, each driver is capable of driving 200 ft. of 33Ω coaxial cable.

V. SUMMARY

The system has been operating well for over two months after installation and debugging. The author appreciates the work done by Miss S. Mills and Mr. A. Finlayson in building up a facility to make printed circuit boards and then making the boards. Thanks also to Mr. F. Potts for wiring the system as well as helping to debug it.

REFERENCES

1. W.P. Johnson, CERN-Report 63-19 79-285(1963).
2. W.P. Johnson, P. SIgg, IEEE Transactions and Nuclear Science, Vol. NS-16 #3(1969).
3. Xerox Data Systems, El Segundo, California XDS T-Series Integrated Circuit Logic Modules.
4. Fairchild Semiconductor Diode-Transistor Micro Logic (DTμL) Series and μA series.

FIGURE CAPTIONS

Figure 1. Block Diagram of the RF-System

Figure 2: Main console, with the Servo-Control Panel on top.

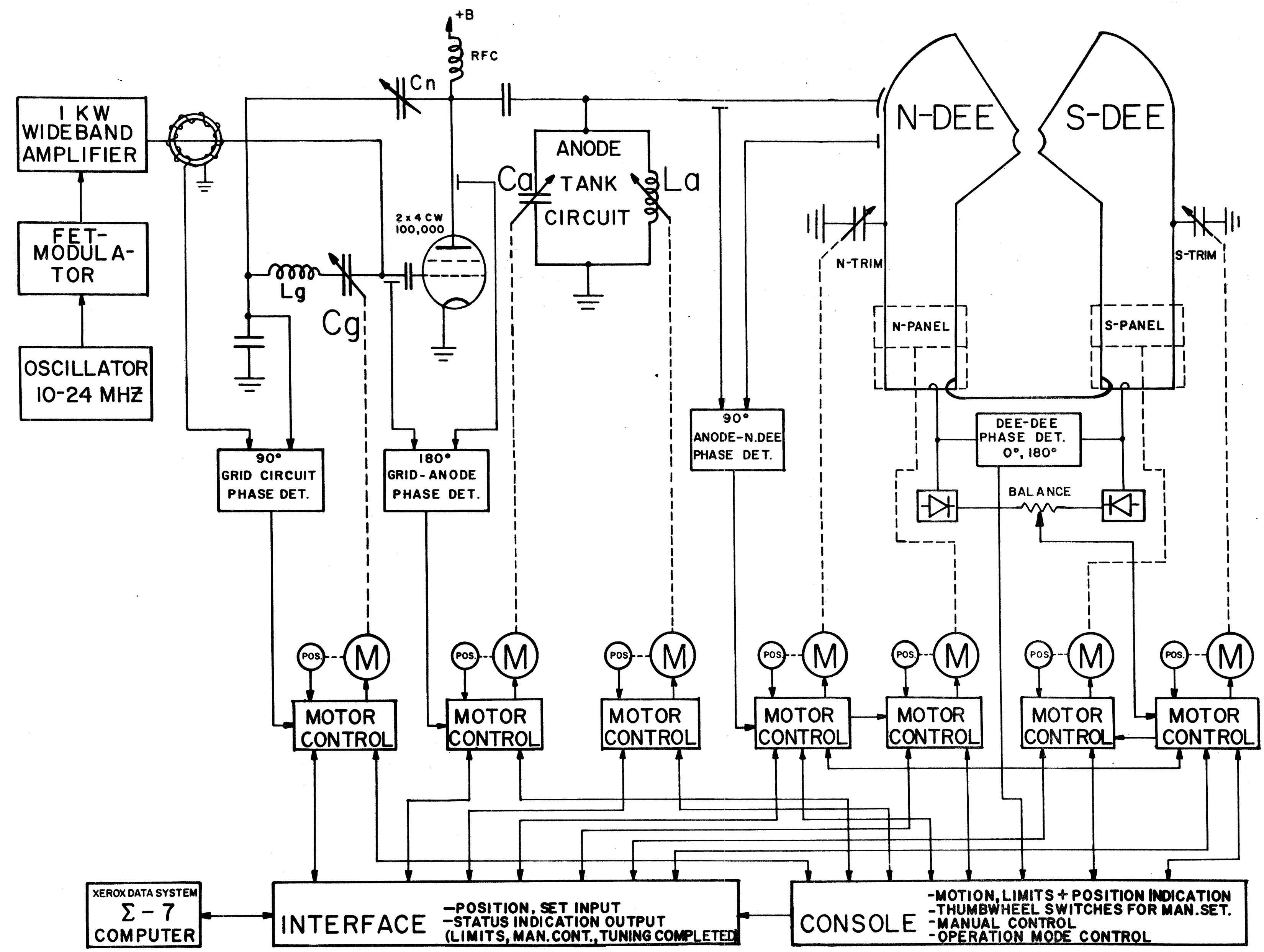
Figure 3: Secondary Panel with logic rack.

