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DESIGN OF A RADIOACTIVE NON-CONTACT ENCODER

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GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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DESIGN OF A RADIOACTIVE NON-CONTACT ENCODER

Use of a semiconductor detector for determining the presence of radioactivity has been made possible by an N-P junction diode detector which permits a compact assembly. An "N" type crystal is formed by addition of controlled amounts of phosphorus, arsenic, or antimony; "P" type crystal is formed by adding boron, arsenic, or antimony.

Figure 1 shows a schematic of a semiconductor diode. In "P" type material, negative charges are shown bound in the crystal structure while holes, positive charge carriers, are free to move under influence of an applied electric field. In the "N" type material, the positive charges are bound while the electrons are free to move.

A potential applied as shown permits the negative and positive charges to move toward the junction, resulting in a current flow. Reversing the potential, causes the negative and positive charges to move from the junction and no current (except for a small leakage current) results. A depletion region free of charge carriers has been formed in the vicinity of the junction. An ionizing particle passing through this region will produce ion pairs resulting in a momentary current flow. The charge produced is proportional to the number of ion pairs produced, one pair for each 3.5 ev of energy lost.

A detector should be selected with a depletion depth equal to or greater than the range of the particle concerned. Silicon is usually chosen as the detector material because of the large number of hole-electron pairs created as compared to the number created in gasses or other materials and also because the pulse rise time is of the order of 10 nanoseconds.

Because the alpha sources available for use are considerably more energetic (in excess of 5 Mev) than the available beta sources (approximately 0.16 to 0.55 Mev), more ion pairs are created with a resultant larger voltage signal. This is the basis for the encoder design.

Referring to the nomograph (Figure 2) of this report, one notes that the required bias and depletion depth for an alpha source is considerably less than that required for a beta source.

ENCODER ASSEMBLY

Normally, a non-contact shaft position encoder consists of three major components - (1) a detector; (2) encoder disk; (3) triggering environment for detector (light or magnetics). These are in addition to the necessary electronics. A radioactive source encoder may contain either all three of the aforementioned components or because a radioactive source requires no wiring, the disk may be eliminated by permitting the radioactive sources to rotate.

Figure 3 represents a laboratory model of the 3 bit encoder assembled by AMF under contract to GSFC. Neither the size nor the assembly indicated a final version but is merely a feasibility model.

RADIOACTIVE SOURCE

The radioactive source used is 241 Am of approximately 160 Curies. It was chosen because it is almost pure alpha, highly energetic (5.48 Mev), and does not come under special Nuclear Materials licensing requirements and has a long half life (548 years).

As assembled in the feasibility model, three separate sources, manufactured by Monsanto Research Corporation, Dayton, Ohio are used and are stationary. Physical size and assembly of the source is shown in Figure 4. The sources are still operational after 3 years.

The same effect could have been accomplished by either (1) using a stationary source with a diameter large enough to cover the three detectors with a mask on the source to expose an area equivalent to the sensitive area of each detector or (2) by permitting the source to rotate with a thin mask which duplicates the geometry of the disk. The charge is the same for a radioactive source 5/16" to 1" diameter.

DETECTOR

A. Description

The semiconductor detector used is a SJ 2400 silicon diode detector packaged in a TO-5 can with a 0.1 mm depletion depth, 1000 ohm cm resistivity manufactured by the RCA Victor Co., Ltd., Montreal, Canada.

B. Theory of Operation

The associated electronics consist of two distinct systems - an amplifier and an integrator. Figure 5 is a schematic of these systems.

These systems developed by AMF for GSFC functions as follows:

The amplifier is a two stage affair with its parameters tailored to amplify and shape the detector output signal for presentation to the integrator circuit. The first stage, consisting of transistors Q1 and Q2, is a current driven feedback pair whose gain is controlled by the ratio of R3 to R6. A large amount of feedback is employed to provide a very low input impedance and high gain stability. The effective low input impedance of this stage then serves to optimize the current output of the detector. The value of capacitor C2 is kept small to limit the noise bandwidth of the amplifier but must be large enough to prevent excessive differentiation of the signal pulse.

The second stage of the amplifier, composed of transistors Q3 and Q4, forms a voltage driven feedback pair whose gain is controlled by the ratio of R11 to R10. This ratio is kept low, giving the circuit a large degree of negative feedback, thereby providing very stable gain, improved frequency response, high input impedance and low output impedance. The high input impedance of this stage minimizes its loading effect of the following circuitry upon the amplifier.

After amplification the detector pulses are applied to the count integrator circuit. Referring to the integrator circuit diagram, the signal from the amplifier is coupled through emitter follower Q1 to a single shot multivibrator consisting of transistors Q2 and Q3. The trigger threshold of the single shot is controlled by the ratio of R4 to R11 so that discrimination against false triggering by noise is provided. The single shot provides a pulse standardized in width and amplitude for the integrator circuit. The integrator circuit, consisting of transistors Q4 and Q5, averages the detected count rate and provides a DC voltage level at the collector of Q5 proportional to the incoming count rate. When this level falls below the conduction voltage of zener diode CR4, transistor Q6 switches off and its collector level goes positive from zero to 20 volts indicating that the input rate count exceeds the preset rate. The value of the preset rate is controlled by the single shot pulse width which is a function of the value of C3 and integration time which depends upon the value of C5. For low count rates C8 can be added, however this increases the system response time. Following is a table of typical values used.

Preset Count Rate	C3	C5	C8
10,000 Counts/Sec	500 pf	2000 pf	None
2,000 Counts/Sec	2500 pf	2000 pf	1.0 mf

OTHER APPLICATIONS

The same system has been applied to indicate the extended length of a spacecraft boom. The boom used is a beryllium copper type wound on a spool before being extended. The radioactive source is positioned so that it rotates with the spool and generates a pulse when it passes the detector which is stationary on the adjoining structure. In conjunction with an electronic counter, multiplying the number of counts displayed by the circumference of the spool, one obtains the extended length of boom.

ADVANTAGES

1. The elimination of a disk should make the encoder more compact than existing encoders, providing closer assembly between source and detector.

2. Elimination of wiring and circuitry required by conventional light sources or other means, could result in less complex electronics.

3. Higher reliability source results since no input is necessary.

DISADVANTAGES

1. The detector is packaged in a TO-5 case rather than a TO-18 case for a light sensitive detector. This results in a slightly larger unit.

