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DECODING MATRIXATRON DEVELOPMENT

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THE PROBLEM

Develop two cathode-ray tubes each to accept a 6-bit input code group and give a separate and usable output for each input. The tube driving power must be kept low. Driving circuits and tube must recover immediately after decoding and be able to accept and decode succeeding codes within 0.1 microsecond after the previous input is removed. The tubes are to be kept as small as possible consistent with low driving power and reliable operation. The tubes are to be developed primarily for use in equipments for individual identification of aircraft.

RESULTS

1. Two tubes have been developed each of which will accept a 6-bit binary input code and give a separate and individual output for each coded input. These tubes are called the Electrical Matrixatron and the Printing Matrixatron.

2. The Electrical Matrixatron has an electrical output of 50 microamps on a separate target for each input code. The Printing Matrixatron gives a separate visible number output for each input code. The two tubes are identical except for the outputs.

3. Low voltage and power are required to drive the tubes.

4. Succeeding inputs can be decoded within 0.1 microsecond after removal of the previous selection.

5. The tubes are easy to fabricate and simple to operate. The tube sizes compare to those of ordinary CRT's used in oscilloscopes.

6. The Printing Matrixatron has been used in an Air Traffic Control Aircraft Identification Unit developed at NEL.

RECOMMENDATIONS

1. Development of the Electrical and Printing Matrixatrons should be considered completed.

2. Consider the Matrixatrons for the following applications:
   a. Detection of a 5-, 6-, or 7-digit code and selection of a load and/or presentation of a display which is a function of the input code. In this respect the Electrical Matrixatron would be used to select a load and the Printing Matrixatron would be used to present the display.
   b. Conversion of data from binary form to octonary or decimal form.
   c. Any application where a high-speed multiposition electronic switch is required.

ADMINISTRATIVE INFORMATION

The work on these tubes was conducted under CA 21501 (AD 04401), NE 010234-2 (NEL A2-1). The Laboratory was assigned the problem by BuShips letter C-S67-(10) (822) Ser 822B-0333 of 5 December 1950. The development of these tubes was completed in June 1954 and the development of an equipment using the Printing Matrixatron was completed in August 1954. This report was approved for publication 17 June 1955.

The original idea for this type of tube was conceived by R. V. Keeran, head of Radar Branch during tube development. The following NEL personnel made significant contributions to the design, construction, and testing of experimental tubes: J. H. Bartens, W. W. Mead, R. E. Kerr, W. R. Scott, N. E. Swensen, and N. D. Rappaport.

Vacuum Tube Products Company, Oceanside, California, fabricated all the experimental tubes.

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INTRODUCTION

Matrixatrons are a family of cathode-ray tubes designed to accept a coded information group consisting of six bits of information and to give an individual output for any combination of the 6-bit input. The input codes are combinations of six individual voltages which are ON or OFF. They occur simultaneously and with approximately equal amplitudes, and may be derived from dc power supplies, coincident pulse trains, detected tones, detected rf, and so forth. These voltages drive electron beam deflection plates, and therefore require very little power.

Matrixatrons were a direct outgrowth of the NEL developed Multiple Deflection Target Tube for Pulse Train Decoding,[1] and were initially conceived for use in equipments being designed to provide individual identification of aircraft for air traffic control.

This report is concerned with the development, manufacture, operation, and use of the Electrical and the Printing Matrixatrons. The two tubes differ only in their outputs. A third tube of the family is now under development.

DEVELOPMENT OF THE ELECTRICAL AND PRINTING MATRIXATRONS

design parameters

The Matrixatron is a cathode-ray tube in which an electron beam is formed by a single electron gun. This beam is deflected by three pairs of vertical and three pairs of horizontal deflection plates whose voltages determine the spot on the end of the tube at which the beam will strike. The beam current produces a useful output at the tube end.

From the outset of the problem it was considered mandatory that (1) the driving circuits be kept as small as possible by using miniature tubes for drivers; (2) the driving circuits and the Matrixatron must recover immediately after decoding and must be able to accept and decode a second input within approximately 0.1 microsecond after removal of the first input; (3) the output current, and therefore the beam current, should be as large as possible; (4) the tubes should be kept physically as small as possible consistent with good deflection sensitivity and driving power requirements; and (5) the tube must accept a 5-bit information group (later modified to a 6-bit) and give a separate output for each input code.

development procedure

Considerable preliminary planning and experimenting were done before any tubes were actually built. Initially, a demountable vacuum chamber was set up at the Vacuum Tube Products Company with which to conduct preliminary experiments. This proved too costly and time-consuming, however, and a more practical method was devised by which the elements to be tested were sealed in a bottle and the tests conducted at the Laboratory.

Under the general procedure evolved at this point, a tube would be designed to be used in the investigation of a specific problem — as, for example, the problem of deflection plate configuration. A sketch was then made of the tube, and if discussions with the Vacuum Tube Products Company revealed no manufacturing difficulties, the tube was constructed. It was then tested at NEL, and if no defects were evident, it was used to investigate the problem for which it had been designed. Design changes indicated by the tests required a repetition of the entire cycle.

Development work was carried out separately on each of three separate but not independent parts of the tube — the deflection system, the electron gun, and the output.

development of the deflection system

The Multiple Deflection Target Tube (MDTT), from which the Matrixatrons evolved, is a cathode-ray target tube in which the electron beam is initially positioned at a point off the electron target. When the proper combination of voltages or code is impressed upon the multiple deflection plates, the beam will be repositioned to hit the target and give an output current. Any input voltage combination, or binary code, except the preset code, deflects the beam to points other than the target, and no output is obtained. An initially positioned beam is deflected to a discrete point for each input binary code or deflection plate voltage combination, and if targets are placed at these points, individual outputs are obtained for each binary coded input.

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[1] R. V. Keeran *Development of Multiple Deflection Target Tube for Pulse-Train Decoding* (Navy Electronics Laboratory, Report 182) 5 July 1950 (CONFIDENTIAL).

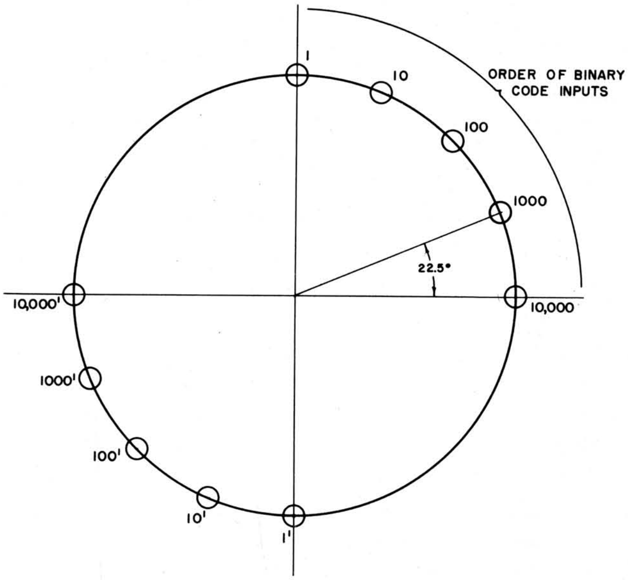


Figure 1. Deflection system with five pairs of radially spaced plates.

Initially, five pairs of deflection plates were considered, similar to MDTT, spaced equidistant from the center and arranged radially with 22.5 degrees separation (fig. 1). This system would give 32 outputs for a 5-bit binary coded input by vectorially adding combinations of the five bits of deflection (fig. 2). These outputs are given the decimal number equivalents of the 5-bit binary input code groups.

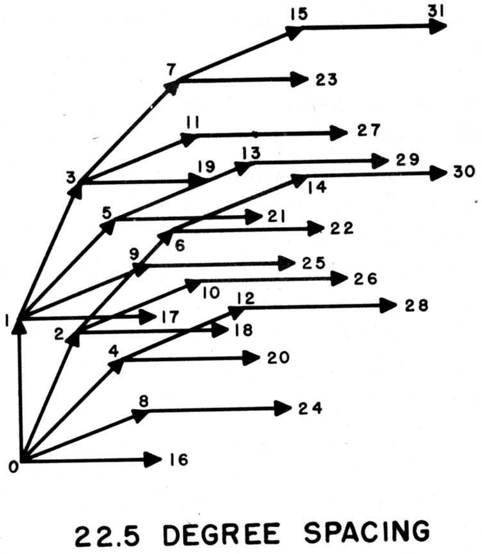


Figure 2. Vector summations of code inputs for the deflection system of figure 1.

The position of the output targets needed for this tube would complicate the building of the tube. Therefore, it was decided that it would be simpler and more practical to add a set of vectors having 1, 2, and 4 units amplitude in the same direction, and a second set of vectors at 90 degrees to the first. Subsequently, the number of outputs was extended from 32 to 64, which required a 6-bit binary code in place of the 5-bit code. It was necessary to put six pairs of deflection plates in the tube to accomplish this.

So that the amplitude of the deflection plate driving voltages would be equal, the three pairs of deflection plates in each direction were designed to have a relative deflection sensitivity of 1, 2, and 4 units (fig. 3). The numbers in the figure designate the units of deflection sensitivity and the letters designate the direction of the deflection. The deflection of the electron beam resulting from a voltage on each pair of plates is then a vector having a direction and a

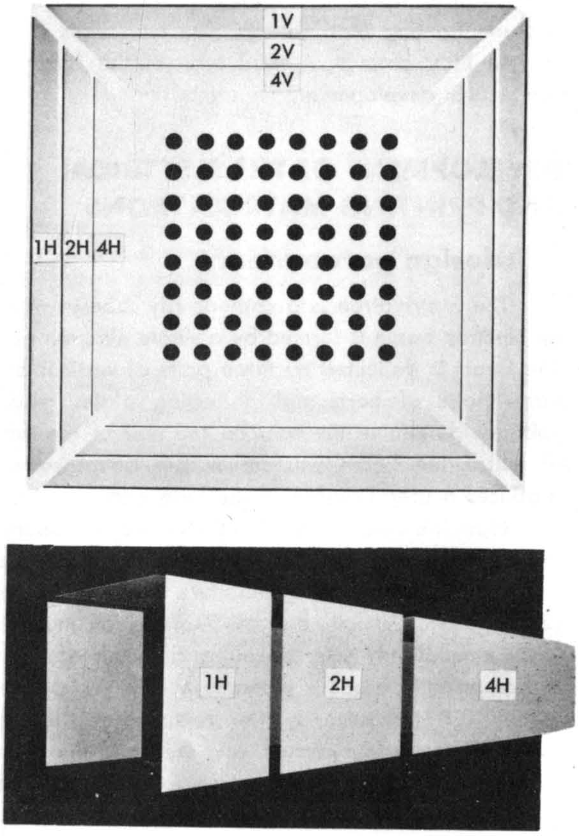


Figure 3. Deflection plates and spot positions for rectangular deflection system.

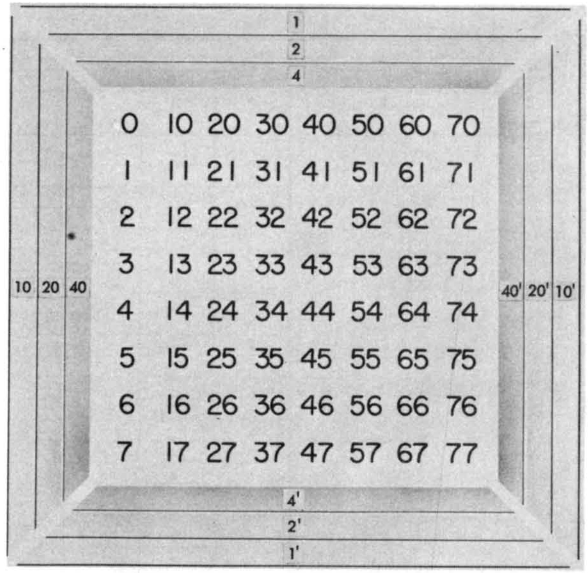
magnitude. The voltage on each pair of plates will be ON or OFF depending on the input code, so that there are three vectors in the V direction, and three in the H direction, any or all of which may be ON or OFF. The vectors have a relative magnitude of 1, 2, and 4 units. If all V vectors are OFF, the vertical position of the electron beam remains unchanged. If 1V only is ON, the electron beam is deflected one unit in the V direction. If 2V only is ON, the deflection is V direction two units. If 1V and 2V only are ON, the deflection is three units in the V direction. If 4V only is ON, the deflection is four units in the V direction. 4V + 1V gives five units; 4V + 2V gives six units; and 4V + 2V + 1V gives seven units. This gives a total of eight equally spaced positions in the V direction. To any one of these eight positions in the V direction may be added any combination of the three vectors in the H direction, providing 64 positions. This will give the symmetrical set of beam positions at the end of the tube shown in figure 3. The targets can be easily arranged to correspond to these positions of the electron beam.