Figure 4: Block Diagram of typical servo loop.

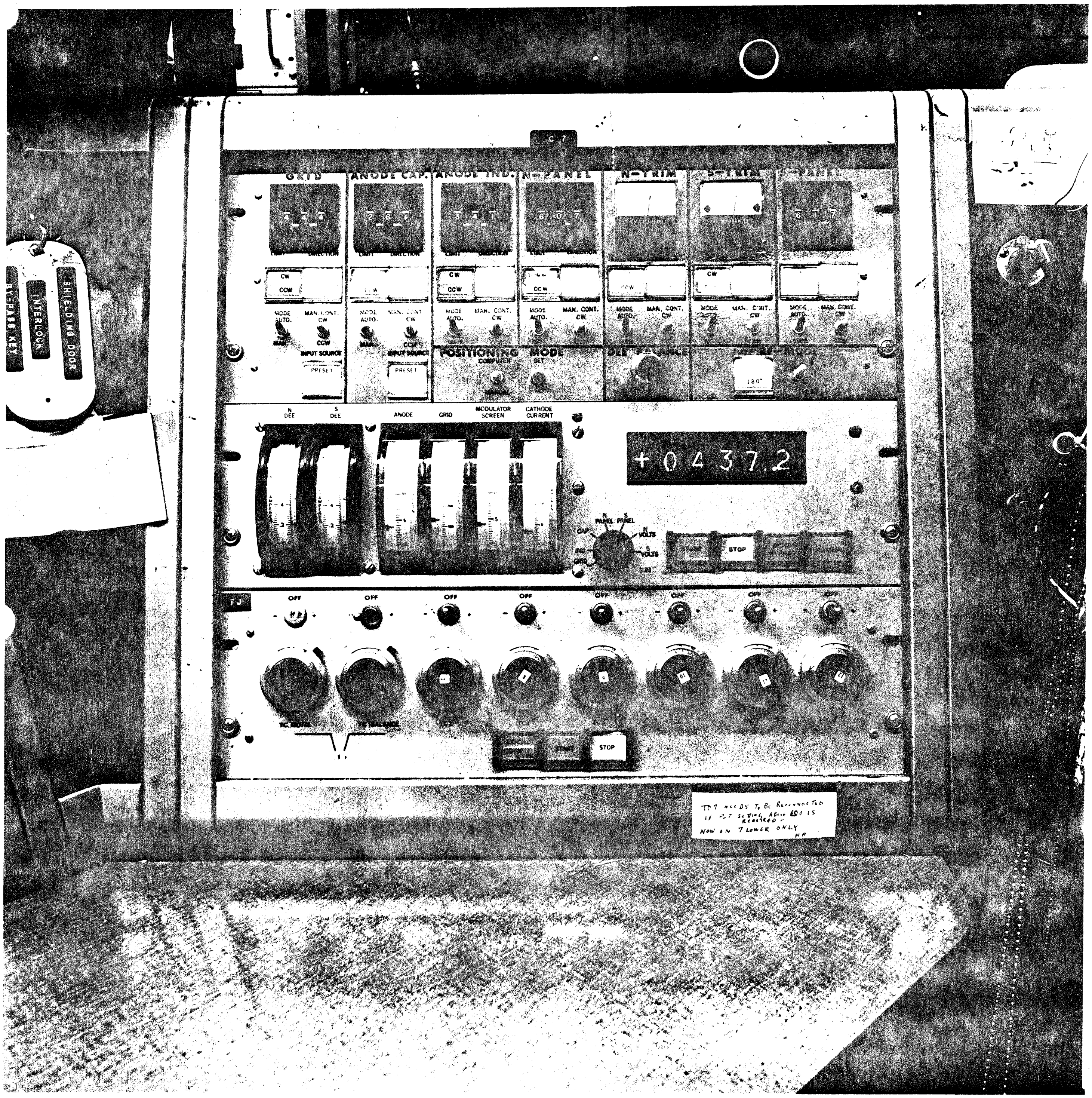
Figure 5: Setting Amplifier and Level Detectors, simplified schemat

Figure 6: Zero Detector, simplified schematic.

