Variance of Camera Gain Dependency on Vdd
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The gain, K, of a CCD camera is normally expressed in electrons/ADU*. There is a variance of the camera gain with respect to the Vdd level that powers the output amplifier of the CCD image sensor at the heart of the camera. This note describes why that occurs.

The illustrations used all come from Janesick and are used under the Fair Use doctrine of US Copyright law.

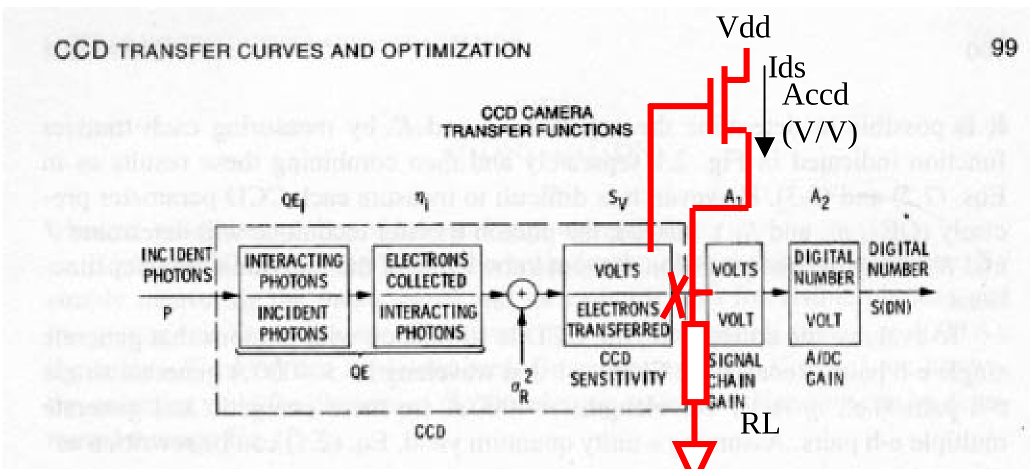


**Figure 2.1** Block diagram of a typical CCD camera showing individual transfer functions.

Referring to Figure 2.1 above is a block diagram of a typical CCD camera. Added in Red is a representation of an output source follower MOSFET such as would comprise the output driver of a typical scientific CCD. The Drain connection of the MOSFET transistor is connected to Vdd and the source is the video output of the CCD and is connected to an off-chip amplifier with gain A1 as shown in the diagram.

The transconductance, gm, of the output source follower is defined as the ratio of output current, Ids to input gate voltage, Vgs as shown in equation 6.6 of section 6.2.1.7 below.

The source follower MOSFET has a transconductance, gm, and when used in conjunction with a load, RL, forms a circuit that has a voltage gain of Accd as shown in equation 6.10 of section 6.2.2 below.

* this work quotes from Janesick who uses the term DN in place of ADU

### 6.2.1.7 Transconductance

Transconductance is defined as the ratio of the change in drain current to an incremental change in gate-to-source voltage (expressed in units of A/V or mhos). That is,

$$gm = \frac{\Delta I_{DS}}{\Delta V_{GS}}. \tag{6.6}$$

### 6.2.2 Voltage Gain

The voltage gain, $A_{CCD}$, for the source follower output amplifier shown in Fig. 6.2 2.1 is given by

$$A_{CCD} = \frac{gmR_L}{1 + gmR_L}, \tag{6.10}$$

In terms of MOSFET parameters the transconductance gm, may be written as shown in equation 6.9 below:

$$gm = \left(2\mu_{SI}C_{OX}\frac{W}{L}I_{DS}\right)^{1/2}. \tag{6.9}$$

Note the dependency of the transconductance on the drain to source current, Ids, which is the output current from the source follower.

Despite the fact that the output transistor is operated in the saturation regime, there is a slight dependence of Ids on the Drain to Source Voltage, Vds as shown in figure 6.5 below.

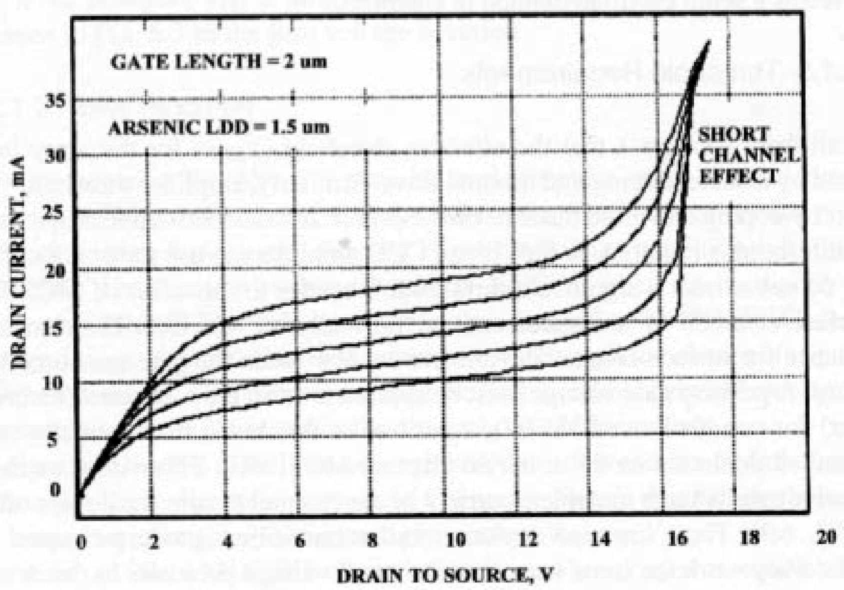


**Figure 6.5** MOSFET short channel effect.

Because the drain current has a slight dependency on the drain to source voltage, Vds, the transconductance also has a dependence on Vds as is seen by examining equation 6.9 and figure 6.5 noting that the transistor is operated in the middle part of the curve.
The transconductance dependency on Vds is also shown in the curve of figure 6.6 below.

