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7 figures to be attached

The Evolution of Picture Tube

Size and Shape

The present trend toward the use of 110 degree TV picture tubes raises the question of "what next?". The prediction of flat, "picture on wall" type of TV viewers, first started by the GE laboratories, is now echoed by Kaiser-Willys on behalf of their Aiken tube and by the British on behalf of their Gabor tube, both named after their inventors.

A prediction of things to come should be related to the history and the history has certainly shown remarkable progress since TV was reborn after the second World War. Initial predictions generally relate the overall length and deflection angles of past tubes to some sort of calendar, and extrapolate the findings in straight lines, to anticipate either that the tubes will have zero length, or that no tube will be used, at some date in the future. As examples of this type of prediction, the "Smith Chart" by B. Smith of TVRD is reproduced (without permission) as Figure 1 and a chart by Messrs. Swedlund-Wimpee, included in their joint IRE paper is reproduced (again, without permission) as Figure 2.

Both of these predictions are too general as they merge all factors together and therefore mask the complexity of invention that took place in order to make the evolution possible. In order to understand this interrelation between the TV picture tube and the associated components found with it in a TV receiver, we should study the system as a whole. Figure 3 shows the general layout of the picture producing mechanism without reference to any particular tube size, and not necessarily to scale. Mr. L. C. Kunz has described the changes that have taken place over the last ten years and his work is included in Appendix A in this report.

In relating tube length to deflection angle, the major dimension affected is the deflecting length - l shown in Figure 3. This length is a trigometric function of the deflection angle and tube diagonal and may be calculated from the formula

$$l = \frac{D}{2} \cot. \frac{\phi}{2}$$

where l = deflecting length
D = picture diagonal for rectangular tubes or diameter for round tubes
ϕ = deflection angle - which is always referred to the diagonal of the picture.

Values of l are plotted in Figure 4 for 10, 14, 17, 21, and 24" tubes for deflection angles of 45° to 180°. At 180 degrees this length becomes zero for all tube sizes and, as can be seen from the graph, the rate of length reduction rapidly decreases as the deflection angle increases. The rate of length reduction with angle increase varies according to this formula

$$\frac{\Delta L}{\Delta \phi} = \frac{D}{4} \left(1 + \cot^2 \frac{\phi}{2}\right)$$

where ϕ is expressed in radians.

Values of the change in length per degree deflection angle increase are plotted in Figure 5 for a 21 inch picture diagonal. Values for other sizes are directly proportional to the diagonal dimension. From this curve it is easily seen that deflection angle increases beyond 110° will decrease length at the rate of 0.120 inches per degree for a 21" tube and half this amount for a 10" tube.

Increase of deflection angle requires more current in the deflecting coil, or a modification of the coil design. The current needed to deflect the beam is given by the formula

$$i = \frac{K \sin\frac{\phi}{2}\, n}{T}\sqrt{\frac{V}{S}}$$

where i is deflecting current in amps
K is a constant value
ϕ is the deflecting angle
n is the neck diameter
V is the anode voltage
S is the span of the deflection coil along the neck
T is the number of turns on the deflection coil

The additional current required to deflect an additional degree $\left(\frac{\Delta i}{\Delta \phi}\right)$ gets less as the angle increases, and, above 90°, decreases faster than the length ratio $\left(\frac{\Delta l}{\Delta \phi}\right)$ decreases so that the additional current required per inch length reduction $\left(\frac{\Delta i}{\Delta l}\right)$ gets less and less as the angle is increased beyond 90 degrees. Up to 90 degrees the opposite was true so we have a past history of change which was accomplished under greater handicaps than future changes.

The deflection current increase from that required for 50° tubes to that required for 90° tubes was accomplished by a series of changes in the TV system other than the picture tube. It is difficult to correctly estimate the contribution made by each of these changes or to attribute a particular system change to an increase in picture tube deflection angle. It must suffice to say that additional deflection power requirements for the progressive increase in deflection angles up to 90 degrees came from component improvements and better circuit design. Mr. Kunz has enumerated some of these in his report, included as Appendix A. As he points out, not only did these changes allow use of wider deflection tubes, but also allowed the use of higher voltages on the picture tube, which also increases the deflection coil current requirements in proportion to the square root of the voltage change.

The change from 90 to 110 degrees was aided by reducing the neck diameter. As may be seen from the formula for deflection current, this reduction of neck diameter reduced the required additional current by the ratio of neck diameter reduction.

