The Fast Intelligent Tracking (F!T) Tube: Feedback Signal Acquisition

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Abstract

The F!T tube is a new type of CRT without a shadow mask. Correct color reproduction is performed by an electronic system that measures the landing positions of the electron beams and corrects through a dedicated deflection system. This paper describes in detail the position sensor and some of the electronics needed to build a functional control system. The principle has been shown in single- and triple-beam 17" and 32" tubes, of which results are included.

1. Introduction

1.1 F!T principle

Cathode-ray tubes (CRTs) are the dominant display technology for monitor and television applications. They are characterized by providing an image with good resolution, high brightness and contrast, and an as yet unequaled price/performance ratio.

In color CRTs, a shadow mask is used for color selection. Recently, a maskless CRT has been proposed and realized in which the electron beams are tracked along phosphor lines [1,2]. This CRT, referred to as Fast Intelligent Tracking (F!T) tube, uses conductive tracks and an electronic tracking system to provide color selection. In case the beams deviate from the intended phosphor lines, the conductive tracks, deposited on either side of the phosphor lines, intercept some of the current. A position signal will be the result for each of the three beams, whose phase and magnitude contains information on how far the beams are above or beneath their intended path. This error signal is used in a feedback loop to keep the beams on track, thereby avoiding color errors and providing an alternative method for color selection. Recently, the conductive tracks have been replaced by phosphor tracks, generating light from which position information can be retrieved. Figure 1 shows a graphical representation of the F!T principle with a conductive tracking structure.

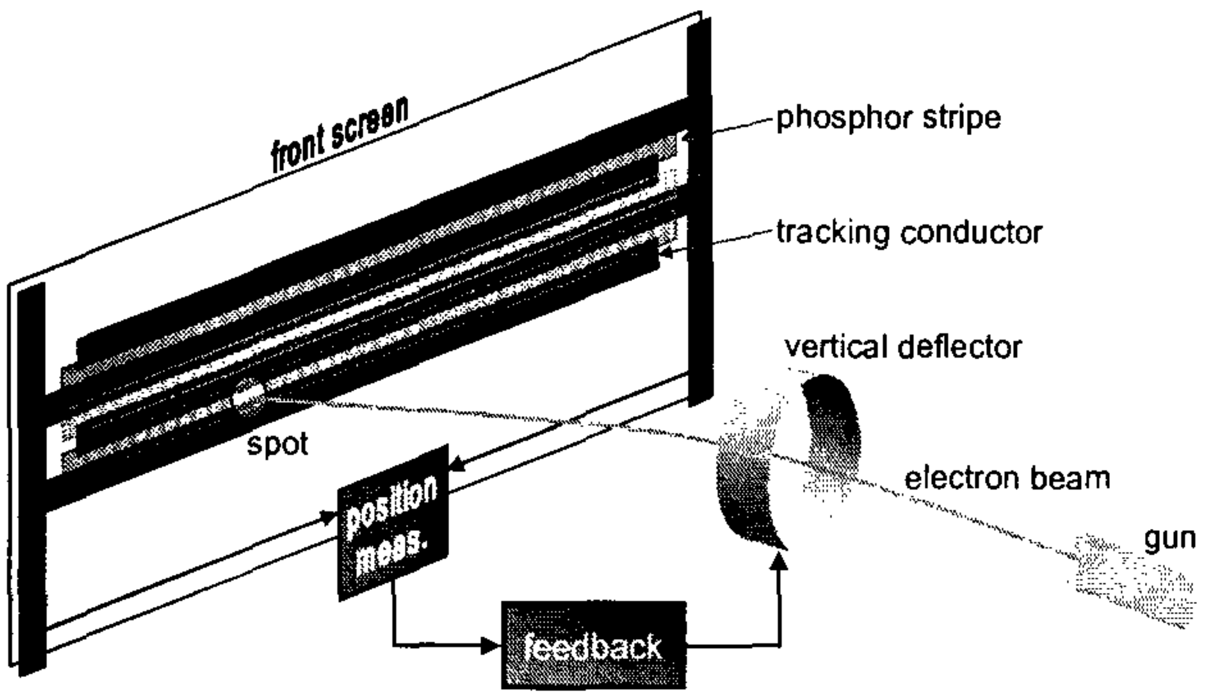

Figure 1: Visualization of the 1-beam F!T principle

Compared to conventional CRTs, F!T has an inherently better picture quality regarding sharpness, contrast, geometry, and uniformity and saves power by making more efficient use of the electron beams. Better sharpness and geometry are obvious from the spot requirements and tracking ability and better uniformity simply results from the absence of doming and microphony, associated with the shadow mask. The less obvious contrast improvement comes from the absence of the mask too. In a shadow mask tube, most of the electrons that are back scattered from the screen are reflected back again by the mask to the screen and on the wrong color. Cost effectiveness is strengthened by less material use (no mask) and simplified manufacturing (no mask handling) on conventional production lines.