2. Since the assembly includes radioactive material extra handling procedures are necessary.

PERFORMANCE

When tested at ambient and cold temperatures (-40°F) in the laboratory the systems performed well with a stepper motor as the driving force. Three years after initial assembly, the encoder's performance at ambient temperature was equal to its initial performance. No testing was done at other temperatures nor was the boom indicator assembly tested at either temperature because of lack of funds.

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4. Bertolini and Coche, Semiconductor Detectors, 1968.

5. AMF Inc., Final Report on Radioactive Encoder Development.

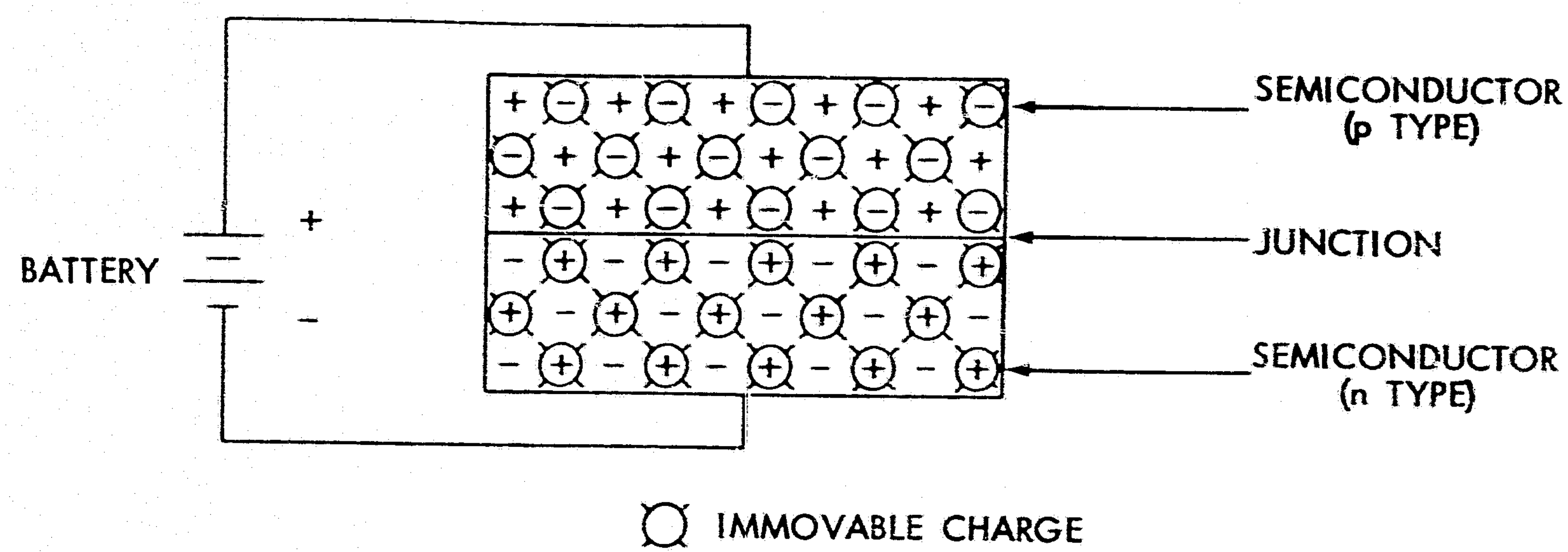
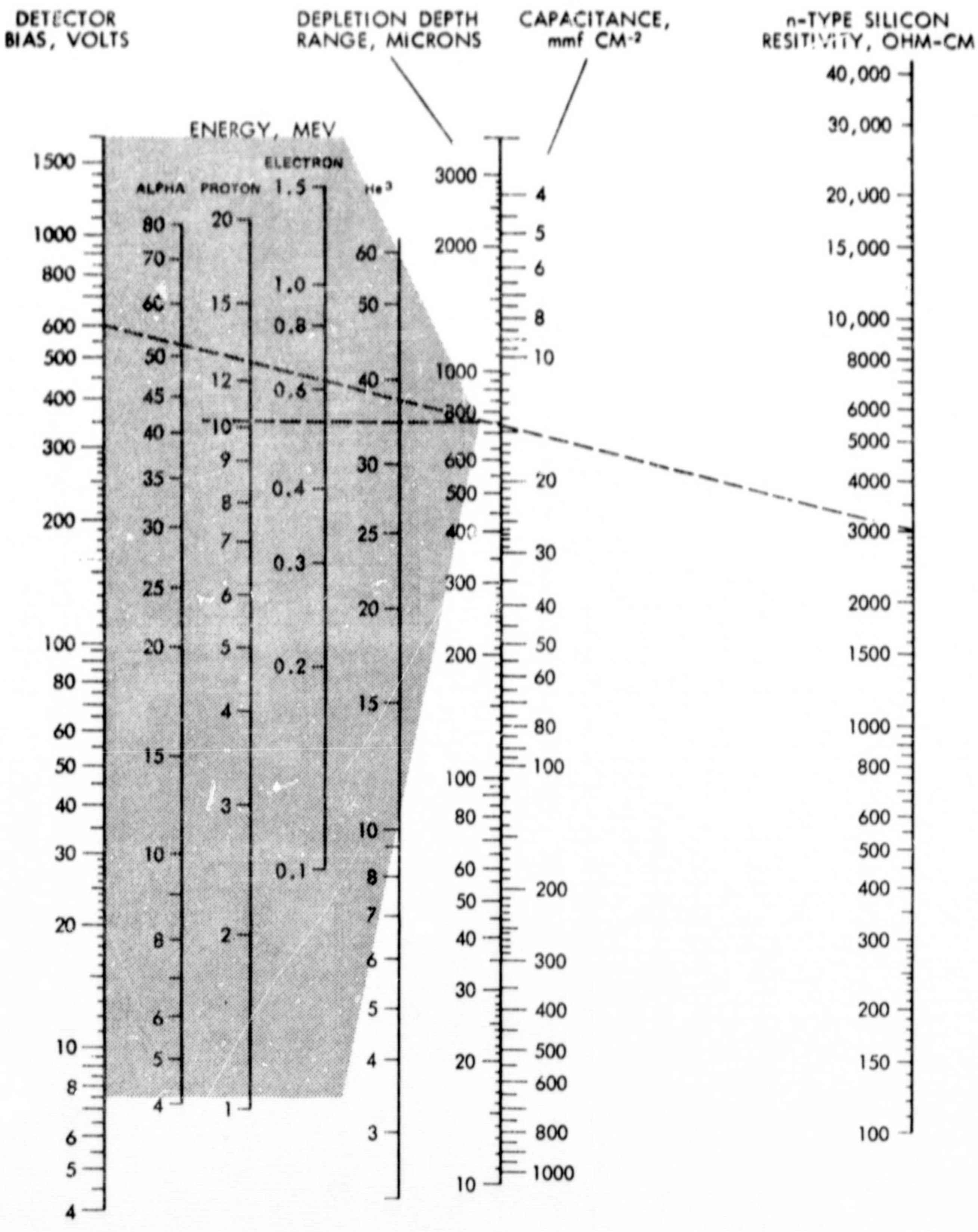
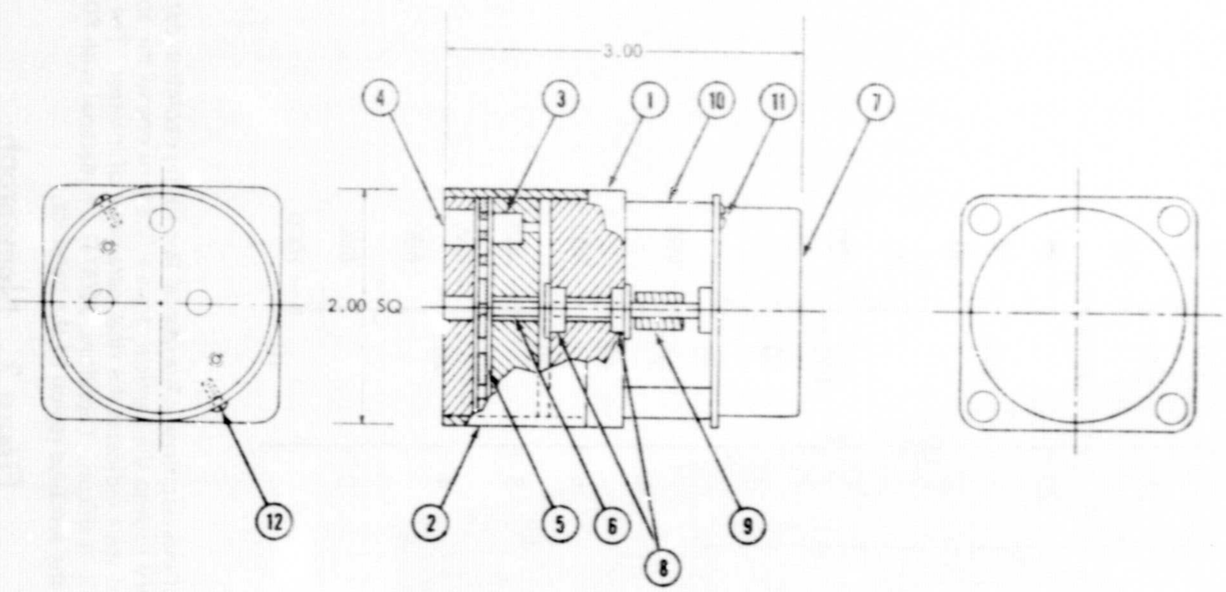


