August 9, 1950

Mr. Grote Reber
P. O. Box 4868
Cleveland Park Station
Washington, D. C.

Dear Mr. Reber:

With reference to your letter of August 4, 1950, we regret to advise that we are in no position to quote either price or delivery on the ML-280 miniature ceramic lighthouse triode.

As requested by you, we are enclosing herewith the Summer Issue of the Cathode Press containing an article by Mr. Rheaume on the ML-280.

Should you desire further information at any time, please contact us.

Very truly yours,

H. J. Hoffman

H. J. Hoffman,
Vice President

oad

HJH;oad
Encls.

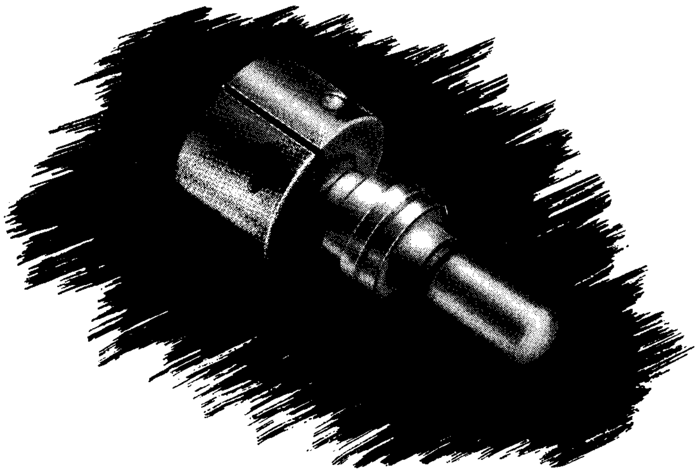
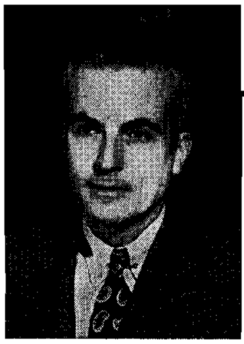


Figure 1 — ML-280 (actual size).

A MINIATURE CERAMIC

The ML-280 is a high-g_m miniature ceramic planar triode, for microwave amplifier, oscillator, frequency multiplier, or detector service. Its unusually small size, including an integral d-c isolated r-f cathode terminal, makes it attractive for compact cavity circuitry. Large gains and gain-bandwidth products are complemented by small drive requirements and low noise figures. D-c and heater power requirements are minimized.



By R. H. RHEAUME

Design Engineer

Machlett Laboratories, Inc.

Introduction

During the recent war, British engineers became interested in the u-h-f possibilities inherent in a miniaturized lighthouse triode. Accordingly, they developed a prototype model known as the VX7021[1] or "collarbutton" tube, having planar electrodes of very small diameter as well as a very compact overall form factor. The structure was further characterized by very small inter-electrode spacings and by the use of a novel electrodeposited grid material[2].

Messrs. J. W. Greer and R. W. Grantham of Code 836, the United States Navy Bureau of Ships Tube Development Group, became interested in working out the attendant manufacturing problems, and in optimizing the electrical and mechanical design for American applications. Machlett Laboratories undertook a Bureau of Ships development contract[3] for the purpose of designing and fabricating typical production tubes, and the ML-280 miniature ceramic lighthouse triode is the outgrowth of that development. A photograph of this new tube is shown in figure 1, and the complete electrical ratings and operating conditions will be found at the end of this article.

---

[1] Com Naveu Report No. X-1355, London, 25 March 1946.
[2] Standard Telephone and Cables Ltd. Report No. VLTR 619, Production of Electrogrids, June 1944.
[3] Bureau of Ships Contract No. NObsa-30045.

ML-280 Design Considerations

1. *General*

Those same properties of space charge triodes which have been so useful for modern communication systems at ordinary frequencies are equally important in the microwave spectrum: namely, their ability to amplify, to oscillate, and to be readily modulated. On account of these attributes, and because of the vast areas of scientific and technological endeavor which have grown up around triode applications, it has proved rewarding to penetrate even further into the domain of ultra high and micro-wave frequencies with these devices.

The difficulties of interelectrode capacitances and lead inductances, circuit stability, electron transit time phenomena, dielectric and skin effect losses, small sizes and high dissipations demanded of electrodes, and severe gain and bandwidth requirements encountered at these elevated frequencies, are offset by the circumstance that very low power levels are often useful, owing to the greatly reduced incidence of natural and man-made interference. For many ultra high frequency purposes, therefore, considerations of highest possible frequency of operation, optimum gain and bandwidth characteristics, lowest attainable noise figure, smallest possible electrical and physical dimensions, and minimum d-c and heater power requirements become of interest for r-f and i-f amplifiers, local oscillators, frequency multipliers, and detectors.

