Using Magnetic Quadrupoles in Cathode-Ray Tubes

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Abstract

CRTs can be improved by means of magnetic quadrupoles. Areas of improvement are convergence, spot shape, image-flatness and space charge compensation.

1. Introduction

This lecture describes how magnetic quadrupoles can help to solve a variety of problems. In CRTs there is a permanent drive to minimize cost, and therefore to reduce the number of components. However, extra components are not a-priori forbidden; they can be used when their contribution to performance adds more value than costs to the CRT. There are roughly four reasons for using magnetic quadrupoles:

1. Optimizing convergence performance
2. Optimizing spot performance
3. Extra mask curvature in RF tubes
4. Compensating space charge repulsion

References will be given in instances where the systems mentioned here are already described in detail elsewhere.

2. Optimizing convergence performance

A well-known application of magnetic quadrupoles is in optimizing convergence. First of all a magnetic quadrupole is used to ensure that the two side beams are converged at the center of the screen. Color CRTs nowadays have so-called "self-converging" deflection fields. This means that the three beams that are converged at the center of the screen remain converged after deflection without additional convergence corrections. Perfect self-convergence can be obtained when the lengths and centers of the line and frame deflection fields can be chosen properly [1]. However it may happen that, for practical reasons like deflection sensitivity or available winding technology, the lengths and centers of the line and frame coils cannot be chosen freely. It may then not be possible to obtain sufficient convergence simultaneously on the axes and in the corners of the screen. In those situations, the most practical solution is to design a deflection unit with a convergence pattern as shown in Figure 1, and correct that pattern by means of a quadrupole. For correction a current is created that has the same sign at the bottom and top of the screen as long as the tube and yoke both have four-quadrant symmetry. Such a current shape is called a frame parabola current, and can be approached by rectifying (a fraction of) the vertical deflection current.

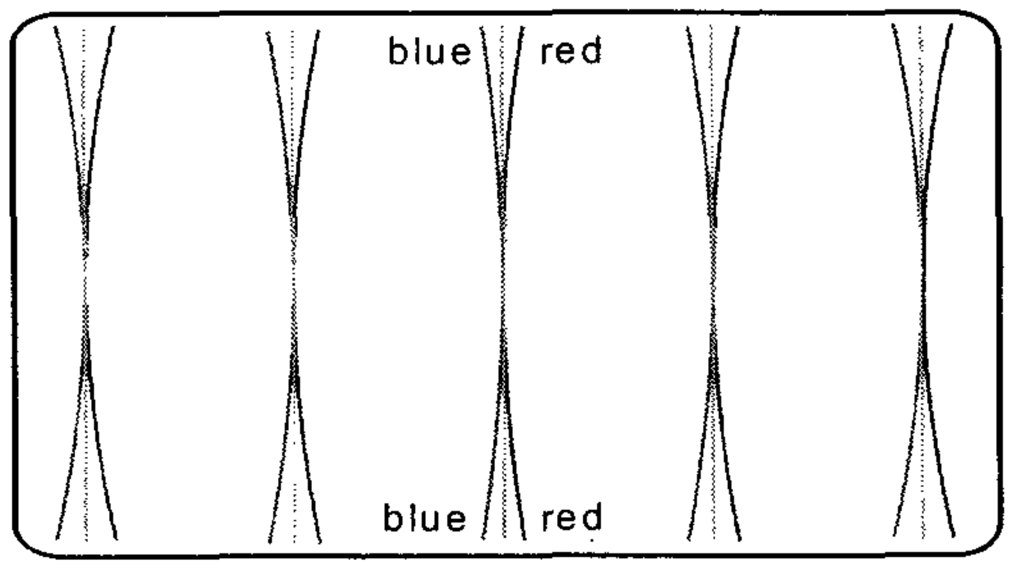

Figure 1: This convergence error pattern is sometimes the best obtainable result due to an improper length of the deflection fields, but it can be eliminated by means of a quadrupole.

Another use for a quadrupole is to compensate alignment errors in the CRT. When the deflection unit is mounted on a tube, it can be tilted horizontally as well as vertically. While tilting the deflection unit, both convergence errors and scan raster distortions can be minimised. However, when either tube or yoke do not have exact four-quadrant symmetry, convergence error and raster distortion do not reach their optimum performances for the same tilt values. A typical convergence error pattern then remains as shown in Figure 2.