The fact that this configuration of deflection plates gives eight rows of eight positions suggested that an octonary numbering system for the ouputs, rather than a decimal numbering system, would be more simple. The tube would then take a binary coded input containing six bits of information and give an octonary numbered output for any input code. By giving each bit of the input code an octonary number (fig. 4) the input code has an octonary rather than a binary form. The deflection plates must be similarly numbered (fig. 5).

	INPUT CODE BITS					
BINARY FORM	1	10	100	1000	10000	100000
OCTONARY FORM	1	2	4	10	20	40

Figure 4. Binary to octonary conversion of input code bits.

This system of numbering greatly simplifies the correlation of the output target number with the input code group. Output numbers can be determined by the simple addition of the octonary numbers assigned to input code bits. Figure 5 shows the octonary number of each beam position. Figure 6 shows the possible combinations of 6-bit information groups. The binary and octonary form for each bit is shown, and the binary, octonary, and decimal equivalents of all combinations are given.



0	10	20	30	40	50	60	70
1	11	21	31	41	51	61	71
2	12	22	32	42	52	62	72
3	13	23	33	43	53	63	73
4	14	24	34	44	54	64	74
5	15	25	35	45	55	65	75
6	16	26	36	46	56	66	76
7	17	27	37	47	57	67	77

Figure 5. Octonary number of spot position and deflection plates.

The numbers assigned to each deflection plate designate the bit of information in the input code which is applied to each plate. The number also gives the relative deflection sensitivity in each direction that each plate must have to produce the required vector deflection when voltages of the same amplitude are impressed on the plates.

Figure 3 shows the shape of the deflection system used in the early tubes. These first tubes, a number of which are shown in figure 7, were all Electrical Matrixatrons.

Experimental work on the Matrixatron was started by checking deflection systems in a demountable vacuum chamber to determine (1) the accuracy of deflection plate design, (2) effects of interaction of plates on spot pattern distortion, and (3) attainable deflection sensitivities. These tests indicated that a deflection system having the general shape shown in figure 3 could be built, and that the system would have 1, 2, and 4 units of relative deflection sensitivity in each direction. The deflection sensitivity was good enough so that miniature tubes could be used as drivers up to 1000 volts electron speed. The distortion of the beam pattern was low provided the deflection distance was kept small compared to deflection plate sepaartion. This deflection system was used in all the experimental tubes shown in figure 7.

	Input Code Bits						Output Numbers		
Binary Form →	1	10	100	1000	10000	100000			
Octonary Form →	1	2	4	10	20	40	Octo-nary	Binary	Decimal
							0	0	0
	x						1	1	1
		x					2	10	2
	x	x					3	11	3
			x				4	100	4
	x		x				5	101	5
		x	x				6	110	6
	x	x	x				7	111	7
				x			10	1000	8
	x			x			11	1001	9
		x		x			12	1010	10
	x	x		x			13	1011	11
			x	x			14	1100	12
	x		x	x			15	1101	13
		x	x	x			16	1110	14
	x	x	x	x			17	1111	15
					x		20	10000	16
	x				x		21	10001	17
		x			x		22	10010	18
	x	x			x		23	10011	19
			x		x		24	10100	20
	x		x		x		25	10101	21
		x	x		x		26	10110	22
	x	x	x		x		27	10111	23
				x	x		30	11000	24
	x			x	x		31	11001	25
		x		x	x		32	11010	26
	x	x		x	x		33	11011	27
			x	x	x		34	11100	28
	x		x	x	x		35	11101	29
		x	x	x	x		36	11110	30
	x	x	x	x	x		37	11111	31
						x	40	100000	32
	x					x	41	100001	33
		x				x	42	100010	34
	x	x				x	43	100011	35
			x			x	44	100100	36
	x		x			x	45	100101	37
		x	x			x	46	100110	38
	x	x	x			x	47	100111	39
				x		x	50	101000	40
	x			x		x	51	101001	41
		x		x		x	52	101010	42
	x	x		x		x	53	101011	43
			x	x		x	54	101100	44
	x		x	x		x	55	101101	45
		x	x	x		x	56	101110	46
	x	x	x	x		x	57	101111	47
					x	x	60	110000	48
	x				x	x	61	110001	49
		x			x	x	62	110010	50
	x	x			x	x	63	110011	51
			x		x	x	64	110100	52
	x		x		x	x	65	110101	53
		x	x		x	x	66	110110	54
	x	x	x		x	x	67	110111	55
				x	x	x	70	111000	56
	x			x	x	x	71	111001	57
		x		x	x	x	72	111010	58
	x	x		x	x	x	73	111011	59
			x	x	x	x	74	111100	60
	x		x	x	x	x	75	111101	61
		x	x	x	x	x	76	111110	62
	x	x	x	x	x	x	77	111111	63

Figure 6. Code forms and number equivalents of 6-bit code combinations.

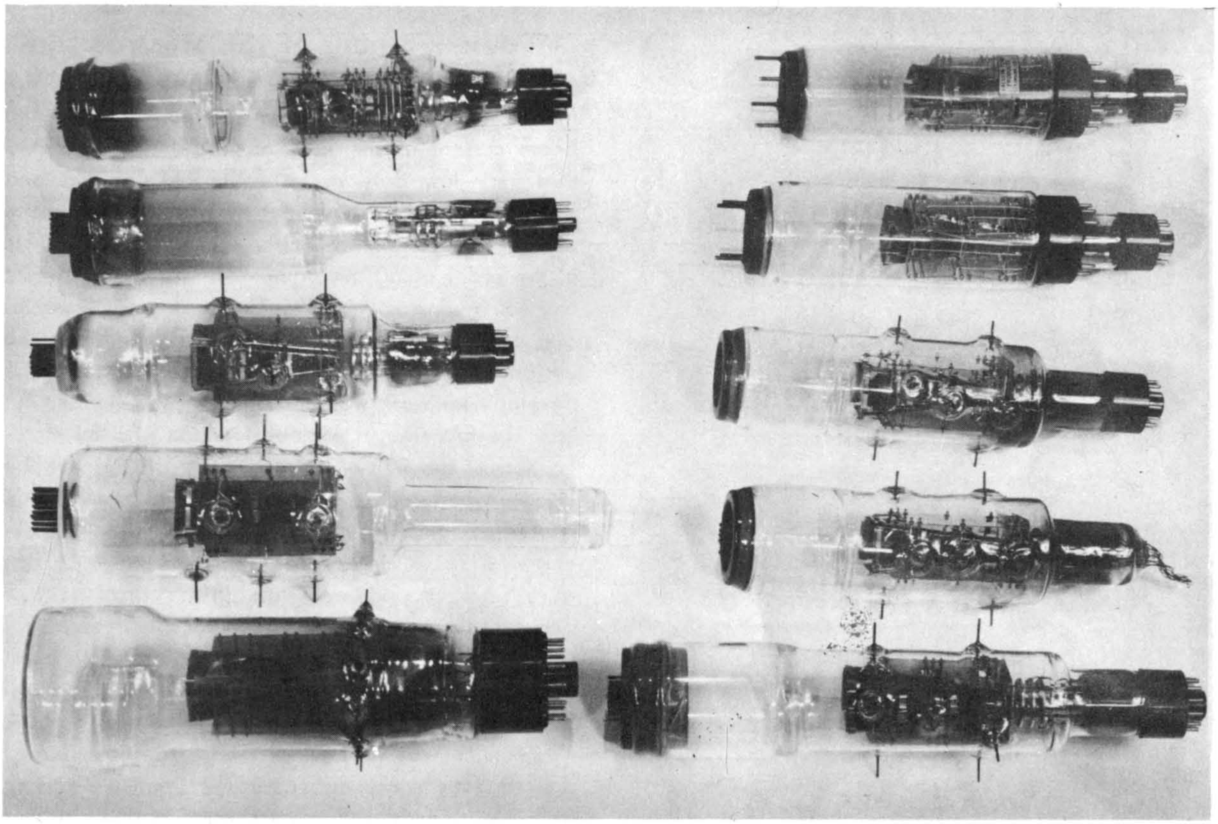


Figure 7. Experimental Electrical Matrixatron.

Figure 8 shows the final tube in which this type of deflection system configuration was used. The tube was found to operate satisfactorily in that it would take a 6-bit input code and switch to the proper target or output. However, the distortion due to barreling made the operation of the tube marginal, and it was decided that further deflection plate development was necessary to improve operation. Additional work on the deflection plate system was also necessitated by demands imposed by the Printing Matrixatron. The development of this tube had been started, and initial tests had indicated that the tube would require a deflection system in which the effective point of deflection would be the same for all pairs of deflection plates. The "effective point of deflection" is the point between a pair of deflection plates at which the path of the electron beam entering the deflection region intersects the path of the electron beam leaving the deflection region.

These considerations led to the development of a cycled and interleaved deflection system (fig. 30, part 1-4; this figure appears as a foldout at the end of this report). In this system, each deflection plate is divided into separate pieces, each piece of the correct length and in the correct position to give an effective point of deflection that is the same for all pairs. The relative deflection sensitivities of the three pairs of plates in each direction were maintained at 1, 2, and 4 units, as in the previous system. This deflection system had less barrel-type distortion than the previous (box type) system although distortion was still present. It was found that it was possible to compensate for this barreling by putting an element immediately after the deflection system that would introduce the opposite (pincushion) distortion. The equalizer pins shown in figure 20, part 1-3, were therefore designed and incorporated into the tubes. By changing the potential on these pins, the spot

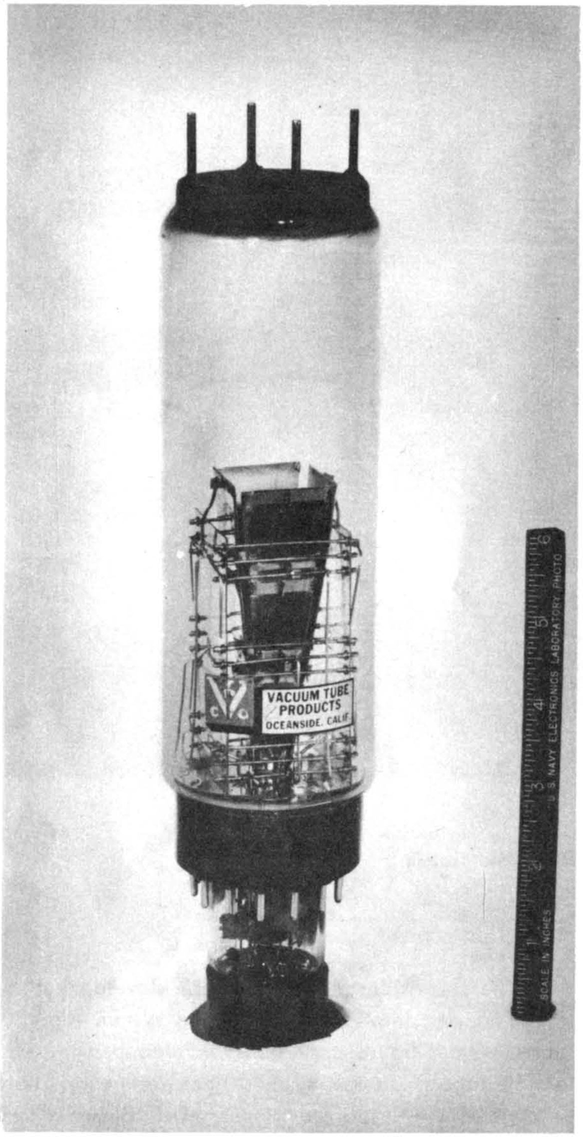


Figure 8. Electrical Matrixatron with box type deflection system shown in figure 3.

pattern can be made to go from a barrel through straight to pincushion as shown in figure 9. The optimum spot pattern is that shown in figure 9B, obtained with a positive potential on the equalizer pins of approximately 150 volts with respect to the average potential of the deflection system. Lower potentials on the equalizer pins result in the barreled type spot pattern of figure 9A, and higher potentials give the pincushion type pattern of figure 9C.

development of the electron gun

During the early stages of development of the Matrixatron it was considered necessary to make the beam current in the tube as large as possible so that very low duty cycles could be attained and still produce useful power at the target. The usable beam current from available commercial guns was in the order of 50 microamperes. The standard 902 electron gun was found to be the best commercial gun available. Starting with this gun, and using the design data presented by Spangenberg *et al*,[2] some development work was done on electron guns.