There exists, accordingly, an important field of application for miniaturized microwave tubes, and the ML-280 miniature ceramic lighthouse triode has been developed in response to that need.

showing maximum technique factors permitted by the Dynamax "20" ratings for self-rectified operation, indicates the possibilities in this respect:

Maximum Techniques
(Self-Rectified)

100 MA

PKV	70	75	80	85	90
Sec	1⅖	1	⅘	⅗	⅖

80 MA

PKV	70	75	80	85	90
Sec	2½	2 1/10	1⅘	1½	1⅕

50 MA

PKV	70	75	80	85	90
Sec	7	6	5½	4⅘	4⅕

30 MA

PKV	70	75	80	85	90
Sec	13	12	11¼	10⅗	10

The Dynamax "20" is also an ideal tube for use with 200 MA rectified units employed in average and light duty service where the total energy requirements are not extremely great. It is particularly advantageous in single-tube "over-and-under" units.

Maximum technique factors for full-wave rectified operations are shown in the following table:

Maximum Techniques
(Full-Wave Rectified)

200 MA

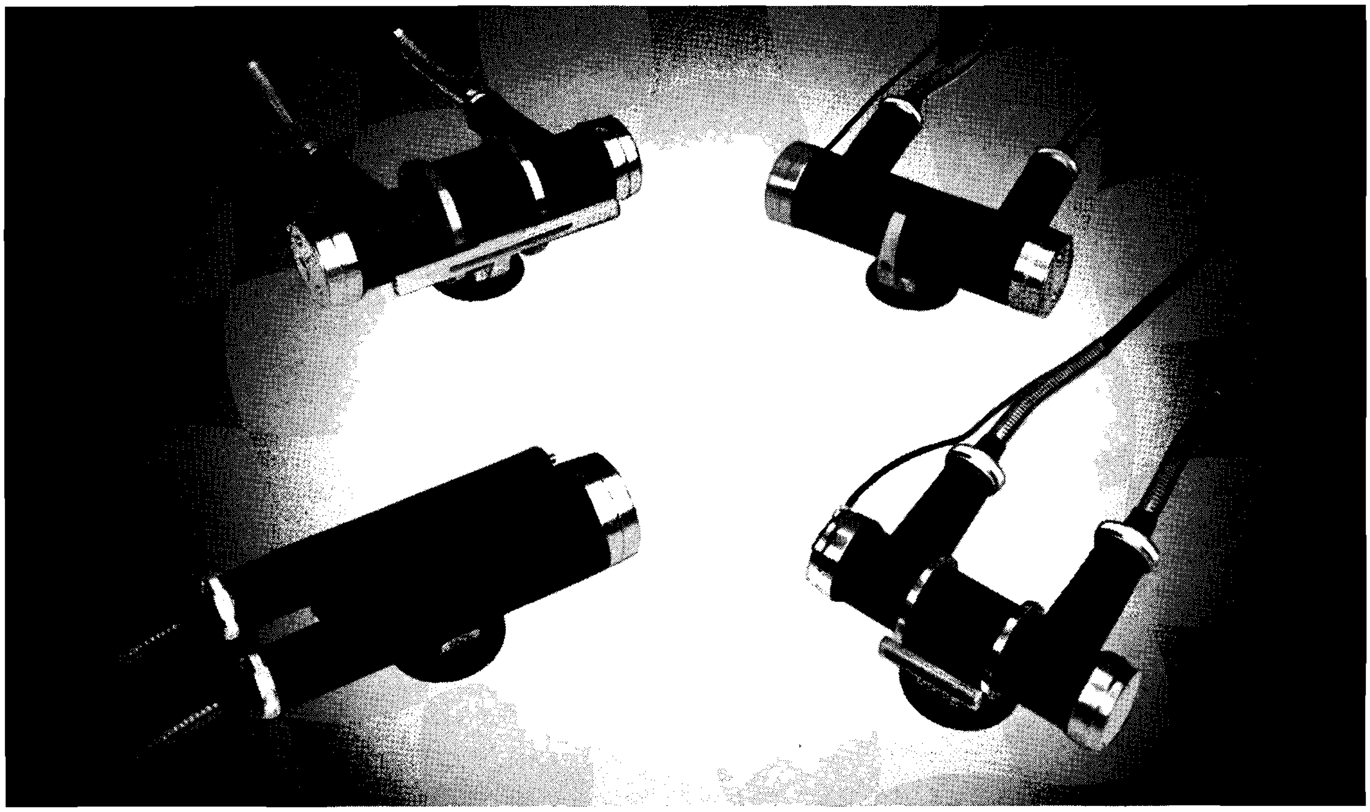
PKV	100	90	80	70
Sec	1/15	3/20	3/10	⅗

100 MA

PKV	100	90	80	70
Sec	1 9/10	2⅖	3 1/10	4

50 MA

PKV	100	90	80	70
Sec	6½	8	9	11



The Dynamax "20", newest Machlett rotating anode tube, along with the Dynamax "25", Dynamax "26" and Super Dynamax, will be on exhibit at the Sixth International Congress of Radiology, London, England, July 1950.

"LIGHTHOUSE" TRIODE

2. *Mechanical*

Externally, the British VX7021 triode was fairly conventional in appearance, in so far as its vacuum envelope was a butt sealed glass and metal structure reminiscent of the 2C40. However, in striving for high r-f conductivity of seals by means of plating procedures, excessively high gas contents had been incurred through porosity of seals, with the result that all of the prototype tubes which were tested in the United States were found to be inoperable. Subsequently, Machlett Laboratories encountered similar difficulties in making copies of the VX7021, and also in attempting various modifications of that design. The necessity for placing electrodes very closely adjacent to each other has further straitened the difficulties with precise spacings and parallelism.