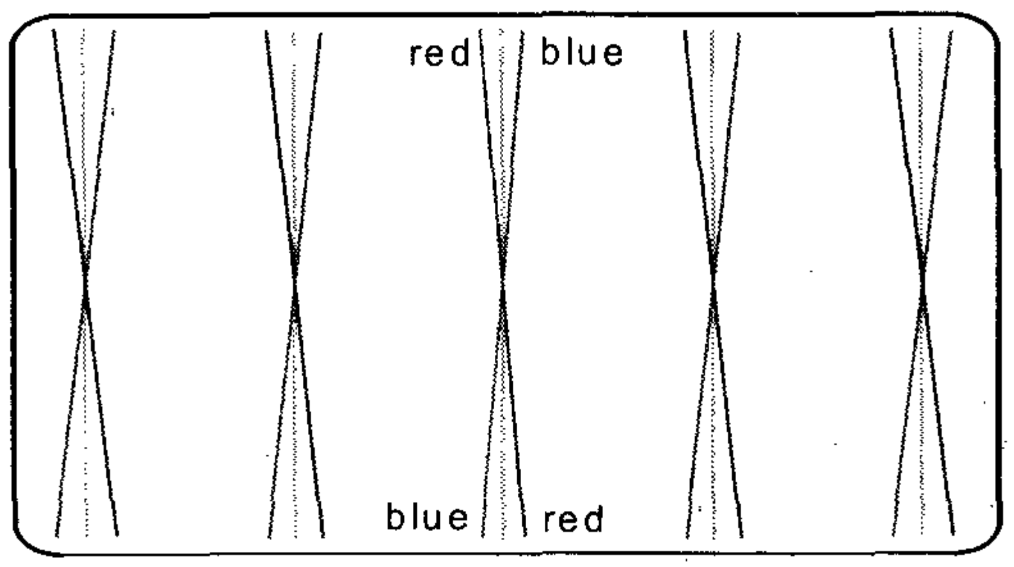

Figure 2: This convergence error pattern arises from a vertical CRT alignment error, but it can be corrected relatively easily by means of a quadrupole.

Feeding a fraction of the frame deflection current also through the quadrupole, leading to a correction with opposite signs at top and bottom of the screen, can eliminate this error pattern. Note that the use of the frame deflection current as a basis for generating quadrupole signals is much more favorable than the use of the line deflection current, because the frequency of the line deflection current is much higher than the frequency of the frame deflection current.

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Magnetic quadrupoles can also be used in a more elaborate way to eliminate convergence errors by driving them from a special electronic circuit that allows fine-tuning at 25 or more screen positions [2] using digital techniques. But this technique is rarely used because of the cost and because acceptable quality can already be obtained without it.

3. Optimizing spot performance

Basically there are three possible ways of using quadrupoles for spot improvements. First of all there is the issue of beam astigmatism. When beam astigmatism is solved, there are the issues of the shape of the deflected spot and the amplitude of the dynamic focus voltage. Those issues are dealt with by the DAF-Q system, DAF-Q^2 system and the DAF-FQ system

3.1 Beam Astigmatism Elimination

Traditionally quadrupoles are used in monochrome CRT displays. In those CRTs, electron guns are used with rotational symmetry. The rotational symmetry of the beam is, however, lost when the beam is deflected, even when the beam is deflected with the most uniform field that can be created (called pure dipole field). This is caused by the fact that, even for such a pure dipole field, the focusing effects caused by deflection are stronger in the direction perpendicular to the direction of deflection than the focusing effects in the direction of deflection [3]. The result is that when a deflected beam is focused such that the spot has minimum size in the direction of deflection, the beam is over-focused into the direction perpendicular to the direction of deflection. This causes haze, which is illustrated in Figure 3 by the shaded areas.

