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APPLIED RESEARCH ON TECHNIQUES

FOR

LIGHT MODULATION DETECTION

S. E. SOBOTTKA

WATKINS-JOHNSON COMPANY
3333 Hillview Avenue
Palo Alto, California

Contractor's Report No. W-J 63-610R12

Interim Engineering Report No. 3
for the period 1 January through 31 March 1963

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Contract No. AF 33(657)-8996
BPSN No. 6799 760E 4156
Task No. 41533

ELECTRONIC TECHNOLOGY LABORATORY

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE
DAYTON, OHIO

## SUMMARY

Techniques have been developed for constructing a convergent gun traveling-wave phototube. The procedure for transferring the photocathode from the fabrication vessel to the tube body has been tested and found successful. If care is taken, no loss of photosensitivity occurs during the transfer. This transfer technique greatly simplifies the construction of the phototube by eliminating the need for cathode fabrication and positioning assemblies inside the photocathode.

The light modulator design and construction has been completed and tested. With 1.3 watts of input rf power at 3420 Mc/sec, the modulation index is 0.1. This modulator, together with a superpressure Hg arc light source, will be used to determine the rf characteristics of the phototubes during the next period.

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## INTRODUCTION

During the last quarter emphasis was placed on two areas: development of techniques for fabricating microwave phototubes with convergent guns and semitransparent S1 photocathodes, and design, construction and testing of the light modulator with which the tubes will be tested. Some additional studies were also made to determine the dependence of cathode photosensitivity on fabrication procedure and some attention was given to the effect of the gun region on the beam modulation.

## TUBE DEVELOPMENT

### Cathode Development

Our cathode development has consisted principally of the modification of the fabrication procedure together with studies of the resulting changes in photosensitivity and the development of techniques for transferring the cathode from the fabrication bulb to the phototube.

At the present time we have had most success with the following procedure for fabricating photocathodes ( also discussed in Interim Engineering Report No. 2 ): Ag is evaporated onto a glass substrate until the light transmission is reduced by 50 percent. Oxygen is admitted to the fabrication vessel and the Ag film is oxidized in an $O_2$ glow-discharge until it is transparent. Cs vapor is admitted to the vessel and the cathode is baked at 200°C in the Cs atmosphere until the thermionic emission begins to decrease. The Cs is removed, the vessel is tipped off, and Ag is again evaporated until the light transmission is reduced by 50 percent.

This procedure has yielded luminous sensitivities of about 20$\mu$a/lumen. The maximum spectral sensitivity is about 1.4$\mu$a/mw and this occurs at about 5000A. Since the

Ag-O-Cs cathode is most useful because it can be made to have its maximum sensitivity in the near infrared, it is desirable to develop techniques to shift the sensitivity maximum of our cathodes towards the infrared. Therefore, we have begun to modify our cathode preparations procedure in an effort to increase the infrared sensitivity.

The procedure we are now using has been recommended[1] because it leads to high sensitivity cathodes. The steps are as follows: Ag is evaporated and oxidized as described above. However, after oxidation and before cesiation, Ag is again evaporated until the light transmission is reduced to 50 percent. The cathode is then cesiated. After the Cs is removed, and the vessel cooled, the vessel is tipped off and the photosensitivity is measured. Ag is again evaporated until the photocurrent reaches a maximum; the cathode is baked at 150°C until the thermionic current begins to decrease and the photosensitivity is again measured. If the photosensitivity has increased the last Ag evaporation and the succeeding steps are repeated.

At the present, this new procedure has not yielded a significant increase in photosensitivity over the old one. The 150 degree bake after the last Ag evaporation has caused a reduction in photosensitivity not an increase. We believe this reduction is caused by cathode poisoning due to the evolutions of gases from the glass vessel walls. The glass used was Corning No. 7720 which contains lead and which darkens noticeably during cesiation. It is possible that a Cs - Pb compound is formed which vaporizes during the bake period and poisons the cathode. The next cathodes will be made in vessels made of Corning No. 7052 glass to remove this difficulty.

All spectral sensitivity measurements are made using a BTL high intensity monochrometer which delivers several milliwatts of light at most of the wavelengths appropriate for S1 cathodes. A photograph of the apparatus is shown in Fig. 1. The photocathode in the figure is still in its preparation vessel which has been tipped off from the vacuum system.