In view of these obstacles, a major redesign of this tube has been undertaken, involving our most recent developments in the field of metallized ceramic silver solder seals and means for achieving a maximum of transconductance. A full scale longitudinal section view of the finished tube, known as the ML-280 miniature ceramic lighthouse triode, is illustrated in figure 2.

The unusually compact form factor of the ML-280, even with the inclusion of an integral d-c isolated r-f cathode terminal, may be largely credited to the mechanical advantages inherent in metal-ceramic construction. No glass enters into the structure in any way, and the novel shaping of the ceramic insulation would be very difficult, if not impossible to achieve with available glass working techniques. From a large scale production viewpoint, the metallized ceramic silver solder seal method has important potential advantages for many different kinds of electron tubes, and is well adapted for the manufacture of miniature tubes. In general, after metallizing ceramics and electro-plating metal parts, all that remains for assembling tubes is to stack these components with rings of silver solder in precision jigs and pass them through an atmosphere furnace. The mechanical strength and alignment of these seals, and consequently of the internal electrodes, appear to be superior to those of conventional metal-glass tubes.

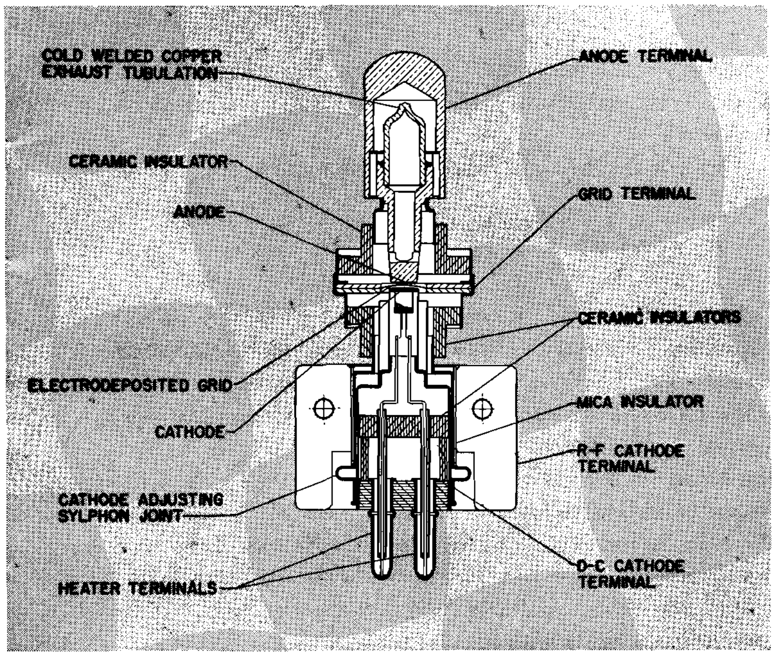


Figure 2

The elimination of glass permits the ML-280 to be outgassed during evacuation to higher temperatures than heretofore, and the subsequent sealing-off operation is performed by severing the copper anode tubulation to form a vacuum-tight cold welded joint. The use of a copper anode affords optimum electrical conductivity and heat dissipation, and takes advantage of the gettering capability of thoroughly outgassed copper surfaces for maintaining high vacuums. No other gettering procedure is needed.