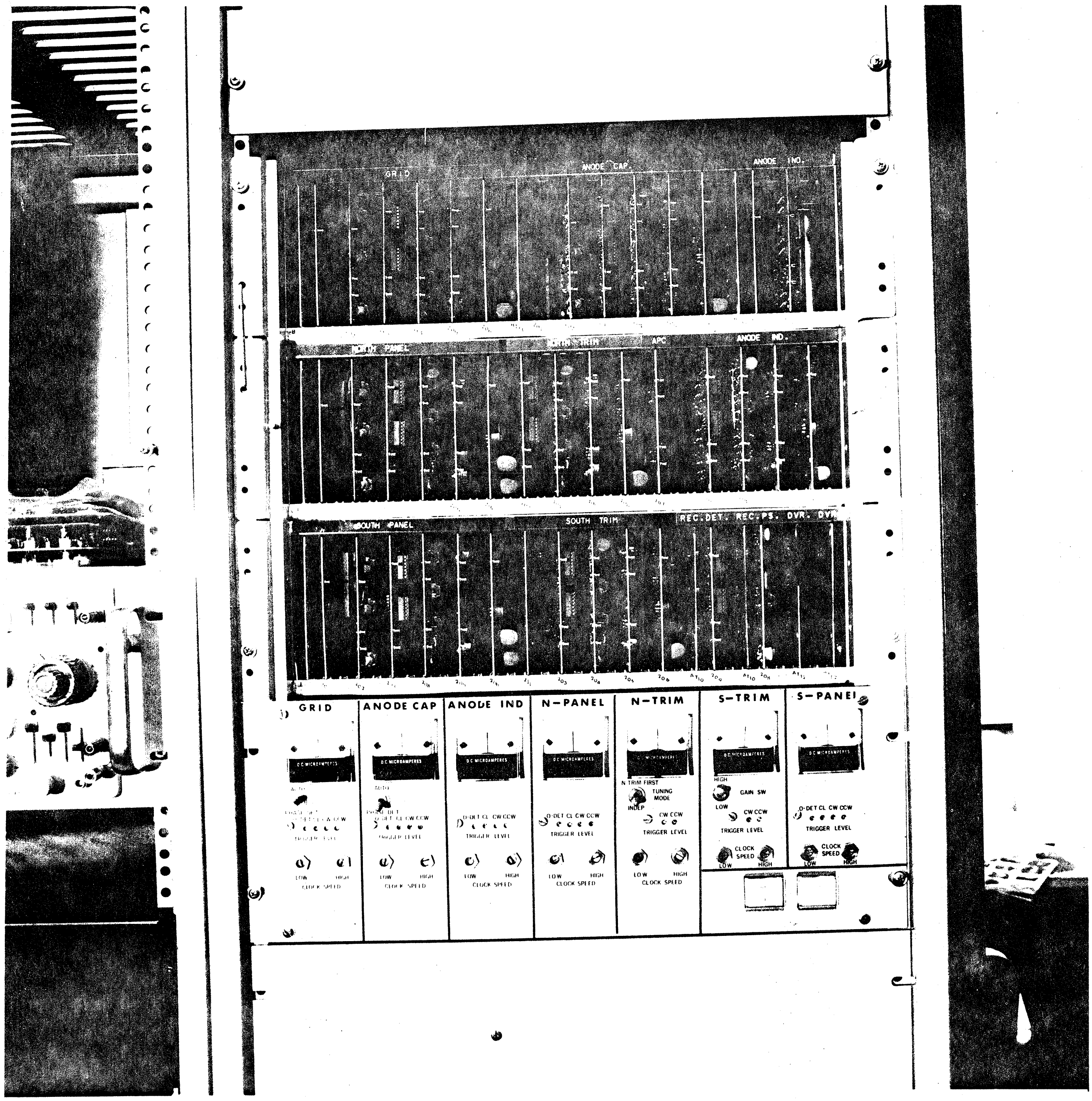
Figure 7: Schematic of the Encoder and Control Unit.