The first step in this development was the modification of the 902 electron gun. By drilling out the anode apertures and changing the grid-cathode spacing, beam current was increased up to 2 milliamperes. Focus characteristics and usable spot size were retained. However, the grid control voltage became too large, and consequently it was necessary to develop a completely new gun that would give approximately the same characteristics as the modified 902, but with somewhat better grid control. However, it was found that a standard gun would provide satisfactory outputs in the Printing Matrixatron if post acceleration were used, and it was unnecessary to continue with the development of the new gun. The standard 902-A tube is used as the electron gun in all Matrixatrons.

outputs

The output from the Matrixatrons is the electron beam current formed by the electron gun and deflected to a discrete and individual spot at the output end of the tube by the deflection system. The only difference between the Electrical and Printing Matrixatrons is the method in which this beam current is used. The outputs of the two tubes are treated separately here.

Electrical Matrixatron Outputs

The Electrical Matrixatron outputs were to be obtained by deflecting the beam to certain spots at the end of the tube. To achieve this output, the target assembly shown in figure 10 was designed for the tube. Figure 11 is a variation of this assembly.

Both assemblies were made by glass-fusing the target pins in a deep metal cup while the pins and

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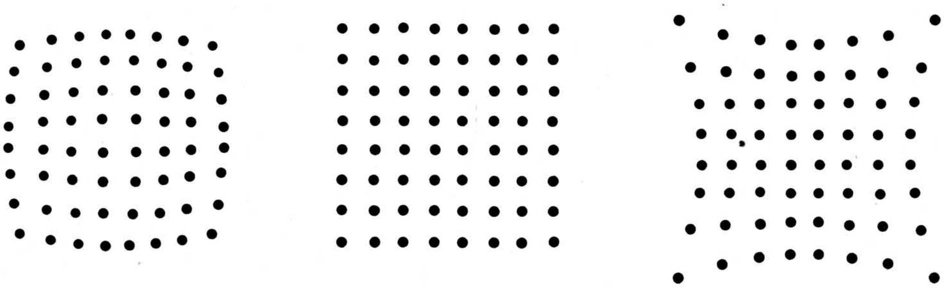
[2] K. R. Spangenberg *et al. The Production and Control of Electron Beams* Federal Telephone and Radio Corp., Newark, New Jersey, 1942.



A
SPOT PATTERN
WITH BARRELING

B
OPTIMUM SPOT PATTERN

C
SPOT PATTERN
WITH PINCUSHION

Figure 9. Effects of barreling and pincushion on spot pattern.

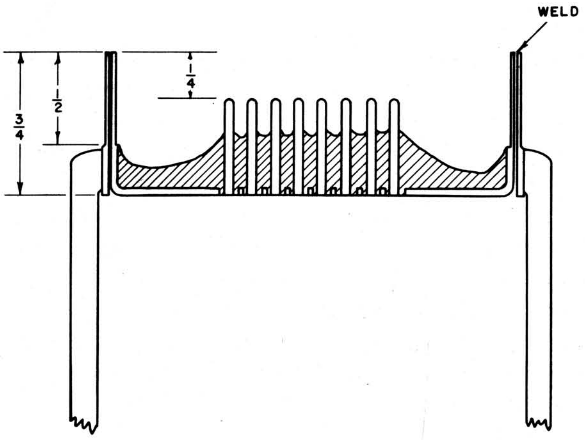


Figure 10. Sketch of Electrical Matrixatron target assembly.

cup were held in a carbon jig. The targets were 0.060-inch Kovar rod. They were centered in 0.100-inch holes in the Kovar cup, and were spaced 0.125-inch, center-to-center, arranged in eight 8-pin rows. The pins and extruding glass were cut flush with the bottom of the cup after they were fused. Thus, a flush target surface was formed, consisting of the conducting shield of the Kovar cup, and the 64 targets insulated from the metal by the fused glass. This complete target assembly was aligned with the deflection system and sealed to the glass envelope.

Considerable difficulty was encountered in sealing the target assembly to the glass envelope without cracking the glass around the pins, and several variations of design were tried. Although no design solved the problem, enough assemblies were successful so that developmental models of the tubes could be built.

Figure 11.
Electrical Matrixatron target assembly constructed at NEL.

The output or target current obtained from this model of the tube was approximately 50 microamperes. To insure switching times of less than 0.5 microsecond, the load resistance had to be limited to approximately 22,000 ohms; therefore an output of approximately 1 volt is available at the target. Where short switching time and greater output are desired, the output must be amplified.

Printing Matrixatron Output

The Printing Matrixatron was designed to receive a 6-bit input code on its deflection system and give an output number for any input code. The number is read from the 5-inch face of the tube. This visual number corresponds to the octonary input code; consequently octonary numbers are used at the output. The electron beam is deflected to 64 different positions at the output end of the tube by the 64 possible input code combinations.

The basic problem involved with the Printing Matrixatron was that of forming the visual numbers with the electron beam. It is obvious that if a phosphor screen is placed on the tube face, the electron beam will form a spot of light at each of the 64 positions. Therefore, if an opaque mask on which numbers have been engraved at each spot position is placed over the tube face, the light output from the spots will appear as numbers. This was the method of producing the first Printing Matrixatron (fig. 12).

The principal disadvantage of this method of producing numbers was parallax caused by the thickness of the glass between the mask and source of light or spot. To eliminate parallax, the engraved number-forming mask was placed just inside the tube face. The electron beam would then reach the phosphor only where the engraving occured, and the resulting illumination would produce visible numbers.

In another approach to the problem of producing number outputs, the inside of the tube face was given an aluminum coating on which the numbers were engraved. A coat of phosphor backed by a second coat of aluminum was then applied. This method of number forming was successful, and was used in the first practical Printing Matrixatrons.

The duty cycle requirement for this tube was extreme. The tube must print a number when the input code is pulsed on for 0.5 microsecond at a repetition rate of 60 inputs per second. It was further required that the number be sufficiently bright for easy recognition when flashed on the tube for 0.05 second, with the tube in a semi-dark room. Consequently, the duty cycle was: $0.5(10^{-6})\ (60)\ 100 = 0.0003$ per cent. The 0.05-second elapsed time requirement meant that the number brightness must be high and the number shape and size must be optimum.

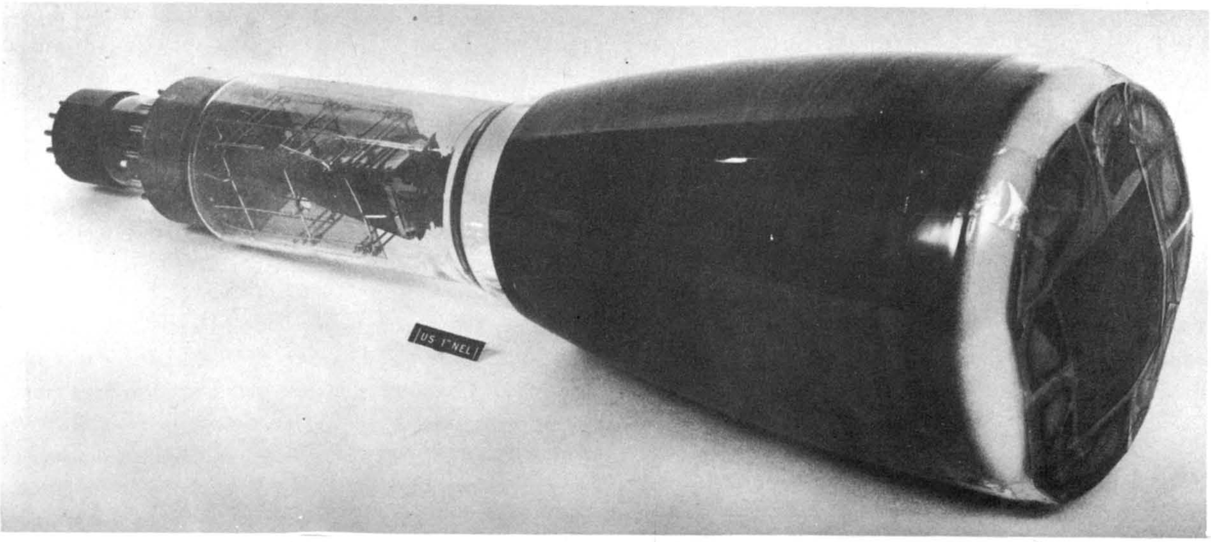


Figure 12. First Printing Matrixatron developed during experimental work.

In selecting the style of numbers to be used, the assistance of the Human Factors Division of the Laboratory was obtained. It was determined that the "Berger" style numbers were most easily recognized and were less likely to be confused with each other. The minimum number size necessary for quick and easy reading was determined to be approximately 0.140 inch. It was considered necessary to have the distance between numbers somewhat greater than the number size to prevent splash-over of the electron beam onto adjacent numbers. A tube face five inches in diameter was necessary to accommodate the 64 numbers, a requirement met by the 5R tube blank which has been used exclusively in all Printing Matrixatrons.

The problem of getting the brightness to a suitable level was attacked from three directions, (1) the phosphor used, (2) the beam current, and (3) acceleration of the electron beam. A study of available phosphors revealed that the P2 type had one of the best efficiencies in light output per watt of power input; also, the frequency of the light output corresponded to the most sensitive range of the human eye. Therefore it was decided that P2 was the best phosphor to use.

It might appear at first glance that if brightness can be increased by increasing the power of the electron beam, equal increases in brightness would result if (1) the number of electrons striking the phosphor screen were increased, or (2) the speed of the electrons were increased. However, this is not the case because of the characteristics of the phosphors. When the current density increases, the phosphor efficiency decreases; but when the speed of the electrons increases, the phosphor efficiency increases. Therefore, more light is obtained from the phosphor by accelerating the electrons than by increasing the beam current. With this fact known, considerable work was done on methods for accelerating the electrons.

The deflection sensitivity of the deflection system had to be kept as good as possible, and to achieve this it was considered mandatory to use a soft beam (in the order of 1 kv). Since input power could not be increased as a means of accelerating the electrons, the alternative was to develop a post-acceleration system that would not appreciably affect deflection sensitivity.

The first method tried was to place the number mask immediately following the deflection system (fig. 13). Accelerating potentials were put on the Aquadag rings in steps that gave minimum distortion of the pattern. The method was not satisfactory however, because the number patterns were distorted.

The method for achieving the required acceleration that proved successful and was ultimately adopted is illustrated in figure 14. In this tube, the speed of the electron beam, approximately 1000 volts on leaving the electron gun, is maintained through the deflection system and all the way to a Monel barrier grid which is spaced approximately ⅝ inch from the tube face. A high voltage is then placed on the aluminized and engraved tube face (up to 20 kv). The electrons, upon passing through the Monel barrier grid, are accelerated to 20 kv, and thus strike the phosphor screen at the desired

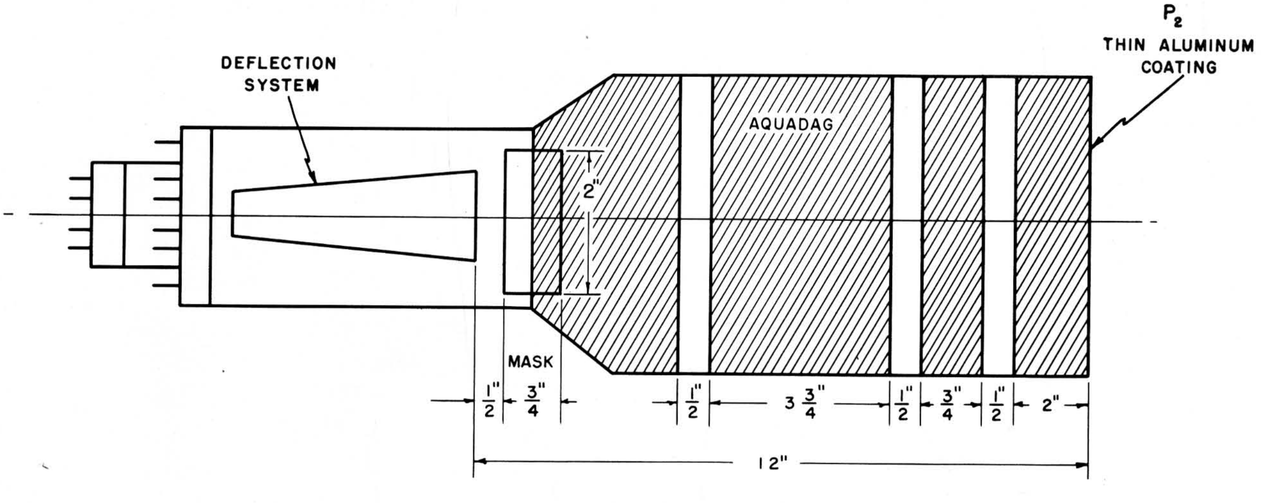


Figure 13. Experimental Printing Matrixatron designed with number mask immediately following deflection system.