A slight contouring of the oxide coated cathode emitter disk and fine mesh electrodeposited nickel grid will be noted in figure 2. This feature ensures that thermal movements of these two electrodes will occur axially in the same sense, thereby keeping the critical grid-cathode spacing effectively constant throughout a wide range of operating conditions. The mechanical rigidity of these electrodes is also enhanced.

The incorporation of a cathode adjusting sylphon joint permits advancing the cathode emitter surface toward the control grid after sealing off the tube. This innovation will be discussed in connection with transconductance.

3. *Electrical*

The electrical design of the ML-280 miniature ceramic lighthouse triode has been carefully worked out, with regard to several fundamental performance criteria:

(a) Remote upper frequency limit, in the neighborhood of 6000 mc/s.
(b) Good gain and bandwidth characteristics, with satisfactory stability and low drive requirements.
(c) Low noise figure.
(d) Small size, to facilitate cascading of stages of amplification.
(e) Minimum d-c and heater power requirements.

In general, the diameters of active areas of planar-electrode tubes constitute a fundamental limitation upon their uppermost frequencies of operation. Accordingly, the diameter of the ML-280 cathode emitter disk has been made as small as possible, consistent with good cathode life, in order that the $\frac{\lambda}{16}$ criterion will be approached only at a very high frequency. Since this dimension for the ML-280 is one-eighth of an inch, the limiting frequency becomes approximately 6000 mc/s.

Space charge triodes suffer from electron transit time effects as operating frequencies rise, thereby reducing gains, increasing drive requirements and electrode dissipations, and ultimately limiting their usefulness from the standpoint of maximum operating frequency. However, the influence of these phenomena upon the ML-280 has been materially diminished by establishing extremely close spacings between electrodes, 0.002 inches between cathode and grid, and 0.009 inches between grid and anode. The three hundred mesh per inch electrodeposited nickel grid, with a thickness of only 0.0004 inches, further minimizes electron transit time losses. The extreme thinness and uniformity of cross section of this grid help to establish uniform electric fields upon the closely adjacent cathode and anode surfaces.

Since the electrodeposition technique is a photographic reduction process, it has been useful for producing economically a choice of fine mesh grids in order to optimize such parameters as plate current, plate and grid biasing potentials, and transconductance. Equivalent parallel wire grids would be more difficult to fabricate, and it is not yet practicable to make woven grids of the desired degree of fineness.

The importance of large transconductance may be appreciated by considering H. V. Neher's equation for the power gain of a class A grid separation amplifier stage[3].

$$G_p = \frac{g_m^2 R_1 R_2}{4} \qquad (1)$$

where g_m is the transconductance, and R_1 and R_2 are, respectively, the shunt resonant resistances of the input and output circuits.

Transconductance may be maximized, first, by maintaining electrodes at as large a diameter as can be permitted, bearing in mind the restrictions as to capacitances and desired upper frequency limit; second, by achieving a high degree of parallelism between active cathode and grid surfaces as demonstrated in figure 3; third, by proper choice of grid mesh size in relation to the ultimate spacing between cathode and grid.

The incorporation of a cathode adjusting sylphon joint in the ML-280, as shown in figure 2, permits a final adjustment of transconductance to be made after sealing off, though before attaching the r-f cathode terminal, by advancing the emitter surface toward the grid with the aid of a special compression-type jig. Simultaneously, the tube constants are observed on a dynamic bridge. In this manner, the transconductance of ML-280 triodes is brought to approximately 10,000 microhmos, at a plate current of twenty milliamperes, with an average value for amplification factor of 85.

[3] U. S. Department of Commerce Report PB-40443, "Some Notes on Space-Charge-Limited Oscillators and Amplifiers at Microwave Frequencies," by H. V. Neher. See also Hamilton, Knipp, Kupet, "Klystrons and Microwave Triodes," 1st Ed., 1948, pp. 146-152.

