Journal of Southeast University (English Edition) Vol. 21, No. 3, pp. 272 – 276 Sept. 2005 ISSN 1003—7985

S-correction in very slim CRTs

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Abstract: To correct the S-distortion in large deflection angle cathode-ray tubes (CRTs), ideal deflection current waveforms are proposed to realize S-correction. Analysis was done for homogenous and non-homogenous magnetic fields, plane and curved screen. For the convenience of circuit design, high order sine waveforms are used to approach the ideal deflection current. After optimization, the deflection current is acceptably close to the ideal one, for a deflection angle range from 90° up to 140°. Harmonic current rank rises to four as the deflection angle reaches 140°. A ladder-type driving circuit to realize these sine wave series is also presented. Simulation and experiments prove the proposed method can correct the S-distortion in a very slim CRT.

Key words: S-correction; very slim cathode-ray tube (CRT); high order sine wave

Although CRT technology has become highly developed with many significant advantages like better image quality, lower cost and longer life span, customers will not be satisfied until the new challenge of ultra slim comes into being. The main disadvantage of CRT compared with the flat panel display is its bulky appearance[1].

The slimmer a CRT, the larger the deflection angle. Deflection angle of the electron beam is controlled by the current passing through the deflection coil[2]. Because the scanning velocity of the electron beam on the screen is not proportional to the deflection current for large deflection angles, an S-shaped correction of the saw-tooth deflection current is needed[3,4]. TV companies such as LG-Philips, Samsung, etc. have been working on S-correction for decades. The deflection angle studied is advancing toward larger than 110°[5]. This paper studies a way to adapt the saw-tooth desired S-shaped for a larger deflection angle up to 140°.

High order sine waves are used to correct the basic deflection current. With the application of these high order components, the scanning velocity of the electron beam on the edge of the screen can be made constant over the screen. Fig. 1 shows the adaption of the deflection current after correction.

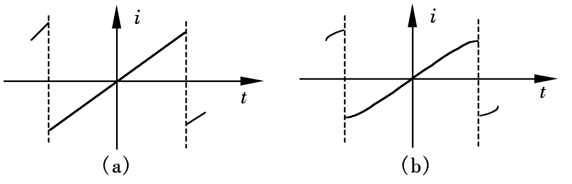

Fig. 1 S-correction of current in deflection yoke for large screen CRTs. (a) Saw-tooth current; (b) S-type current

This paper describes the analysis of the deflection current. From the results, it can be seen that the different high order current correction is required with large deflection angles.

1 Description of Ideal Deflection Current

As mentioned above, to achieve a constant velocity over the screen, an S-shaped correction is needed to adapt a pure saw-tooth current applied to the deflection coil of a CRT. In this paper, we first discuss what the ideal deflection current should be. After we obtain the ideal waveform of the deflection current, some approaches are studied to realize this ideal deflection current as close as possible.

1.1 Ideal deflection current with a flat screen

In this section, it is assumed that the screen is perfectly flat. Fig. 2 gives the trajectory of an electron after deflection. To simplify the analysis, the deflection magnetic field is assumed to be homogenous with length D. The deflection center is taken to be fixed at point F in Fig. 2.

When electrons are within the magnetic field, they travel along a circular track. The radius of the

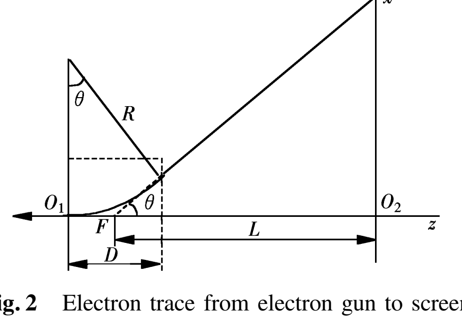

Fig. 2 Electron trace from electron gun to screen

Received 2005-03-17.

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circle satisfies

$$R = \frac{1}{\mu H}\sqrt{\frac{2mU_a}{e}} \quad (1)$$

where R is the radius of the circle, μ is the vacuum permeability, H is the strength of the magnetic field, m is the mass of an electron, e is the charge of an electron and U_a is the voltage of the anode.