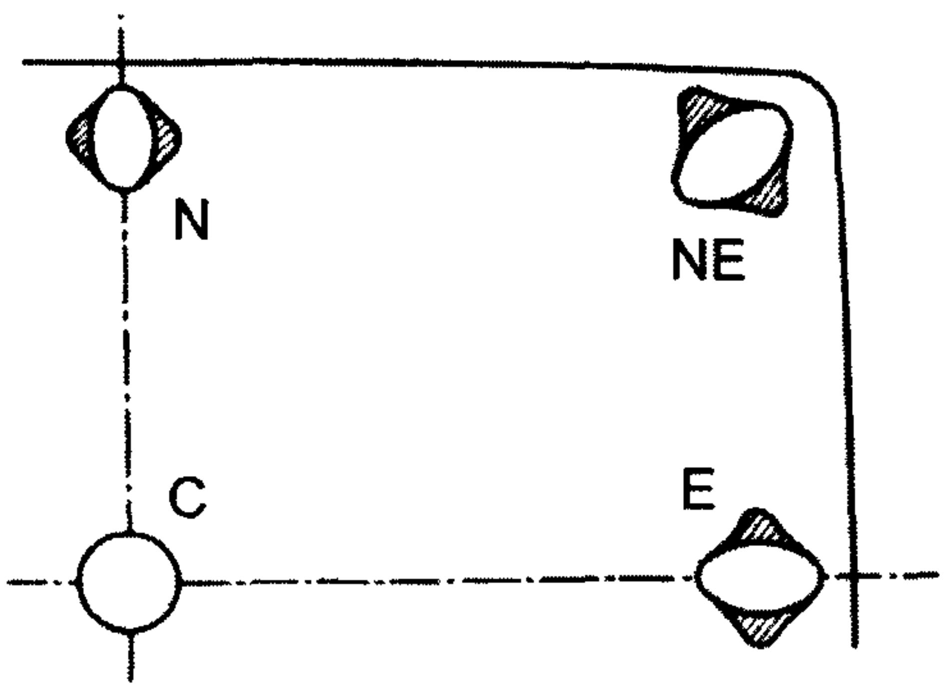

Figure 3: Astigmatism of an electron beam generated by an electron gun with rotational symmetry and deflected with the most uniform field, at the right top quadrant of the screen. The shaded areas indicate haze.

A beam that cannot be focused properly is called an astigmatic beam. These problems are overcome by means of magnetic quadrupoles, one having a normal horizontal orientation and one having a diagonal orientation. This is the common approach in monochrome monitors for medical applications [4].

In color CRTs, self-converging deflection yokes are used, often in combination with so called Dynamic Focus and Astigmatism (DAF) guns. By adding a dynamic focus voltage to such a gun, the astigmatism problem of beams is solved. Therefore, no haze is present when sufficient dynamic focus voltage is applied, but the deflected spots are elliptical, as shown in Figure 4 and the required dynamic focus voltage may be high.