It must be assumed that improvements in component and circuit design, and reductions of neck diameter, have not been exhausted. More deflection angle increases will come.

We have seen how deflecting length - l varies with deflection angle but tube length is composed also of face bulge and neck length. (See Figure 3).

Face bulge is dependent on face radius and picture diggonal according to the formula

$$a = r - \sqrt{r^2 - \frac{D^2}{4}}$$

where a is face bulge
r is face radius
D is picture diagonal

From the standpoint of deflection distortion, it is desirable to have r equal deflecting length so that all parts of the screen will be equal distant from the center of deflection. From the standpoint of focus distortion, it is desirable to have r equal the focal length, which is r plus the distance from center of focusing lens to the center of deflection. When r is equal to focal length the picture is in focus at all points on the screen. From the customers' viewpoint it is desirable to have a flat picture (r infinite). However, such a flat picture would have intolerable focus and deflection distortion unless complicated circuits were used to dynamically correct these distortions at every point on the screen.

On the basis of past customer reaction, it appears that the minimum acceptable face radius is that equal to the diagonal. A tube of this design would have no deflection distortion at 60 degree deflection angle. This tube would appear quite "bug eye" and would suffer in comparison with flatter tubes. The maximum permissible face radius is limited by the distortion difficulties mentioned and by strength considerations. The glass would have to be very thick to withstand the atmospheric pressure if it wereflat. Some arch is necessary to insure that the glass is under compression from this atmospheric pressure as glass has no strength under tension. These considerations place a practical upper limit on the radius of approximately 50 inches. Actually, the tube easily meets the customers' demands for flatness when the radius is double the diggonal. Most TV picture tubes have had face plate radii between 1 and 2 times the picture diagonal, except the very small sizes (10"-12") which went to 3 times.

Figure 6 shows the relation between r and D for ratios from 1 to 3. In this curve, face bulge is plotted as a % of D for various ratios of r/D. The present 110° tubes have an r/D ratio of approximately 1.4 which gives a value a = 0.09D or a = 1.9" for a 21" tube
1.25" for a 14" tube.

If we are to preserve the same degree of deflection distortion with increasing deflection angle, it is desirable to keep the ratio of face radius to face deflection length. For 110° tubes this value is approximately 4. From this the r/D ratio should always equal 2 cot $\frac{\phi}{2}$ in order to hold constant r/l ratio. Unfortunately, this requires that r/D decrease with increasing angle and the ratio 1 is reached for 127 degrees. Beyond this, more deflection correction must be applied, as the customer will not accept a more "bug eye" tube than this. Therefore, with increasing deflection angle, the r/D ratio may decrease slightly but for all practical purposes the face bulge will remain at approximately 10% of picture diagonal for all larger angles. Thus face bulge will not vary with deflection angle.

Neck length (see Figure 3) should be defined as the distance from center of deflection to end of base. Past practice has deviated slightly from this due to uncertainty as to exact center of deflection, but the deviation merely added to cone length and subtracted from neck length or vice versa with no change in overall tube length. Our definition gives a more exact method of measurement.

The deflection coil is centered over the center of deflection and ½ of its span must be over the neck. This requires approximately 1½ inches of neck room for deflection and the electron gun must be behind this so as not to absorb energy from the deflection coil. Some day gun and coil designs will permit overlap and allow us to reduce this required neck length for deflection to ½ inch. Our non ion trap design has already taken ¼ inch off this length. This method of neck shortening is related to deflection angle but only in a general way such that increased deflection angle makes it more difficult to advance the gun under the deflection coil.

Approximately 3/4 inch is required for the electrostatic focus lens and this is independent of deflection angle but may possibly be shortened to ½ inch in the future. One of the major reasons for past neck length shortening is that the electrostatic focus lens requires less length than a magnetic focus coil.