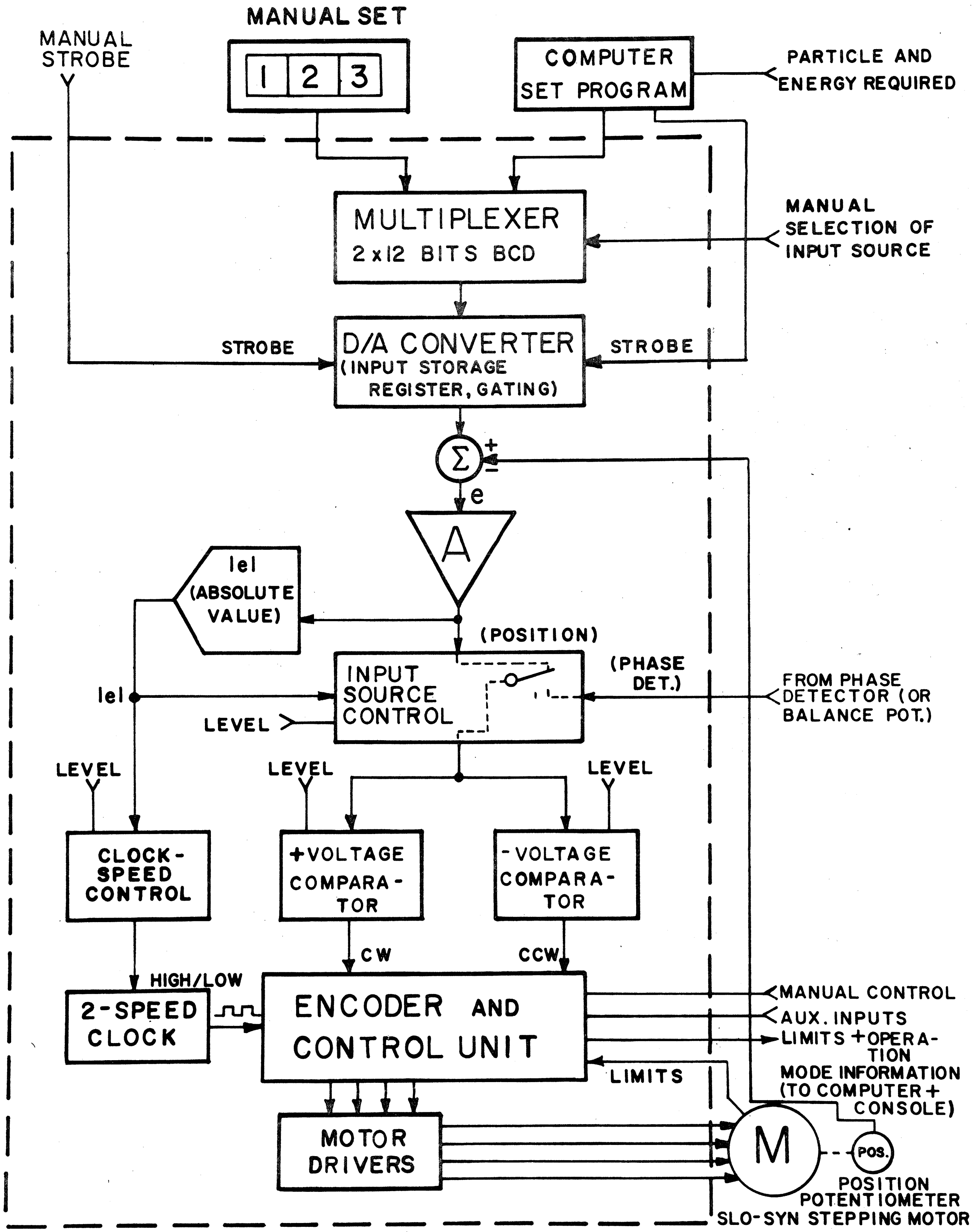
I KW WIDEBAND AMPLIFIER
FET-MODULATOR
OSCILLATOR 10-24 MHZ
+B
RFC
Cn
2x4CW 100,000
Lg
Cg
Ca
ANODE TANK CIRCUIT
La
90° GRID CIRCUIT PHASE DET.
180° GRID-ANODE PHASE DET.
90° ANODE-N.DEE PHASE DET.
N-DEE
S-DEE
N-TRIM
S-TRIM
N-PANEL
S-PANEL
DEE-DEE PHASE DET. 0°, 180°
BALANCE
POS.
M
MOTOR CONTROL
XEROX DATA SYSTEM Σ-7 COMPUTER
INTERFACE
-POSITION, SET INPUT
-STATUS INDICATION OUTPUT
(LIMITS, MAN.CONT., TUNING COMPLETED)
CONSOLE
-MOTION, LIMITS + POSITION INDICATION
-THUMBWHEEL SWITCHES FOR MAN.SET.
-MANUAL CONTROL
-OPERATION MODE CONTROL