From Fig. 2, we can derive the following two equations:

$$\sin\theta = \frac{D}{R} = D\mu H\sqrt{\frac{e}{2mU_a}} \hat{=} aH \quad (2)$$

$$\tan\theta = \frac{x}{L} \quad (3)$$

Therefore, we have

$$\frac{x}{L} = \frac{aH}{\sqrt{1-a^2H^2}} \quad (4)$$

This can be transferred into

$$H = \frac{x}{a\sqrt{L^2+x^2}} \quad (5)$$

This formula describes the relationship between x-position and the magnetic field. For a constant scanning speed over the screen, the following equation is true:

$$x = vt \quad (6)$$

where v is the scanning speed and t denotes time.

Eq. (5) can be transferred into

$$H = \frac{vt}{a\sqrt{L^2+v^2t^2}} \quad (7)$$

Normally, it is supposed that the deflection current is proportional to the magnetic field strength. Hence, the ideal deflection current can be expressed as

$$i(t) = k\frac{vt}{\sqrt{L^2+v^2t^2}} \quad (8)$$

where k is a coefficient determined by the structure of the deflection coil and the anode voltage. The coefficient k does not change within the scanning period. In this paper, it is assumed that $k=1$. Fig. 3 gives an example of the waveform of an ideal deflection current. For more realistic situations, a non-uniform magnetic field[6] can also be introduced into the model and only numerical current waveforms can be got, which is similar to Fig. 3.

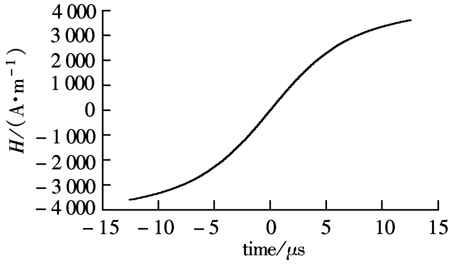

Fig. 3 Ideal current waveform within a period

1.2 Ideal deflection current with curved screen

In section 1.1, the screen is regarded as a flat screen. However, the screen in practice is a curved one. In this section, the ideal waveform of the deflection current with a curved screen is analyzed.

In this paper, the profile of the curvature can be described as

$$Z = A_1x^2 + A_2y^2 + A_3x^4 + A_4x^2y^2 + A_5y^4 + A_6x^6 + A_7x^4y^2 + A_8x^2y^4 + A_9y^6 + A_{10}x^4y^4 \quad (9)$$

In a line scanning process, the y coordinate is fixed as y_0. Hence, the shape of the scanning line is expressed as

$$\begin{aligned} Z &= A_1x^2 + A_2y_0^2 + A_3x^4 + A_4x^2y_0^4 + A_5y_0^4 + A_6x^6 + A_7x^4y_0^2 + A_8x^2y_0^4 + A_9y_0^6 + A_{10}x^4y_0^4 = \\ &(A_2y_0^2 + A_5y_0^4 + A_9y_0^6) + (A_1 + A_4y_0^2 + A_8y_0^4)x^2 + (A_3 + A_7y_0^2 + A_{10}y_0^4)x^4 + A_6x^6 \hat{=} a_0 + a_1x^2 + a_2x^4 + a_3x^6 \hat{=} f(x) \end{aligned} \quad (10)$$

and the differential equation of $f(x)$ is

$$f'(x) = 2a_1x + 4a_2x^3 + 6a_3x^5 \quad (11)$$

With a curved screen, the S-correction is demonstrated in Fig. 4. The screen is expressed as the curve $f(x)$ in the figure.

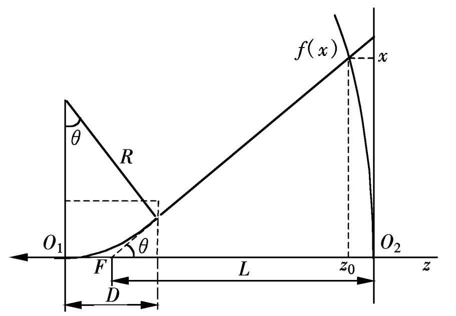

Fig. 4 S-correction with a curved screen

With a curved screen, Eqs. (1) and (2) still hold. However, Eq. (3) changes into

$$\frac{x}{L-f(x)} = \tan\theta \quad (12)$$

Analogous to Eqs. (4) and (5), we get

$$\frac{x}{L-f(x)} = \frac{l/R}{\sqrt{1-(l/R)^2}} \quad (13)$$

$$H = \frac{x}{a}\frac{1}{\sqrt{[L-f(x)]^2+x^2}} \quad (14)$$

Another difference to the flat screen is the equation of the scanning speed. With the given screen function $f(x)$, the length of the scanned line l_1 can be calculated as

