R E P O R T   R E S U M E S

ED 015 680   24   EM 005 976

GRAPHIC INPUT TABLETS FOR PROGRAMMED INSTRUCTION.

BY- BOOKER, C.A., JR.   AND OTHERS
PITTSBURGH UNIV., PA., LEARNING RES. AND DEV. CTR.

REPORT NUMBER TR-6   PUB DATE   AUG 66
REPORT NUMBER BR-5-0253-TR-6
CONTRACT OEC-3-16-043
EDRS PRICE   MF-$0.25   HC-$1.00   23P.

DESCRIPTORS- *PROGRAMED INSTRUCTION, *TEACHING MACHINES, *COMPUTER ASSISTED INSTRUCTION, *ELECTRONIC EQUIPMENT, *EDUCATIONAL EQUIPMENT, RAND TABLET

TO FACILITATE STUDENT-COMPUTER COMMUNICATION IN PROGRAMED INSTRUCTION, A MODIFICATION OF THE RAND TABLET, WHICH CONVERTS POSITION INFORMATION INTO ELECTRICAL SIGNALS, IS PROPOSED. MANUFACTURE OF THE DEVICE WOULD BE MORE ECONOMICAL, AND THE ELECTRONICS PACKAGE, REDESIGNED WITH INTEGRATED CIRCUITS, WOULD BE SMALLER AND MORE FLEXIBLE. MODIFICATION OF THE DEVICE'S SCREEN WILL BE STUDIED FURTHER. (LH)

UNIVERSITY OF PITTSBURGH - LEARNING R & D CENTER

TECHNICAL REPORT 6

GRAPHIC INPUT TABLETS FOR PROGRAMMED INSTRUCTION

C.A. BOOKER, B.R. DOW AND J.E. LAMBRIGHT

GRAPHIC INPUT TABLETS FOR PROGRAMMED INSTRUCTION

C. R. Booker, Jr.

B. R. Dow

J. E. Lambright

of the

Westinghouse Research Laboratories

in conjunction with the

Learning Research and Development Center

University of Pittsburgh

August, 1966

The research reported herein was performed pursuant to Contract OE-3-16-043 with the Office of Education, U. S. Department of Health, Education, and Welfare. Contractors undertaking such research under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the research. Points of view or opinions stated do not, therefore necessarily represent official Office of Education policy or position.

GRAPHIC INPUT TABLETS FOR PROGRAMMED INSTRUCTION

C. A. Booker, Jr., B. R. Dow, and J. E. Lamright

Abstract

Problems of developing a Rand Tablet, modified for more economic manufacture, have been investigated. The electronics package is extensively redesigned with integrated circuits, to give smaller size and greater flexibility. The screen, or pad, has been studied for simplified manufacturing processes; but none of the proposals advanced have been extensively investigated. A simpler graphic input system has been tested and is to be further investigated.

Introduction

A major obstacle to effective computer utilization in any system is the inadequacy of the available man-machine communication devices.[1,2] The problem is accentuated in the design of computer controlled instructional systems, where multiple student-computer interfaces must accommodate two-way communication. It is preferable that a minimum of student training should be required to secure effective use of the interface device. This extends the usefulness of instructional systems for teaching children or the mentally retarded. As a multiplicity of student stations is generally required, two rather incompatible requirements are imposed, necessitating a compromise between required computer time and cost per station. The student station should exchange concise binary information with the computer, to minimize demands on computer time. This requirement tends to increase the cost per station, whereas the large number of stations restricts the permissible cost per station.

One device which might be made to satisfy the economic and technical requirements for instructional systems is the Rand Tablet. The Rand Tablet is an interface device which converts two dimensional position information into binary coded electrical signals. The position is a point on the active surface of a tablet about 10" square. The output consists of two ten-bit binary numbers representing the X and Y coordinates of a pickup

stylus position on the tablet. The Rand Tablet was developed by the Rand Corporation of Santa Monica, California, under a contract with the Advanced Research Projects Agency of the U. S. government.[3]

The investigators at Rand Corporation were interested in demonstrating feasibility and did not develop particularly economic manufacturing techniques.

The Instructional Technology Directorate at the Westinghouse Research and Development Center has contracted with the University of Pittsburgh to provide student station equipment for an operational computer controlled learning system. As part of this government sponsored contract, two Rand Tablet type devices must be provided to the University of Pittsburgh by Westinghouse. Since the work for the University of Pittsburgh is government sponsored, access to the construction details of the Rand Tablet as embodied by the Rand Corporation has been provided. The Instructional Technology Directorate has authorized the Information and Control Circuitry Department of the Electrical Systems and Power Conditioning Directorate to supply the Rand Tablet type devices for fulfillment of the University of Pittsburgh contract.

While examining the original embodiment of the Rand Tablets, several worthwhile improvements have been proposed. The Rand Tablet consists of two interconnected units: the tablet, or screen from which the position information is derived, and the control electronics. Since the two units present quite different design problems, they are discussed separately below.

Description of Rand Equipment

Rand screen. The screen is a transparent film, with printed circuit wiring on both sides, which accomplishes both signal routing and encoding. The principle employed for encoding is illustrated in Figure 1, reproduced from reference 3. This illustrates the wiring for a three-bit system. The drive signals are applied sequentially to the encoding pads, e.g., P_1, P_2, P_3, the shape of which causes a unique serial signal to be capacitively coupled to the information lines on the opposite side, e.g., Y_1, Y_2,...Y_8.