Figure 1. Schematic Diagram of a Semiconductor Diode



To find the range of the particle of interest, draw a horizontal line to the depletion depth scale. To find the operating voltage and resistivity necessary to stop the particle, draw a line thru one of the above parameters and the range. Where it intersects the third scale indicates the final parameter of interest. The above example shows that a 10 mev proton has a range of 730 μ in silicon. Therefore, 3000 Ω cm material with 600 volts applied bias is necessary to stop a 10 mev proton in the sensitive region of the detector.

Figure 2. Nomograph



ITEM	SIZE	PART NO.	REQ'D	DESCRIPTION
12		ST. STL.	6	SCREW, MACH. PAN HD. #4-40 x 1/4 LG.
11		ST. STL.	4	SCREW, MACH. PAN HD. #6-32 x 7/8 LG.
10		2103	4	SPACER, 3/4 LG. H. H. SMITH
9		DI-1		COLLAR, P.I.C.
8		EZ-1	2	BALL BEARING, P.I.C.
7		A18134	1	STEPPING MOTOR, A. W. HAYDEN
6	B	PD 1090	1	SHAFT
5	B	PD 1086	1	CODED DISC
4	B	PD 1087	1	DETECTOR MOUNT
3	B	PD 1088	1	HOLDER
2	B	PD 1091	1	TUBE
1	B	PD 1089	1	HOUSING