Deflection angle variation affect the length of the anode cylinder. For the same degree of depth of focus the length from the top of grid 1 to center of focus cylinder (image distance) should vary in proportion to the focal length, which is made up of deflection length + face bulge + distance of focus cylinder to center of deflection. Of these, deflection length is the only variable with deflection angle and accounts for 80% of the focal length. The ratio image distance/focal length should be approximately 0.15 from which we may conclude that the gun, and therefore the neck, can be shortened approximately 12% as much as the deflection length is shortened. Thus the values of deflection length reduction shown in Figure 5 multiplied by 112% will give the total overall tube length variation as there are no other shortening factors to consider. Due to deflection angle increase we may expect the usual sizes of tubes to have the following length reductions:

Tube Size	Length Reduction inches/degree	Length Reduction-inches 110 to 135 degrees
24	0.156	3.9
21	0.135	3.4
17	0.110	2.75
14	0.090	2.25
10	0.064	1.6

In addition to these reductions, we can expect neck length reductions as follows: elimination of tubulation tip ¼ inch, elimination of base 1/8 inch, use of mica bridge construction to permit mounting gun closer to stem ¼ inch, shortening focus lens ¼ inch, penetrate deflection coil 1 inch. The ultimate neck length will be less than $3\frac{1}{2}$ inches compared with the present $5\frac{1}{2}$ inches on the 110^{o} tubes. The non ion trap tube to be introduced in the first quarter of 1958 will have a $4\frac{1}{2}$ inch neck length.

In order to assist in deflecting wider deflection angles it is probable that we will reduce the neck diameter from the present 110 degree 1-1/8" diameter to 7/8 inch diameter. This will not in itself provide any additional length reduction.

The foregoing tabulation of length reduction gave the total reduction for 135 degree bulbs. It is felt that this is the final step inddeflection angle increase. Mechanical considerations require a bowed faceplate in order to adequately withstand atmospheric pressure and presumably the maximum deflection angle possible is had by sealing two face plates back to back. It is generally agreed that this would require a minimum dimension 1 of 2" on a 10" bulb and 3" on a 21" bulb. If this holds, then the maximum feasible deflection angle would run from 135^{o} on a 10" bulb to 147^{o} on a 21" bulb. The Aiken so called "flat face tube" will have thickness of at least the 2-3 inches mentioned with the resultant equivalent deflection angles. Of course, the Aiken tube has the gun coming out the side rather than out the back and therefore no neck length.

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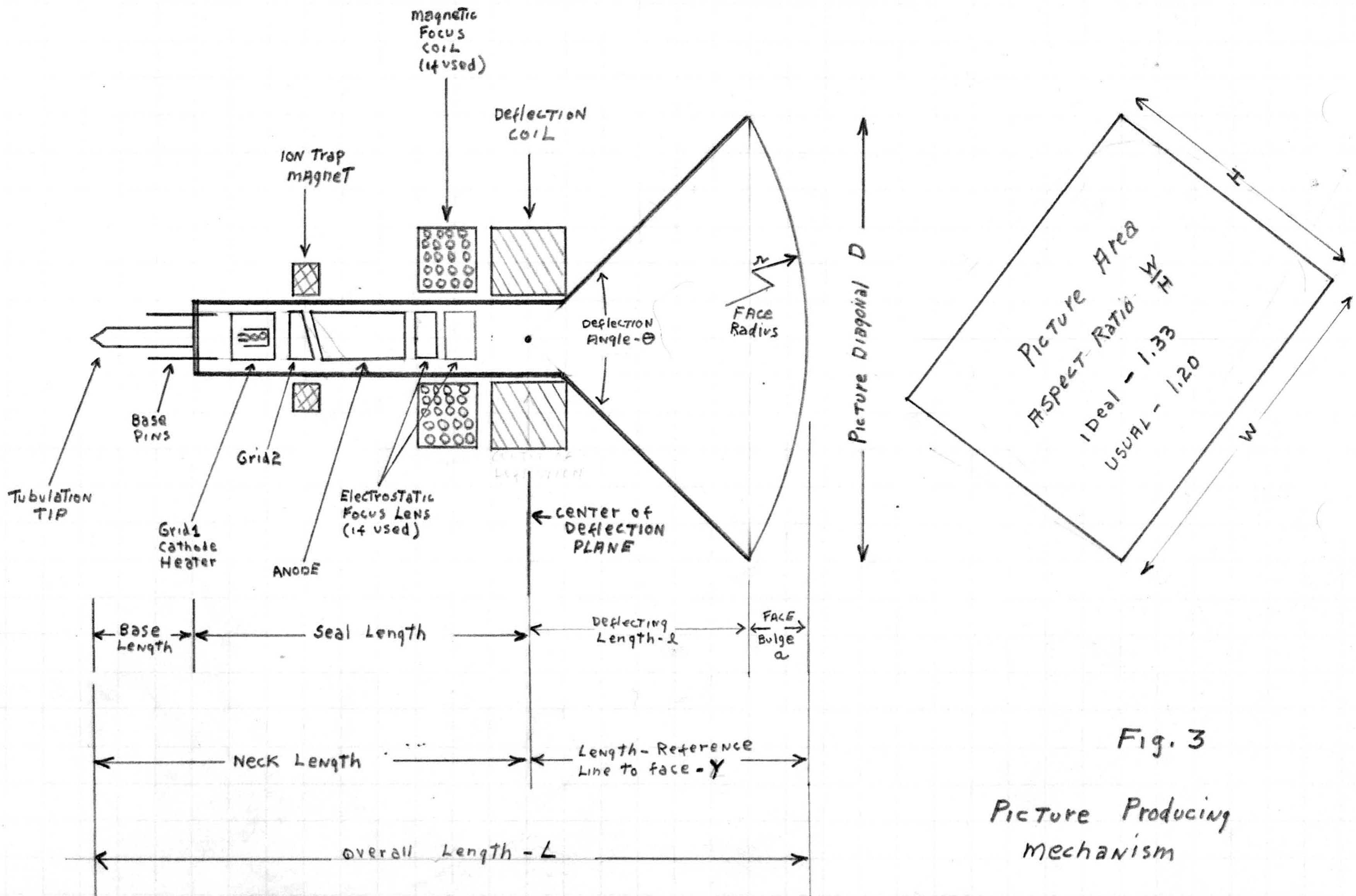