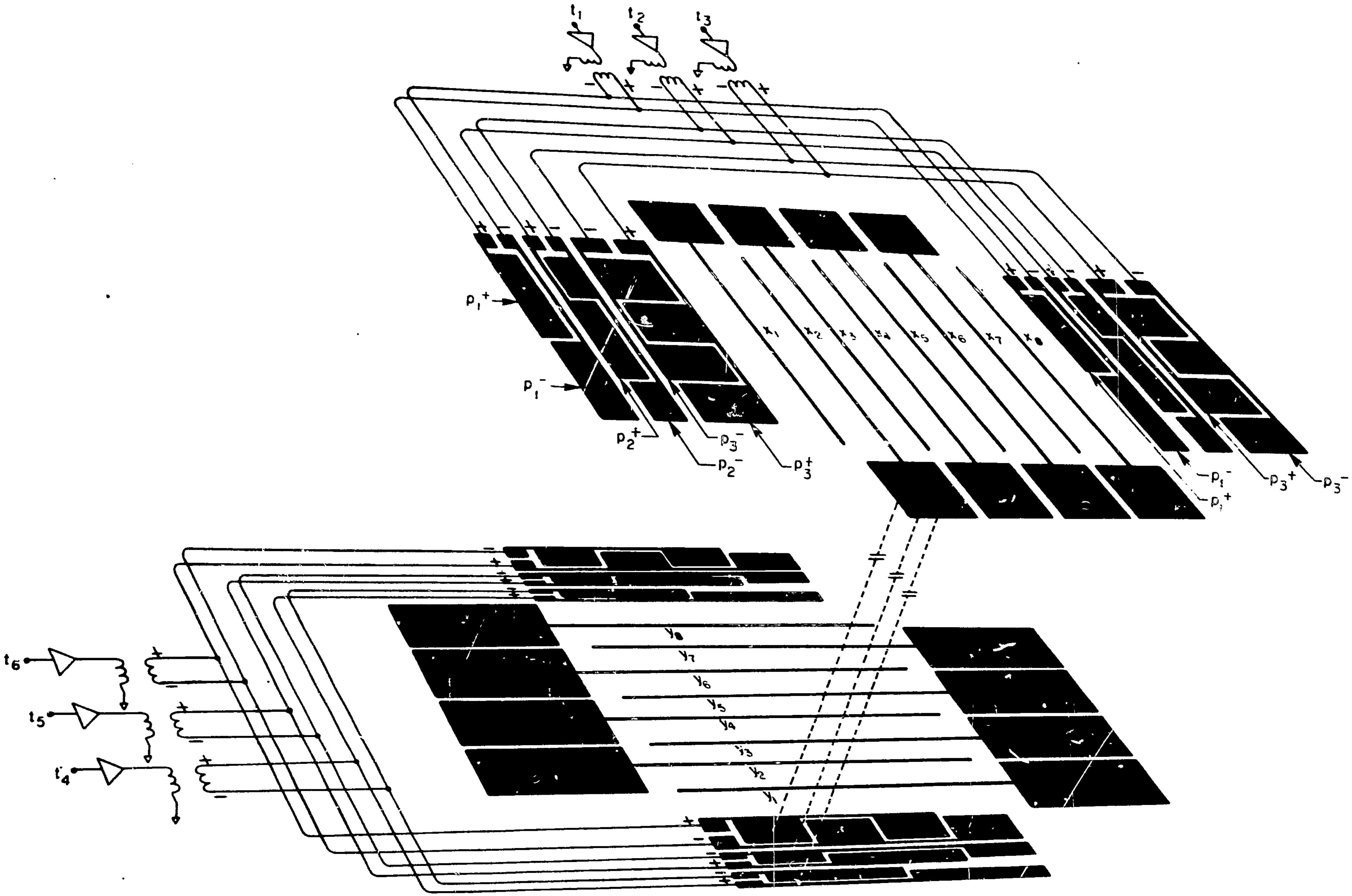


Fig. 1 —Double-sided printed-circuit layout for 8x8 system

The actual system employs this basic approach extended to ten bits. The signal lines cover an area of 10.24 by 10.24 inches, on which the operator positions a stylus. An insulating film covers the screen so that both X and Y gray code coordinates are capacitively coupled from pad to stylus. The stylus contains a high impedance amplifier and a ready/standby switch. The X and Y encoding pads are driven sequentially, so the stylus detects a twenty-bit signal consisting of the two gray coded coordinates. Gray code is employed to facilitate electronic error checking. The pulse rate is so rapid that the operator normally cannot move the stylus fast enough to traverse more than one line in a sample period. Thus only one bit of the gray code can change between consecutive samples. This criterion is continuously monitored by the electronics for error detection. The surface is protected by a transparent film and a layer of wax.

Connections to the bottom side encoder pads are made by destroying the film over the pad with a drop of acid, flushing with a basic solution and then distilled water, and soldering to the copper film. The acid is preheated to accelerate its action on the film. All soldered connections are made with 63/37 solder and liquid soldering flux.

After all wires are attached, the finished pad and backing plate are inserted in the aluminum alloy cover which protects the encoding pads, but leaves the active surface exposed for use.

Discussions with Photo-Etch management revealed that they have invested considerable time and money in the process and are interested in future work. They were prepared to sell screens with customer source inspection as of March 1965. They are also interested in fabricating the entire pad, if Westinghouse would contract for acceptance of a specified number of pads. The present arrangements with Rand permit license-free utilization of the Rand Tablet only for government supported projects. The question of licensing arrangements would have to be considered before indulging in unrestricted use.

Rand electronics. The functional requirements of the Rand circuitry and the germanium-transistor discrete-component embodiment developed by Rand Corporation is described below. Proposed improved circuitry, using integrated circuits, is described in section III.

The electronic portion of the Rand Tablet provides:

1. Pulses to drive the screen
2. Sequencing for the pulses
3. Logic to convert the gray coded pulses from the stylus to serial binary coded signals
4. Shift registers to store the serial binary information
5. Registers to store the position information for transfer to a computer or display device
6. Logic to perform automatic error checking of the tablet signals
7. Automatic level control to balance pickup sense circuitry
8. Stylus high input impedance sense amplifier

The pulses to drive the screen encoders are provided by 20 blocking oscillators. Each oscillator is connected to the appropriate drive pad on the screen and is fired at the proper time by the sequencing circuit. The locking oscillator is a monostable circuit with floating transformer coupled output. Each oscillator has a two-input AND circuit. These inputs are controlled by the sequence signal which selects the proper oscillator and the strobe signal which fires the oscillator at the proper time in the minor timing cycle.

The main sequence chain is composed of 30 one-shot multivibrators and 30 NOR circuits. The one shots are used as the timing and sequencing elements, while the NOR's are used as inverters to provide coupling between one shots. Twenty-three of each are connected in series, alternating NOR's and one shots, to form the main timing chain. Two of each are connected to produce a 4.55 kc clock. The remainder are used for a minor loop timing chain to control the transfer of information in the storage shift registers. The main timing chain consists of 21 periods of 9 usec and two periods of 5 usec, for a total of 199 usec. The remaining 21 usec of the main clock cycle are idle. The 9 usec minor timing cycle is divided into five time periods by another series of one shots and NOR's. The first is a one usec period during which a blocking oscillator is fired and information is detected from the tablet. The second, third, and fourth are each 2 usec periods during which information is shifted in the storage register.

Because of the large number of individual circuits required to provide the timing function, 8 circuit cards are used. These cards contain the one shots, the NOR's required, and the timing capacitors for the one shots.

The gray to binary converter consists of three NOR's which perform the logic: $B_j = (B_{j+1} \wedge \overline{G}_j) \vee (\overline{B}_{j+1} \wedge G_j)$; and $B_n = G_n$, where B_n is the most significant bit of the conversion and $j < n$.

The shift register which stores the serial output of the gray to binary converter is constructed from six NOR elements per bit. The gating is accomplished by using four separate shift signals. These signals are derived from the minor timing loop. The complete twenty-bit shift register requires four separate circuit cards to contain all the required NOR's and drivers.

During the time that new information is being shifted into the storage shift register, previous X-Y coordinate information is being shifted out. This old information is compared bit by bit with the new information. By comparing the old and new data, a validity check of the new data is made. If two or more bits differ in either coordinate, it is assumed that the new data is invalid and should be rejected. The new data is considered invalid because in normal operation neither gray coded coordinate can change more than one bit per sample period.

If data changes more rapidly than one bit per cycle, the stylus has been lifted off the tablet, has just been put in contact with the tablet, or an error in signal detection has occurred.

An automatic level control (ALC) is provided in the Rand Tablet electronics. This circuit is designed to automatically maintain the balance of the differential amplifier which amplifies the signal output of the stylus. The outputs of the differential amplifier then drive a bistable. The state of this bistable is determined by the signal coming from the stylus. During periods of no signal, the bistable will randomly be in one or the other of its states. The output states are insured of being random by the action of the ALC circuit.

The signal pickup by the stylus is an electrostatic process with very small signal coupling capacitances and large shunting capacitances to ground. Also, the signal levels are very small. For this reason, a high input impedance, high gain amplifier is used to detect the coded signal from the tablet. The amplifier is small and is contained completely within the 1/2" diameter, 5" long stylus pickup. The maximum output is a 4 V_{p-p} signal to the ALC differential amplifier.