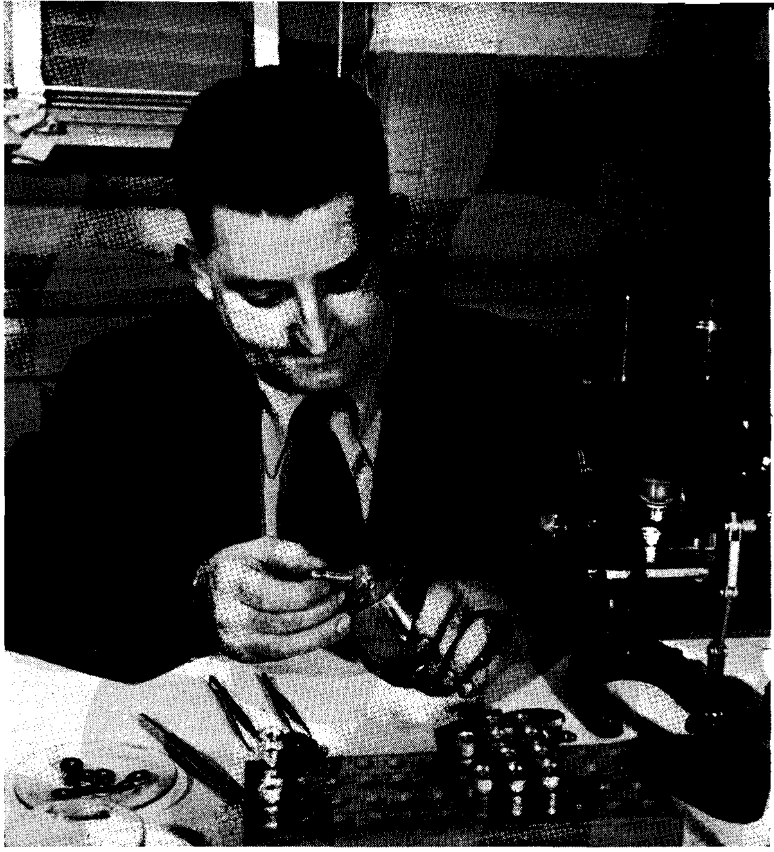


Figure 3—"W. A. Zarth, Project Engineer, demonstrates ML-280 Cathode Contouring Operation."

It is often necessary, at high frequencies, to introduce the concept of gain-bandwidth product. Frequency bandwidth is defined as

$$\Delta f = f_1 - f_2 = \frac{R_2 + R_L}{2\pi C_2 R_2 R_L} \qquad (2)$$

where f_1 and f_2 are the frequencies at which the voltage gain is diminished to $\frac{1}{\sqrt{2}}$ times the voltage gain at resonant frequency, C_2 is the output capacitance. R_2 is the shunt resonant resistance of the output circuit, and R_L is the load resistance.

Then for matched conditions, the gain band-width product may be expressed

$$G_p \, \Delta f = \left(\frac{g_m^2 R_1 R_2}{4}\right)\left(\frac{1}{\pi R_2 C_2}\right) = \frac{g_m^2 R_1}{4\pi C_2} \qquad (3)$$

In equation (3) it will be noted that the output capacitance C_2 and the input shunt resonant resistance R_1 appear explicitly, and that C_2 must be small and R_1 must be large for optimum gain-bandwidth products. It can also be shown that the input capacitance C_1 is implicit in R_1: i.e., the larger the magnitude of C_1, the smaller the value of R_1, on account of skin effect and dielectric losses associated with the seals and insulation of the vacuum envelope of the tube via the mechanism of charging currents and impressed alternating potentials. Similarly, the output capacitance C_2 has an implicit relation with R_2.

Merely to minimize the capacitances between active electrode surfaces of microwave triodes is therefore not enough. As frequencies ascend, it becomes increasingly necessary to eliminate, in so far as possible, those additional capacitances associated with other portions of the tube structure, along with their attendant seal and dielectric losses. In the ML-280, the substitution of AlSiMag #243 forsterite ceramic and pure silver seals for glass and metal construction has greatly reduced these losses, remembering that the d-c conductivity of pure silver is approximately twenty-eight times that of the customary glass sealing metal (kovar), and that the ceramic dielectric loss factor at high frequencies is but one-tenth that of the corresponding #7052 glass.

It will also be observed from figure 2 that the ceramic insulators between cathode and grid and between grid and anode have been given a specially flanged shape, affording at once a maximum of mechanical seal strength with a minimum of residual capacitance, since this contouring is designed to diminish markedly the electrostatic permittance.