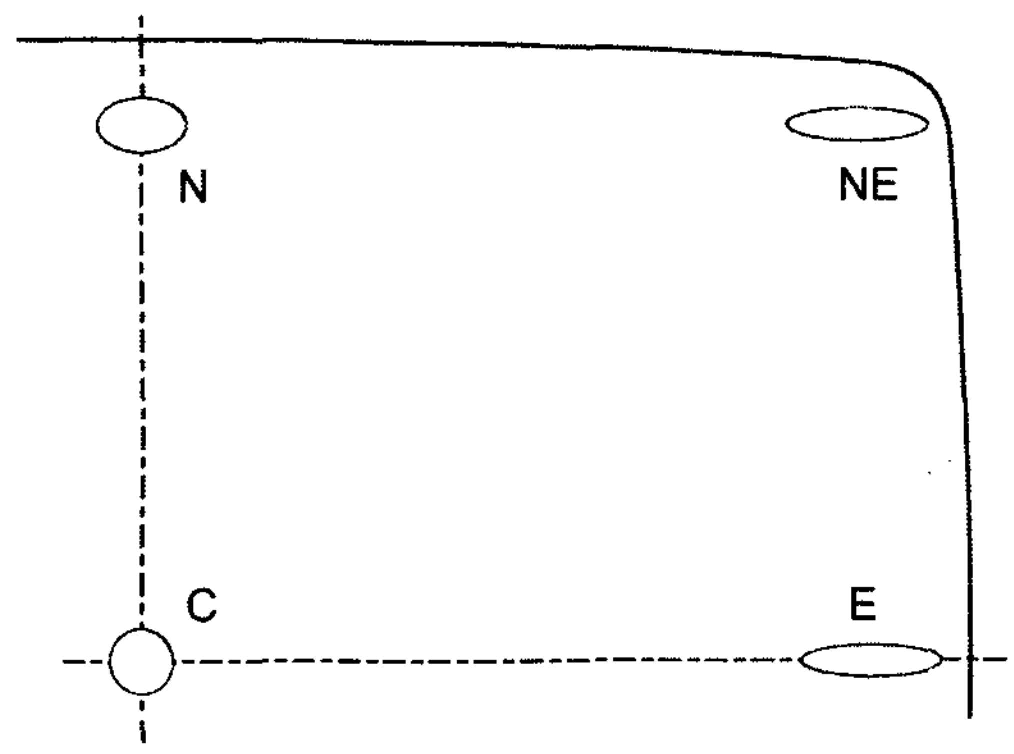

Figure 4: Shape of the spot of an electron beam generated by a Dynamic Focus and Astigmatism (DAF) gun and deflected by a self-converging deflection field, at the right top quadrant of the screen.

The next three systems, using magnetic quadrupoles, can be used to attack these problems.

3.2 The DAF-Q system

In the DAF-Q system [5] one quadrupole is added which is driven by a current that is proportional to the squared horizontal deflection current. Adjusting the field of the deflection coil then compensates the convergence error caused by this quadrupole.

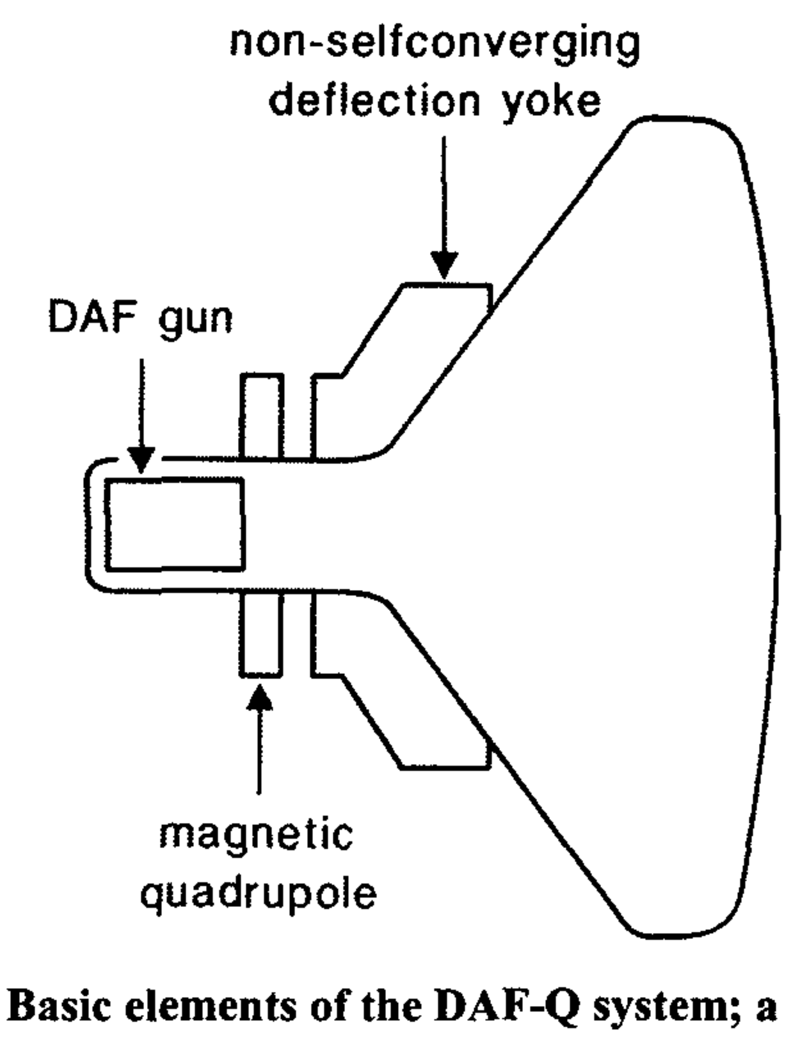

Figure 5: Basic elements of the DAF-Q system; a DAF gun, a quadrupole driven with a line deflection dependent current and a deflection yoke that is only self convergent in combination with the driven magnetic quadrupole.