Description of Proposed Rand-Type Equipment

Proposed rigid substrate screen. The fragility of the screens fabricated by the techniques employed at Rand leads to cost and yield problems. The direct labor cost per screen which must be incurred to maintain a tolerable yield represents a large portion of the total Rand Tablet cost. Most of the problems are due at least in part to the flexible nature of the film on which the printed circuits are etched. Accordingly, techniques have been considered for fabricating the same structure layer by layer on a rigid substrate. Messrs. Jesty and Ridout, of Communication and Display R and D, have suggested a system for generating the artwork without photo-masters. This would employ a special machine which has been employed for somewhat similar work and might be successfully adapted. The problems are not trivial, however, and a cost of $10,000 has been estimated for the first screen so made. Another approach has been suggested by Mr. Thornhill of Information Devices R and D. In this approach the conductor of patterns would be evaporated on a rigid substrate, much as interconnections on a silicon monolithic integrated circuit. A problem exists in obtaining sufficiently large vacuum facilities; whether acceptable yields could then be obtained is uncertain. No extensive work s been carried out on any of these approaches.

A somewhat simpler approach has been considered which makes use of deposited films. The lower wiring pattern would be etched by conventional printed circuit techniques, using a copper clad glass plate. A film layer would be deposited over the first wiring pattern, a layer of copper deposited, and a second photo-resist etching process employed. Another film

layer would insulate the top layer. This system will be further investigated. An alternative system, which features a much simpler screen, is described in section IV.

Proposed electronics. Inspection of the circuitry associated with the Rand Tablet disclosed that many worthwhile improvements could be made. The results of these improvements are a more reliable, more economical, and smaller version of the electronics package. Since development of the original model of the Rand Tablet, many advances have been made in semiconductor technology. The MADT and ECDC germanium transistors of the original have been replaced by planar silicon transistors and silicon monolithic integrated circuits. The integrated circuits allow a great reduction in the packaging and wiring complexity of logic circuitry. Using the Westinghouse WM series integrated circuits, many of the logic functions of the original circuitry can be performed by a single integrated logic element. The sections most amenable to the application of the integrated circuits are:

1. Sequencing for the blocking oscillator pulsers
2. Gray code to binary converter
3. Storage shift registers
4. Output registers and drivers
5. Automatic checking logic
6. ALC and pen amplifier circuits

The WM series of Westinghouse integrated circuits is DTL type logic capable of speeds in excess of 10 mc. Three WM series elements are used to advantage in the electronics package. The WM213T is a pulse binary counter stage. By proper connection of leads and application of signals, the WM213T can be used as a binary counter element, shift register element, a clocked R-S flip-flop, or a direct R-S flip-flop. The entire unit is packaged in a TO-5 type 12 lead can. These elements can be used for any logic function performed by the NOR elements which were extensively used in the original electronics.

The WM210T is a dual three-input NAND line driver packaged in the 12 lead modified TO-5 can. This unit is used as a clock driver or line driver where heavy loading is expected. There are many places where they are useful in the modified electroncis which will be described.

The sequencing for the blocking oscillators can be done by connecting twelve WM213T's together to form a shift register ring counter. Figure 2 is a logic diagram of this counter. A clock drives the inputs at 110 kc. This gives 24 timing period of 9 usec each. The first 20 periods are timing for the blocking oscillators. The remainder are intervals for transferring information to a computer or display device, resetting registers, and adjusting ALC balance.

The outputs of the WM213T pulse binaries which comprise the shift counter must be decoded. This is easily accomplished using WM211T dual NAND's. For each WM213T there is one WM211T with 2 outputs per can. Using a standard 4 1/2" x 6 1/2" printed circuit board with spaces for 27 TO-5 12 lead cans, the sequencing logic requires only one board.

The second major circuit revision is the use of integrated circuits for the storage shift register. This consists of WM213T's connected as shift register elements. The logic diagram, Figure 3, shows twenty-one bits of storage. This provides ten bits for X position and ten bits for Y position. The extra bit is necessary to reconvert the binary information into gray code. This gray code is necessary in order that a bit by bit comparison of the old information stored in the storage register can be made with the new incoming information.

The output register also consists of WM213T pulse binaries. They are reset and then loaded with the contents of the storage register if the information in the storage register is accepted as being the coordinate of a new and valid point.

The automatic checking logic, shown in Figure 4, again utilizes WM elements to provide logic which decides if valid point coordinates have been placed in the storage shift register. The decision is made bit by bit as the gray coded signal detected by the stylus amplifier is received.

The pen amplifier and ALC circuit of Figure 5 also benefit from a redesign for silicon planar transistors. A pen with circuitry similar to the original has been built and tested as far as possible without having a Rand Tablet screen. The pen utilizes a ceramic tab transistor for the input