Fig. 3

Picture Producing mechanism

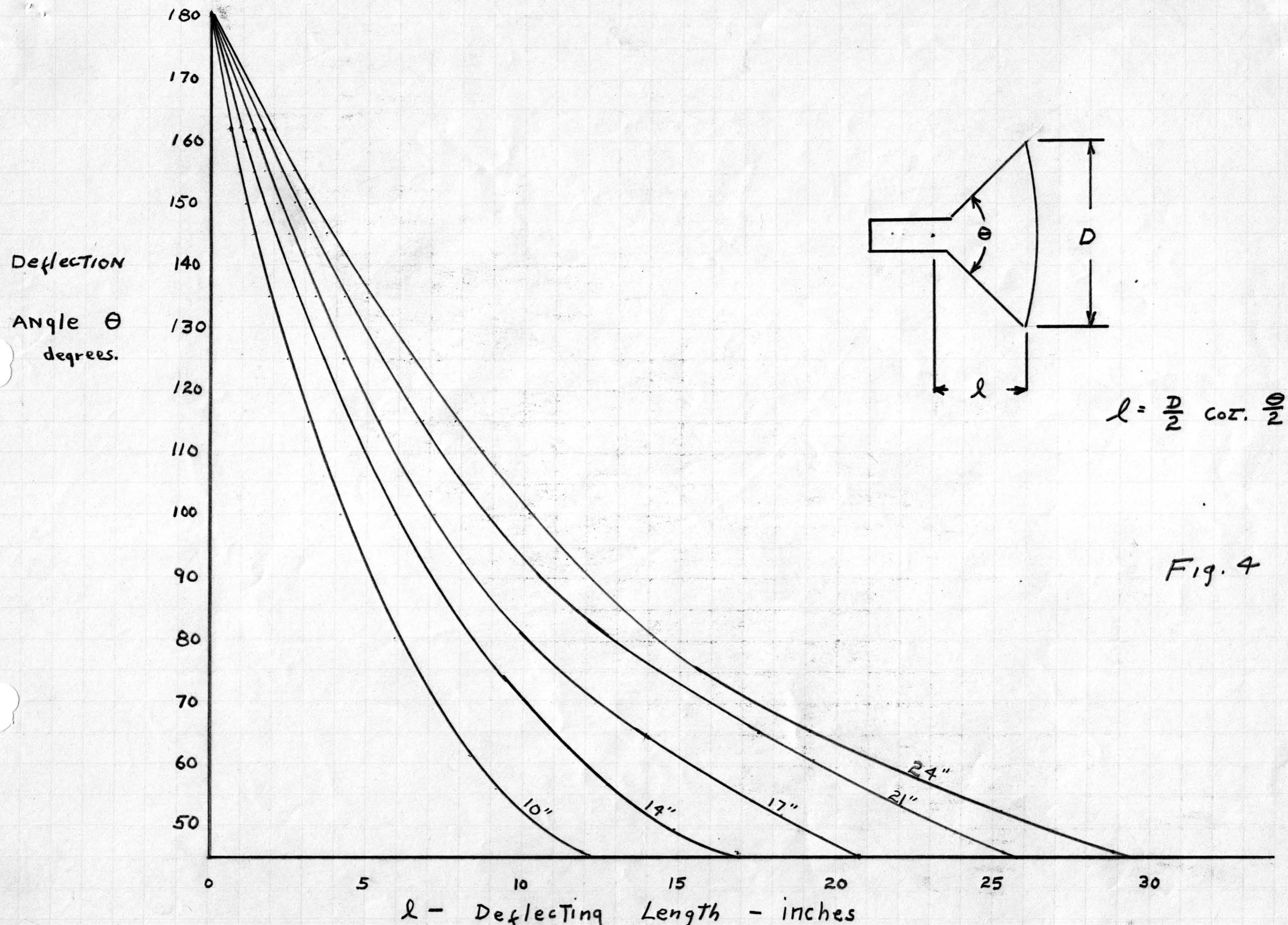

Fig. 4