1.2 Screen structure

Conducting tracks, structured as two interdigitated combs (cf. figure 1), are deposited onto the inside of the panel glass. On top of this tracking structure, the image phosphors are structured in horizontal stripes. Finally, an aluminum mirror is laid across the entire screen structure. Figure 2 shows a cross section of this stack, in which also black matrix material is present between the tracking conductors and the panel glass.

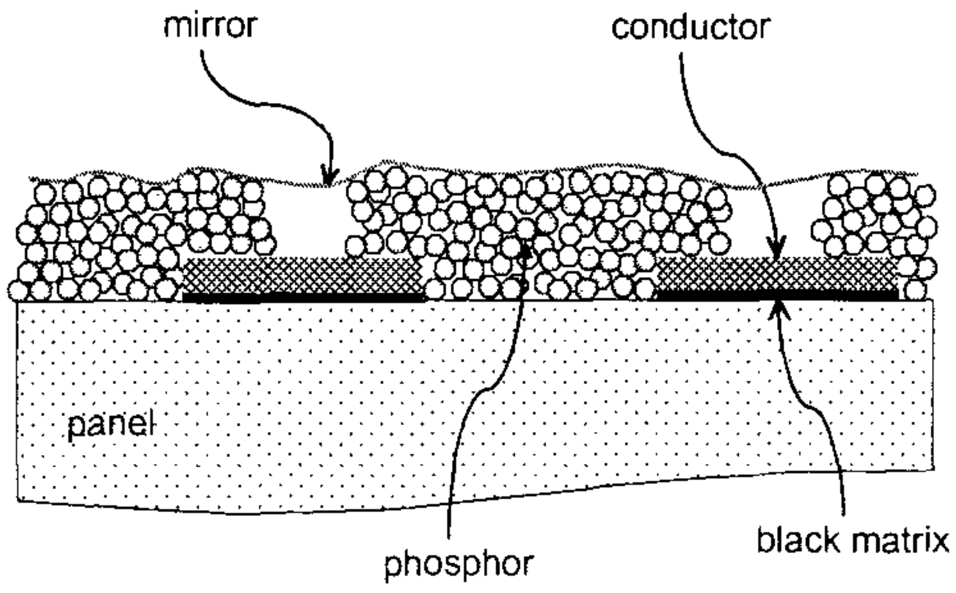

Figure 2: Cross section of the screen structure

2. Position measurement model

Assuming a spot with a Gaussian current density profile, the tracking currents as a function of spot position and physical spot and tube parameters can be calculated. This will be described in the following sections. After that, an electrical model that can be used in DC simulations will be presented.

2.1 Mechanism

2.1.1 Spot profile

Assume a Gaussian spot with the following current density function:

$$J(x,y) = \hat{J} e^{-\left(\frac{x}{R_x}\right)^2} e^{-\left(\frac{y}{R_y}\right)^2} .$$

Here, is the current density in the center of the spot and R_x and R_y are horizontal and vertical space constants respectively. These parameters can be related to more practical parameters as follows:

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$$R_x = \frac{d_{x,5\%}}{1.3859},\quad R_y = \frac{d_{y,5\%}}{1.3859},\quad \hat{J} = \frac{I_{beam}}{\pi R_x R_y},$$

where $d_{5\%}$ is the diameter within which 95% of the current is enclosed and I_{beam} is the total beam current.

2.1.2 Measurement principle

At the landing position of the spot, the beam current is divided across the metal tracks of the tracking sensor and the aluminum mirror. Figure 3 shows the spot landing position in detail.