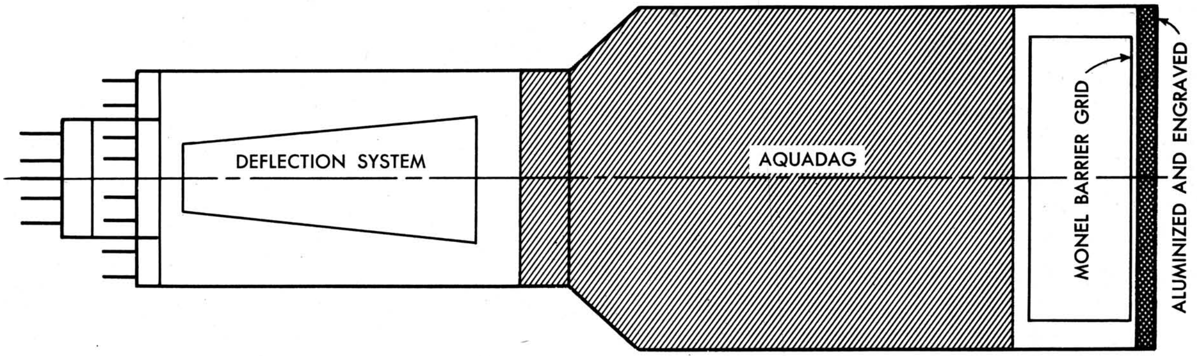


Figure 14. Sketch of Printing Matrixatron with monel barrier grid and numbers engraved on aluminized tube face.

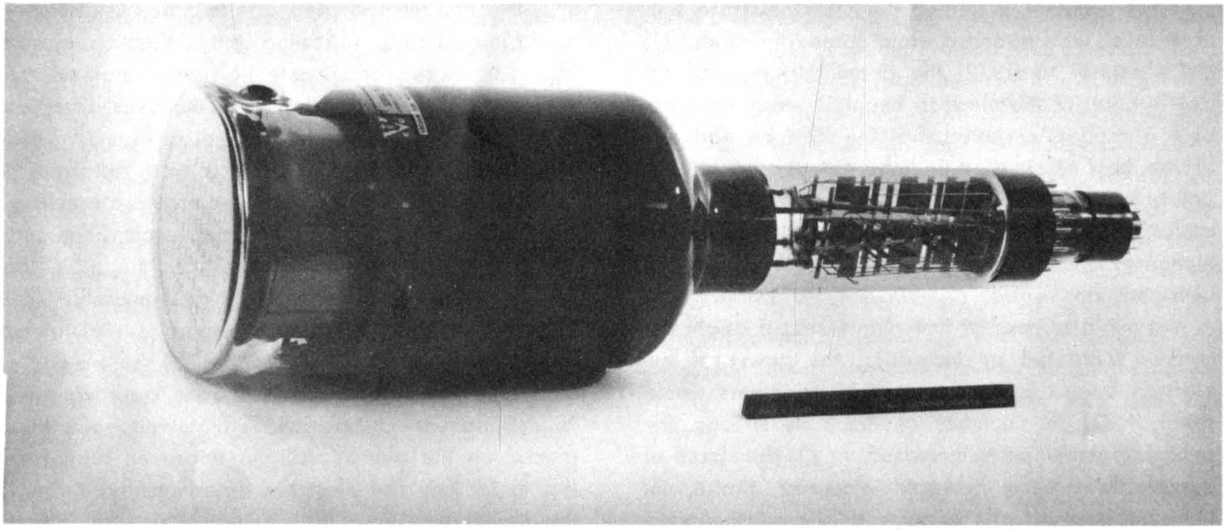


Figure 15. Printing Matrixatron with monel barrier grid and numbers engraved on aluminized tube face as completed for experimental work.

high speed. The Monel barrier grid completely shields the portion of the tube below it from this high field, and because the barrier grid and tube face are essentially parallel conductors, the electrons passing through the barrier grid are accelerated in a direction perpendicular to these planes. Therefore, the deflection sensitivity is completely independent of the acceleration voltage.

This is a good method of post acceleration, and tubes were built which printed the numbers at a brightness that approached that desired at the required low duty cycle. Because of the satisfactory performance of the tube, the design was tentatively frozen while five production models were built (fig. 15).

Production of the tubes was delayed by the problem of how to engrave the numbers on the aluminized inside of the tube face.

While the problem was being studied, it was proposed that the number mask be put in the same position as the barrier grid. The disadvantage of this method, in that it required stencil-type numbers, was more than outweighed by a gain in electron current. This increase in current resulted from the intense electric field between the tube face and the number mask, producing a lens action at the number. Secondary emitted electrons from the mask are sucked through the number slot; also, primary electrons that are slightly off the number slot are pulled through due to focusing action.

Before any actual printing tubes were built with the mask so spaced, experiments were conducted to determine the gain in current provided by different mask materials. It was also desired to determine the optimum thickness of the mask material, and to determine the clarity of the numbers as a factor of mask material and position.

The results of these tests indicated that a gain of number current in the order of 4 to 6 was most practical. Higher currents could be obtained by using materials that gave high secondary emissions, but since high secondary emission caused exaggerated halo effect, a low secondary emission material had to be used. Carbon, with the lowest secondary emission, gave the required gain in current. However, it was very difficult to fabricate a number mask of pure carbon. The mask was finally made of either brass or copper over which a thin layer of carbon was deposited by an acetylene flame.

The Printing Matrixatrons built using this type of number forming and electron acceleration arrangement (fig. 16) meet the requirements for number brightness and clarity with the low duty cycle (0.0003 per cent). This is attained using a standard 902A electron gun. The deflection sensitivity of the deflection system is completely unaffected by post acceleration.

present status of Matrixatron development

Development work on the Electrical and Printing Matrixatrons is considered complete. The Printing Matrixatron has been used in an Air Traffic Control Aircraft Identification Unit developed at this laboratory. An NEL report is currently being prepared on this unit. The unit has been evaluated at NANEP, Patuxent River, Maryland, and the results of the evaluation are given in a NANEP report.[3]

The third tube of the Matrixatron family, the PPI Matrixatron, is currently under development. Four experimental tubes have been fabricated (fig. 17).

MANUFACTURE OF MATRIXATRONS

The Electrical and the Printing Matrixatrons are identical from the lower base past the deflection system and equalizer pins. This lower portion of both tubes is fabricated and then sealed to the output portion which is separately fabricated. Therefore the same manufacturing procedure is used for both tubes except for the output sections.

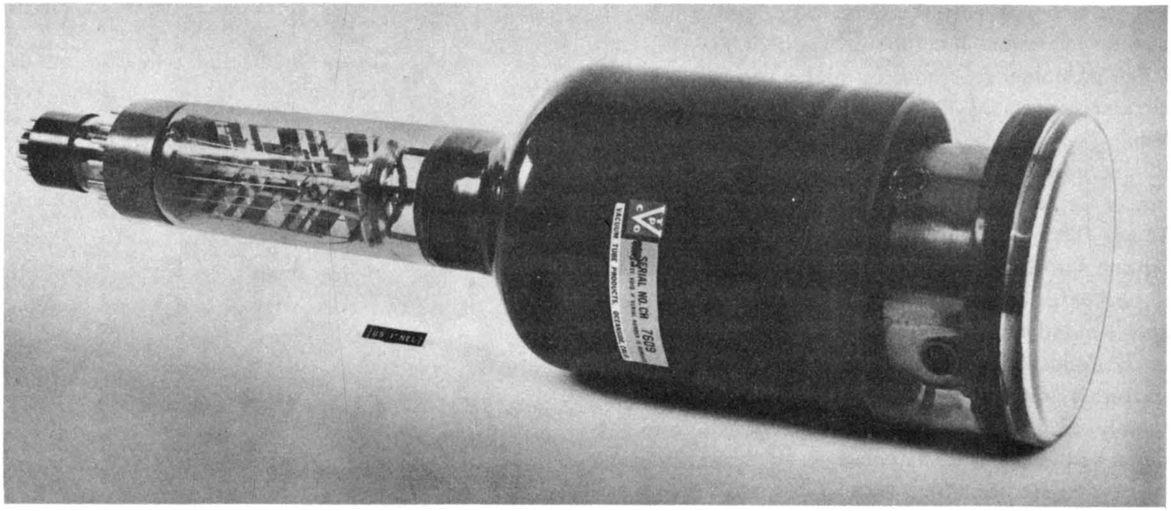


Figure 16. Final model of Printing Matrixatron.

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[3] Naval Air Test Center, Patuxent River, Maryland, Report ET 334-01 *Evaluation of Air Traffic Control Aircraft Identification Unit; Interim Report* 4 January 1955 (CONFIDENTIAL).

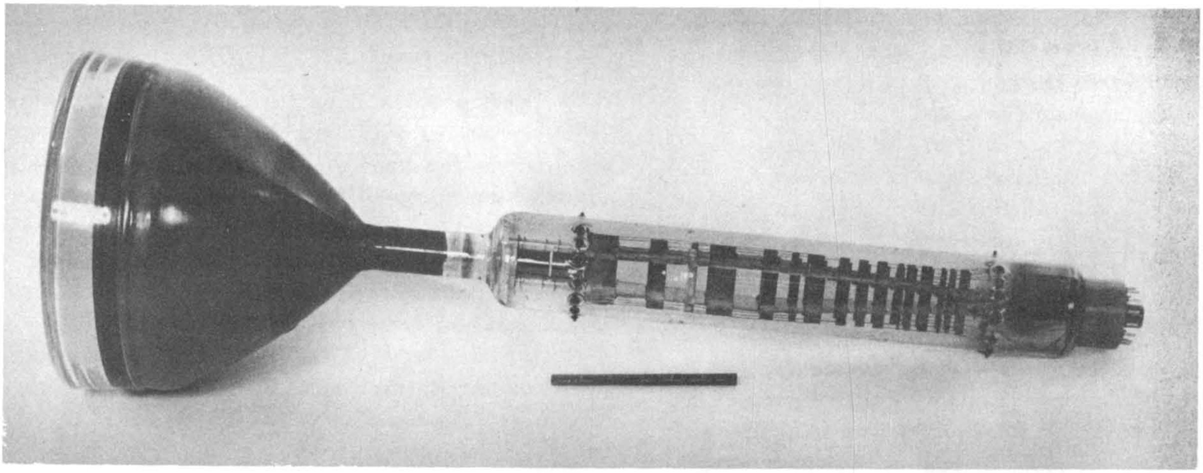

Figure 17. Experimental PPI Matrixatron.

deflection system

The deflection system is made of flat, nonmagnetic, stainless steel plates cemented on ceramic rods. Each deflection plate is cycled; that is, it is divided into more than one part — actually, 32 individual pieces of plate are used in the system. These pieces have five different widths (fig. 30, part 1-4). The plates are made by shearing 0.020-inch stainless sheet and removing rough edges with a file or sand paper. After plates are cut they must be cleaned thoroughly to remove all grease and other contaminates that would ruin a vacuum.

The ceramic rods used are 3.94 inches long, and have a 0.04 inch diameter bore, and a 0.1 inch outside diameter. The rods are jigged (fig. 18) with 0.040-inch steel rod, and the plates are stacked with circular spacers 0.020-inch thick between each piece. While jigged in this manner, the plates are cemented to the ceramic rods with Sauereisen Insa-lute Adhesive Cement No. 1. The cement is air dried for 12 hours. The deflection system is then taken from the jig and the circular spacers are removed. The cement is further dried by heating. Stainless steel tabs are spot welded onto the deflection plates, the parts of each deflection plate are connected, and a mica spacer is installed (fig. 19). The equalizer pin assembly of figure 30, part 1-3, is installed, and the deflection system is mounted in a specially constructed glass neck (fig. 20).

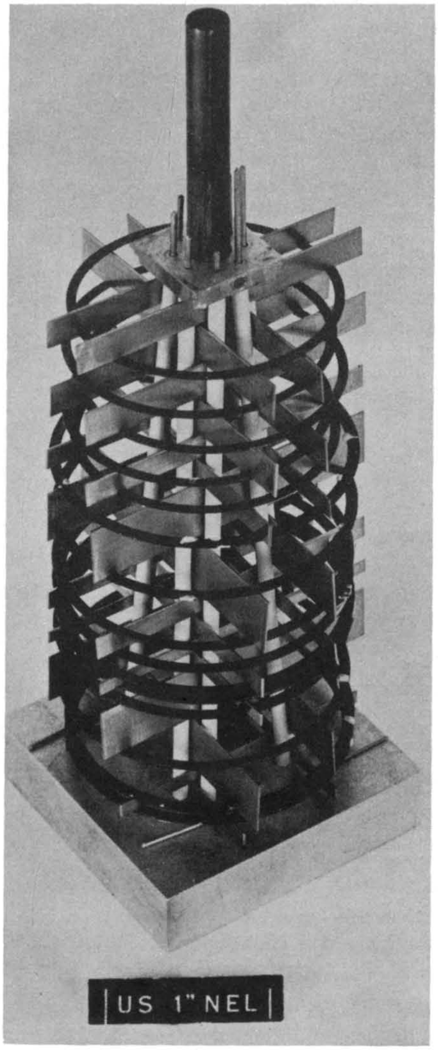

Figure 18. Deflection plates assembled in jig.