Dwg. 748A079

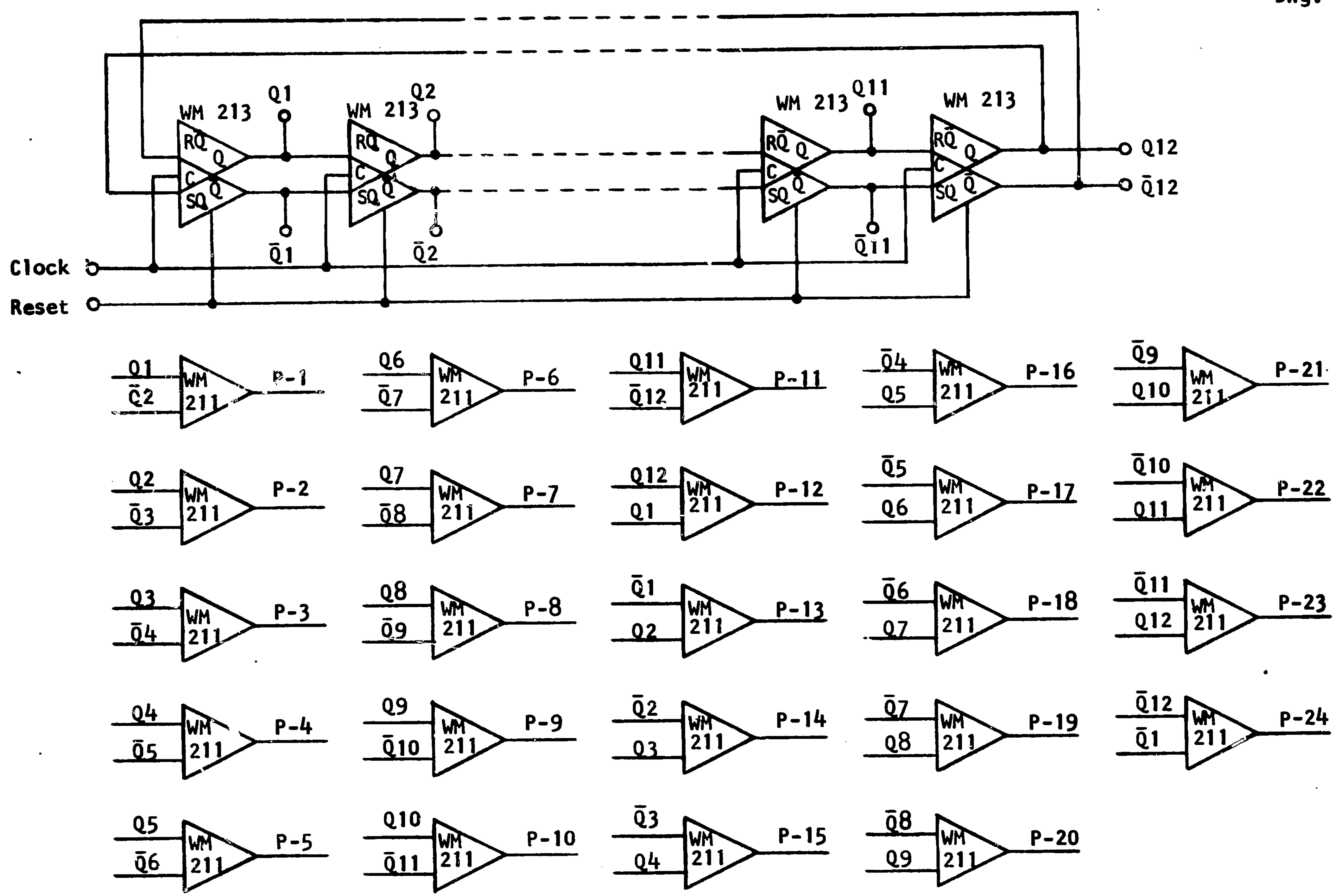


Fig. 2-Shift register

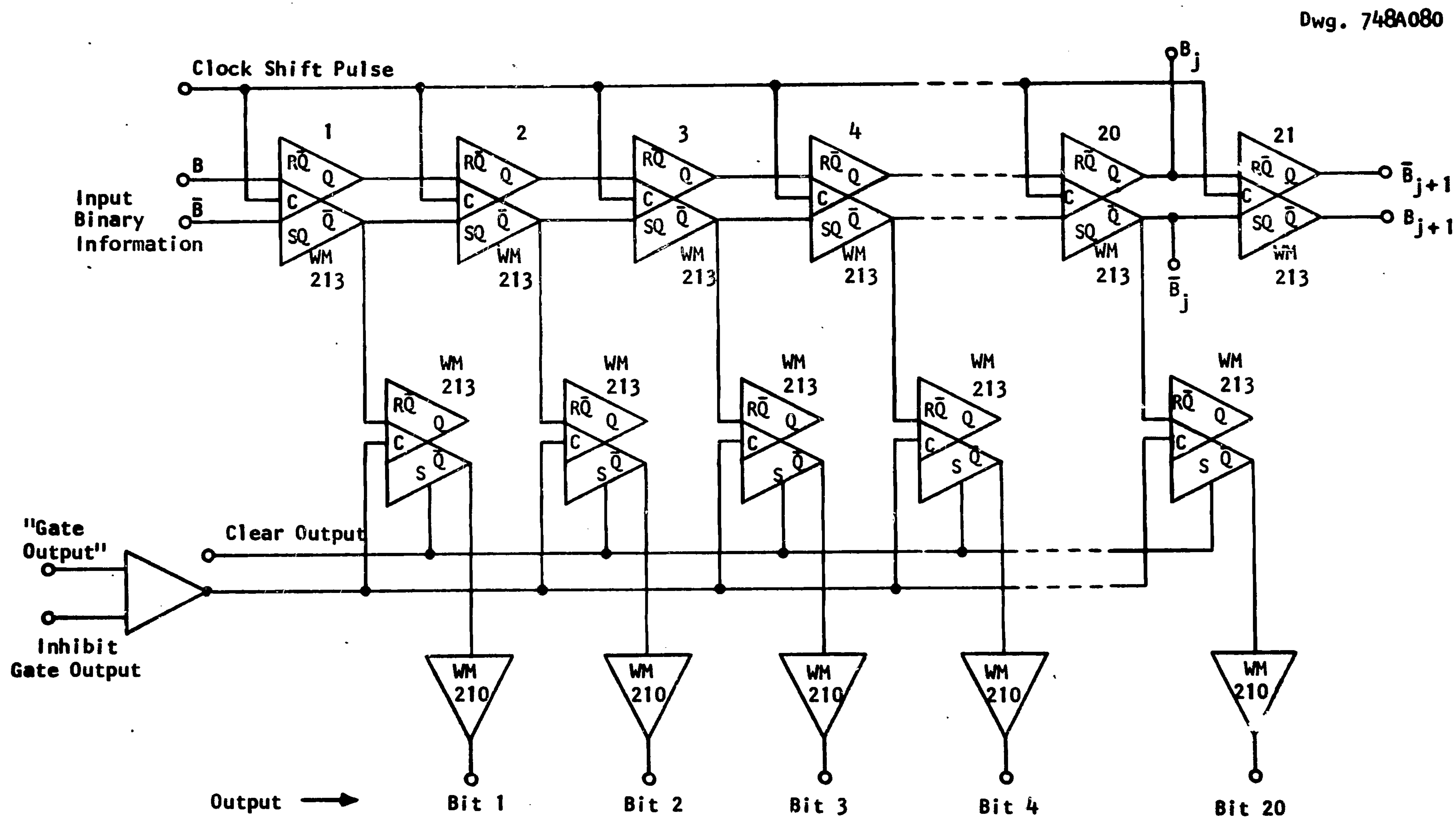


Fig. 3-Storage shift register and output register

Dwg. 748A081

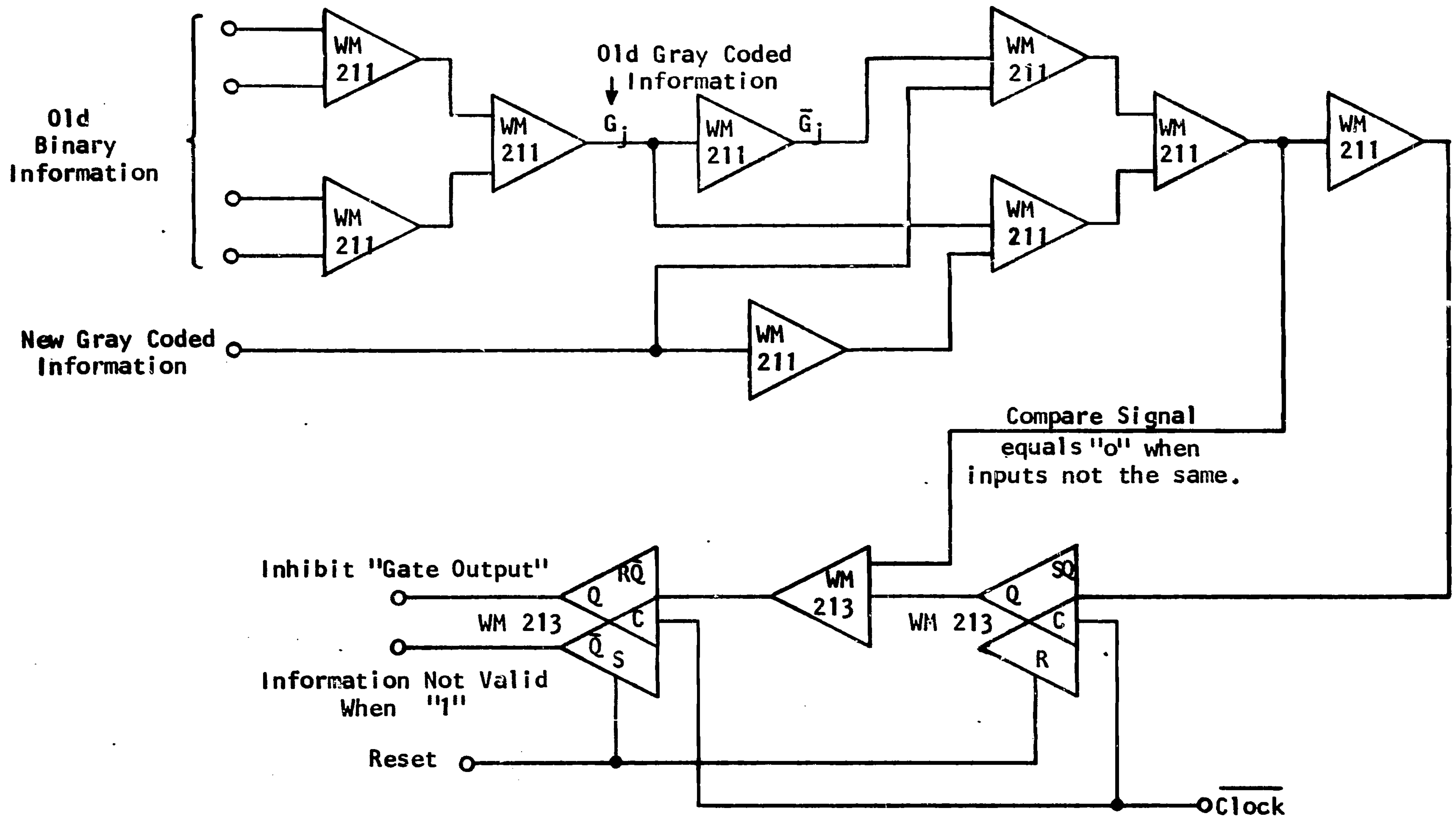


Fig. 4-Validity checking logic

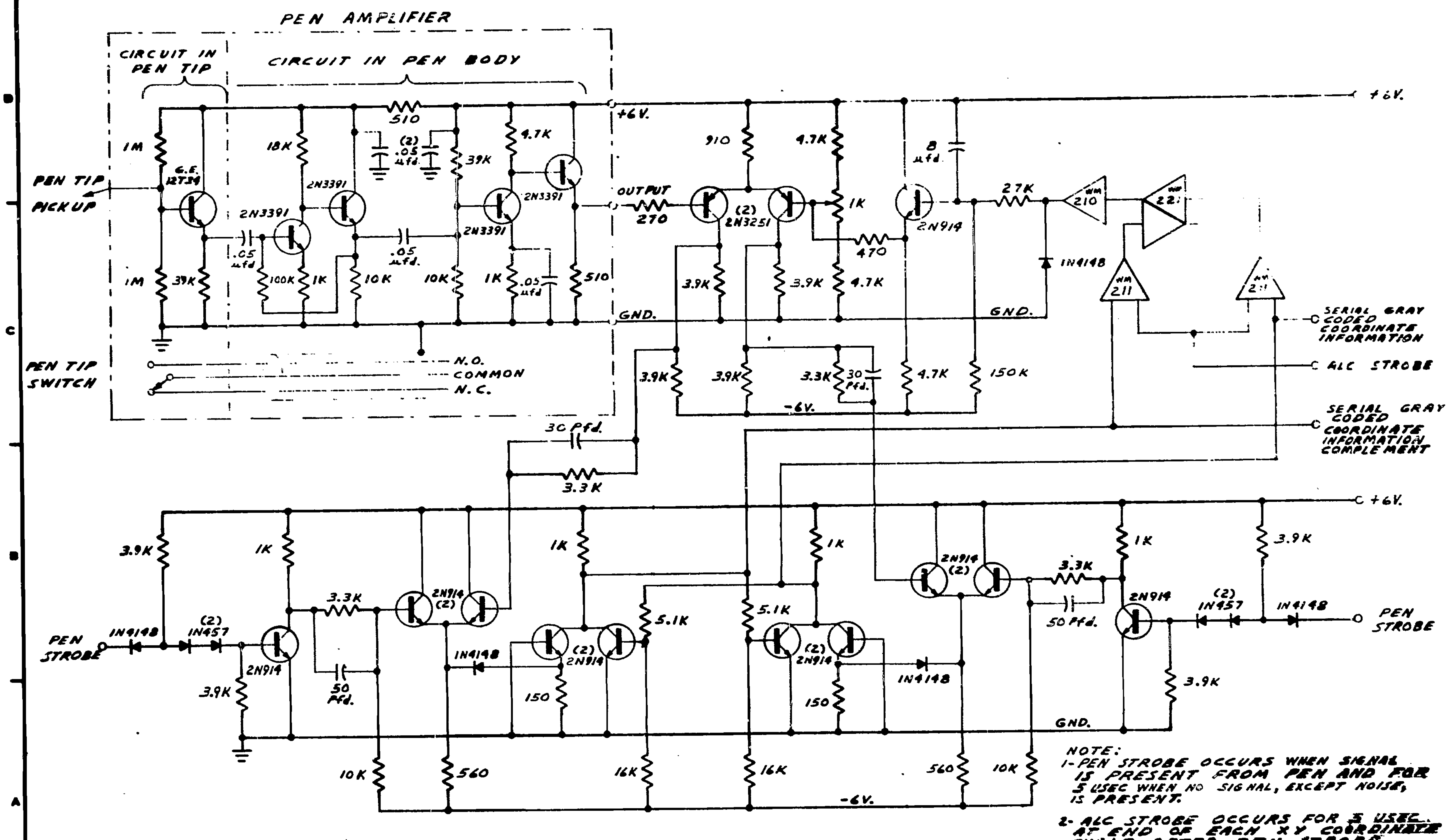


FIG. 5- PEN AMPLIFIER AND ALC

WESTINGHOUSE ELECTRIC CORPORATION

TITLE PEN AMPLIFIER AND ALC SCHEMATIC

DIMENSIONS IN INCHES—DO NOT SCALE DRAWING | SUB. 1

DFTM C. Leah 3-24-'66

181 C 376

RESEARCH LABORATORIES CHURCHILL BORO. PITTSBURGH 35, PA., U.S.A.

stage. This miniature transistor is placed in the extreme tip of the pen to minimize noise pickup. The remainder of the pen amplifier is constructed on an .031" printed circuit board and located in the pen body. It is possible to improve the pen amplifier by using an integrated circuit operational amplifier. This can provide more gain and better frequency response in a smaller package. The higher gain available would reduce the problems created by unequal signals from opposite sides of the screen. Since the pen is now a convenient size, further reduction presents no advantage. However, more circuitry could be included in the pen to provide a higher level signal. This would reduce the external circuitry and possibly eliminate a complete circuit card from the electronic package.

The investigation of methods to improve the Rand Tablet electronics indicates that the design evolved will be more reliable, more flexible, more compact, less expensive, and provide faster data handling capabilities. Most of these improvements are made feasible by the use of integrated circuits. A system properly designed with integrated circuits can be more reliable than a similar system built from discrete components.

The original design contained 26 printed circuit cards housed in a standard card rack. In addition, three power supplies were required. The new system, when completed, will consist of only 7 or 8 circuit cards including computer interface. Also, since the WM series of integrated circuits require only one power supply, the entire package can be contained in a single card rack with space available for other equipment.