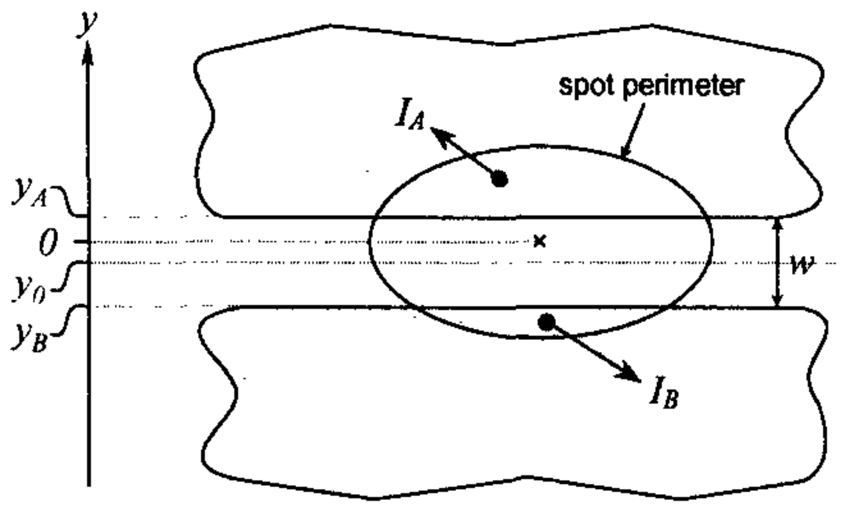

Figure 3: Detail of spot landing position

For the moment, it is assumed that there are only two tracks, extending infinitely upward and downward. The origin of the coordinate system is chosen to coincide with the spot center.

Assume that all current directly projected onto a track will flow into that track and the remainder of the current (projected onto the image phosphor) will, eventually, flow into the aluminum mirror. The amount of current flowing into a track can be determined by integrating the current density function over the track area:

$$I_A = \int_{y=y_A}^{\infty}\int_{x=-\infty}^{\infty} J(x,y)dxdy,\quad I_B = \int_{y=-\infty}^{y_B}\int_{x=-\infty}^{\infty} J(x,y)dxdy.$$

These integrals can be evaluated, yielding:

$$I_A = \frac{1}{2}I_{beam}\left[1-\operatorname{erf}\left(\frac{y_A}{R_y}\right)\right],\quad I_B = \frac{1}{2}I_{beam}\left[1+\operatorname{erf}\left(\frac{y_B}{R_y}\right)\right],$$

where y_A and y_B are dependent on the position y_0 of the spot with respect to the tracks and the spacing distance w of the tracks as follows:

$$y_A = y_0 + \frac{w}{2},\quad y_B = y_0 - \frac{w}{2}.$$

Figure 4 shows I_A and I_B as a function of y_0 graphically for typical parameter values (I_{beam}=500µA, R_y=215µm, w=130µm).