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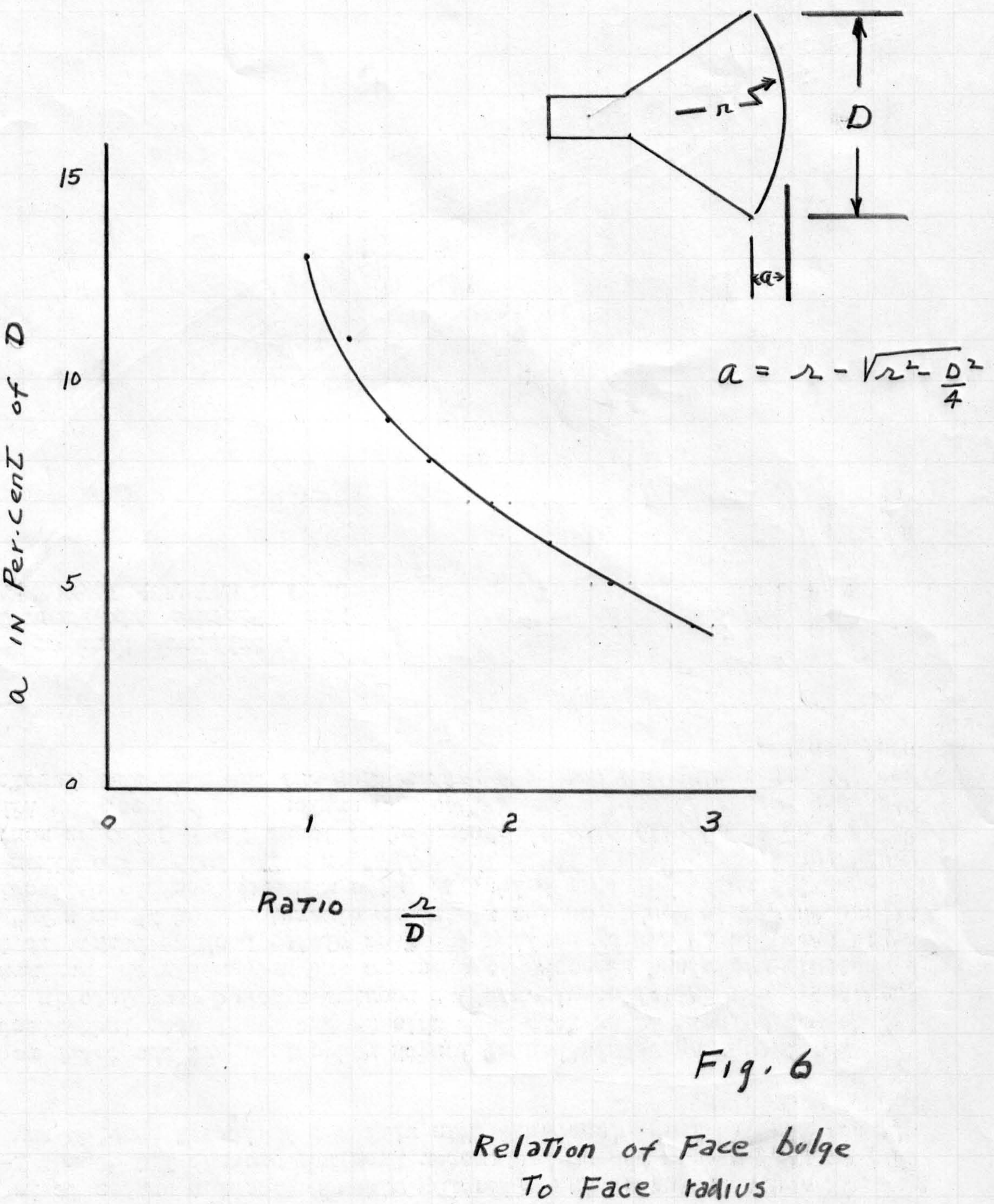