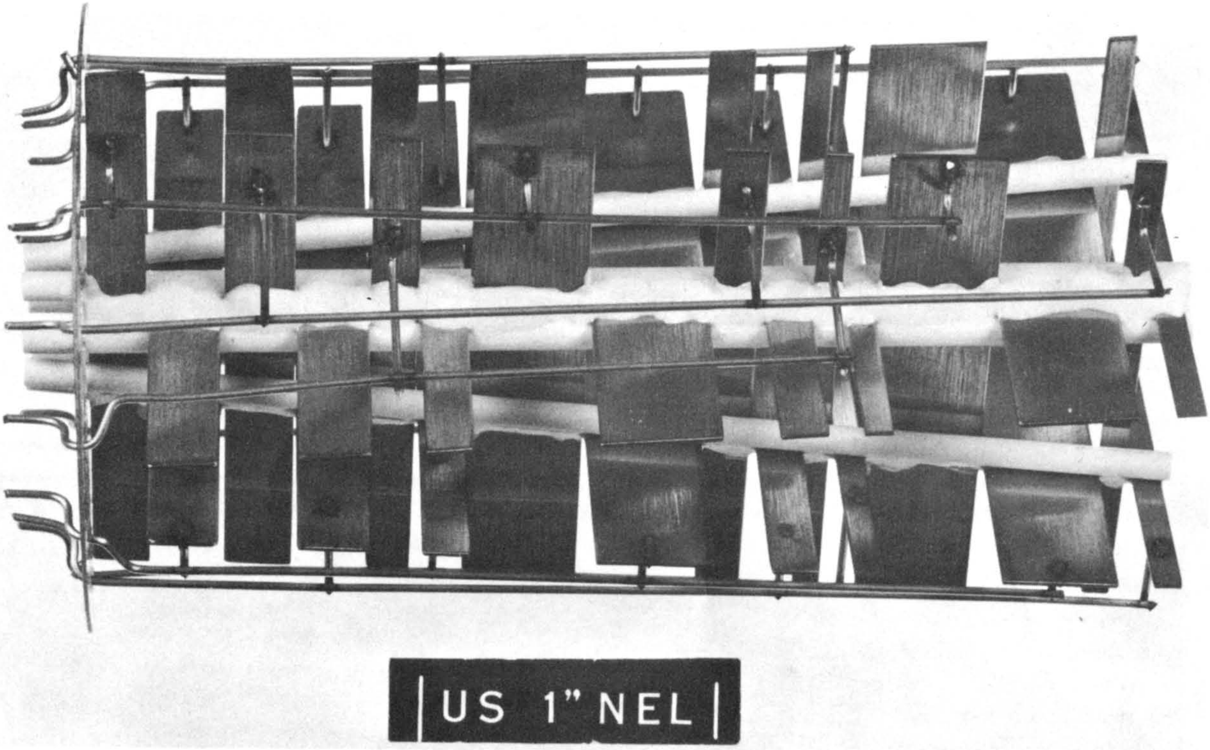

Figure 19. Assembled deflection system with connections.

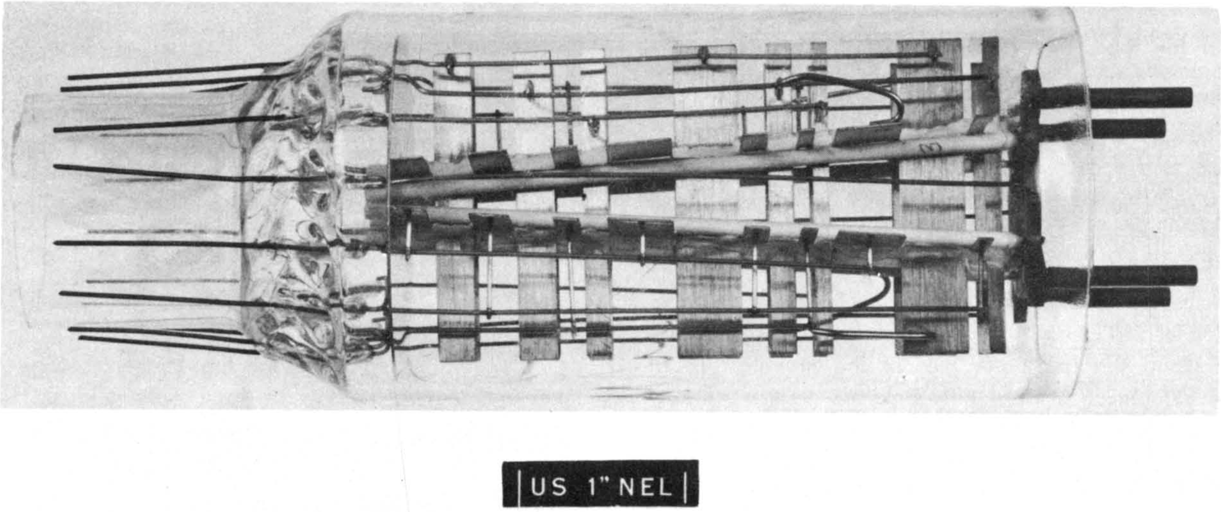

Figure 20. Deflection system mounted in specially constructed glass neck.

electron gun

The electron gun is a standard RCA 902A gun with the standard deflection system removed.

Outputs

The only difference in manufacture of the Electrical and Printing Matrixatrons is in the output end

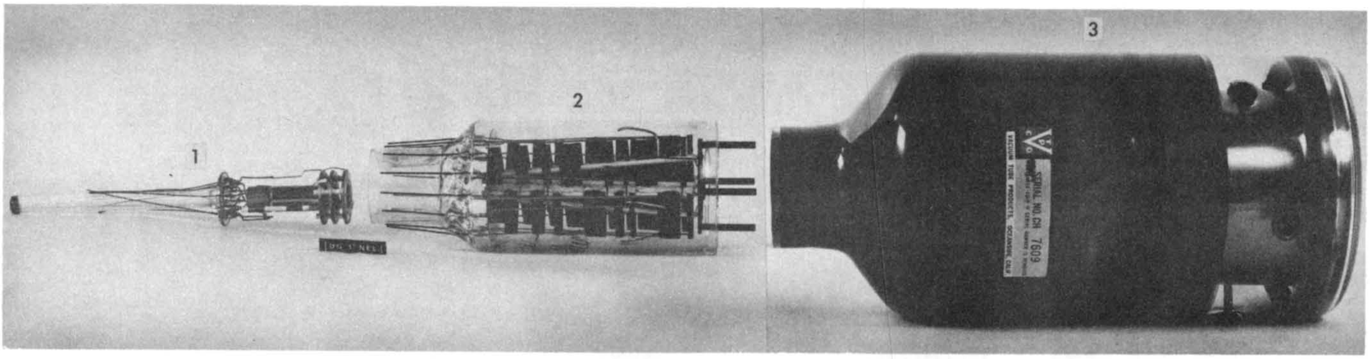

Figure 21. The three sections of the Printing Matrixatron before final assembly.

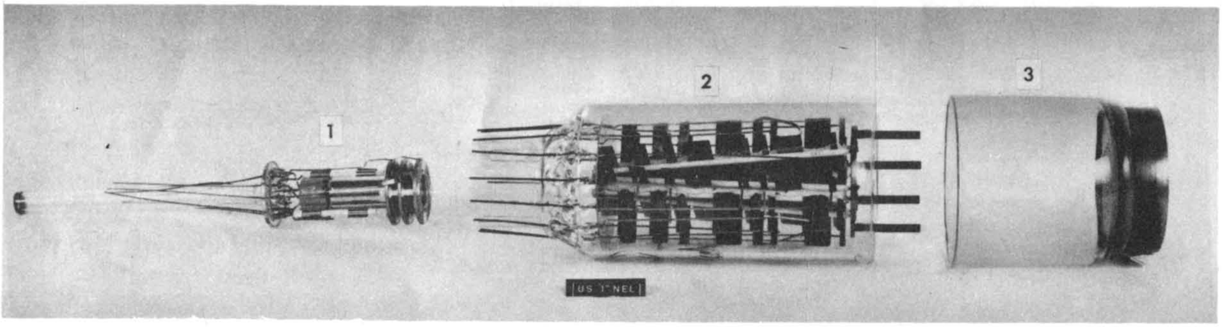

Figure 22. The three sections of the Electrical Matrixatron before final assembly.

of the tube, and fabrication of the outputs is discussed separately.

The electrical output end of the tube is called the target assembly. It contains 64 metal pins, glass-fused in holes in a metal cup. Several methods of manufacture were tried on this target assembly, all of which were partially successful. However, none of them would be suitable for quantity production because of the high percentage of rejects due to cracking of the glass in the vicinity of the pins and cup. Despite the difficulties met in the manufacture of development models, it is believed that a suitable technique can quite easily be found for building quantities of production models. The process was not perfected during development work because of the pressure of time.

The output end of the Printing Matrixatron presented difficulties in manufacture during development but these difficulties were completely eliminated in the final model of the tube. Figure 30 shows the complete tube in detail. The large portion of the glass envelope is a standard 5R bottle with the contact buttons added, and with the neck enlarged to fit the 2.5-inch glass tubing in which the deflection system is mounted. The number mask of figure 30, part 1-5, is mounted on the three buttons as shown. To install this mask, it is necessary to cut the tube approximately 4 inches from the face, install the number mask, and then reseal the bulb.

assembly

The final assembly of the tubes involves alignment and sealing together of three sections (figs. 21 and 22). Section No. 1 is the electron gun, section No. 2 is the deflection system, and section No. 3 is the output.

Sections No. 1 and 2 are first aligned by inserting the jig (fig. 23) between the deflection plates, and moving the electron gun into position so that the pins are inserted into the holes in the electron gun anodes. With the gun held in position in this manner, the glass seal is made between the two sections.

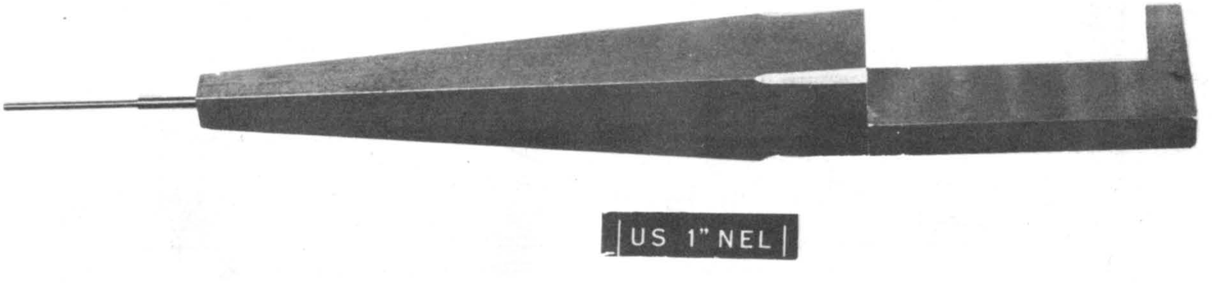

Figure 23. Alignment jig used in final assembly of Matrixatrons.

The final seal is made between sections 2 and 3 by chucking the parts in the two ends of a glass turning lathe. Before the seal is made, the deflection system is aligned with the number mask in the Printing Matrixatron and with the target assembly in the Electrical Matrixatron. When this has been done, the tube is evacuated, tipped off, and based. The specially constructed neck containing the deflection system was designed to receive a modified 14-pin medium-shell diheptal base. The electron gun base is a standard small-shell-duodecal. Pin connections are shown in figure 30.

OPERATION OF MATRIXATRONS

The Matrixatrons are cathode-ray tubes containing an electron gun, a deflection system, and outputs. The Electrical and Printing Matrixatrons are identical except for the output section.

The electron gun in both tubes operates like the electron gun in any ordinary cathode-ray tube. In fact, it is a standard electron gun of the type used in most oscilloscope CRT's when electrostatic focus and deflection are used. All tubes built contain the standard 902-A electron gun; its characteristics are available in the RCA tube manual.