Figure 3. Laboratory Model of the 3 Bit Encoder Assembly

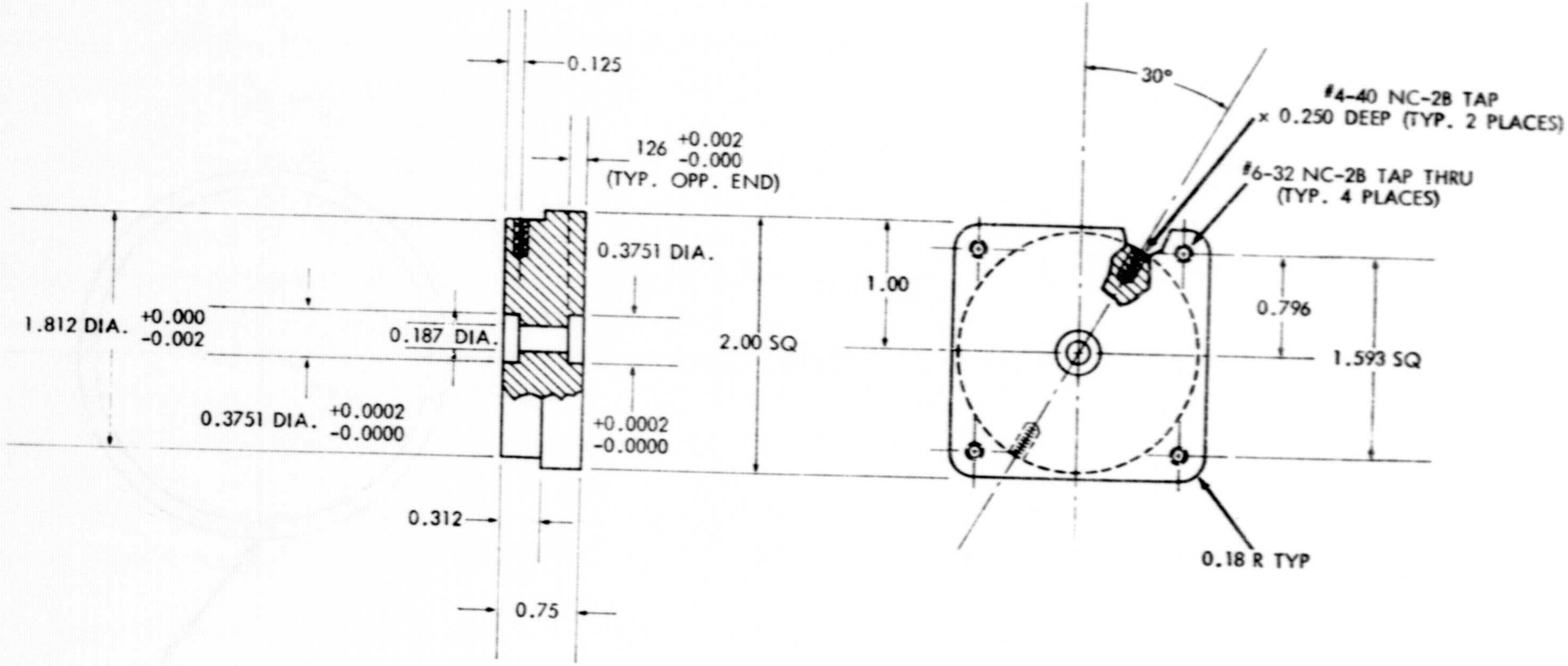


Figure 3a. Housing

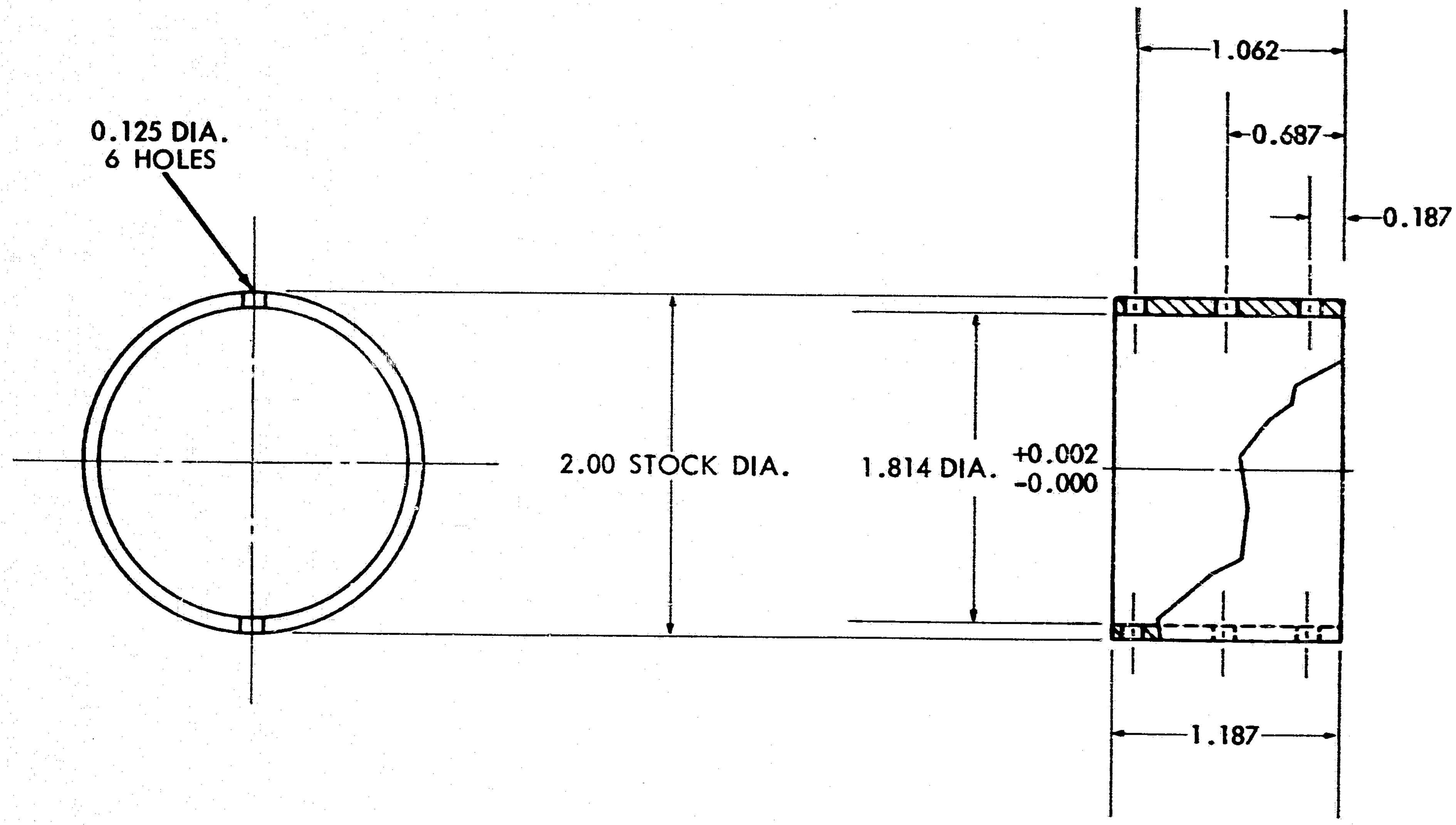


Figure 3b. Tube

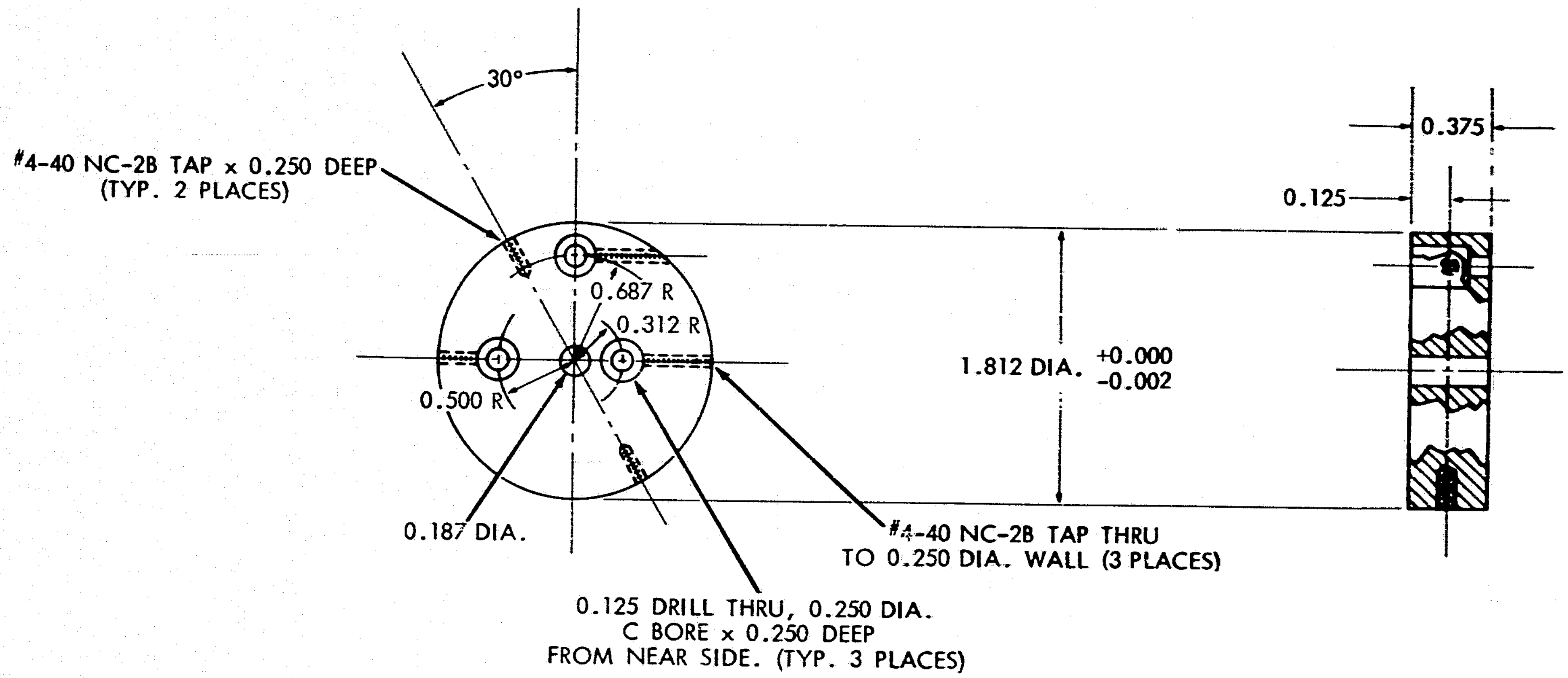


Figure 3c. Holder