Depending on the amount of convergence effect of the quadrupole, the spot in the corners becomes more circular. For instance, in a 36" tube with a spherical screen and a 106° deflection angle, the spot elongation at the line axis is reduced from 1.88 to 1.65 by a quadrupole introducing a negative convergence error of 12.7 mm. The result is a spot that is more circular along the edges of the screen. The dynamic focus voltage drops from 1100 V to 650 V. The drawback of this system is that the adjustment of the deflection coil leads to additional North/South pincushion distortion. Any attempt to straighten the North/South raster again leads to an increase in the spot deformation, which brings us almost back to where we were before introducing the quadrupole. For very large deflection CRTs the system is nevertheless attractive [6].

3.3 The DAF-Q^2 system

A way to improve the spot uniformity without introducing additional North/South pincushion distortion is to use two quadrupoles between the electron gun and the deflection unit.

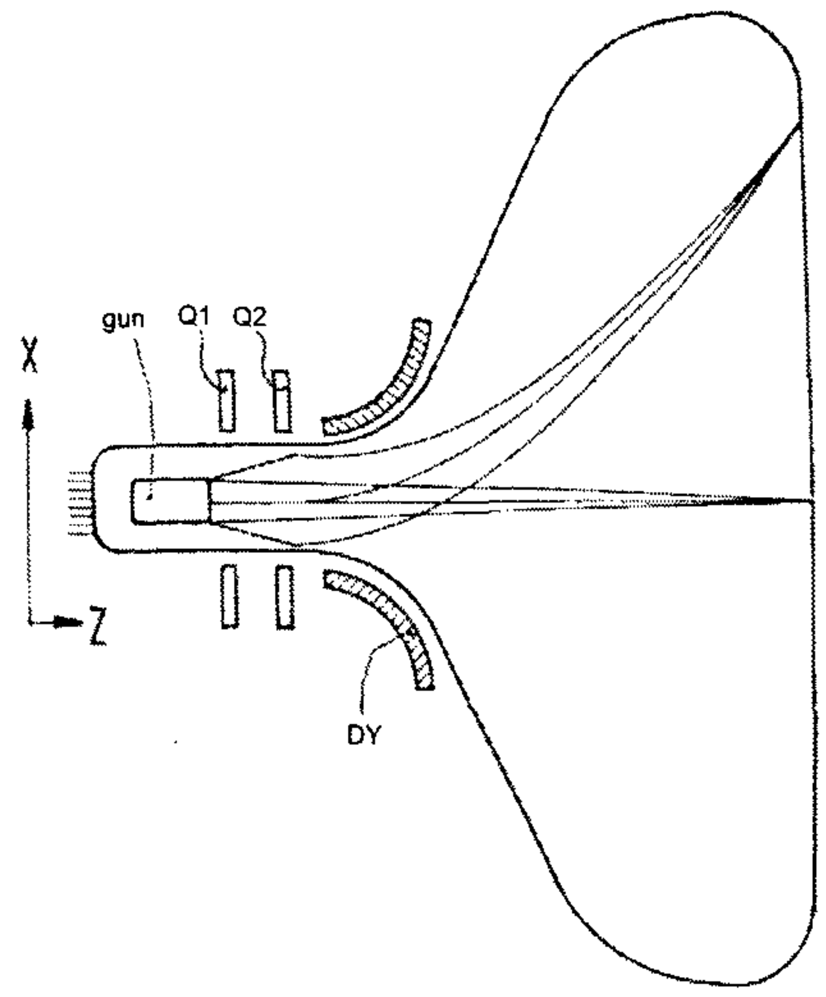

Figure 6: Basic elements of the DAF-Q^2 system, a DAF gun, two quadrupoles and a fully self-converging deflection yoke.

By varying the angles between the beams, and thereby also the angle within the beams, the shape of the spot can be controlled. The difficulty here lies the fact that they have to be driven accurately, which is not easy when they are driven with line frequencies. This approach has found an electrostatic equivalent and is now used in the electron guns themselves [7]. There each beam has its own set of quadrupoles and they are coupled to the dynamic focus voltage of the gun. The advantage of using magnetic quadrupoles between the gun and the deflection yoke is that its effect is not limited by spherical aberration properties of the gun.