$$l_1 = \int_0^x \sqrt{1+[f'(s)]^2}\,ds \quad (15)$$

To achieve a constant scanning speed across the screen, the following relation is applied:

$$\int_0^x \sqrt{1 + [f'(s)]^2}\,\mathrm{d}s = vt \tag{16}$$

By Eqs. (15) and (16), the waveform of the H-field/current can be determined numerically. At each discrete position x, corresponding H and t are calculated. The difference between the two ideal waveforms (with a flat and a curved screen) is shown in Fig. 5.

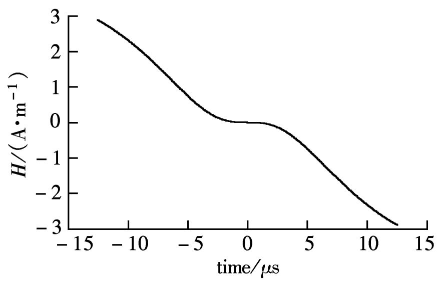

Fig. 5 Difference between ideal currents for a curved and a flat screen

Fig. 5 shows that the difference is rather small (3 A/m compared with 4 000 A/m as shown in Fig. 3 by magnitude), which indicates that the profile of the screen is not a key point in S-correction for high deflection angles.

2 Correction of Saw-Tooth Current with High Order Sine Waveforms

In section 1, the ideal deflection current has been determined. In this section, we attempt to minimize the difference between the ideal waveform and the practical waveform with the high order sine wave function.

In this paper, the basic deflection current is supposed to be a saw-tooth current. Therefore, the scanning current is shown as

$$f_0(\tilde{\omega}t) = A_0 t \tag{17}$$

As mentioned above, the difference between the saw-tooth current and the ideal current becomes larger when the deflection angle increases. Consequently, a serious S-distortion is generated. In this paper, high order sine waveforms are used to correct the saw-tooth current. We use $\sin(\omega t)$, $\sin(2\omega t)$, ..., and $\sin(4\omega t)$ to correct the basic deflection current. New deflection currents are named $f_1(\omega t)$, $f_2(\omega t)$, ..., $f_4(\omega t)$, respectively. They are shown in Eq. (18).

$$f_k(\tilde{\omega}t) = A_0 t + \sum_{i=1}^{k} A_i \sin(i\tilde{\omega}t)$$

$$k = 1, 2, 3, 4; \quad -\frac{T}{2} \leqslant t \leqslant \frac{T}{2} \tag{18}$$

where A_0 to A_4 are the amplitudes for different frequency sine waves. The coefficients A_0 to A_4 are optimized to minimize the difference between the practical deflection current and the ideal current.

The target function $g(\tilde{\omega}t)$ is

$$g(\tilde{\omega}t) = \frac{vt}{\sqrt{L^2 + v^2 t^2}} \tag{19}$$

In our calculations, the screen size is assumed to be 32″. For different deflection angles, i. e. 90°, 110°, 120°, ..., 140°, the distance L in Fig. 2 changes, but the screen size keeps constant. The difference between the ideal current and the practical current is calculated as

$$F = \frac{\int_{-\frac{T}{2}}^{\frac{T}{2}} \sqrt{(f(\tilde{\omega}t) - g(\tilde{\omega}t))^2}\,\mathrm{d}t}{TI_{\max}} \tag{20}$$

where T is the period of the scanning, and $I_{\max}$ is the maximum deflection current in the scanning. In our calculation, the time changes from −26 μs to 26 μs. Fig. 6 gives the deviation with different approaches. Fig. 7 and Tab. 1 show the coefficients A_0 to A_4, which are obtained in the optimization.