To produce a more versatile machine new logic functions can readily be included if desired. The rate of X-Y coordinate information could be varied by merely changing the internal clock rate. In the old system 33 individual capacitors would have to be changed to effect a shift in clock rate. A change in clock rate would permit coarse or fine data to be supplied to the control computer. This would depend on the needs of the computer or its work load at any time during the control program. Since a large amount of data is supplied by the tablet in normal operation, it may be convenient to synchronize the tablet output with the computer cycle. The data can then be more efficiently transferred to the computer, thus improving the efficiency of computer utilization.

Alternative Graphic Input Device

Early in the investigation of Rand Tablets for instructional electronic systems, it was recognized that the resolution available might be far greater than that required. This led to consideration of a Rand Tablet of lower resolution and also other systems of inherently lower precision. It was discovered that various analog graphic input systems employing electrical or acoustic potentiometry had been tried without notable success by others.[4] A relatively simple scheme to permit sequential interrogation of a uniform resistance sheet for X and Y coordinates of a probe point was proposed by Gordon A. Rose.[5] A system has been constructed by using this approach and employing NESA[R] glass as the resistance sheet. Figure 6 illustrates the diode network which directs the drive signals to the sheet. When the drive voltage is pulsed positive, the top and bottom diodes conduct, establishing a virtual equipotential at top and bottom of the sheet. When pulsed negative, the sides are similarly energized. In this system the "off" electrodes contribute minimum distortion to the field produced by the equipotentials.