Fig. 6

Relation of Face bulge
To Face radius
and Picture Diagonal

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"The Evolution of Picture Tube Length"

Since the start of the mass TV market, set designers have strived to style their sets to be most acceptable to the consumer. Generally, style requirements are: (1) a picture size sufficiently large for family viewing in the living room; (2) a cabinet size having normally pleasing appearance including a depth close to that of a book case. The first requirement is the most important. Obviously, the speed at which the industry progressed toward these goals has been determined by technical ability and economics. The picture size evolution seems to have reached its goal in that a 21" picture has proved very satisfactory and larger sizes have not displaced it. The cabinet depth goal is about 12" and has not yet been reached.

Cabinet depth is governed by tube length which in turn is dependent on three factors:

1. Picture size (larger sizes mean longer tubes)
2. Deflection angle (wider angles make shorter tubes)
3. Neck length

Progress in glass technology during the past tensyears has permitted picture size to increase in discrete steps from 10" to 24" and 27" sizes. This has placed an even heavier burden of reducing tube length on the tube designers to reduce neck length and on set designers to sweep wider deflection angles.

Widening of sweep angles has been an interesting development. Theoretically, bending or sweeping an electron beam with a magnetic field does not consume energy; however, from a practical standpoint, the electronic circuits and components available to do this job result in a high stored energy content with considerable energy loss. It has not been economical from the receiver design standpoint to obtain wider sweeps by increasing energy input. All gains must be made at equal or lower power levels.

The components of the system are: horizontal output tube, deflection transformer, damping tube and associated circuit and deflection yoke. Sweep angles of 50° become possible through an inovation of using some of the stored energy to develop high voltage whereas it had previously been radiated as heat in a resistor. Use of a damping circuit wherein some more of the stored energy is used to boost the plate voltage on the output tubes contributed to the step to 70° sweep. The invention and use of low loss ceramic iron cores in transformers and yokes made 70° possible. Next, improvements in horizontal output tubes, damping circuits, and a more efficient sweep transformer (obtained through better knowledge) made possible 90° sweep angles. The most recent step to 110° is being accomplished through higher efficiencies and more material in the deflection yoke and through a reduction in the diameter of the yoke (smaller neck diameter).

Throughout all of this progress in the direction of wider sweeps, anode voltages have increased from about 8KV to 18KV. Larger picture sizes have necessitated it. Unfortunately, this has made the sweep design job even tougher.

Picture tube neck lengths are dependent somewhat on deflection angle and on electron gun design. In the period of increase in deflection angles from 50° to 110° neck lengths have been reduced from $8\frac{1}{2}$" to $5\frac{1}{2}$".

The early 10" tubes with 50° deflection were 17-5/8". The new 10" 110° tube is only 9-7/8" or about ½ as long. The first 21" tubes were 70° having a 23½" length. The step to 90° took 3½" off this and the new step to 110° reduces the 21" tube to 14-3/4", less than the early 10" tubes. A comparison of these lengths is made on the attached print.

Currently portable sets are popular. Reduced tube length has helped to make them practical. For example, the popular 14" portable if introduced during the 50° deflection days would have a length about 18-3/4", much too long for an acceptable portable. The 70° 14" reduced this by 2", the 90° version 2¼" and now the 110° 14" removes over 3 more inches to provide a tube length of only 11½". This allows a far more acceptable portable depth, however, still shorter tubes are desired. It is reasonable to expect the 14" portable to eventually attain an 8" depth.