3.4 The DAF-FQ system

The real benefit of the previous systems is the reduction of the amplitude of the dynamic focus voltage. But that benefit can also be obtained without driving the quadrupoles dynamically [8]. By using fixed quadrupoles the required focus voltage in the screen corners reduces dramatically. Although the focus voltage also reduces in the center of the screen, in total the reduction in the dynamic focus voltage is the greatest. This is shown in Figure 7, where the reciprocal vertical image distance is a measure of the focus voltage. This system is particularly interesting when the deflection angles increase and/or the electron guns become longer. A reduction of the dynamic focus voltage by 40% has been obtained in practice.

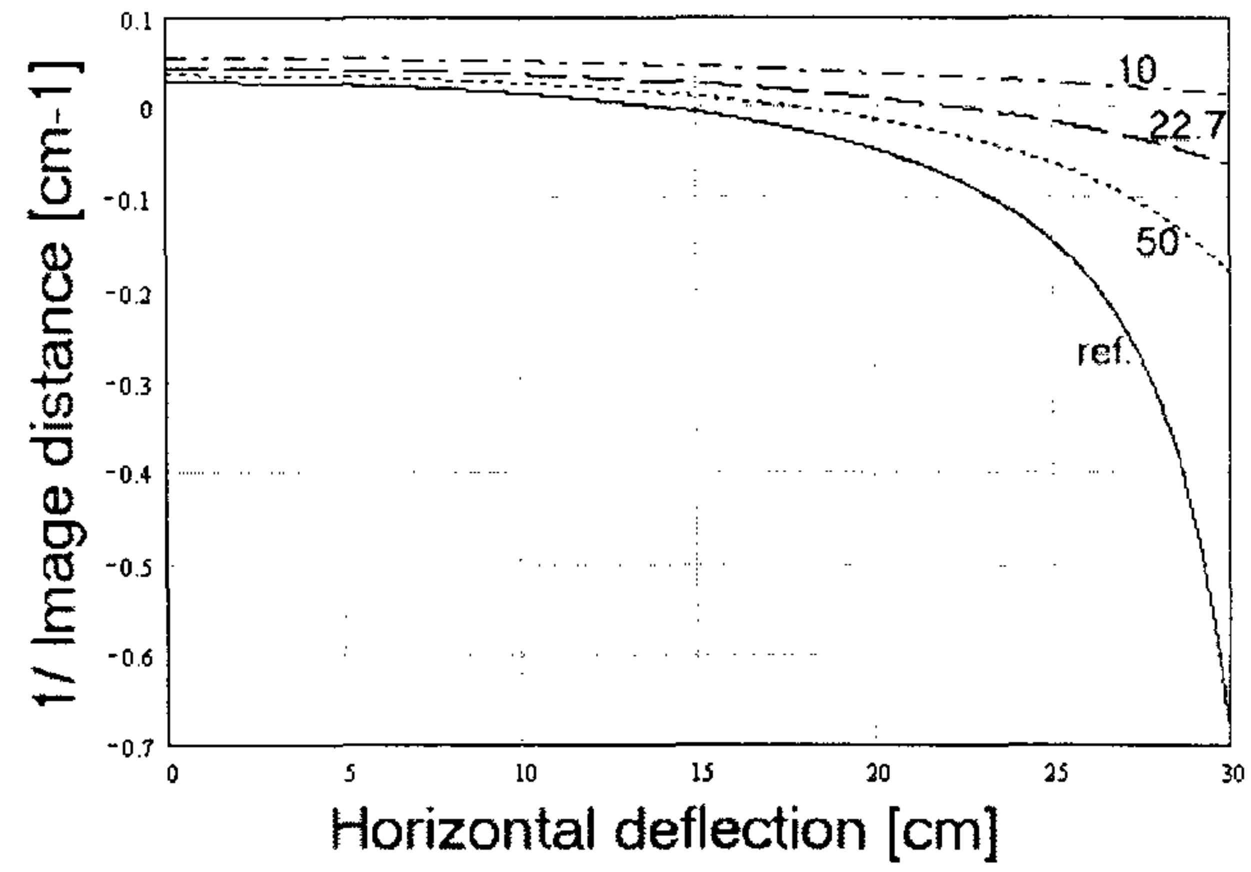

Figure 7: The required vertical reciprocal image distance of the gun as a function of deflection, for various focal lengths (indicated in cm in the figure) of the fixed quadrupole