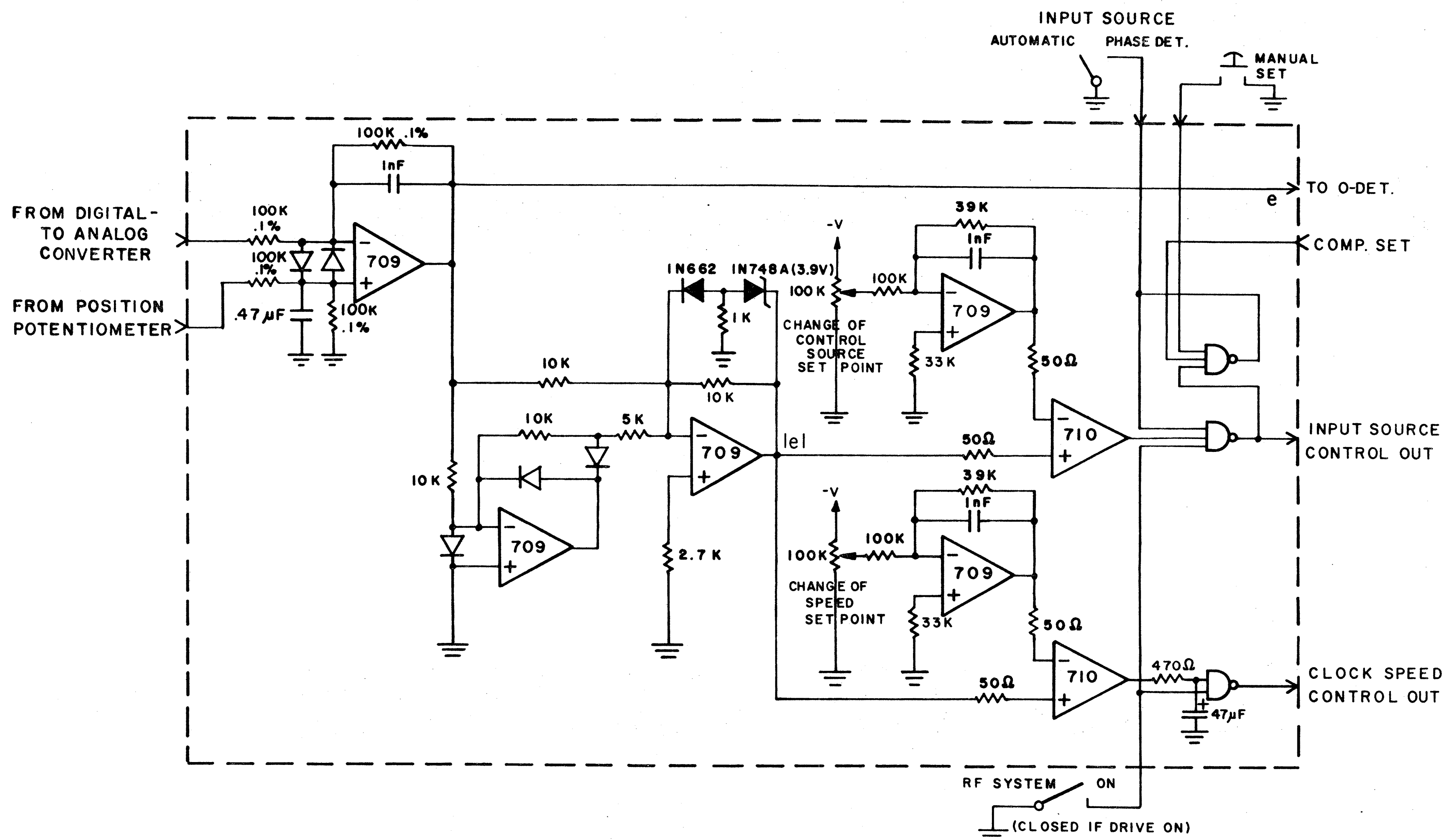


C 7
GRID
ANODE CAP.
ANODE IND.
LIMIT
DIRECTION
CW
CCW
MODE
AUTO.
MAN.
MAN. CONT.
CW
CCW
INPUT SOURCE
PRESET
POSITIONING MODE
COMPUTER
SET
DEE BALANCE
180°
SHIELDING DOOR
INTERLOCK
BY-PASS KEY
N DEE
S DEE
ANODE
GRID
MODULATOR SCREEN
CATHODE CURRENT
+0437.2
CAP.
N PANEL
S PANEL
N VOLTS
S VOLTS
STOP
OFF
START
STOP
TC7 NEEDS TO BE RECONNECTED IF POT SETTING ABOVE 600 IS REQUIRED.
NOW ON 7 LOWER ONLY
HR