## Cathode Transfer and Tube Fabrication

After the cathode has been prepared it is transferred from the fabrication vessel to the tube body. In order to prevent cathode poisoning during the transfer it is done in a vacuum chamber at a pressure less than $10^{-5}$ mm Hg. The transfer procedure consists of undoing the brazed seal holding the cathode assembly in the preparation vessel, removing the cathode, moving it to the tube and brazing it into place. For our purposes tin appears to be the best brazing material. Its melting point is 232°C, slightly above our cathode activation temperature of 200°C. Its vapor pressure at 232°C is so low that it is not easily measurable, but is considerably less than $10^{-8}$ mm Hg. Because of its low vapor pressure any cathode poisoning during the brazing operations is likely to be

[1] D. Blattner, J. Ruedy, F. Sterger, RCA Second Quarterly Progress Report, USARDL Contract No. DA 36-039 SC-90846

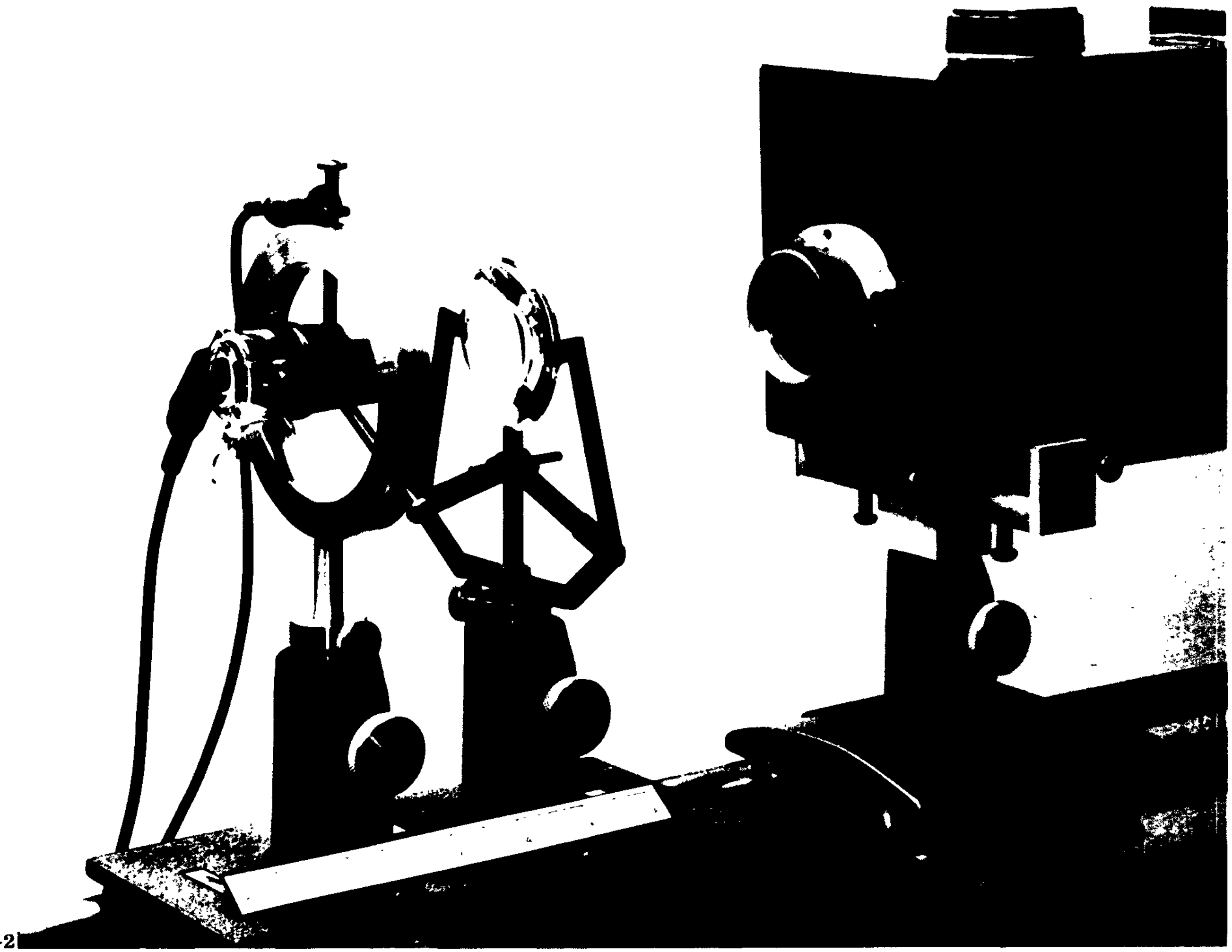

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Fig. 1 - Photograph of spectral sensitivity measurement apparatus.

due to dissolved impurities and these can be evaporated off at high temperatures before brazing.