The electron beam formed by the 902-A electron gun is deflected to an individual position at the output end of the tube by the presence of a 6-bit coded information group of voltages impressed upon the Matrixatron deflection system. This deflection system is made up of six pairs of deflection plates. Three pairs of these plates are arranged so that the beam is deflected in a vertical direction; the other three pairs deflect the beam in a horizontal direction. The three pairs of deflection plates in each direction are designed to have relative deflection sensitivities of 1, 2, and 4 units. This means that a voltage of the same amplitude, when impressed upon the respective plates, will deflect the electron beam 1, 2, and 4 units respectively. When a voltage is impressed upon more than one plate simultaneously, the resulting deflection is the vector sum of the individual deflections. The simplified drawing of figure 24 illustrates the paths that the electron beam will take as plates are energized in various combinations. The beam is initially positioned at 0 by voltages impressed on all plates through isolation resistors. The dark line indicates the approximate path of the electrons reaching the 0 position. The dotted lines indicate the approximate deviation from this path when voltages are present upon the deflection plates indicated by the numbers written next to these lines. The deflection plates in the other direction are numbered 10, 20, and 40 as shown in figure 5. The outputs are numbered so that the number out can be obtained simply by adding the numbers of the deflection plates on which voltages have been impressed. The input code has an octonary form, and the output is the corresponding octonary number. The deflection plates in the tubes are actually cycled and interleaved so that all sets of plates have the same effective point of deflection.

The pattern of beam positions at the output end of the tube will tend to have a barreled type distortion due to interaction between plates. This distortion is compensated for by a dc voltage on the equalizer pins. Figure 9 shows the patterns that can be obtained by variation of voltages on these pins. For an electron speed of 1000 volts, the optimum pattern is obtained if the pins are set at approximately 150 volts positive with respect to the deflection system mean voltage.

The outputs are completely different for the Electrical and Printing Matrixatrons. In both cases, however, the output results from the electron beam originated by the electron gun and deflected to a position at the output end of the tube by the deflection system. In the Electrical Matrixatron, the beam

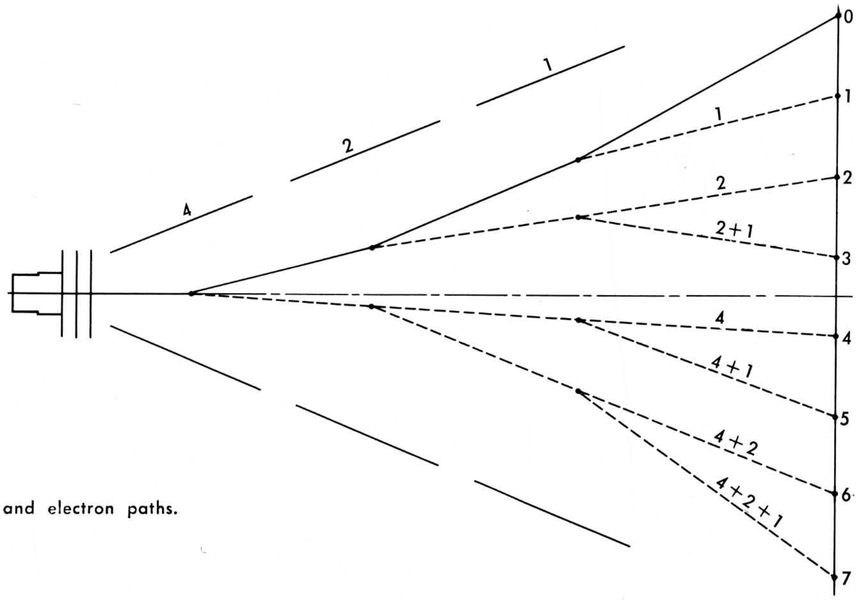

Figure 24.
Simplified Matrixatron and electron paths.

current, approximately 50 microamperes, is picked up on a metal target and is used to drive some external circuit. In the Printing Matrixatron, the electron beam is formed into a number shape and strikes a phosphor screen to give a lighted number output. The Matrixatrons are essentially 64-position electronic switches and can be compared to gate-tube switches, resistance matrix switches, and crystal matrix switches. Switches of this type are discussed in an MIT Project Whirlwind Report.[4] The crystal matrix switch can be designed to give switching times that are comparable to the Matrixatron up to an 8- or 16-position switch. Above this, the number of components required becomes excessive and the amount of power required to drive the circuit becomes large. The Matrixatron is believed to be more practical, easier to operate, and more reliable for any application that requires more than 4-digit input codes with 16 outputs.

The block diagram of figure 25 illustrates the Matrixatron and associated driver circuits necessary to receive a 6-bit input and give 64 outputs. The power required to drive the Matrixatron is low so that miniature tubes can be used in the driver cir-

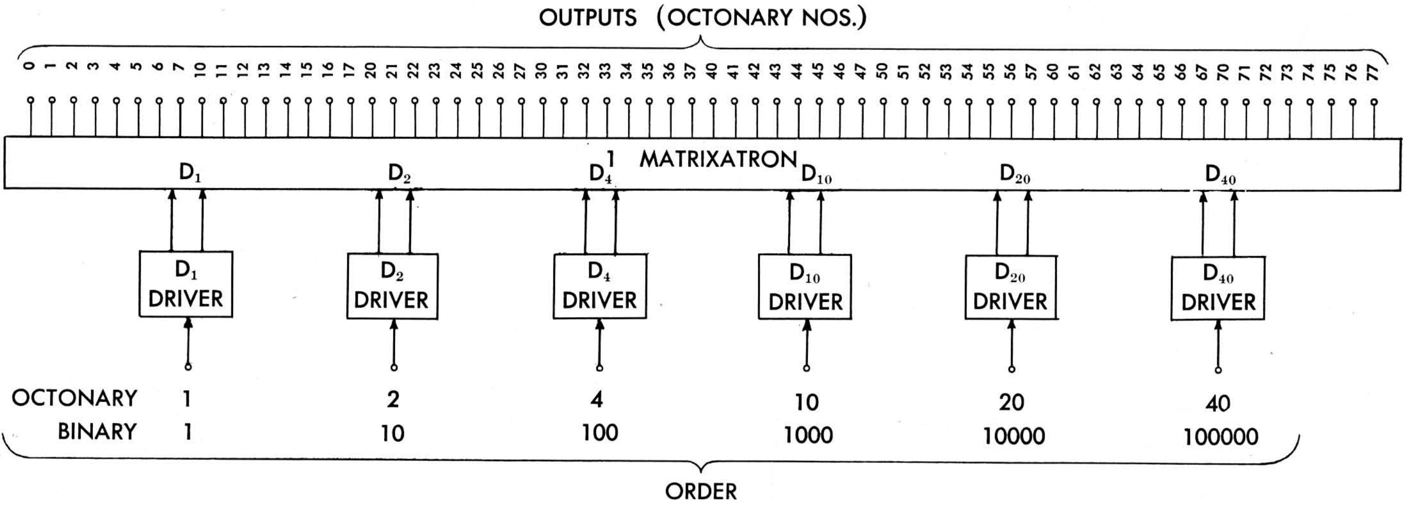

Figure 25. Block diagram of Matrixatron and driver circuits.

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[4] D. R. Brown *A High-Speed Multi-Position Electronic Switch* (Massachusetts Institute of Technology. Servomechanisms Laboratory, Report R-157) 7 March 1949.

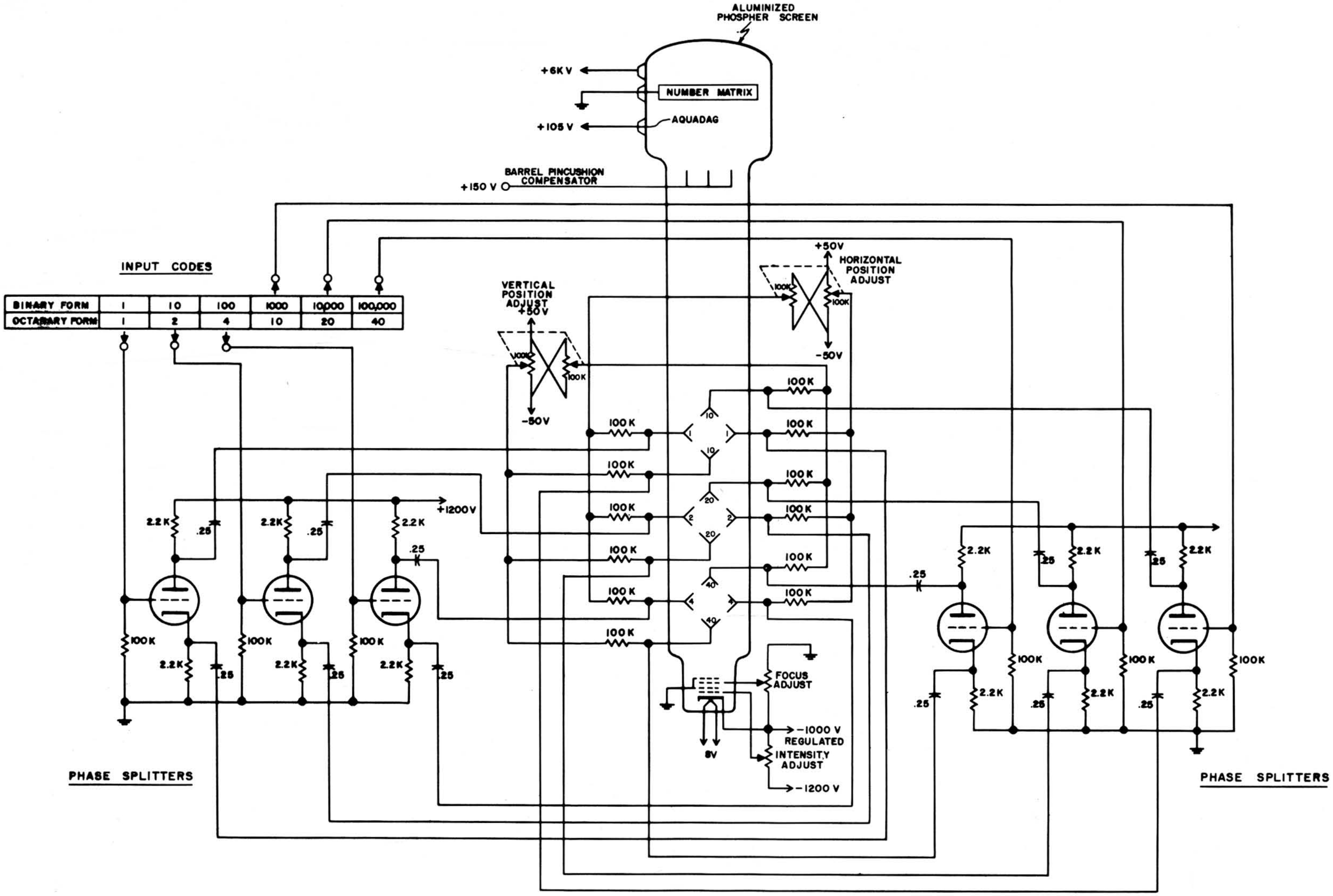


Figure 26. Schematic diagram of typical Matrixatron and driver circuits.

cuits. These drivers can be flip-flop circuits, phase splitters, and so forth. The Matrixatron will perform the required switching and give usable outputs from inputs that vary in length from 0.5 microsecond to infinity. The limiting factor in the Matrixatron switching time is the electron transit time and the input capacity of the deflection system. The transit time is approximately 0.01 microsecond. The input capacity of each deflection plate is 11 micromicrofarad, ±20 per cent.

The circuit diagram of figure 26 is a typical set-up in which the Matrixatron can be used. This circuit will accept a 6-bit input code group and switch to the correct number within 0.1 microsecond. The outputs from the phase splitters are capacity-coupled into the deflection plates; therefore an intermittent or recurring type of input must be used. The maximum length of pulse that these circuits (external of the tube) will handle is approximately 250 microseconds. This can be extended indefinitely by increasing coupling. The circuit will handle very short pulses and will print a number that is easily recognized upon receipt of the equivalent of six code groups of one-half microsecond duration, received at a repetition rate of 60 per second up to 400 per second.

The function of the phase splitters is to put push-pull voltages on the deflection plates. This is necessary to reduce astigmatism.

The codes used to energize this circuit may be derived from switched dc, coincidized pulse trains, detected tones, detected rf, and so forth. The voltages needed to drive the phase splitters are approximately 35 volts ±20 per cent. The Matrixatron control grid can be biased to cut off the beam current. If this is done, an output will be obtained only when a gate pulse is present on the grid. This gives another element in the tube into which intelligence can be inserted.