4. Extra mask curvature in RF tubes

The notion that quadrupoles can be used to influence the angle between the beams has found a new application in the first generation of Real Flat tubes as designed by Philips Components [9]. Based on the desire to create a CRT with a flatness impression resembling a tension mask tube, and the notion that tubes with a large screen wedge would be expensive, quadrupoles have been used to design a CRT in which the shadow-mask is more curved than the inner surface of the screen. Important for this application was the experience built up with quadrupoles for spot uniformity improvement. This experience relates to the cost effective construction of the quadrupoles, but most of all to knowledge about how to drive the quadrupoles. Previous experience indicated that the quadrupoles should not be driven as a function of horizontal deflection but only as a function of vertical deflection. With this technology, referred to as Gun Pitch Modulation, it is possible to combine a screen with a vertical radius of curvature of 7 m and a mask with a vertical radius of curvature of 3 m. Grading of the screen pitch creates additional curvature of the mask in the horizontal direction.

Recently it has been shown that the electron gun can also be designed such that it performs the Gun Pitch Modulation action [10].

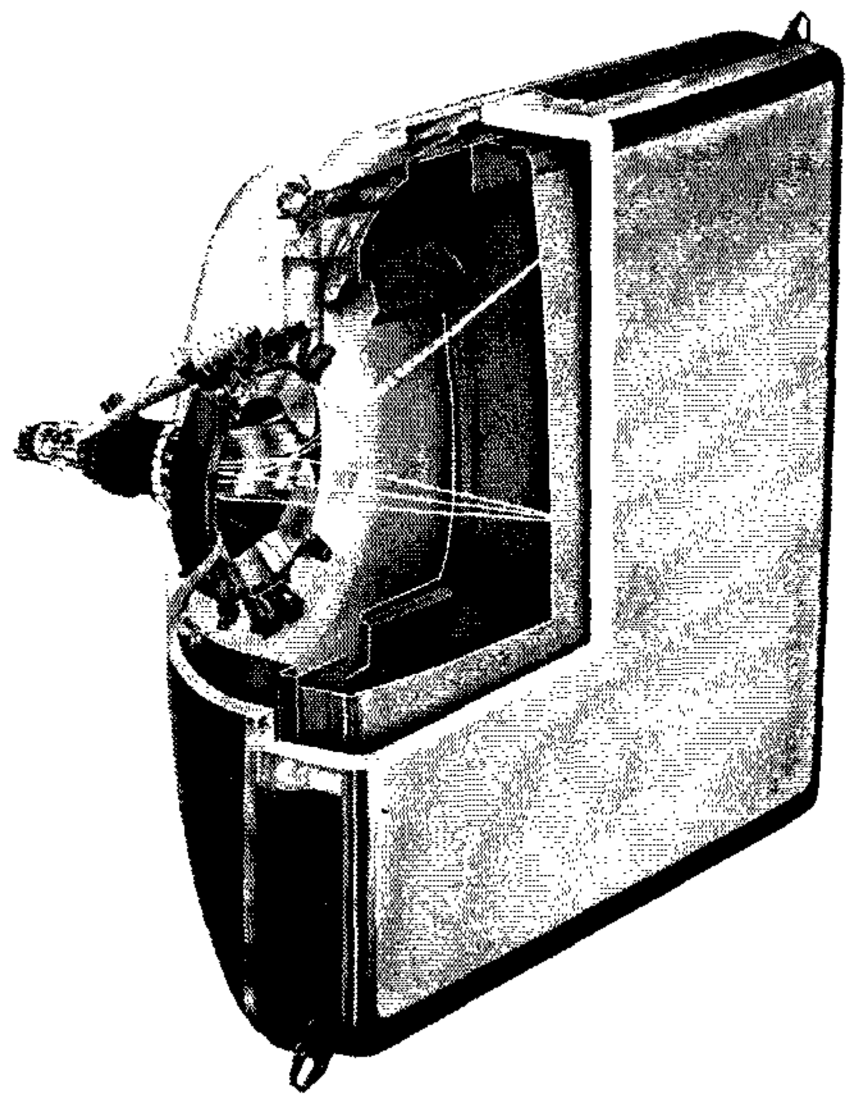

Figure 8: A Real Flat tube in which the shadow-mask is made more curved in the vertical direction than the inner surface of the screen. This is possible because two quadrupoles are used to reduce the (virtual) pitch of the gun.