As shown in Figs. 6 and 7, the following conclusions can be obtained:

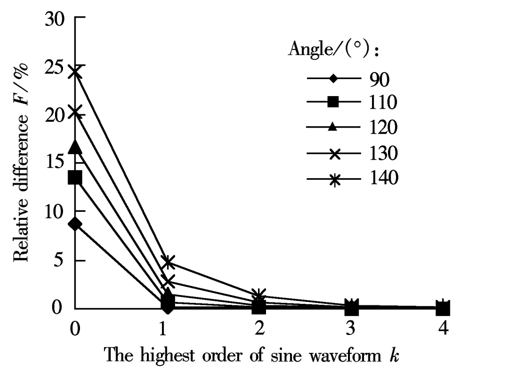

Fig. 6 Comparison of the deviation with different approaches

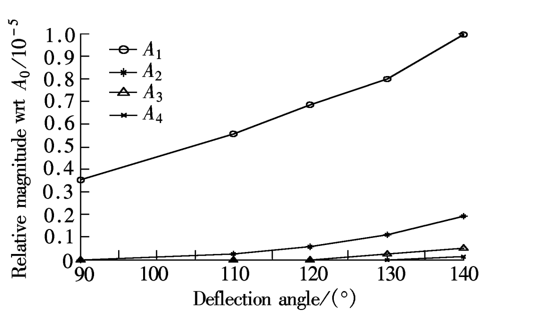

Fig. 7 Magnitude of A_1 to A_4 with different deflection angles

Tab. 1 The coefficients A_0 to A_4

Angle/(°)	$A_0/10^4$	A_1	A_2	$A_3/10^{-3}$	A_4	Deviation/10^{-11}
90	2. 68	0. 094 771	0	0	0	8. 498 42
110	3. 11	0. 173 538	0. 007 311	0	0	6. 602 08
120	3. 29	0. 225 339	0. 018 984	0	0	19. 761 6
130	3. 44	0. 285 995	0. 038 117	8. 341	0	2. 081 99
140	3. 57	0. 355 404	0. 068 524	18. 342	0. 004 4	2. 400 41

1) If only $f_1(\omega t)$ is used to approach the ideal current $g(\omega t)$, the deviation is less than 1% when the deflection angle is smaller than 110°.

2) For the cases where the deflection angle is between 110° to 130°, $f_2(\omega t)$ is needed to correct the deflection current. This will make the deviation between the ideal current and the practical current less than 1%.

3) When the deflection angle is larger than 130°, the triple frequency correction is needed to reach our limit of 1%. When $f_3(\omega t)$ is used to approach $g(\omega t)$, the deviation is only 0.35%.

4) The difference between the deflection currents with a flat screen and with a screen having a practical inner curvature is neglectable.

3 Circuit Simulation

According to the method discussed in the above section, an electronic circuit is simulated to study the possibility to realize the high order correction current[7].

A ladder circuit approach is proposed to mix the currents with different frequencies. The circuit is shown in Fig. 8.

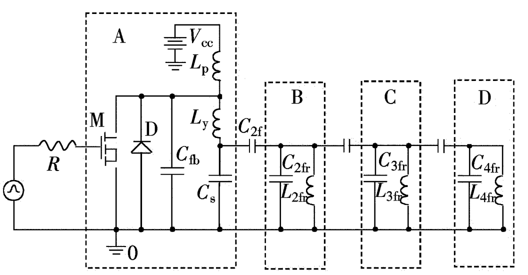

Fig. 8 A ladder circuit

In Fig. 8 the basic deflection current is generated by self-inductor L_y of Part A, while the $\sin(\omega t)$ component is generated by capacitor C_s and self-inductor L_y. Part B, Part C and Part D are simple L_C resonance circuits. By adjustment of C_{2fr}, L_{2fr}, …, C_{4fr}, L_{4fr}, the $2\omega t$, $3\omega t$ and $4\omega t$ signals can be tuned. C_{2f}, C_{3f} and C_{4f} are used as high frequency signals coupling to Part A.