By using two tubes, the input code can be extended to 7 digits and 128 individual outputs can be obtained. If the deflection plates of the two tubes are paralleled, and the two guns are connected as shown in the circuit of figure 27, the tubes will accept a 7-bit input code and give an individual output for any input code. In this circuit the bias of T1 and T2 is set so that T1 will conduct and T2 will be cut off, except when a positive voltage is impressed on the input. A positive voltage pulse will turn T1 off and T2 on. When there is no voltage present on this input, T1 will conduct and will give an individual output for any combination of the remaining six bits of input information. If this bit of information is

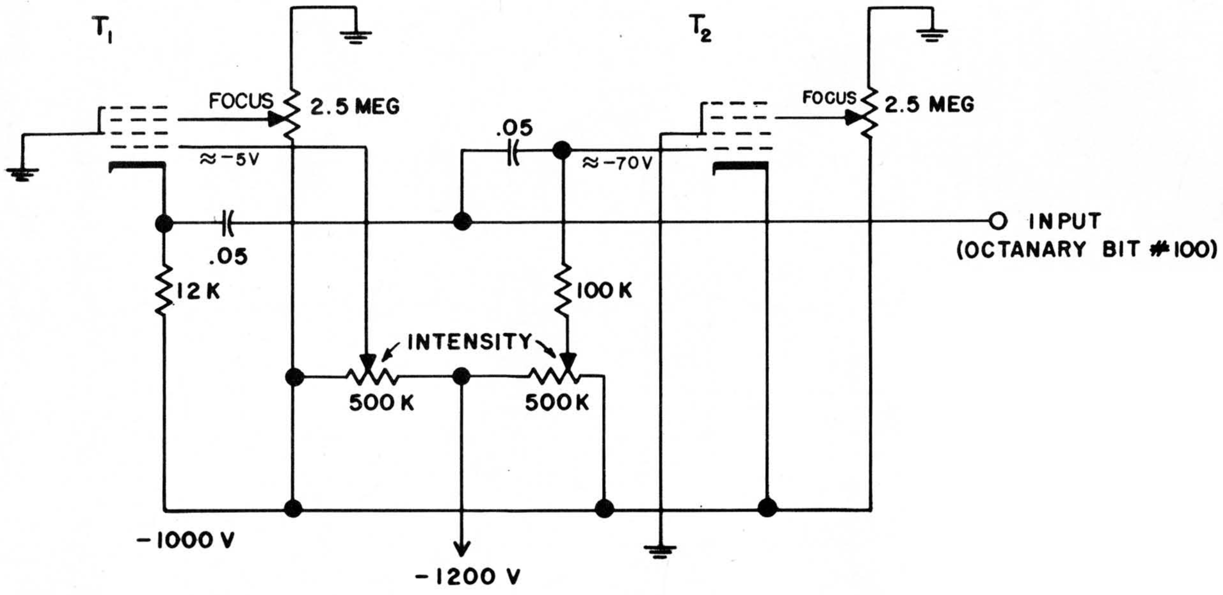


Figure 27. Schematic diagram of typical electron gun circuit of two Matrixatrons for extension to 7-digit input codes and 128 outputs.

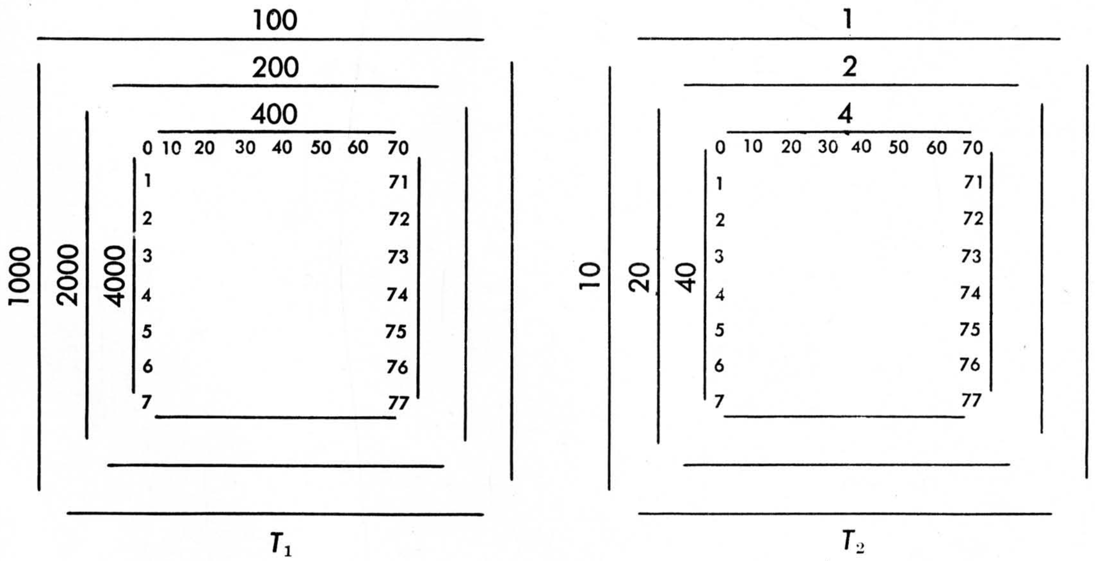
ON, T1 will be cut off and T2 will conduct, giving an individual output for any combination of the remaining six bits of input information. This input bit is essentially the same as the other six bits, and may be derived from the same sources. However, approximately 65 volts is required, compared to approximately 35 volts for the other six bits.

The capabilities of the tubes alone are limited to 7-digit input codes and 128 outputs, by using two tubes. However, the use of external mixers extends the limits indefinitely. These mixers can be used on the inputs to the tubes or the outputs of the tubes.

It is rather simple to extend two Printing Matrixatrons to handle a 12-digit input. This would give 4096 different combinations, or the octonary equivalent of 7777 combinations, and would provide an individual number output for each input code combination. The table of figure 28 gives the octonary and binary number of each input code bit for a 12-digit code. Figure 29 shows the deflection plates of the two Matrixatrons into which each bit would be fed. The numbers appearing on T1 would make up the first two digits of the output and the number appearing on T2 the last two digits. As an example, suppose that the input code contained the following octonary bits: 4000, 1000, 200, 100, 20, 10, 4, 2. With this input, the lighted number that appears on T1 will be 53, and the number that appears on T2 will be 36. Combining the numbers as outlined above gives 5336, the octonary number of the octonary code given in the example. This solution can be easily checked by adding the bits present in the input code. Thus: 4000 + 1000 + 200 + 100 + 20 + 10 + 4 + 2 = 5336.

	CODE BITS											
OCTONARY FORM	1	2	4	10	20	40	100	200	400	1000	2000	4000
BINARY FORM	1	10	100	1000	10,000	100,000	1,000,000	10,000,000	100,000,000	1,000,000,000	10,000,000,000	100,000,000,000

Figure 28. Octonary and binary numbers of the input code bits for 12-digit codes.



T_1 T_2

Figure 29. Two Matrixatron deflection systems showing octonary input bits for 12-digit input code.

POTENTIAL USES OF MATRIXATRONS

The primary function of the Matrixatrons is to take an input code group containing six bits of binary information and give an individual output for each input code. The Matrixatron is essentially a 64-position electronic switch. By means of a 6-digit code, any one of 64 loads can be selected. This can be extended to 7-digit code input, and 128 outputs, by using two tubes. The characteristics of the tube are such that extremely fast switching times can be easily obtained. Only one output can be selected at a time; however, another output may be selected within 0.1 microsecond after removal of the previous selection. In the absence of a coded input, the electron beam is automatically reset to the zero position.

The Matrixatron can be used to detect a 5-, 6-, or 7-digit coded input and select a load, and/or present a display which is a function of the coded input. The Electrical Matrixatron would be used in applications where the selection of a load is required, and the Printing Matrixatron to present the display.

These tubes can be used as a means of rapidly converting data from binary form to data of octonary or decimal form.

The Matrixatrons can be used in any application that requires a high-speed multi-position electronic switch. Compared to other type multi-position electronic switches, such as the resistance-matrix, crystal matrix, or gate tube matrix, it is believed that the Matrixatrons would be simpler, easier to operate, and more reliable for most applications that require more than 4-digit inputs and 16 output positions.

The applications for the Matrixatron are most likely to occur in communication, telemetering, remote control, computers, coded identification, and indicators.

The Printing Matrixatron has been used in an Air Traffic Control Aircraft Identification Unit developed at this laboratory. An NEL report is currently being prepared on this unit. The unit has been evaluated at NANEP, Patuxent River, Maryland. The results of this evaluation are contained in a NANEP report.[3]

CONCLUSIONS

Two Matrixatrons have been developed, each of which will accept a 6-digit binary code input and give a separate and individual output for each coded input. Each tube contains an electron gun, a deflection system, and an output assembly. The two tubes, termed the Electrical Matrixatron and the Printing Matrixatron, are identical except for the output assembly. The Electrical Matrixatron has an electrical output of 50 microamps on a separate target for each input code. The Printing Matrixatron gives a visible number output for each input code. Low voltage and power are required to drive the tubes. The tube sizes are comparable to CRT's used in oscilloscopes. The tubes are easy to fabricate and simple to operate. The characteristics of the tubes are such that extremely fast switching times can be easily obtained. Only one output can be selected at a time; however, another output can be selected within 0.1 microsecond after removal of the previous selection. In the absence of a coded input, the electron beam is automatically reset to the zero position.

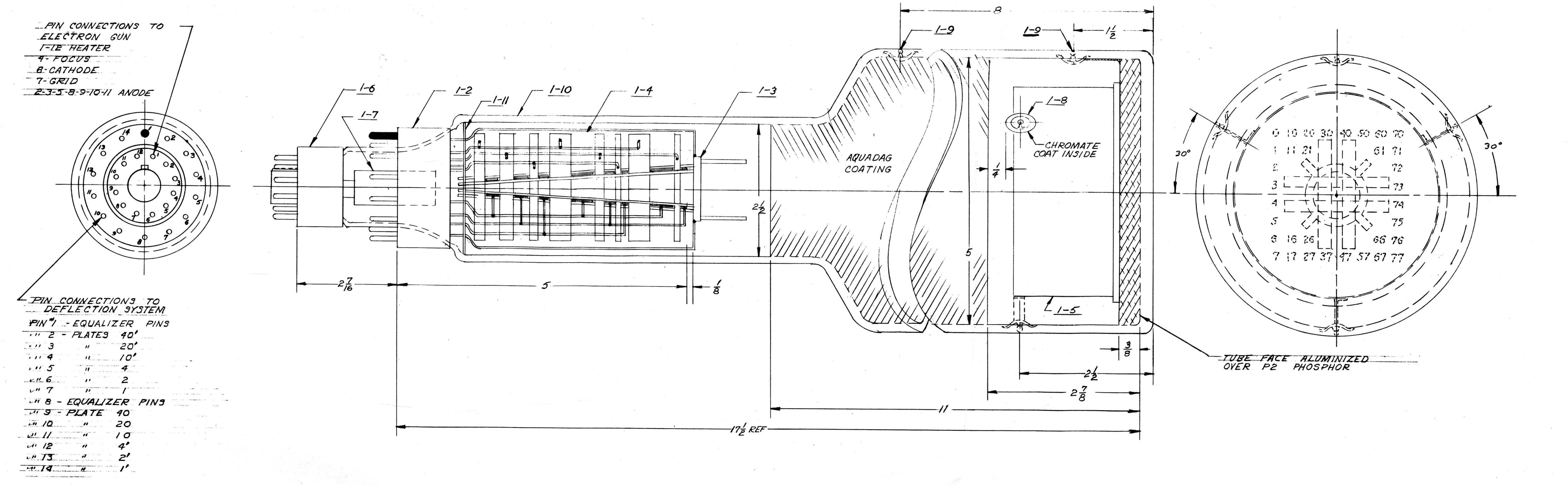
The Matrixatron is essentially a 64-position, very high-speed electronic switch. By means of a 6-digit code, any one of 64 loads can be selected. This can be extended to a 7-digit code and 128 loads by using two tubes. The capacity of the tubes alone is limited to 7-digit code inputs and 128 outputs. However, this can be extended indefinitely by the addition of mixing circuits in either the input to the tubes or the outputs.

A third Matrixatron, the PPI Matrixatron, is now under development.

RECOMMENDATIONS

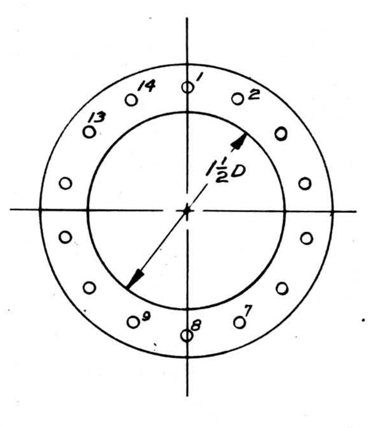
It is recommended that the Matrixatrons be considered for use in the following applications:

1. Detection of a 5-, 6-, or 7-digit code and selection of a load and/or presentation of a display which is a function of the input code. In this respect the Electrical Matrixatron would be used to select a load and the Printing Matrixatron would be used to present the display.
2. Conversion of data from binary form to data of octonary or decimal form.
3. Any application where a high-speed multi-position electronic switch is required.