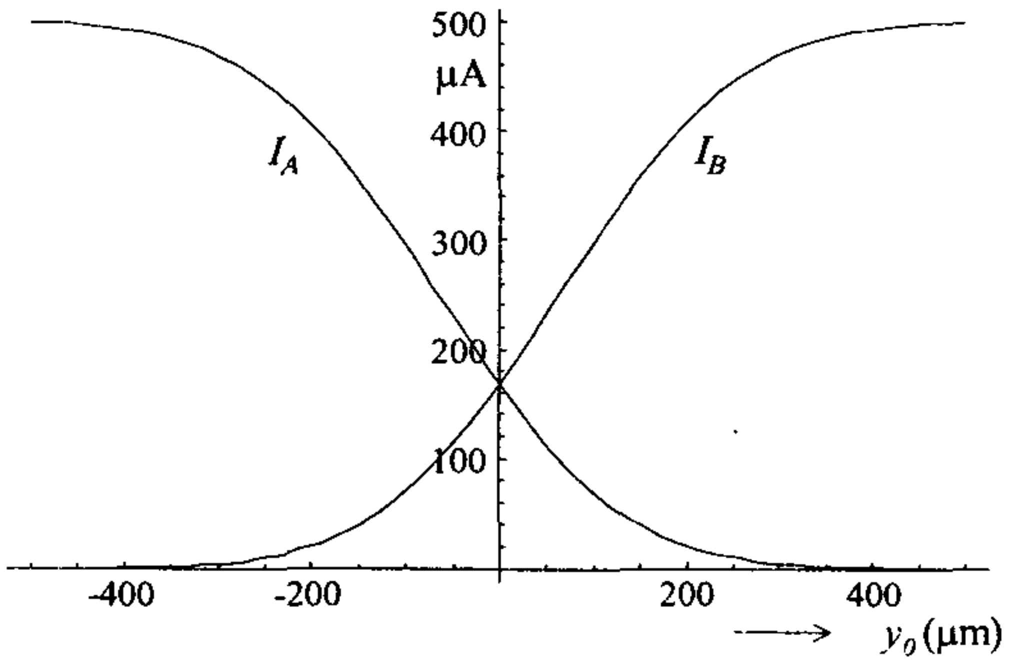

Figure 4: Tracking currents versus beam displacement

In reality there are not just two tracks, extending infinitely upward and downward, but the structure is periodic from top to bottom across the screen. Again, the current flowing into the tracks can be determined by integrating the current density function over the complete track area of the periodic tracking structure, which is irradiated by the electron beam. This leads to a sum of integrals, which will not be further elaborated here.

Figure 5 shows I_A and I_B as a function of y_0 graphically for typical parameter values (I_{beam}=500µA and R_y=215µm) and a periodic tracking structure with 130µm wide tracks at a distance of 130µm.

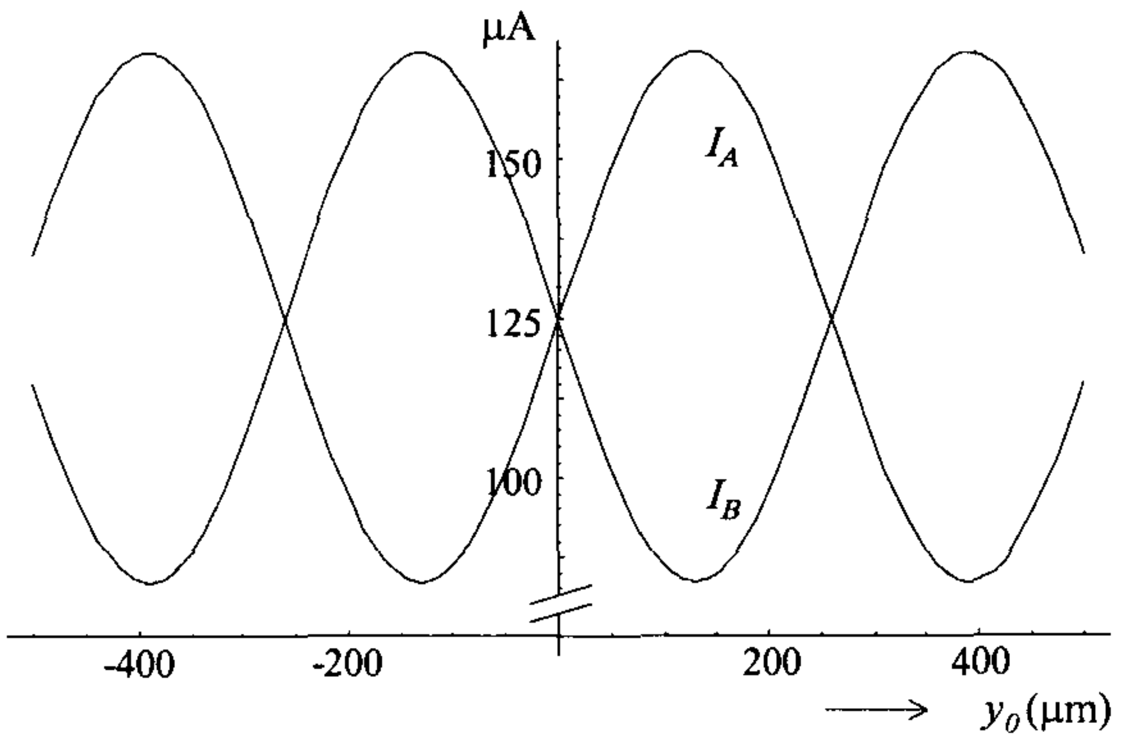

Figure 5: Tracking currents for a periodic tracking structure

From the balance of the currents flowing into both conductors, the position of the spot relative to the track center can be determined. When I_A=I_B, the spot is positioned exactly at the track center.

2.2 Electrical DC model

Now the dependence of tracking currents on physical parameters as well as on spot displacement is known, an electrical equivalent of the tracking mechanism can be constructed.