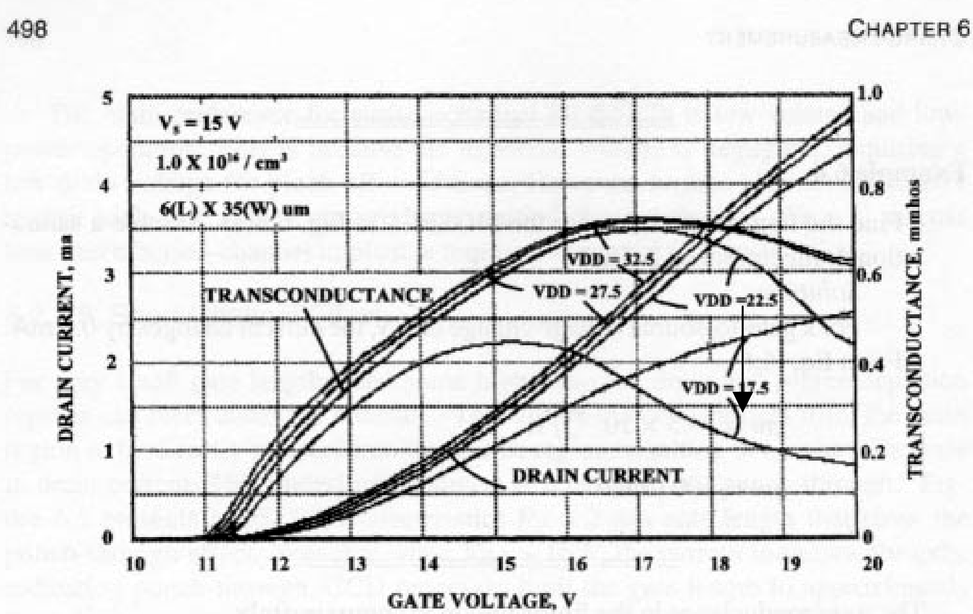


**Figure 6.6** MOSFET drain current and transconductance as a function of gate voltage.

It follows that the voltage gain, Accd, is dependent on Vds as can be seen by inspection.

Because the camera gain K is dependent on Accd as shown equation 2.2 below,
it it is clear that the camera gain, K is dependent on Vdd.

$$K = \frac{1}{S_V A_{CCD} A_1 A_2} \quad (2.2)$$

As Vdd drops, Vds is also reduced due to the constant current flowing through the output transistor and the fixed resistance of the load RL in Figure 2.1 above. This causes Accd to be reduced and that increases K.

The variance of K is dependent on K as shown in equation 2.19 below. Note the accompanying text uses "DN" where this work uses the term "ADU". S(DN) means the ADU count of the Signal at any pixel.

As long as $\sigma_S(\mathrm{DN}) \ll S(\mathrm{DN})$, which will be true for reasonable signal levels, we can use the approximation $1/S(\mathrm{DN}) \ll 2K$, reducing Eq. (2.18) to the final result,

$$\sigma_K = \left[\frac{2}{N_{pix}}\right]^{1/2} K. \quad (2.19)$$

It is interesting to note that the uncertainty of $K$ is independent of signal level as long as the read noise is negligible and the signal level is large compared to the shot noise. Equation (2.19) has been experimentally confirmed with good precision.

As a result as K increases so does the variance. This can happen as a result of reducing the Vdd value for the source follower as is shown in figure 2.8(b).

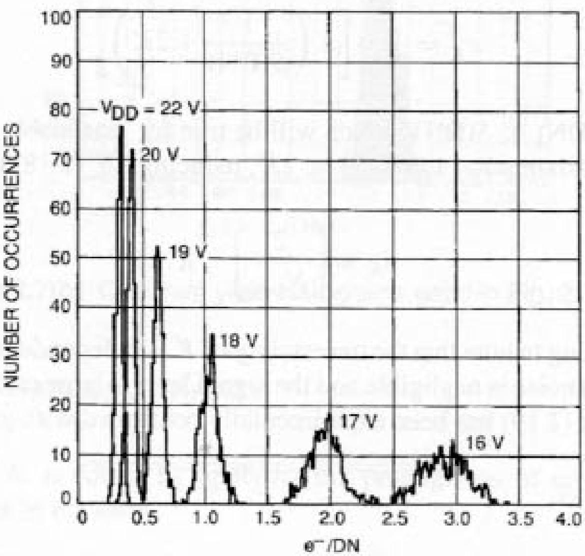


**Figure 2.8(b)** Camera gain histograms taken at different $V_{DD}$ potentials.

Figure 2.8(a) presents three camera gain histograms showing that the variance of $K$ decreases with increasing $N_{pix}$. Figure 2.8(b) plots camera gain histograms for different drain voltages ($V_{DD}$) to the on-chip amplifier. As $V_{DD}$ is lowered, the CCD gain, $A_{CCD}$, decreases, causing $K$ to increase and the histogram width to broaden.

The dependency of the variance of K on Vdd has therefore been shown and the root cause explained.