ML-280 TENTATIVE TECHNICAL DATA

GENERAL CHARACTERISTICS

Electrical

Heater Voltage	5.0 volts
Heater Current at 5.0 volts	0.38 amps
Amplification Factor	85
Transconductance (Ib=20 mA)	10000 umhos
Interelectrode Capacitances	
Grid-Plate	1.8 uuf
Grid-Cathode	2.9 uuf
Plate-Cathode	0.02 uuf max.

Mechanical

Mounting Position	Optional
Type of Cooling	Forced Air*
Maximum Incoming Air Temperature	45°C
Required Air Draft on Anode	7 ft./s
Maximum Anode Temperature	175°C
Net Weight	2 oz.

*For maximum plate dissipation of 6 watts, air flow at a velocity of 7 ft./sec is recommended. Cooling must be sufficient to limit anode seal temperature to 175°C. Cavity should be ventilated and an air flow provided, when necessary, to limit seal temperatures to 175°C maximum.

MAXIMUM RATINGS AND TYPICAL OPERATING CONDITIONS

Class A, Amplifier-Grid Separation Circuit

	Typical Operation	*Maximum Ratings*
Plate voltage	220	250 volts
Cathode-bias resistor	30	ohms
Amplification factor	85	
Transconductance	10,000	umhos
Plate current	20	23 ma
Plate resistance	8,500	ohms

Class C, CW Oscillator-Grid Separation Circuit

	Typical Operation	*Maximum Ratings*
D-C plate voltage	220	250 volts
D-C grid voltage	−12	−30 volts
D-C plate current	.007	amps
D-C grid current	.005	.008 amps
Plate input	1.6	watts
Plate dissipation	0.6	watts
Plate power output	1.1	watts
Frequency	1000	mc/s

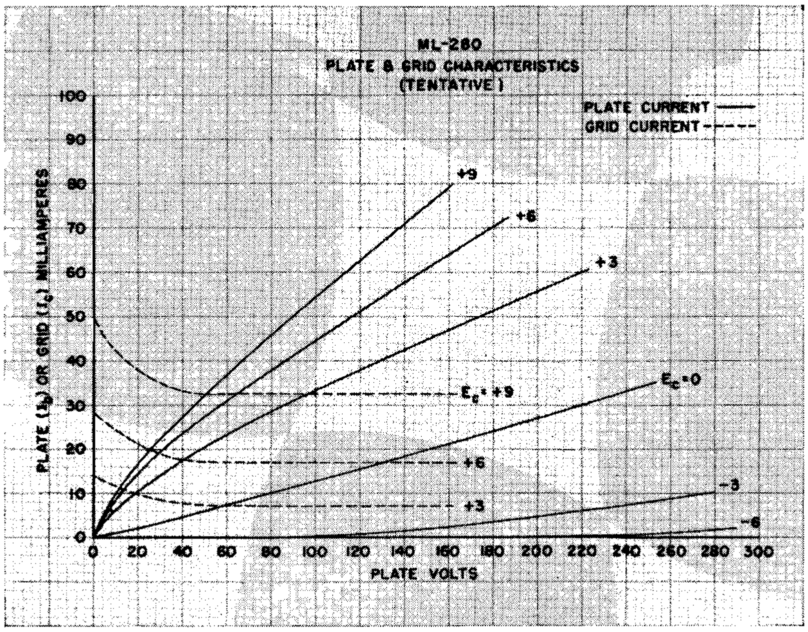


Figure 4 — ML-280 Tentative Grid Plate Characteristics.

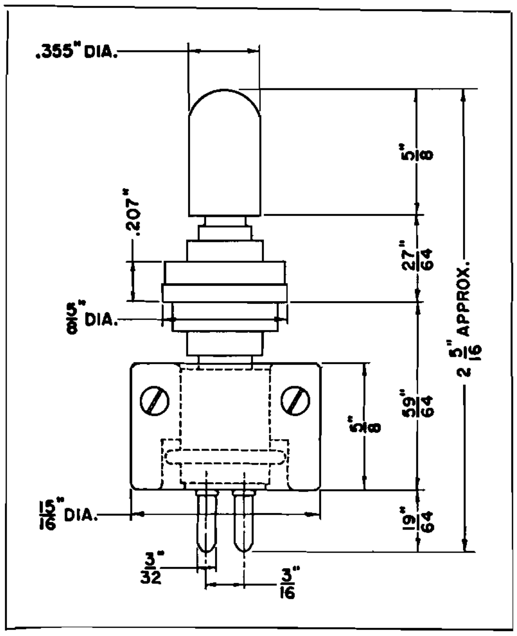


Figure 5 — ML-280 Dimensional Drawing.