Electrons are drawn from the cathode to form an electron beam. At the screen side of the tube, the beam partly lands on the aluminum mirror, which leads the electrons to the anode. The remainder is split in two parts (as shown in the previous section) by the tracking structure. The electrons are then conducted through the position measurement circuitry to the anode. Finally, the EHT-source leads the electrons back from anode to cathode.

Figure 6 shows the electrical model of this mechanism. By definition, electrical currents are running in the opposite direction compared to electrons.

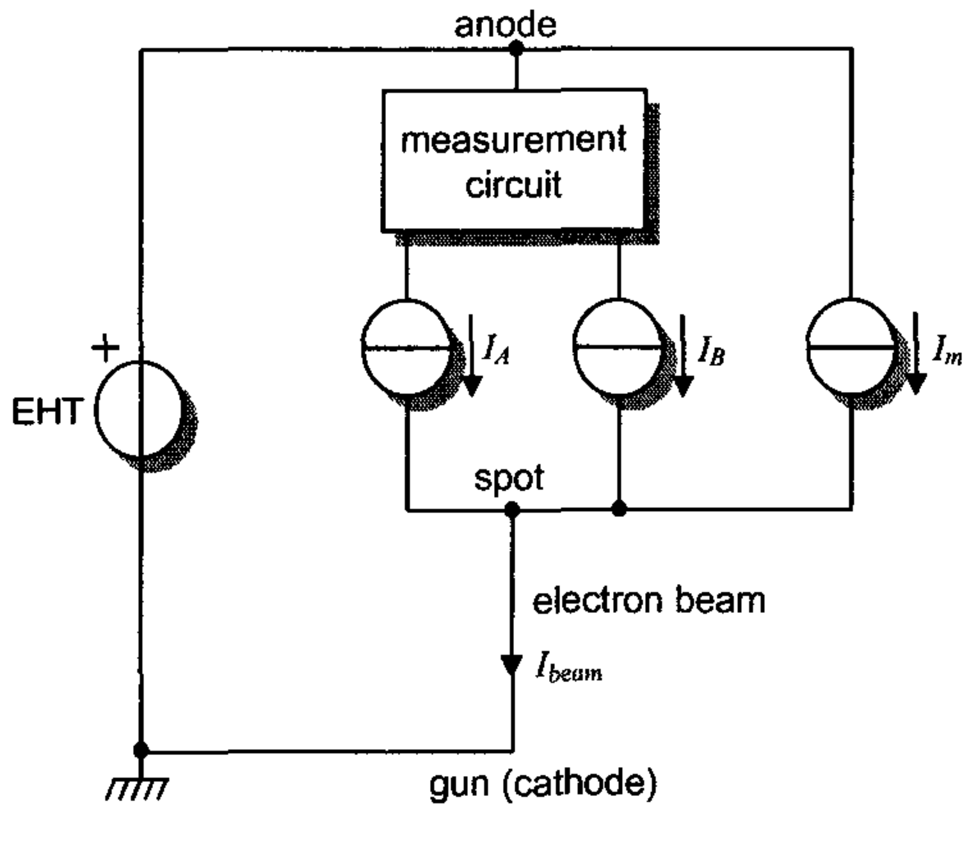

Figure 6: Electrical model of the tracking tube

The value of the current sources is according to the expressions as derived in paragraph 2.1. The sum of the two tracking currents I_A and I_B and the current in the aluminum mirror I_m is equal to the beam current I_{beam}.

3. Screen structure model

When constructing a tracking system, using a position sensor as described previously, not only the DC behavior of the tracking structure is important, but also the AC behavior. In this section, an AC model will be presented.

3.1 Physical structure

From the layout of the tracking structure, it becomes clear that there are three main contributors to the AC behavior: track resistance, inter-track capacitance and track-to-mirror capacitance. These will be explained in more detail next.

3.1.1 Track resistance

Depending on track material, track thickness, track width and track length, there will be a certain resistance from the spot landing position to the point where the measurement circuit is connected.

Early F!T tubes (17") contained evaporated aluminum tracks with negligible resistance. Later tubes (32") contain flow coated silver tracks. These silver tracks have a typical thickness of 15μm, resulting in a sheet resistance of 10mΩ , and a typical width of about 130μm. The tracks thus have a typical resistance of 77Ω/m. For a single track in a 32" tube, the resistance is 54Ω.