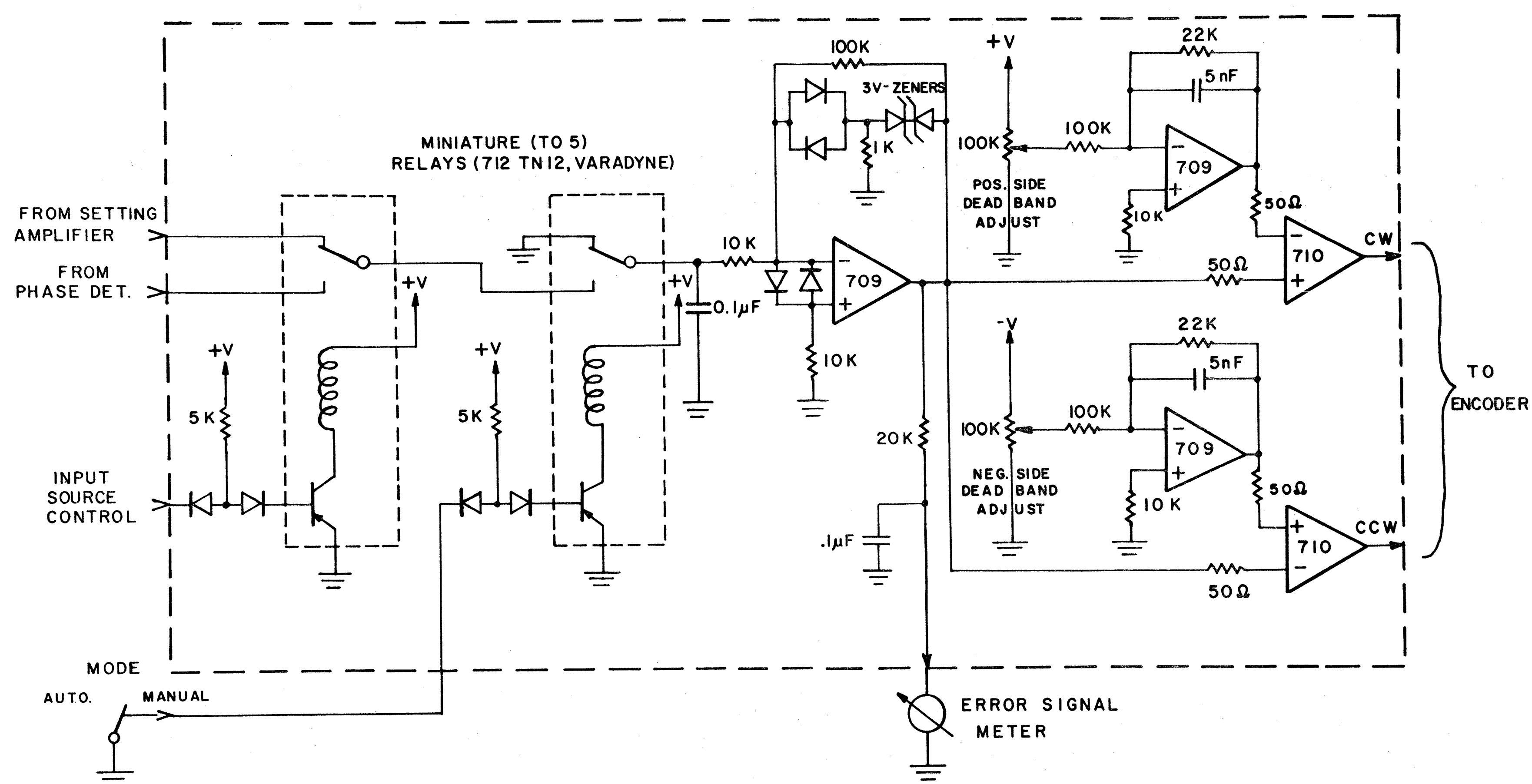


GRID
ANODE CAP.
ANODE IND.
SOUTH PANEL
SOUTH TRIM
REC. DET. REC. PS. DVR. DVR.
GRID
ANODE CAP
ANODE IND
N-PANEL
N-TRIM
S-TRIM
D-DET CL CW CCW
TRIGGER LEVEL
LOW
HIGH
CLOCK SPEED
N TRIM FIRST
TUNING MODE
INDEP
CW CCW
GAIN SW