The circuit of Figure 7 is employed for driving the NESA[R] glass pad. The 2N2102 and 2N3251 transistors comprise a cross-coupled multivibrator for timing. The 2N1711 and associated circuitry ensure self-starting. If both 2N2102's conduct, the 2N1711 deprives both of base drive so that at least one must block. The remaining four transistors are so driven that there is no conduction overlap which would cause failure of the transistors and/or power supply. The DRIVE 1 and DRIVE 2 signals which energize the pad also gate the sample and hold circuit of Figure 8. This circuit presents X and Y coordinate voltages indicative of probe position to a storage oscilloscope or to an a-d converter.

The system has so far been employed with the storage scope only, as adequate information is thus obtained for evaluation of its instructional utility. An a-d converter for the system has been considered, and one embodiment is illustrated in Figure 9. The system illustrated is amenable to

[R]Pittsburgh Plate Glass Trademark

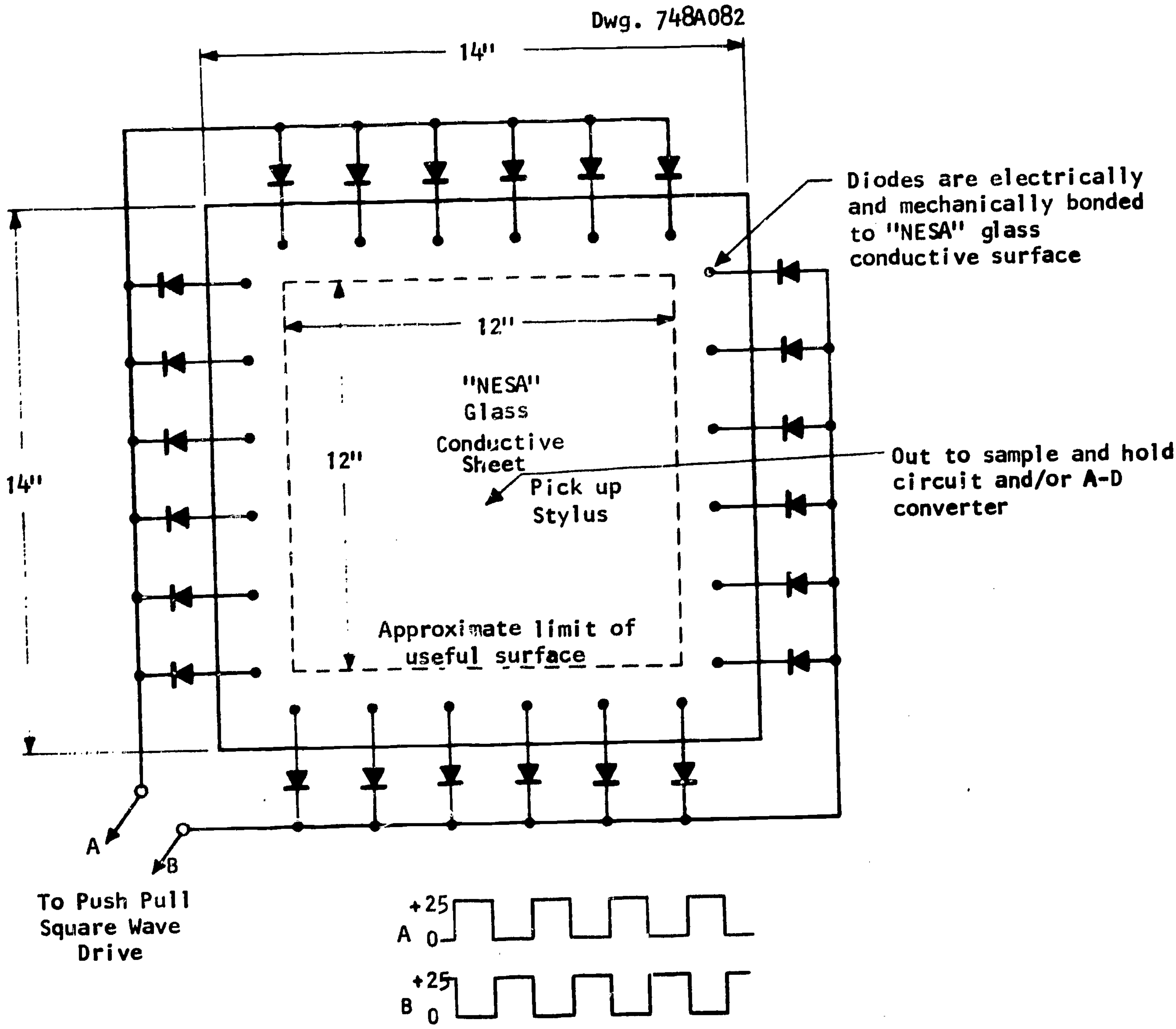


Fig. 6-Scratch pad

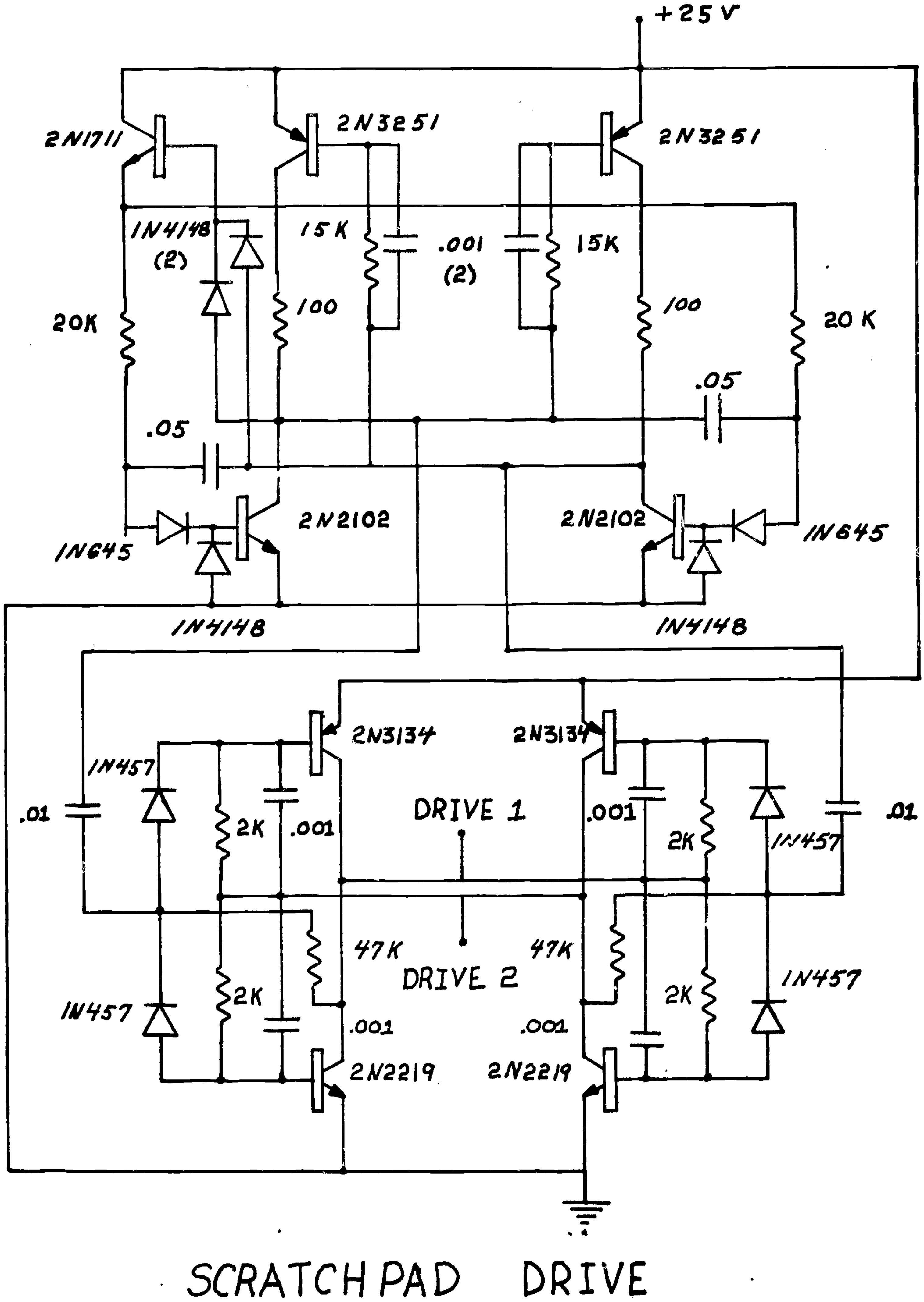
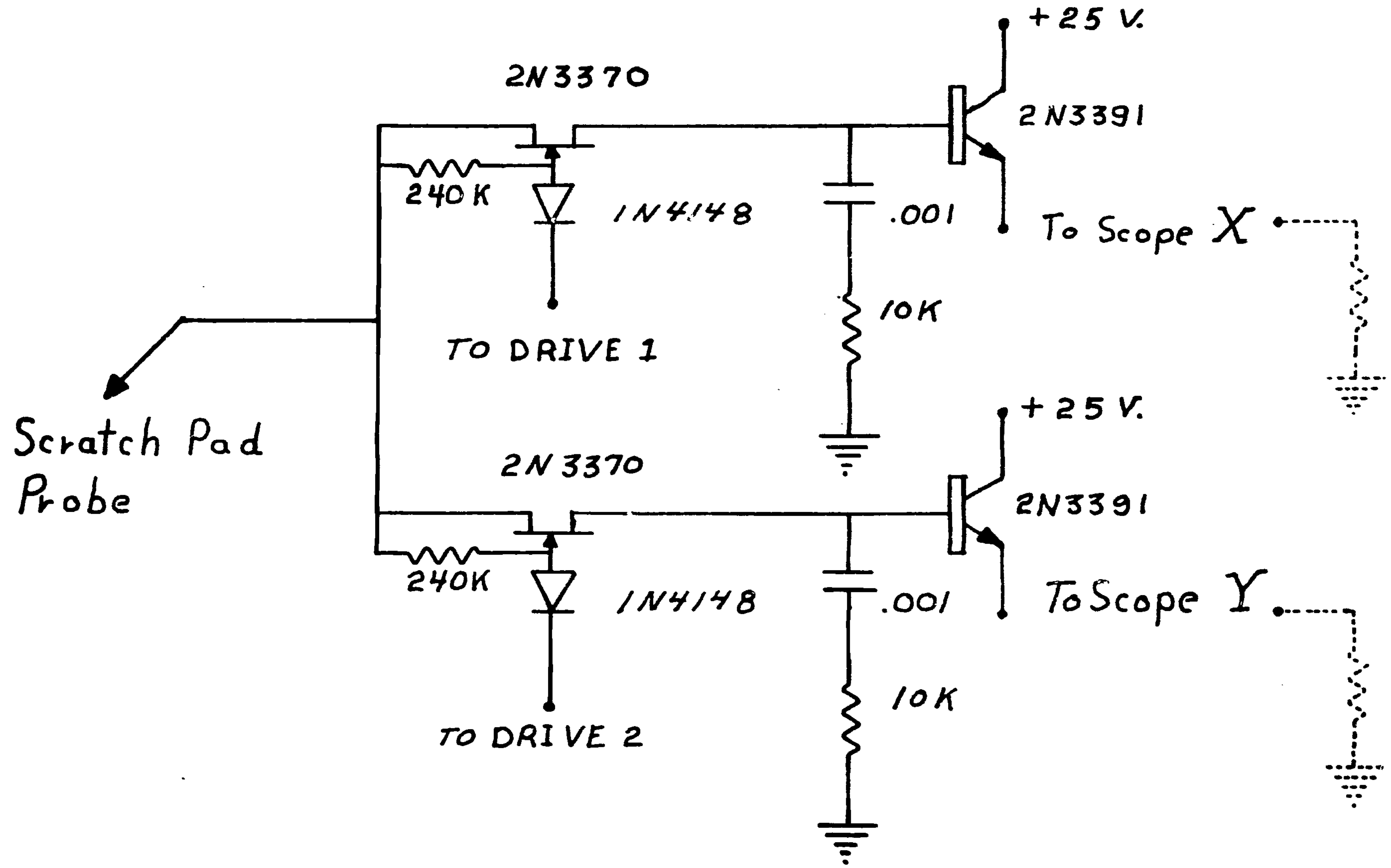

+25V
2N1711
2N3251
2N3251
1N4148
(2)
15K
.001
(2)
15K
20K
100
100
20 K
.05
.05
2N2102
2N2102
1N645
1N645
1N4148
1N4148
2N3134
2N3134
1N457
.01
2K
.001
DRIVE 1
.001
2K
1N457
.01
47K
47K
DRIVE 2
1N457
2K
2K
1N457
.001
.001
2N2219
2N2219
SCRATCHPAD DRIVE