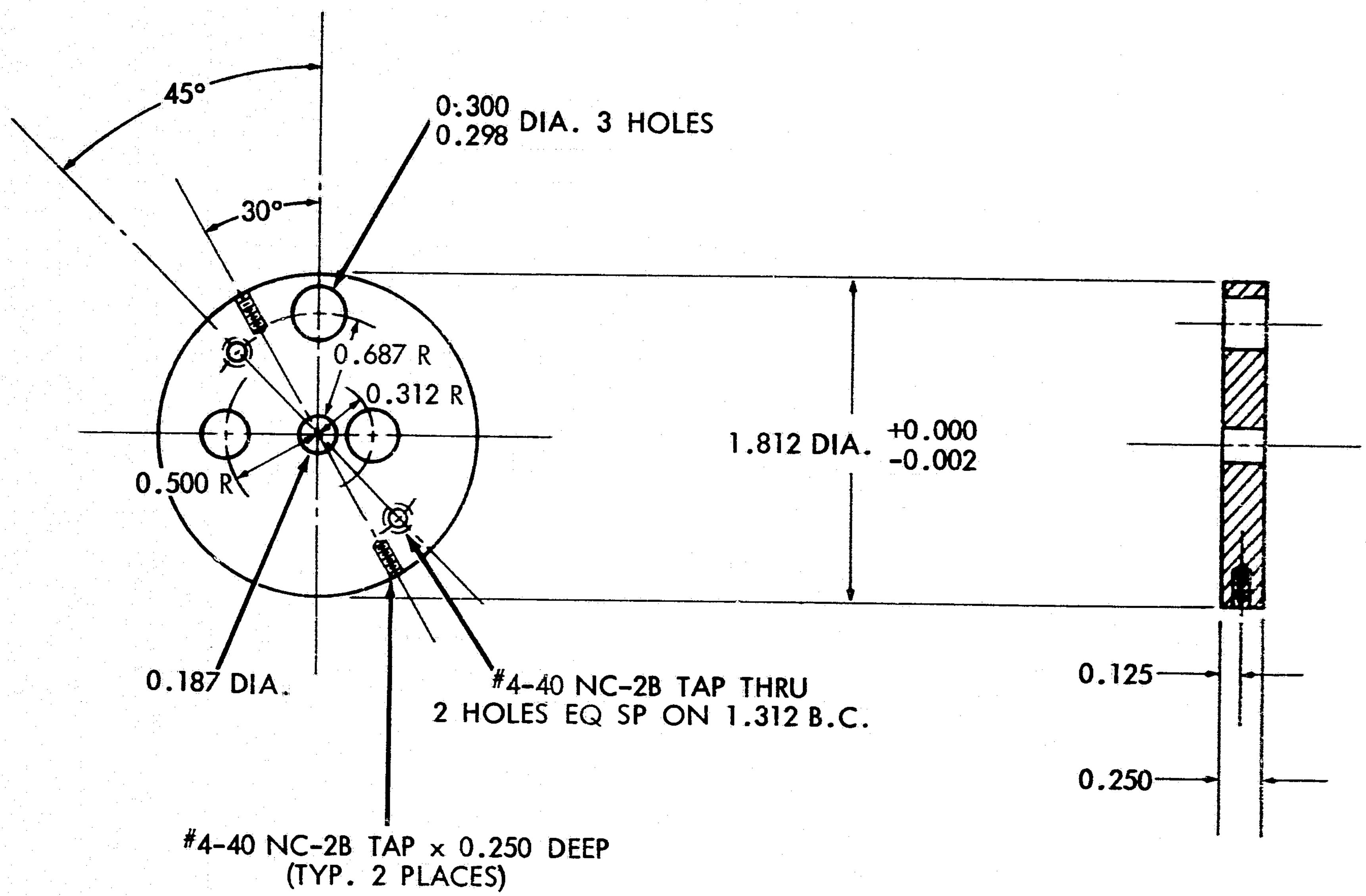


Figure 3d. Detector Mount

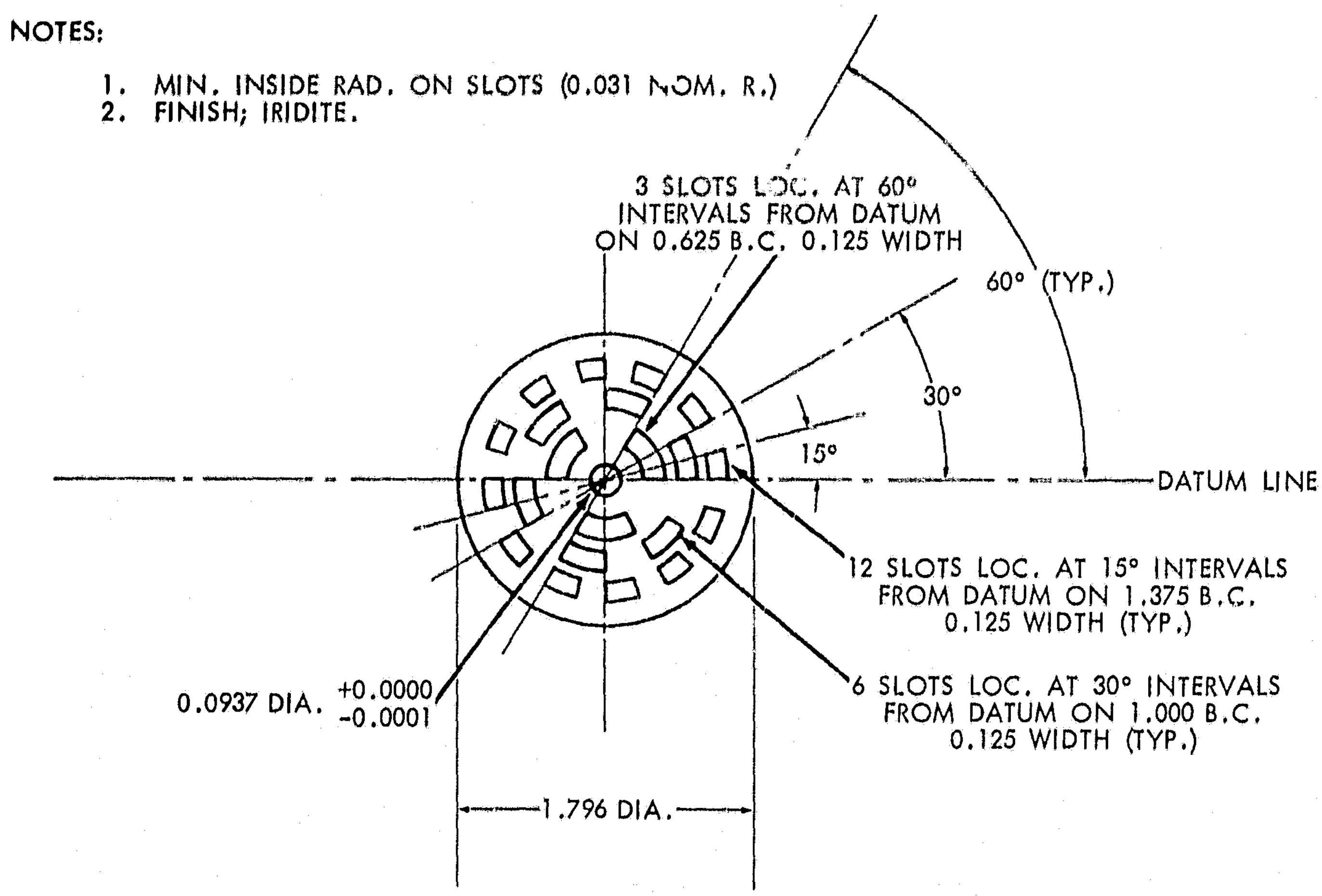


Figure 3e. Coded Disc

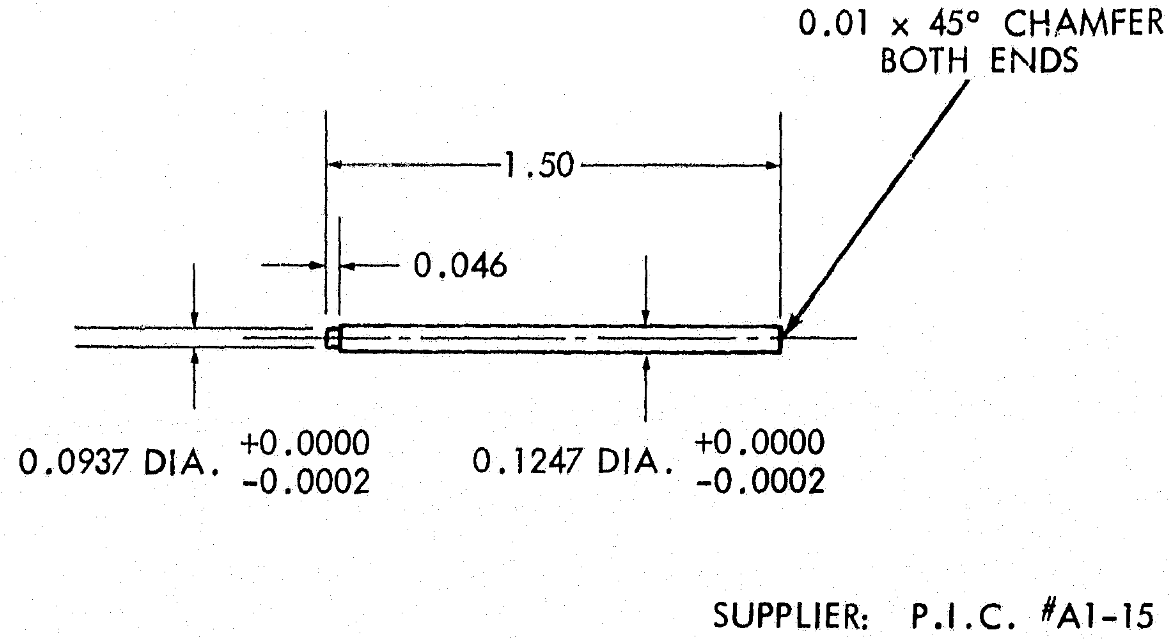
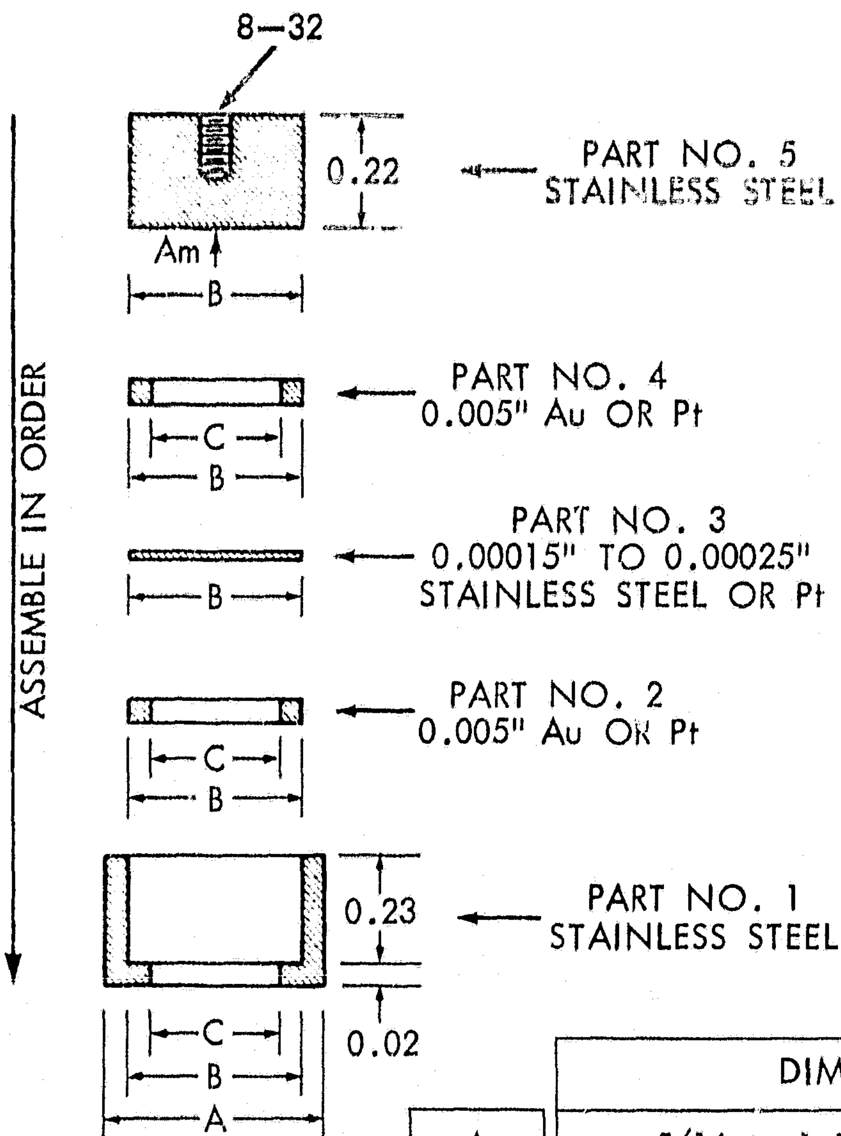


Figure 3f. Shaft



	DIMENSIONS (in.)
A	5/16 to 1 in. increments of 1/8
B	1/4 to 15/16 in. increments of 1/8
C	1/8 to 13/16 in. increments of 1/8

NOTES:

1. SEAL IS EFFECTED BY PRESSING PARTS TOGETHER OR BY WELDING OR SOLDERING
2. CONCENTRATIONS ARE UP TO 100 mc/cm^2
3. LEAK TEST BY WIPING FOR ALPHA
4. USE WITH NO MORE THAN ONE ATMOSPHERE CHANGE IN PRESSURE AND CHANGE PRESSURE SLOWLY
5. USE IN DRY ATMOSPHERE
6. USE IN A PROTECTED AREA
7. WIPE TEST RIM, BUT DO NOT APPLY PRESSURE TO COVER

Figure 4. Am Alpha Source Container (Model MRC-A-SS-P-Am)