As shown in Fig. 8, the $2\omega t$, $3\omega t$ and $4\omega t$ currents which are generated by Part B, Part C and Part D are influenced by the basic deflection waveform through the capacitors C_s, C_{2f} C_{3f} and $C_{4f.}$ The amplitudes of the high order frequency components are the functions of C_s, C_{2f}, …, C_{4f} as described in Eq. (21).

$$\begin{aligned} f_4(wt) = {} & A_0(C_s, C_{2f}, \dots, C_{4f})\,t + \\ & A_1(C_s, C_{2f}, \dots, C_{4f}) \sin[w(C_s, C_{2f}, \dots, C_{4f})\,t] + \\ & A_2(C_s, C_{2f}, \dots, C_{4f}) \sin[2w(C_s, C_{2f}, \dots, C_{4f})\,t] + \\ & A_3(C_s, C_{2f}, \dots, C_{4f}) \sin[3w(C_s, C_{2f}, \dots, C_{4f})\,t] + \\ & A_4(C_s, C_{2f}, \dots, C_{4f}) \sin[4w(C_s, C_{2f}, \dots, C_{4f})\,t] \end{aligned} \tag{21}$$

The capacitors C_s, C_{1f}, …, C_{4f} are optimized to minimize the difference between the theoretical current and the practical current. The simulation results are shown in Fig. 9.

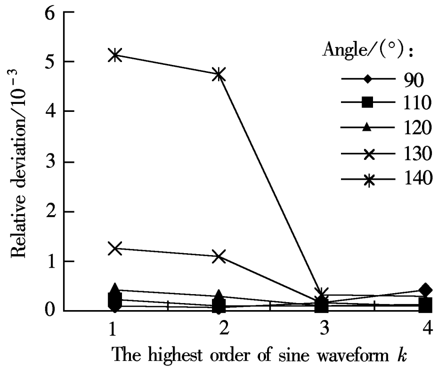

Fig. 9 Deviation after the optimization of capacitors

Fig. 9 describes the deviation between the ideal current and the practical current. The curves in Fig. 9 are a little different from the curves in Fig. 6. In a ladder circuit as shown in Fig. 8, there are many couplings between Part A, Part B, Part C and Part D. Due to these couplings, slightly different frequency signals are used in our optimization. Although there is difference between Fig. 6 and Fig. 9, the general behavior is very similar. However the power consumption will increase with Part B, Part C and Part D added. For less than 110° deflection angle, Part B, Part C and Part D are not required.

4 Conclusion

In a CRT, the S-distortion increases when the deflection angle becomes large. In the trend towards less deep CRTs, it is important to understand the phenomenon of the S-correction. This paper studies a way to correct the saw-tooth driving current with multiple frequency sine currents for large deflection angles. This paper describes a ladder circuit to correct the saw-tooth current as well. From theoretical calculations as well as circuit simulations, it can be concluded that:

1) When the deflection angle is smaller than 110°, only the saw-tooth and $\sin(\omega t)$ deflection currents are required. This is already a well-known practice in industry.

2) When the deflection angle ranges from 110° to 130°, $\sin(2\omega t)$ deflection current is required to get a good approximation to the ideal current.

3) Above 130°, a $\sin(3\omega t)$ component has to be applied for an accurate approximation.

4) The difference between the deflection currents with a flat screen and with a screen having a practical inner curvature is neglectable.

Acknowledgements The work is sponsored by the PPD Department of the LG-Philips Display Company. The authors wish to express their thanks to them for this help and especially to thank professor Kees Kortekaas.

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超薄 CRT 的 S 校正

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摘要:为了对大偏转角下的超薄 CRT 图像 S 畸变进行校正,针对匀强磁场和六极场以及理想纯平和实际曲率荧光屏的情况,分别推导了进行 S 校正以实现匀速屏幕扫描所需的扫描电流理论形式. 继而采用高阶正弦信号来逼近这一理论电流波形,以便于电路实现. 优化计算后的扫描电流可以在 90°直到 140°的偏转角范围内以足够精度逼近理论值,谐波阶数随着角度增大而增加直至四阶. 提出了一种梯形电路来实现这一方法,模拟和实验结果证实了该方法对校正 S 畸变的效果.

关键词:S 校正;超薄 CRT;高阶正弦波

中图分类号:TN141