3.1.2 Inter-track capacitance

A track will have a capacitance to neighboring tracks, depending on the width, length and thickness of the track, the distance to neighboring tracks and the dielectric material in between tracks.

The heart-to-heart distance between tracks is 260μm, the track width is 130μm and the thickness is 15μm. The dielectric material consists of glass for one half and phosphor for the other half, resulting in a relative dielectric constant of about 5.5. The typical inter-track capacitance then becomes 60pF/m from one track to one neighbor track. For a single track in a 32" tube, this means a capacitance of 42pF to each of its neighbors.

3.1.3 Track-to-mirror capacitance

The aluminum mirror will cover the complete tracking structure. Each track will have a capacitance to the mirror depending on the area of the tracks, the distance to the aluminum mirror and the dielectric material in between the tracks and the mirror.

The average distance between the tracks and the aluminum mirror is determined by the thickness of the phosphor layer, which is about 12μm. The relative dielectric constant of this phosphor layer is about 4.5. The typical track-to-mirror capacitance thus comes to 3.3μF/m^2. For a single track in a 32" tube, this gives a capacitance of 300pF.

3.2 Electrical AC model

With the three main contributors to structure impedance, a lumped element matrix can be built. The higher the number of lumps in this matrix, the higher the accuracy of the model. Investigation showed that using 10 lumps per line is sufficiently accurate.

When using 10 lumps per line, each of the lumps represents a piece of track with a length of 7cm. Figure 7 shows part of the model, which can be extended in all directions. Besides the passive components representing the screen structure, the current sources representing the electron spot have to be incorporated.