A photograph of the transfer chamber is shown in Fig. 2. Shown in position are a cathode preparation vessel and a tube body. A sketch of this chamber and a description of its operation was given in Interim Engineering Report No. 2.

The transfer procedure and its effect on a photocathode was first checked by completely removing a cathode from its preparation vessel and rebrazing it into the same vessel. The luminous sensitivity following this operation was not less than that prior to it. Thus, we believe that the transfer need not affect significantly the photosensitivity of the cathode.

We have made one transfer to a tube body when we were able to make complete spectral sensitivity measurements both before and after the transfer. In this case, some poisoning had occurred and the photosensitivity had decreased by about a factor of 30 over the entire spectral range. We are not sure of the cause of this poisoning but it may have resulted because the tin braze was not fired and cleaned at a high enough temperature before use. In view of the success of our previous test, this particular transfer must be considered to be not representative of the potentiality of the procedure but it does indicate that caution is necessary and extreme care must be taken to prevent the admittance of impurities at every stage of the operation.

All of the components for several tubes have been fabricated, except for the photocathodes. The effort of the remainder of this program will be devoted to fabricating complete tubes and measuring their optical and electrical characteristics. A completed tube is shown in Fig. 3. Because this tube developed an air leak, no electrical measurements were possible.

## Effect On Signal of Beam Acceleration Region

Since the beam modulation is present throughout the gun region, it is necessary to consider the question of whether the gun region will have any affect on the signal amplitude. This question can be answered quite simply for the case of small dc beam currents. In order to have any degradation of the initial current modulation, the gun length must be a significant fraction of a space charge wavelength. In our tube ( as in other similar traveling-wave tubes ), a rough estimate indicates that the dc beam current must be of the order of several tens of microamperes before the gun approaches a quarter of a space charge wavelength. Typical simple detector operation might use dc beam currents of a few microamperes or less and for these currents, the signal current at the helix will be simply equal to the ac charge density multiplied by the dc beam velocity. Hence, the gun region will produce no significant degradation of the output power.


Fig. 2 - Photograph of transfer chamber with cathode fabrication vessel and tube body in position for transfer.