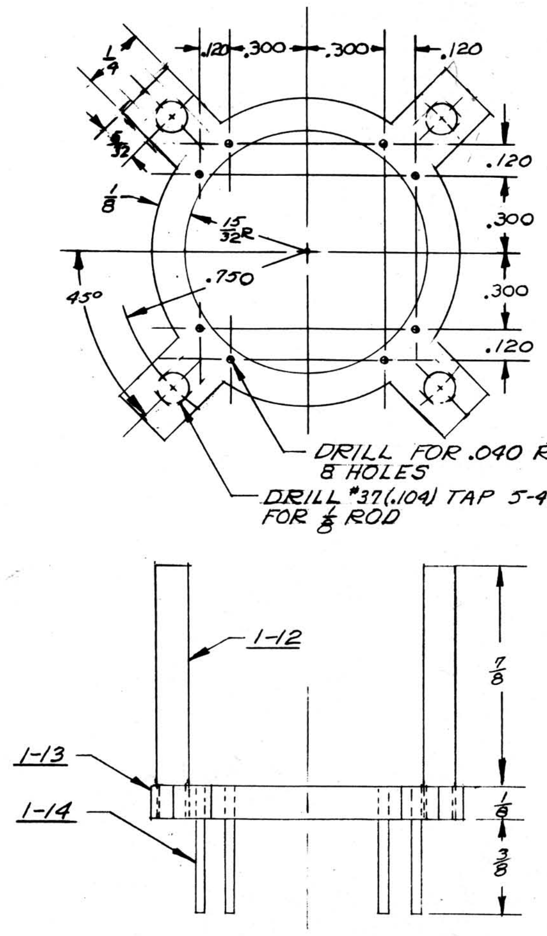


1-1 TUBE ASS'Y

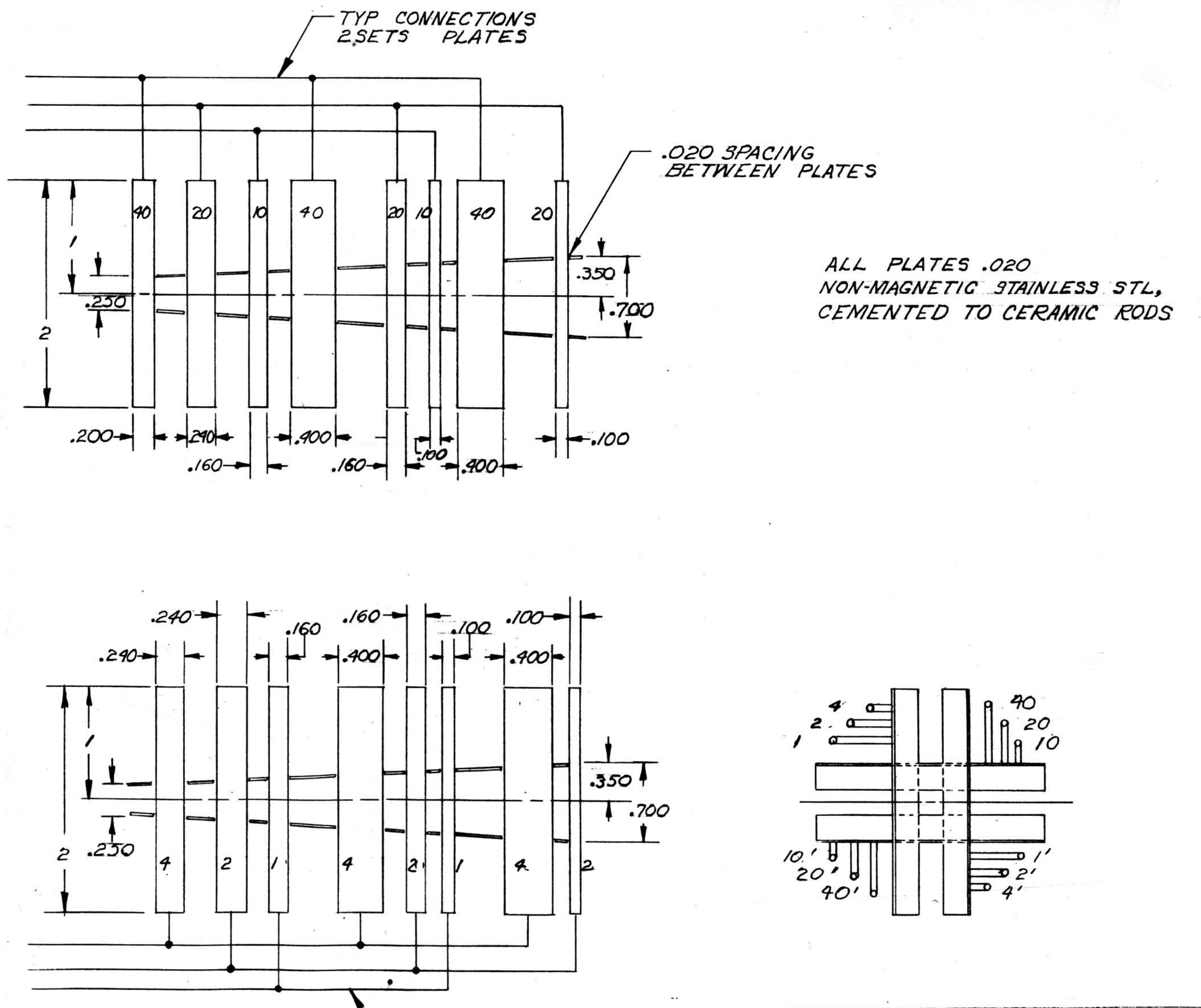
SCALE 1/7



1-2 BASE (14 PIN) MODIFIED SCALE 1/1



1-3 EQUALIZER PINS SUB ASS'Y SCALE 2/1

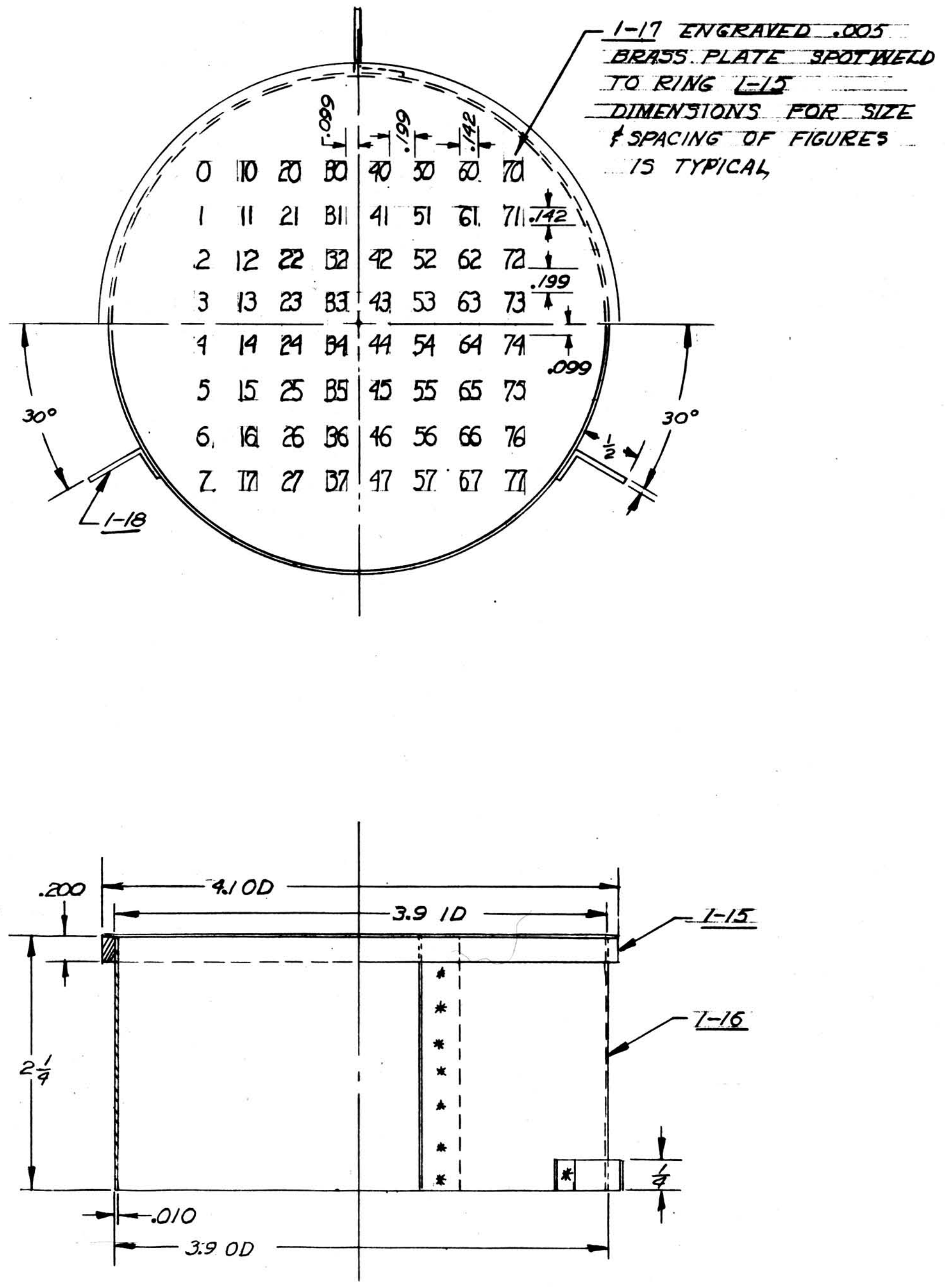


REQ	PART NO.	DESCRIPTION	MATERIAL	MATERIAL SPECIFICATION
3	1-18	BRACKET	CRES	.020 SHT
1	1-17	GRID	BRASS	.005 SHT
1	1-16	COLLAR	CRES	.010 SHT
1	1-15	RING	CRES	
8	1-14	PIN	CRES	.040 X 1/2
1	1-13	RING	CRES	1/8 SHT
4	1-12	PIN	CRES	.125 X 1
1	1-11	SPACER	MICA	
1	1-10	ENVELOPE	GLASS	MFR AS PER SPECS
2	1-9	CONTACT BUTTON		
3	1-8	CONTACT BUTTON		
1	1-7	ELECTRON GUN		TYPE 902
1	1-6	BASE (SMALL SHELL DUO DECAL 12 PIN)		
1	1-5	BARRIER GRID SUB ASSEMBLY		
1	1-4	DEFLECTION SYS SUB ASSEMBLY		SEE TABLE
1	1-3	EQUALIZER PINS SUB ASSEMBLY		
1	1-2	BASE (MED SHELL DIHEPTAL 14 PIN)		
1	1-1	TUBE ASSEMBLY		

PLATES PER UNIT

WIDTH	Nº REQ
.100	8
.160	8
.200	2
.240	6
.400	8

1-4 DEFLECTION SYSTEM SUB ASS'Y SCALE 1/1



1-5 NUMBER MASK

Figure 30. Detail drawing of the Printing Matrixatron.

Navy Electronics Laboratory
Report 605

DECODING MATRIXATRON DEVELOPMENT, by C. H. Cash and W. R. Dawirs. 25 p., 17 June 1955.
UNCLASSIFIED

Two cathode-ray type tubes, termed the Electrical Matrixatron and the Printing Matrixatron, have been developed at NEL. They are, essentially, very-high-speed electronic switches that will accept a 6-digit coded input and select a separate output for any input code. The tubes, identical except for the output, consist of an electron gun, a specially developed deflection system, and an output section. The Electrical Matrixatron switches an electron beam to 64 separate targets and gives an output current of approximately 50 microamp. The Printing Matrixatron prints a visible number for each electron beam position. Low voltage and driving power are required to drive the tubes. They can be produced in quantity at reasonable cost.

The Matrixatrons can be used for communication systems, telemetering, remote control, indicators, computers, etc., and have been used in an Air Traffic Control Aircraft Identification Unit developed at NEL.

1. Electronic switches
2. Matrixatrons

I. Cash, C. H.
II. Dawirs, W. R.

CA 21501 (AD 04401)
NE 010234-2 (NEL A2-1)

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DECODING MATRIXATRON DEVELOPMENT, by C. H. Cash and W. R. Dawirs. 25 p., 17 June 1955.
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Two cathode-ray type tubes, termed the Electrical Matrixatron and the Printing Matrixatron, have been developed at NEL. They are, essentially, very-high-speed electronic switches that will accept a 6-digit coded input and select a separate output for any input code. The tubes, identical except for the output, consist of an electron gun, a specially developed deflection system, and an output section. The Electrical Matrixatron switches an electron beam to 64 separate targets and gives an output current of approximately 50 microamp. The Printing Matrixatron prints a visible number for each electron beam position. Low voltage and driving power are required to drive the tubes. They can be produced in quantity at reasonable cost.

The Matrixatrons can be used for communication systems, telemetering, remote control, indicators, computers, etc., and have been used in an Air Traffic Control Aircraft Identification Unit developed at NEL.

1. Electronic switches
2. Matrixatrons

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CA 21501 (AD 04401)
NE 010234-2 (NEL A2-1)

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