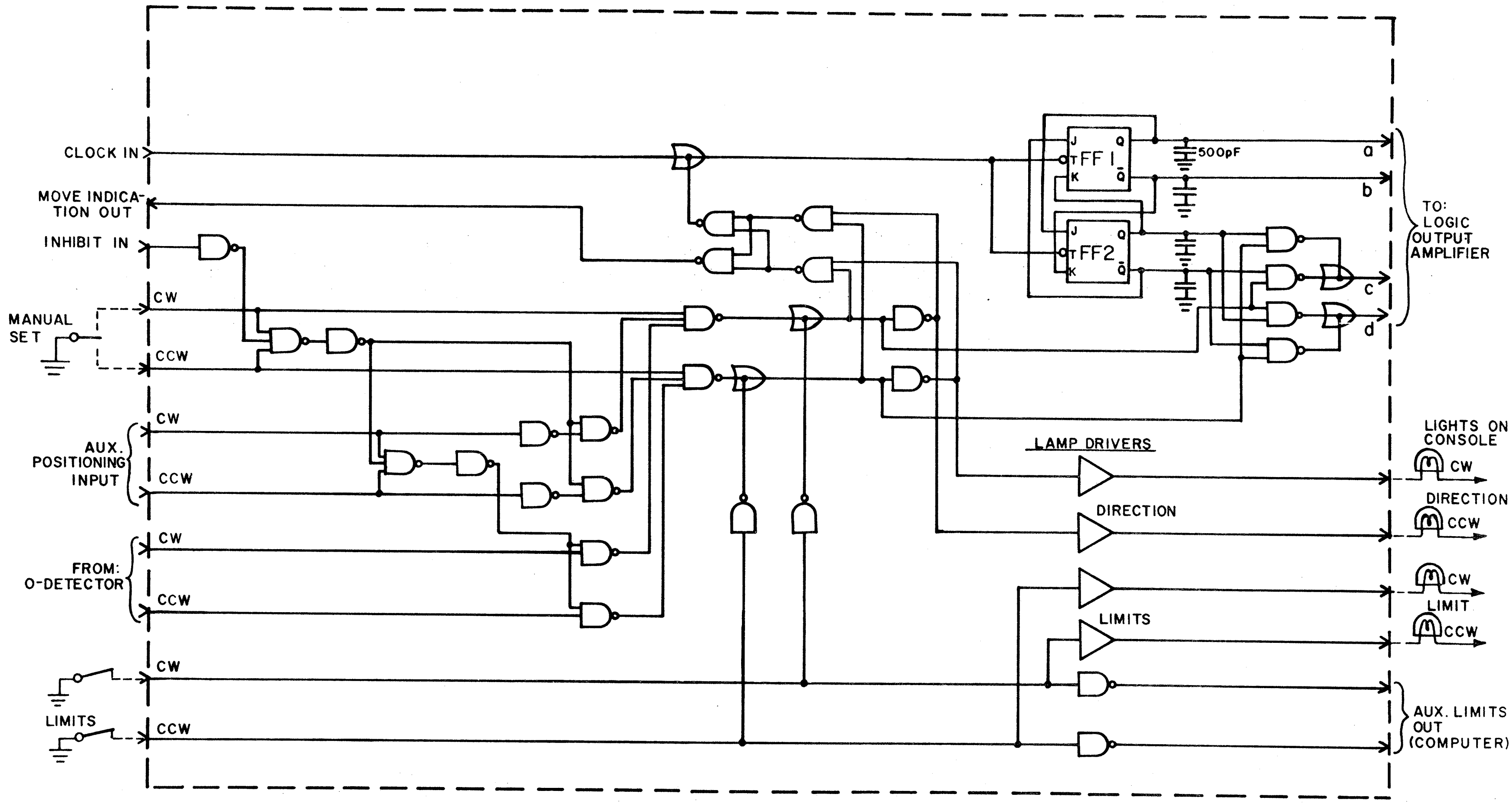

MANUAL SET
1 2 3
MANUAL STROBE
COMPUTER SET PROGRAM
PARTICLE AND ENERGY REQUIRED
MULTIPLEXER 2 x 12 BITS BCD
MANUAL SELECTION OF INPUT SOURCE
STROBE
D/A CONVERTER (INPUT STORAGE REGISTER, GATING)
STROBE
Σ
+
−
e
A
|e| (ABSOLUTE VALUE)
(POSITION)
(PHASE DET.)
|e|
INPUT SOURCE CONTROL
LEVEL
FROM PHASE DETECTOR (OR BALANCE POT.)
LEVEL
LEVEL
LEVEL
CLOCK-SPEED CONTROL
+VOLTAGE COMPARA-TOR
-VOLTAGE COMPARA-TOR
CW
CCW
HIGH/LOW
2-SPEED CLOCK
ENCODER AND CONTROL UNIT
MANUAL CONTROL
AUX. INPUTS
LIMITS + OPERA-TION MODE INFORMATION (TO COMPUTER + CONSOLE)
LIMITS
MOTOR DRIVERS
M
POS.
POSITION POTENTIOMETER
SLO-SYN STEPPING MOTOR



INPUT SOURCE
AUTOMATIC
PHASE DET.
MANUAL SET
100K .1%
InF
TO O-DET.
e
FROM DIGITAL-TO ANALOG CONVERTER
FROM POSITION POTENTIOMETER