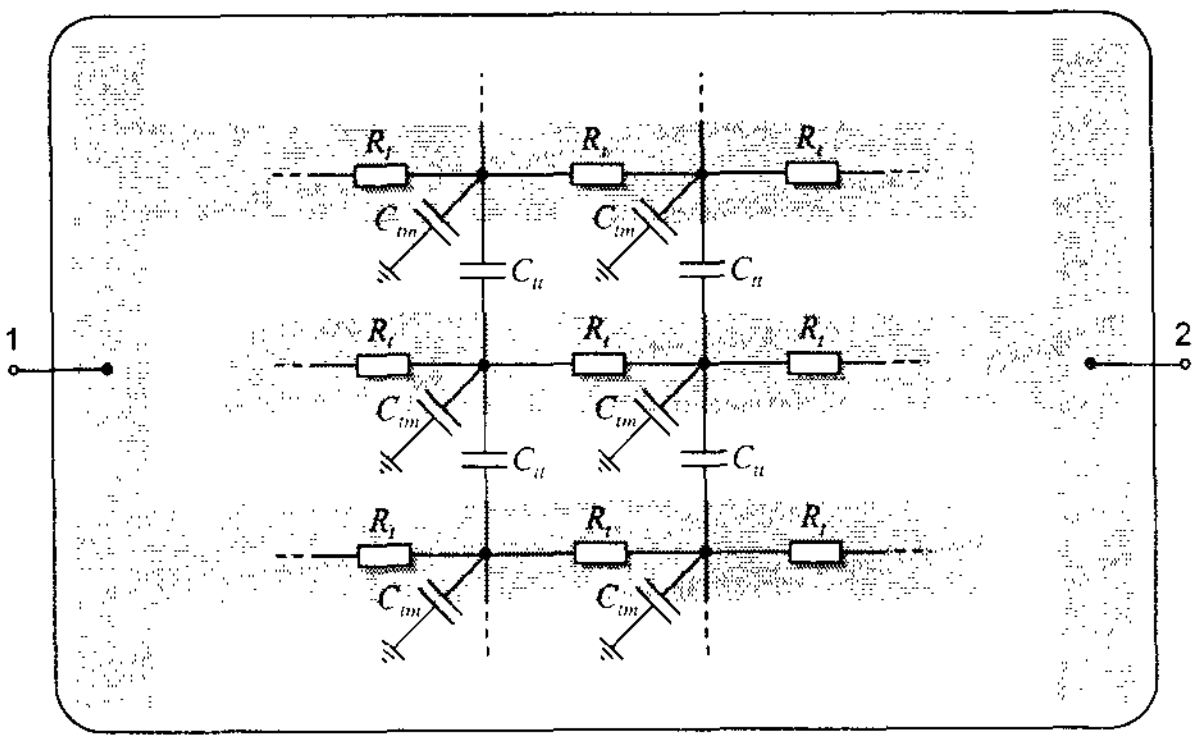

Figure 7: AC model of the tracking structure

Here, R_t is the track resistance (5.4Ω/lump), C_{tt} is the inter-track capacitance (4.2pF/lump) and C_{tm} is the track-to-mirror capacitance (21pF/lump). The measurement circuitry has to be connected to terminals marked '1' and '2'. The ground-symbol indicates the AC-ground, which is in fact the aluminum mirror at anode potential.

4. F!T electronics

Having an accurate electrical model of the tracking sensor proves to be very useful when designing the electronics to complete the tracking system. The next paragraphs will discuss two of these blocks: the measurement amplifier input stages and the auto-normalizer.

4.1 Amplifier input stages

The AC model shows that the tracking structure represents a large capacitance. To maintain the spectral content of the tracking signals, the measurement circuitry should have extremely low input impedance over a large frequency range. Furthermore, the input stages should be able to source a current into the screen structure. This current is in the range of less than 1μA to about 1mA. Last but not least, to achieve a high signal-to-noise ratio of the tracking signal, the input stages should have a high gain.

The topology that has been used in most demonstrators is an I/V-converter, employing an opamp with high DC gain as well as high unity gain bandwidth (UGBW). The circuit is shown in figure 8.

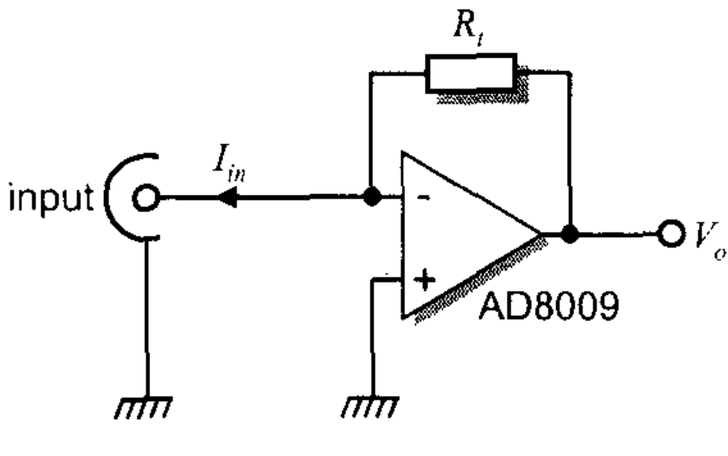

Figure 8: Input stage topology

The feedback resistor R_t determines the transimpedance of this circuit. The input impedance is linearly proportional to R_t and inversely proportional to the open loop gain of the opamp. A value of 5kΩ was chosen for R_t, which makes the output voltage range 5mV to about 5V. The DC gain of the opamp is about 100dB (10^5), giving a DC input impedance of 5mΩ (5kΩ/10^5). Because of the high UGBW of the opamp, the input impedance stays low up to 200kHz, after which it increases linearly with frequency.

4.2 Auto-normalizer

It has been shown that the tracking currents are (unwantedly) dependent on beam current. When constructing a feedback loop, beam current variations will result in loop gain variations. Because of the large dynamic range in beam current (10^3, or 60dB, for a typical contrast ratio of 1:1000), it will be hard to maintain loop stability as well as loop accuracy under all circumstances. Therefore, the tracking currents are first normalized, giving a position signal that is independent of beam current.

The fact that the tracking signal consists of two differential parts, both linearly dependent on beam current, can be exploited to perform normalization without using any other signals: auto-normalization. By dividing the difference of the tracking currents by their sum, an error signal ε that is independent of beam current is obtained:

$$\varepsilon = \frac{I_A - I_B}{I_A + I_B} \neq f(I_{beam}).$$

It is a relative error signal, which is zero in the wanted situation when the center of the spot is exactly aligned with the center of the phosphor track. Furthermore, it is an odd function, such that the sign indicates whether the spot position is either too high or too low with respect to the wanted position. Figure 9 shows the error signal graphically (for an arbitrary beam current, R_y=215μm and tracks of 130μm at a distance of 130μm).