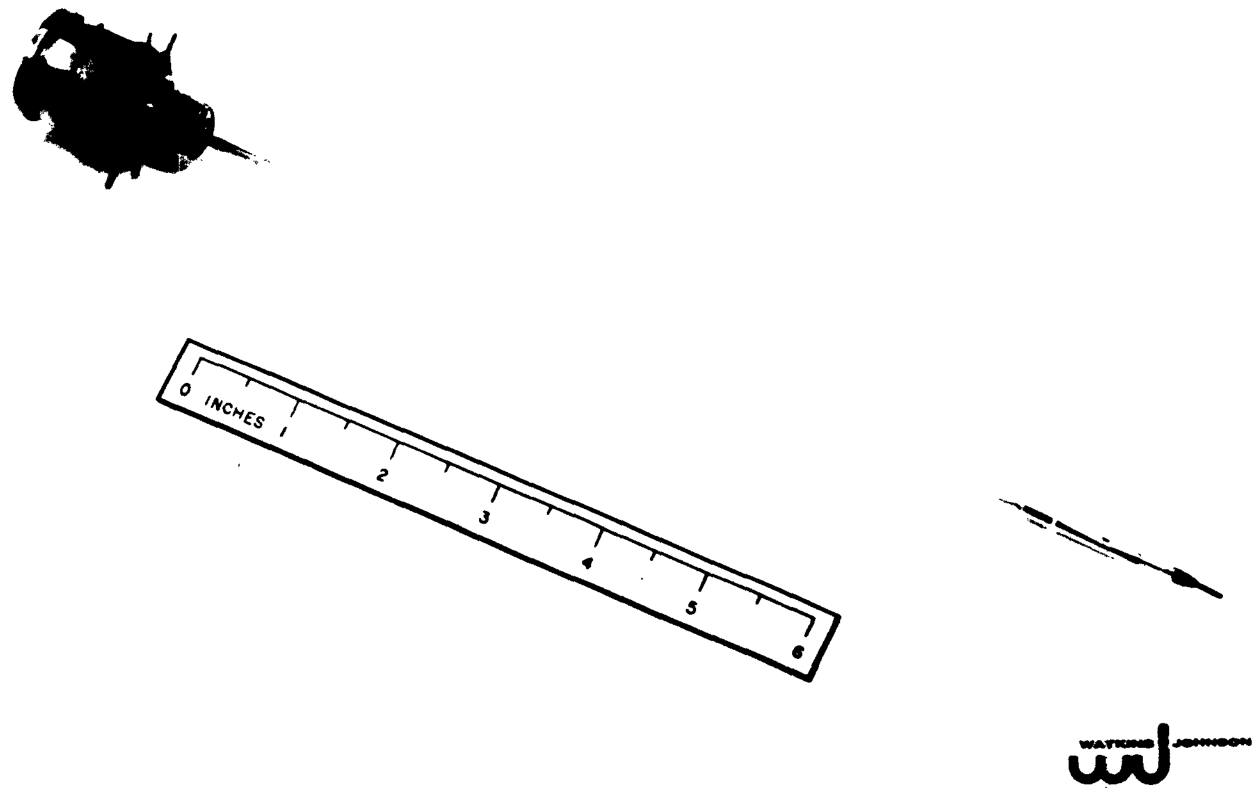


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Fig. 3 - Photograph of light demodulator tube with convergent gun.

## PROGRESS ON LIGHT MODULATOR

The light modulator has been completed and a photograph of it plus associated apparatus is shown in Fig. 4. The superpressure mercury arc light source, polarizing prisms and microwave cavity with KDP rod are mounted on the optical bench. The table at the left holds the microwave power source and power measuring instrument, while a photomultiplier, power supply and voltmeter for measuring photomultiplier output are located adjacent to the optical bench.

It is of interest to calculate the characteristics necessary for the optics used to focus the light from the arc lamp onto the KDP crystal. Maximum light will be transmitted through the KDP rod when the Hg arc source is imaged in the center of the rod, as shown in Fig. 5. We wish to have the arc image height h' approxiamtely equal to the diameter of the KDP rod. But, from elementary optics

$$\frac{h'}{h} = \frac{q}{p}$$

so this ratio is fixed by the available arc length and KDP rod diameter. Secondly, the birefrigent properties of the KDP rod restrict the maximum usable entrance angle which is approximately $\frac{d}{q}$. We shall calculate this angle shortly. Then, from the simple lens formula $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$ and the known value of $\frac{q}{p}$ and $\frac{d}{q}$, we can find $\frac{f}{d}$, the minimum usable f number of the lens.

In order to calculate the maximum entrance angle $\frac{d}{q}$, we consider the index ellipsoid of revolution for KDP, whose projection in the x, z plane is shown in Fig. 6. The equation for this projection is

$$\frac{x^2}{a^2} + \frac{z^2}{b^2} = 1 \tag{1}$$

Here a is the ordinary refractive index, b the extraordinary index. For KDP, a = 1.468 b = 1.510. It is more convenient to work with polar coordinates, in which Equation (1) becomes

$$n^2 = \frac{a^2 b^2}{a^2 \sin^2 \theta + b^2 \cos^2 \theta} \tag{2}$$


Fig. 4 - Photograph of light modulator and associated apparatus.