Figure 7



SCRATCH PAD SAMPLE AND HOLD

Figure 8

Dwg. 748A083

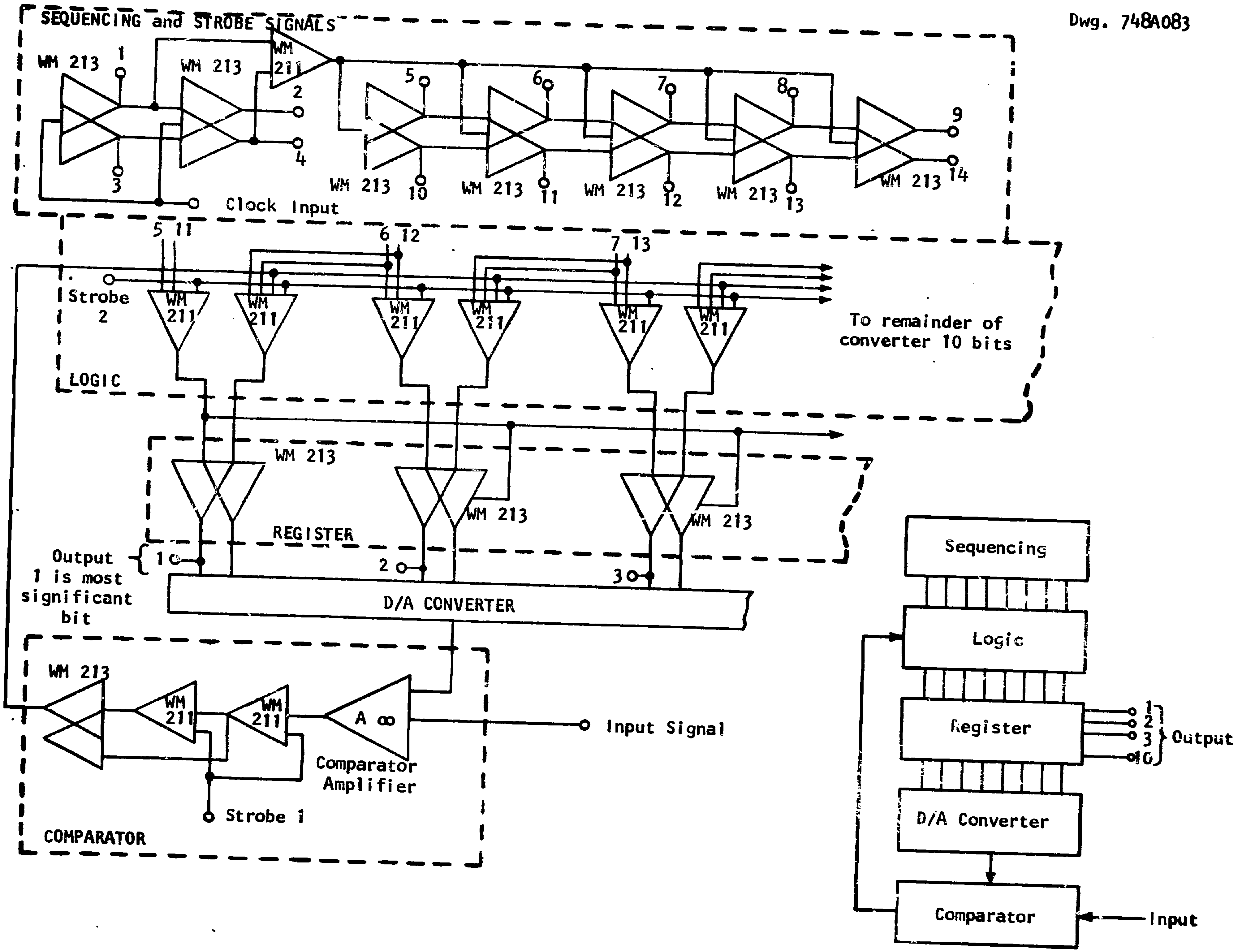


Fig. 9-Successive approximation A/D converter

Dwg. 748A083

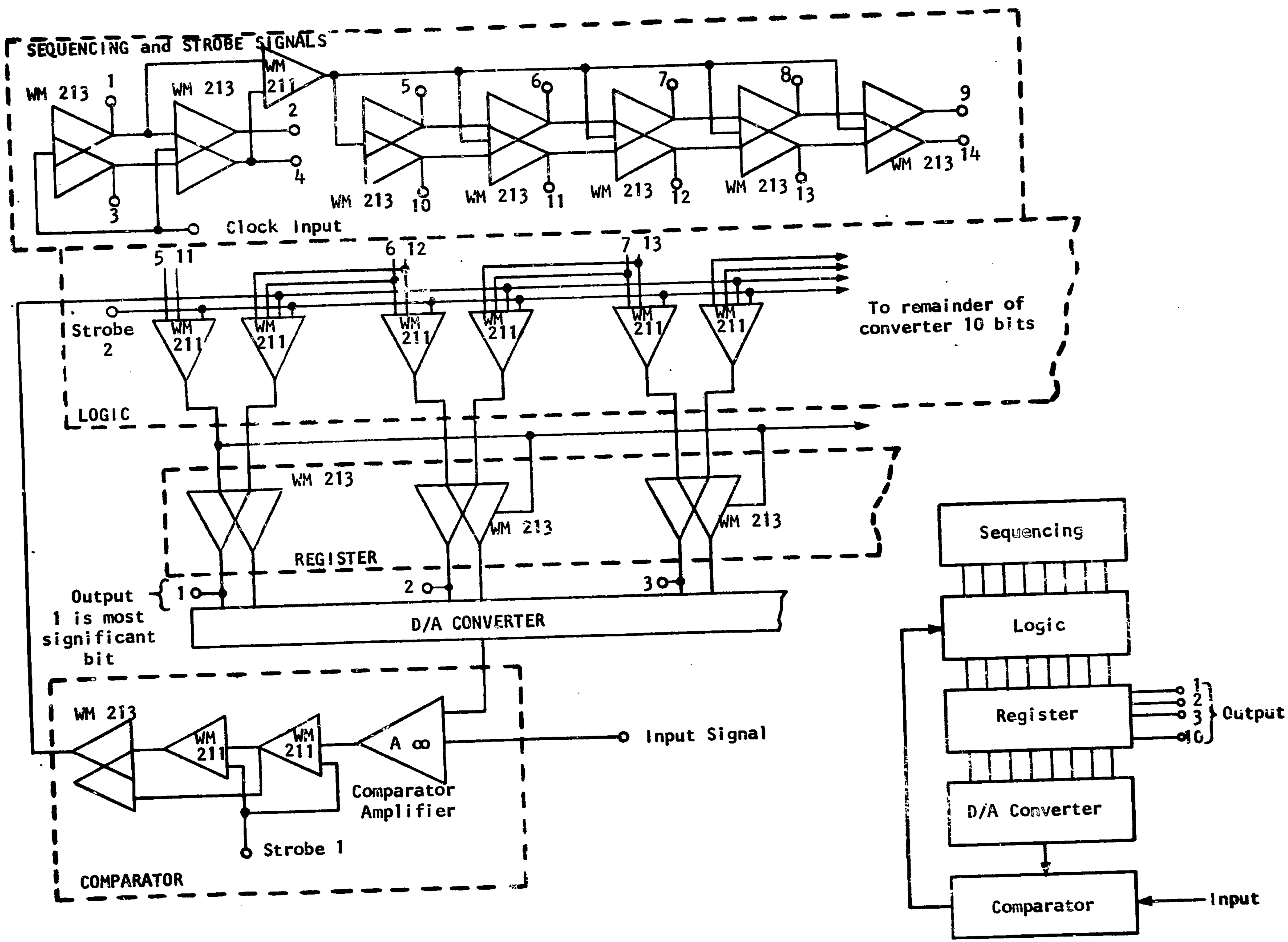


Fig. 9-Successive approximation A/D converter

construction with integrated circuits and can be made very fast. The real problems, however, are with the NESA glass plate. The linearity of resistance may be as bad as 10 percent and improvement is necessary. Also, it is not yet certain whether the coating of the glass will prove sufficiently durable in continuous use. Several suggestions for improvement in these respects are currently being investigated.

Summary of Progress

The possibility of constructing the screen or pad of the Rand Tablet on a rigid plate without using a flexible film has been investigated, but so far no attempt to fabricate a model has been made. Considerably more progress has been made with the electronics, the original germanium transistor circuitry having been bypassed in favor of a new design based on the use of Westinghouse WM series DTL integrated circuits. This and improvements in circuitry will allow a considerable reduction in size, without any cost penalty. A few portions such as the ALC circuitry have been redesigned for discrete components, using only silicon planar semiconductors. Portions of the improved circuitry have been experimentally verified. Construction of the complete improved electronic system has been deferred until an operational screen is obtained. A developmental model of the alternative graphic input device described in section IV was built and delivered to the University of Pittsburgh for evaluation. Although a breadboard exists, the system is still quite developmental and requires further study to establish whether or not it can satisfy any long term requirements.

Future work will comprise: investigation of a layer by layer depositing process for screen construction, assembly of electronics package, and study of proposed simpler system.

References

1. Communicating with Computers, George H. Jenkinson, Computers and Automation, pp. 18-24, September 1958.

2. Input-Output Equipment for Research Applications, W. S. Holmes and H. M. Maynard.

3. The RAND Tablet, a Man-Machine Graphical Communication Device, M. R. Davis and T. O. Ellis, AFIPS CONFERENCE Proc., Vol. 26, 1964 F.J.C.C.

4. Research Trip Report No. 14, B. R. Dow, Proprietary Class I.

5. "Light-Pen" Facilities for Direct View Storage Tubes, an Economical Solution for Multiple Man-Machine Communication, Gordon A. Rose, IEEE Transactions on Electronic Computers, August 1965, Vol. EC-14, No. 4, pp. 637-9.