6-4

Bias Charge Optimization of High Speed CCD Operation

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It has been found that the bias charge is the most effective means for enhancing the speed and efficiency of charge transfer in CCD.[1,2,3] In this paper, bias charge dependence of transfer efficiency and linearity in high speed partial transfer mode of operation is investigated for the purpose of optimizing charge transfer characteristics.

To express the charge transfer process, the following recurrence formula is adopted as a basic equation[4]:

$$N_{n,m} = \eta_{n-1,m-1} N_{n-1,m-1} + (1 - \eta_{n-1,m}) N_{n-1,m} - W_{n,m} \qquad (1)$$

where $N_{n,m}$ and $W_{n,m}$ are charge density and charge loss respectively, beneath the m-th electrode just before the n-th charge transfer. $\eta_{n,m}$ is transfer efficiency for $N_{n,m}$ and the relation between $\eta_{n,m}$ and $N_{n,m}$ is expressed as[5]

$$\eta_{n,m} = N_{n,m} / (N_{n,m} + A). \qquad (2)$$

When an injected charge density $N_{1,1}$ beneath the 1st electrode is the maximum storable amount, transfer efficiency at the 1st transfer is universally determined from Eq.(2) and defined as initial transfer efficiency η_o. In a partial transfer mode of operation ($\eta_{n,m} \leq 0.99$), the charge is transferred mainly by the aid of a drift field, so that A is given by $A=CL^2/\mu t$. Where L, μ, t, and C are length of the transfer electrode, carrier mobility, transfer time, and a constant respectively. In the mode of operation, a charge loss smaller than 0.1 % per transfer is negligible compared with transfer inefficiency, so that $W_{n,m}$ is omitted in the following.

In the condition that the bias charge B exists beneath all transfer electrodes, the maximum storable signal charge for each electrode diminishes to (1 - B). When a single pulse of the input charge $a_I(1-B)$ is added to the first electrode, the total charge beneath the first electrode becomes $N_{1,1}=a_I(1-B)+B$. We can obtain the first output signal charge stored beneath the m-th electrode $N_{m,m}$ from Eq.(1) as

$$N_{m,m} = N_{1,1} \prod_{k=1}^{m-1} \left[\eta_{k,k} + \frac{B}{N_{k,k}} (1 - \eta_B) \right] \quad (3)$$

where η_B is transfer efficiency for bias charge B. The part of the signal charge in the output is $N_{m,m}-B$, whose dependence on the bias charge B is shown in Fig.1. From the figure, the optimum bias charge values which make the output signal maximum are obtained for each level of input charge $a_I=(1/2)^{I-1}$, where I(1,2,3...) is an index of signal level. Regarding the measure of linearity, the value L given by

$$L = \left(\frac{\text{output for min. input}}{\text{output for max. input}}\right) \left(\frac{\text{min. input}=(1/2)^{I-1}}{\text{max. input}=1}\right)^{-1} \quad (4)$$

can be caluculated by Eqs. (2) and (4). The relation between L and input signal level is shown in Fig.2 under the bias condition that makes signal component($N_{m,m}-B$) maximum.

From the above results, the optimum condition in high speed operation for each input signal level can be obtained and compared with the experimental results. The analysis can be applied over a wide range of operating conditions with minor alternations when necessary.

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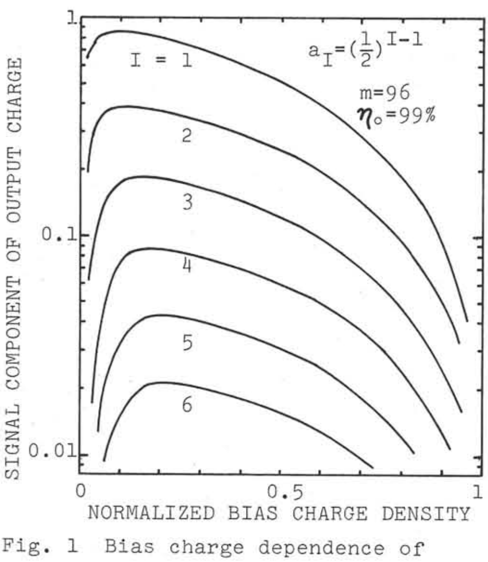

Fig. 1 Bias charge dependence of signal component of output charge.

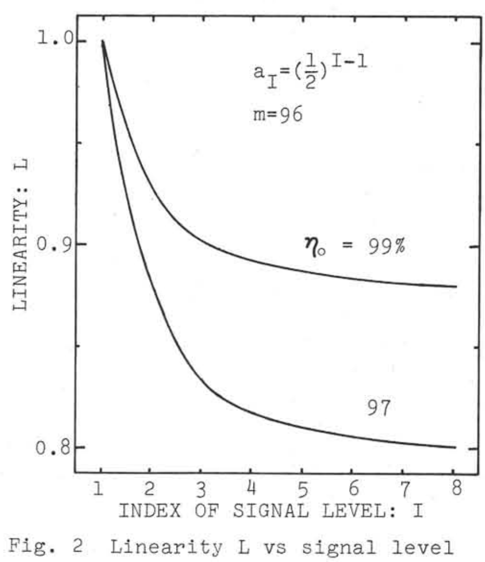

Fig. 2 Linearity L vs signal level under optimum bias charge condition.