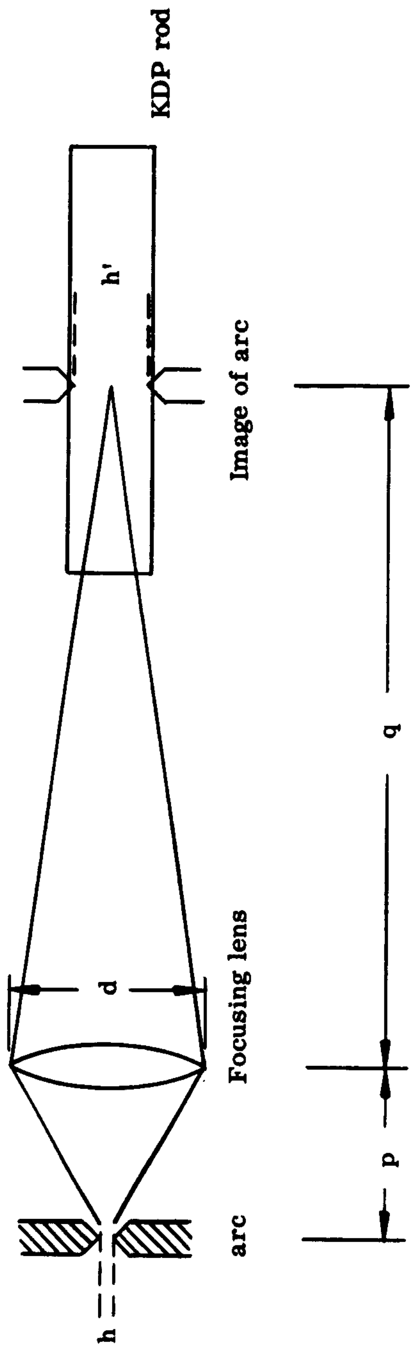


Fig. 5 - Geometry for source and optics of light modulator.

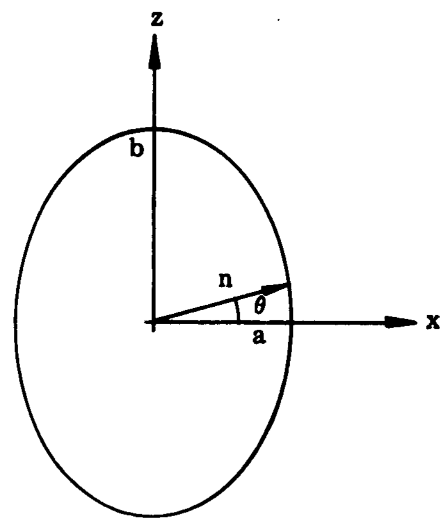


Fig. 6 - Projection in x, z plane of index ellipsoid for KDP. The z direction is along the optic axis and the ellipsoid is a figure of revolution about the z axis.

We wish to consider the situation for small $\theta$ $\theta \simeq \frac{1}{2}\frac{d}{q}$, in which case Equation (2) becomes

$$n^2 \simeq \frac{a^2 b^2}{a^2\theta^2 + b^2\left(1-\theta^2\right)} \simeq a^2\left[1 - \left(\frac{a^2 - b^2}{b^2}\right)\theta^2\right] \tag{3}$$

The second term in Equation (3) is the change in the square of the extraordinary index of refraction as $\theta$ goes from zero to some small value.

The change in wavelengths $\Delta N$ of the KDP sample for a change $\Delta n$ in the index of refraction is then given by

$$\Delta N \simeq \frac{L\,(\Delta n)}{\lambda_o} = \frac{L}{\lambda_o}\,\frac{1}{2}\,a^2\left(\frac{a^2 - b^2}{b^2}\right)\theta^2$$

where L is the sample length and $\lambda_o$ is the free space wavelength. The value of $\Delta n$ for which the maximum usable value of $\theta$ occurs is then given by setting $\Delta N = 1/2$. Thus, we have

$$\theta^2_{max} = \frac{\lambda_o}{L}\,\frac{b^2}{a^2\left(a^2 - b^2\right)} \tag{4}$$

For $L = 3.5$ cm, $\lambda_o = 5 \times 10^{-5}$ cm, we have

$$\theta_{max} \simeq 0.01 \text{ rad.}$$

This is the maximum useful angle that a light ray can make with respect to the optic axis of the KDP crystal. If $\theta$ is the angle with respect to the axis inside the crystal, then the angle of incidence $\theta'$ is given by Snell's law and is, in this case, $\theta' \simeq 0.015$ rad. Then the maximum useful entrance angle is

$$2\theta' = \frac{d}{q} = 0.03 \text{ rad.}$$

This value of $\frac{d}{q}$ together with the value of $\frac{q}{p}$ determined from the arc length and KDP rod diameter then give a value of $\frac{d}{f} = 4$ for our case. Nothing is gained by using a smaller f number than this because the natural interferance pattern of the KDP crystal does not allow the use of light rays entering at larger angles.

Measurements have been made of the modulation index m produced by the modulator as a function of rf input power. The following equation [2] for the intensity I of the light transmitted through the polarizer following the cavity defines m:

$$I \simeq I_0 \, (1 + m \sin \omega t)$$

where $\omega$ is the modulation frequency. The light intensity obeys this approximate equation when circularly polarized light of intensity $2I_0$ is incident on the KDP crystal.