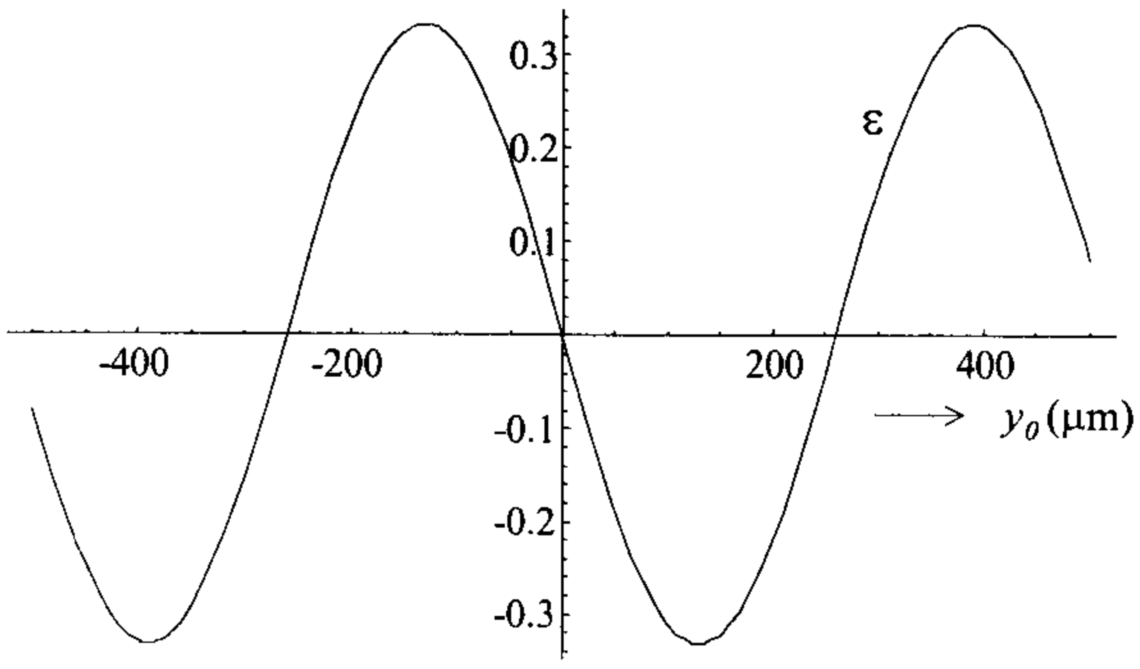

Figure 9: Normalized error signal

The normalizer can be implemented using translinear techniques, in which e.g. a division is embodied as a subtraction of signals in the logarithmic domain. The dynamic range of such a circuit has to be at least the same as the dynamic range of the input signals (60dB), which is hard to reach in practice. The realized normalizer has a dynamic range of 50dB and its gain gracefully decreases to zero for very small beam currents.

5. Results

Figure 10 and 11 show a 32" WideScreen RealFlat F!T tube without and with tracking respectively. This tube is equipped with a tracking system as described before. As can be seen in figure 10, without tracking there is a moiré pattern, resulting from interference of the scanned raster with the phosphor tracks. Color errors are obvious. When the tracking system is enabled, these color errors are corrected, resulting in the picture as shown in figure 11.

6. Conclusions

A color CRT without a shadow mask has been built. It contains a tracking system, which ensures correct color reproduction. Electrical DC and AC models of the applied tracking sensor have been constructed. These models have been used fruitfully in the design of an electronic tracking system. Functioning 1- and 3-beam 17" and 32" demonstrators show correctness of the developed models, as well as feasibility of the position sensor, which is based on intercepting a small part of the beam current to determine spot landing positions.

Figure 10: 32" WideScreen RealFlat *without* tracking

Figure 11: 32" WideScreen RealFlat *with* tracking

7. Acknowledgement

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8. References

[1] Bergman, A.H., H.B. van den Brink, F.P.M. Budzelaar, P.J. Engelaar, A.H.M. Holtslag, W.L. IJzerman, M.P.C.M. Krijn, P.J.G. van Lieshout, A. Notari, O.H. Willemsen, H. Bechtel, W. Busselt, 'The Fast Intelligent Tracking (F!T) tube: A CRT without a Shadow Mask', SID 2002.

[2] Horne, R., 'Scaling-up the F!T Technology', SID 2002