100K .1%
100K .1%
709
.47μF
100K .1%
COMP. SET
39K
InF
-V
1N662
1N748A(3.9V)
100K
100K
709
CHANGE OF CONTROL SOURCE SET POINT
33K
50Ω
10K
10K
1K
10K
5K
709
|e|
50Ω
710
INPUT SOURCE CONTROL OUT
10K
709
2.7K
39K
InF
-V
100K
100K
709
CHANGE OF SPEED SET POINT
33K
50Ω
710
50Ω
470Ω
47μF
CLOCK SPEED CONTROL OUT
RF SYSTEM
ON
(CLOSED IF DRIVE ON)



FROM SETTING AMPLIFIER
FROM PHASE DET.
INPUT SOURCE CONTROL
MODE
AUTO.
MANUAL
MINIATURE (TO 5) RELAYS (712 TN12, VARADYNE)
+V
5K
10K
0.1μF
100K
3V-ZENERS
1K
709
20K
.1μF
ERROR SIGNAL METER
100K
POS. SIDE DEAD BAND ADJUST
NEG. SIDE DEAD BAND ADJUST
-V
22K
5nF
50Ω
710
CW
CCW
TO ENCODER



TRUTH TABLE

		t_1	t_2	t_3	t_4	t_1
CW	a	0	0	1	1	0
	b	1	1	0	0	1
	c	1	0	0	1	1
	d	0	1	1	0	0
CCW	a	0	0	1	1	0
	b	1	1	0	0	1
	c	0	1	1	0	0
	d	1	0	0	1	1