Figure 7 is a graph of m as a function of the square root of the rf power. At 1.3 watts rf power the modulator produces 10 percent modulation. This is a convenient power level to work with. The resonant frequency of the cavity loaded with the KDP is 3420 Mc/sec.

## CONCLUSIONS

The successful test of our technique for transferring photocathodes from the fabrication vessel to the phototube body indicates the usefulness of this method of construction. Even though the method requires care to eliminate sources of cathode poisoning agents, it will greatly simplify the construction of microwave phototubes.

The gun region in our tube will have little affect on the ac modulation current for dc beam currents of a few $\mu$amp or less. Thus, the particular electric and magnetic field profiles used to converge the beam can be chosen without regard to their possible deamplification of the signal current.

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[2] S. E. Harris, Stanford Electronics Laboratories, Electron Devices Research, QSR numbers 19-21.

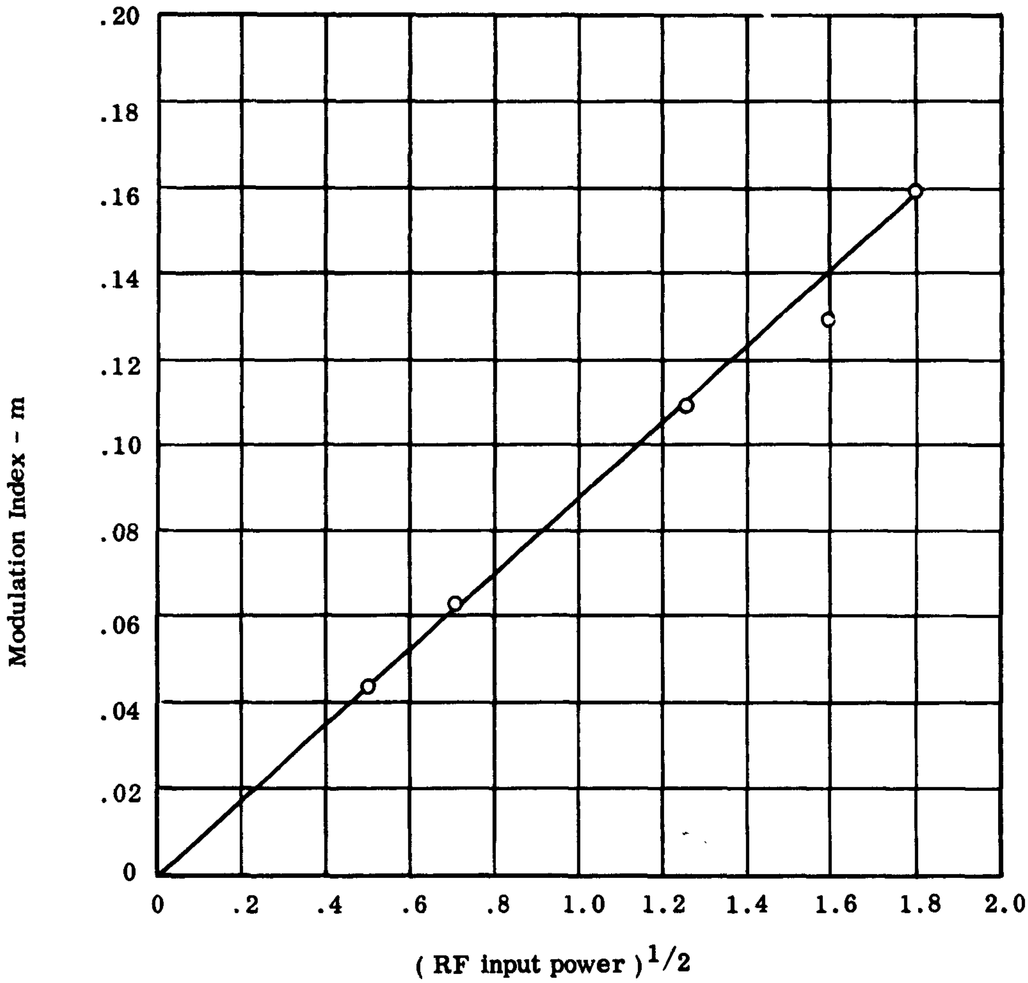


**Fig. 7 - Modulation index as a function of the square root of the rf input power.**

## RECOMMENDATIONS

During the remaining period effort should be concentrated on fabricating and testing convergent gun microwave phototubes.

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