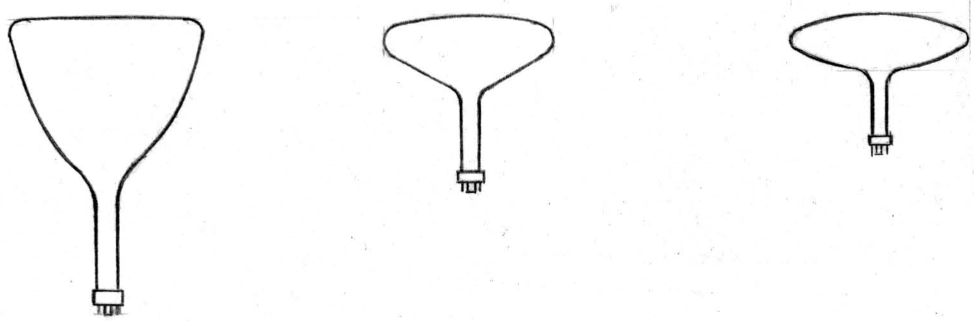
For the future it is certain that TV set designers will attempt to still further improve their sweep designs, putting far more pressure on the receiving tube designers for improvements in their area. Still smaller neck diameters are feasible and will yield much toward a sweep angle of say 130°. Neck length too can be further reduced. It is estimated that a 21" tube in the future may be only 12" long which will come very close to that ideal cabinet depth. For portable sets 10" could be 8" deep and a 14" 130° will probably be 9". Similar reductions in length of 17" and 24" tubes will be expected.

Styling advantages of 130° tubes in this highly competitive set market will eventually be realized. GE as a leader cannot afford to fall behind in this development.

L. C. Kunz

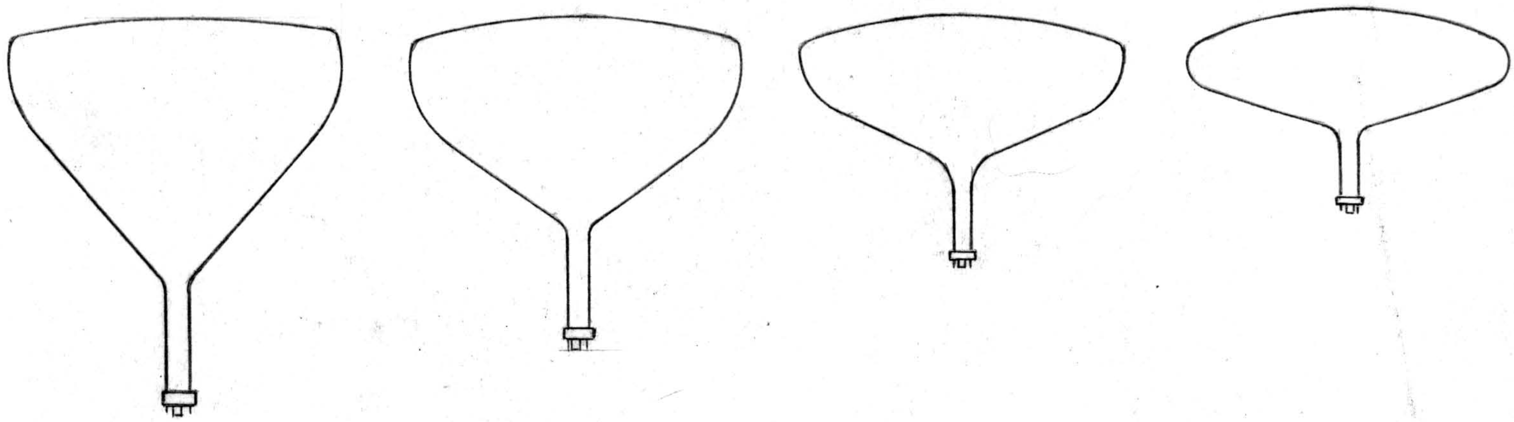
PICTURE TUBE LENGTH COMPARISON

10" TUBES



Deflection	50°	110°	130°
Neck Diameter	1-7/16"	1-1/8"	?
Neck Length	8-3/16"	5-1/2"	?
Over-all Length	17-5/8"	9-7/8"	?

21" TUBES



Deflection	70°	90°	110°	130°
Neck Diameter	1-7/16"	1-7/16"	1-1/8"	?
Neck Length	7-1/2"	7-1/2"	5-1/2"	?
Over-all length	23-1/32"	20"	14-3/4"	?