5. Compensating space charge repulsion

In future, quadrupoles are also likely to be used to compensate for the effect of space charge repulsion. Due to space charge repulsion, the beams are repelled from each other on the screen. However, contradictory as it may seem, the microscopic spots of the three beams (the projections of the beams through a single mask hole) are pushed towards each other (the gun pitch seems to be reduced) as illustrated in Figure 9. To overcome both problems, two quadrupoles can be used. The first quadrupole, closest to the electron gun, is used to repel the two beams even more, while the second quadrupole, closer to the screen, restores convergence of the beams on the screen. This might be needed in the future because space charge repulsion between beams increases when the size of the beam spot reduces. Spot size reduction is the main requirement for a tube with improved resolution.

Ideally, the current through these quadrupoles is proportional to the total current of the three beams. A less ideal, but more practical approach is to derive the current through the quadrupoles from the peak beam currents or average beam currents that occurred in the previous image frame. Alternatively the current through the quadrupoles can also be derived from the contrast setting of the TV set.

6. Conclusions

There is a wide range of CRT aspects that can be improved by means of magnetic quadrupole. In many cases the additional cost of the quadrupoles is exceeded by the additional value that is given to the CRT.

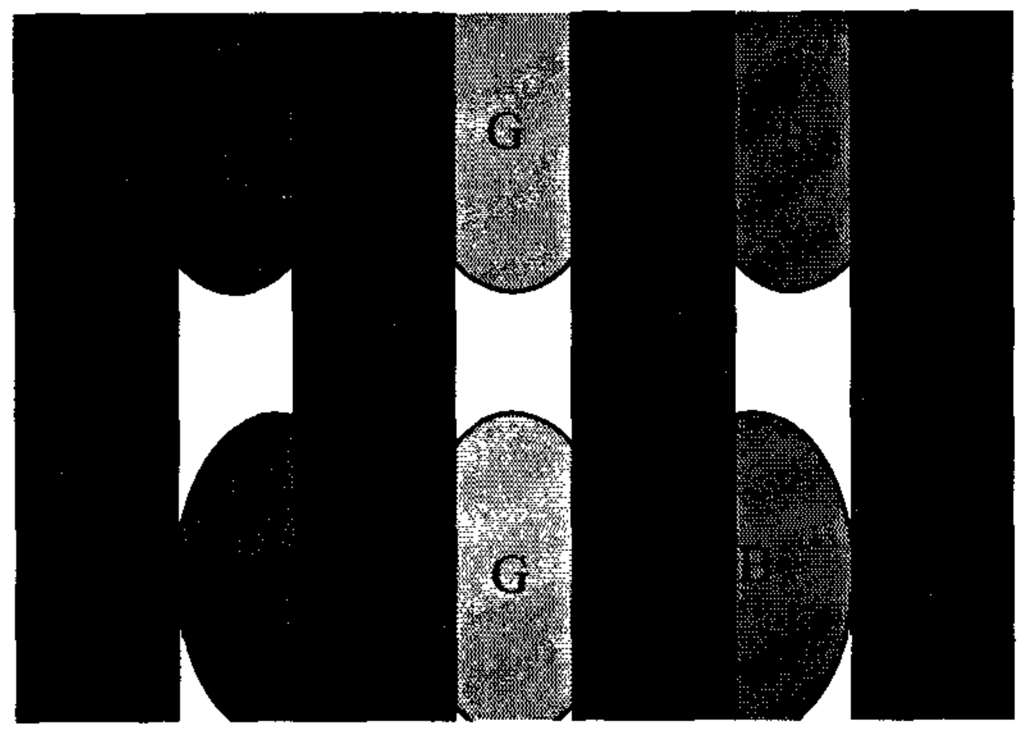

Figure 9: Microscopic spots at low (top) and high (below) beam currents behind the black matrix lines on the screen. Due to space charge repulsion the microscopic spots of one triplet creep closer to each other.

7. References

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