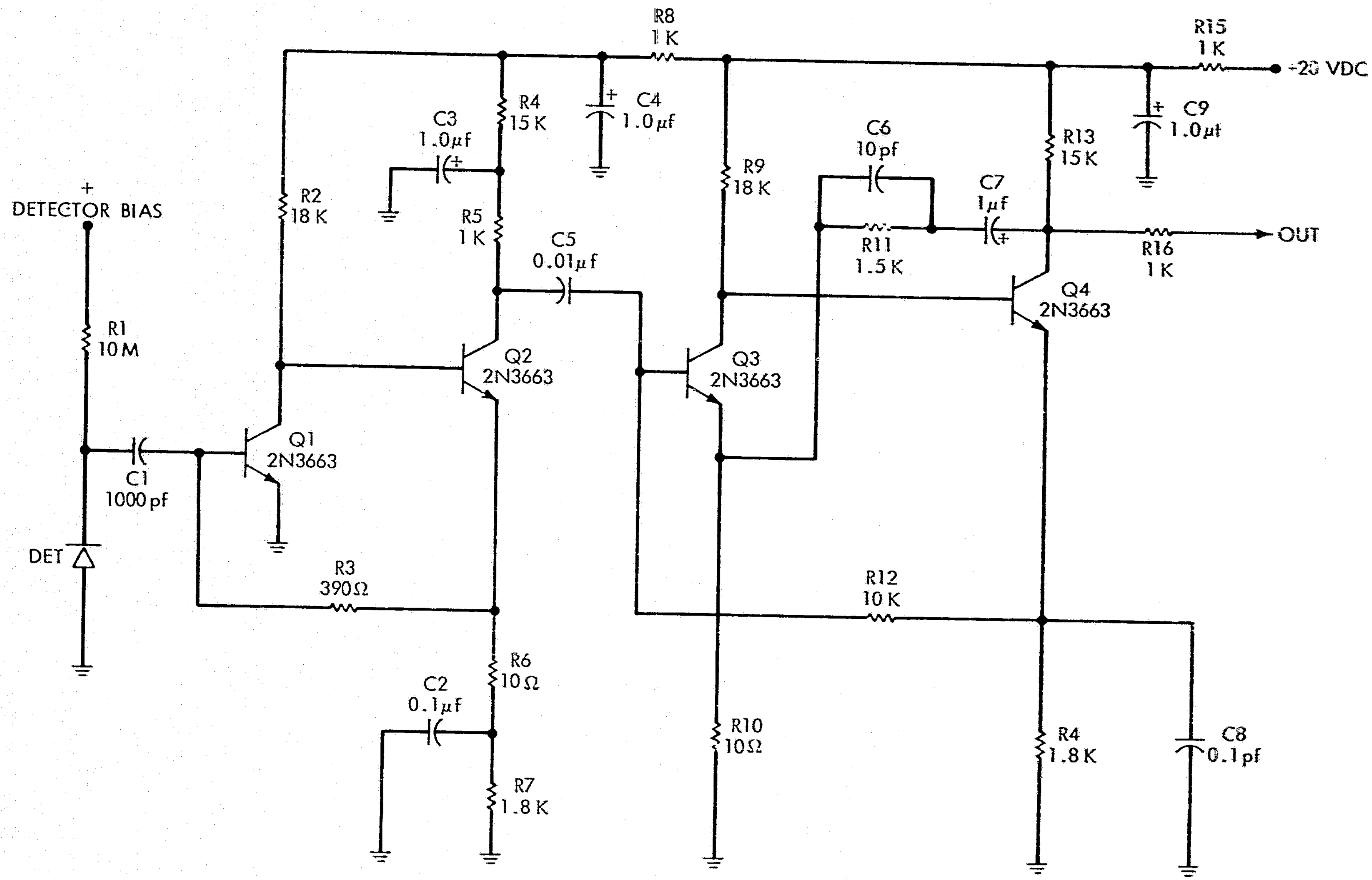


Figure 5a. Nuclear Detector Amplifier

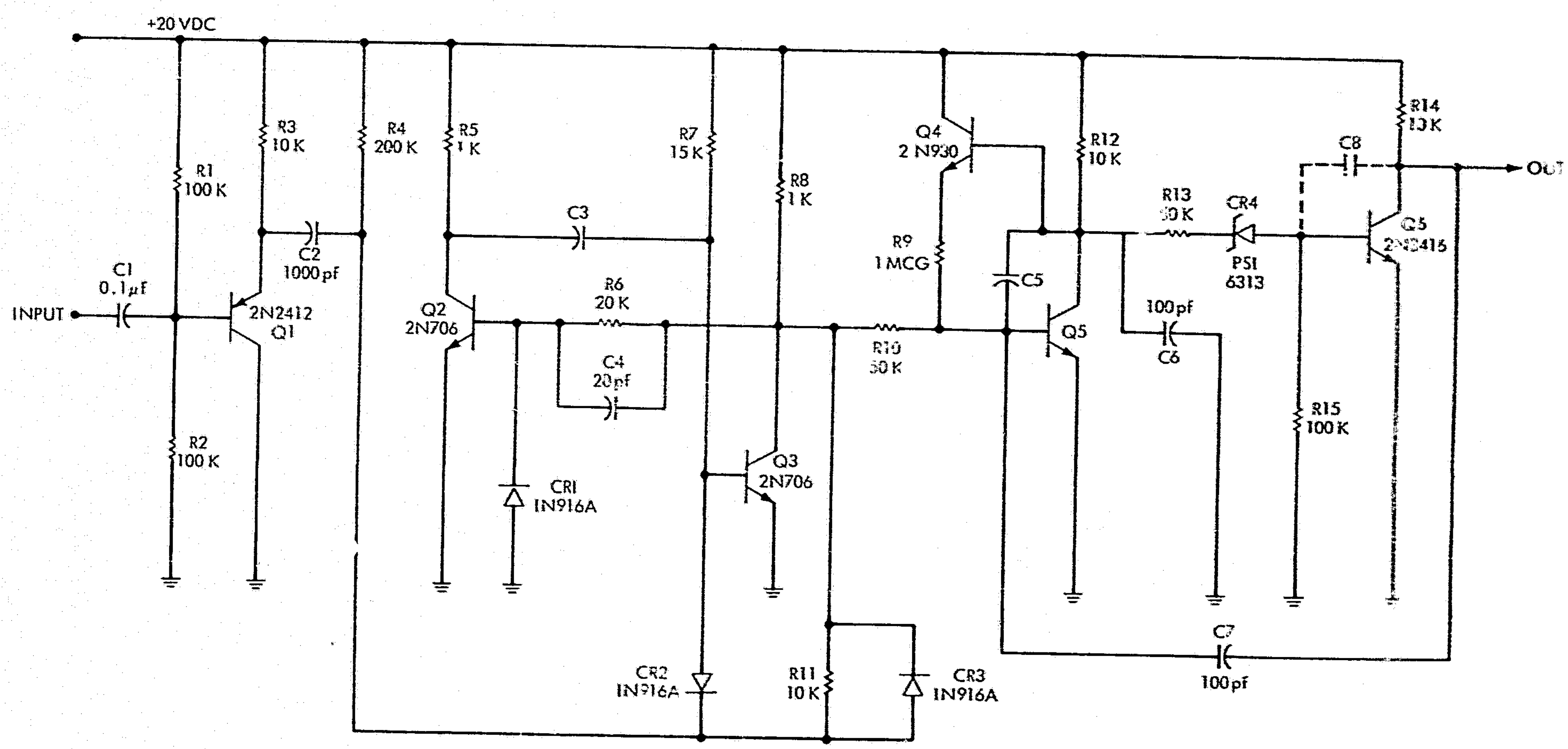


Figure 5b. Nuclear Detector Count Integrator