8 Practical operation of CCDs

Modern CCD

- Predictable in their operation and characteristics, but there are many subtleties to operation, like
  1. Maximizing the ratio of signal to noise
  2. Obtaining stability and repeatability in performance
  3. Finding suitable methods of control

In this section, we'll show practical issues of CCD for potential user.

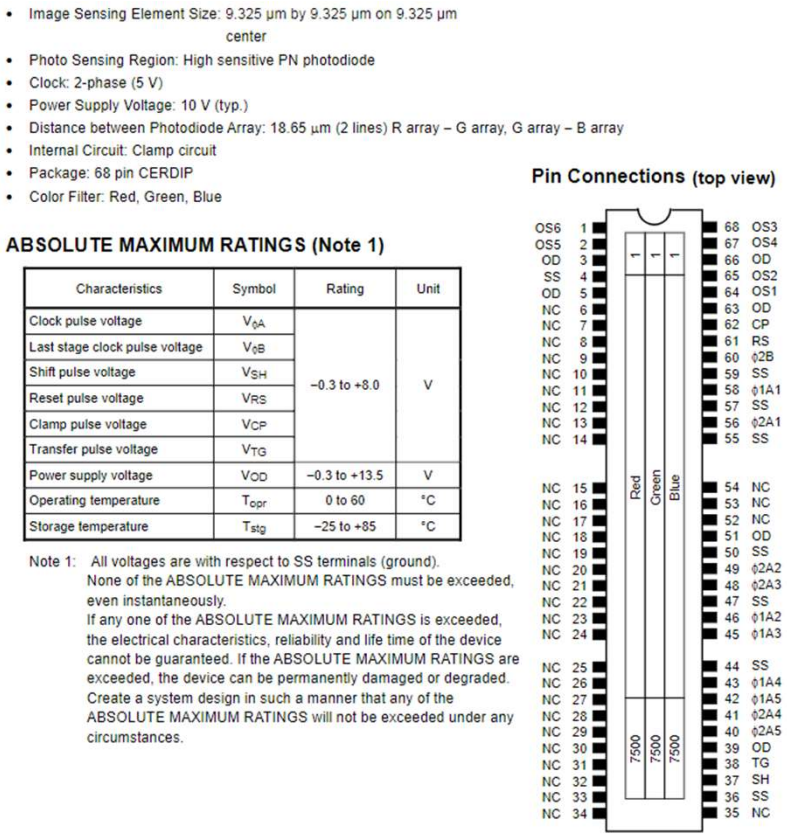
8.1 Clock Voltages and Basic Electrical Factors

Data sheets

- Provided by CCD manufacturer
- Shows features of CCD
  - Electrical pin connection diagram
  - Names and symbols for each pin
  - Voltages or range of voltages

Voltages for CCD operation

1. Fixed voltages
   (remain unchanged)
2. Pulsed voltages
   (switched back and forth between two voltages level)



- Image Sensing Element Size: 9.325 µm by 9.325 µm on 9.325 µm center
- Photo Sensing Region: High sensitive PN photodiode
- Clock: 2-phase (5 V)
- Power Supply Voltage: 10 V (typ.)
- Distance between Photodiode Array: 18.65 µm (2 lines) R array – G array, G array – B array
- Internal Circuit: Clamp circuit
- Package: 68 pin CERDIP
- Color Filter: Red, Green, Blue

ABSOLUTE MAXIMUM RATINGS (Note 1)

Characteristics	Symbol	Rating	Unit
Clock pulse voltage	$V_{\phi A}$	−0.3 to +8.0	V
Last stage clock pulse voltage	$V_{\phi B}$		
Shift pulse voltage	V_{SH}		
Reset pulse voltage	V_{RS}		
Clamp pulse voltage	V_{CP}		
Transfer pulse voltage	V_{TG}		
Power supply voltage	V_{OD}	−0.3 to +13.5	V
Operating temperature	T_{opr}	0 to 60	°C
Storage temperature	T_{stg}	−25 to +85	°C

Note 1: All voltages are with respect to SS terminals (ground).
None of the ABSOLUTE MAXIMUM RATINGS must be exceeded, even instantaneously.
If any one of the ABSOLUTE MAXIMUM RATINGS is exceeded, the electrical characteristics, reliability and life time of the device cannot be guaranteed. If the ABSOLUTE MAXIMUM RATINGS are exceeded, the device can be permanently damaged or degraded. Create a system design in such a manner that any of the ABSOLUTE MAXIMUM RATINGS will not be exceeded under any circumstances.

Pin Connections (top view)

Example of CCD data sheets
(https://www.alldatasheet.com/datasheet-pdf/view/1519473/TOSHIBA/TCD2711DG.html)

Structures of frame transfer CCD

1. Serial register clocks

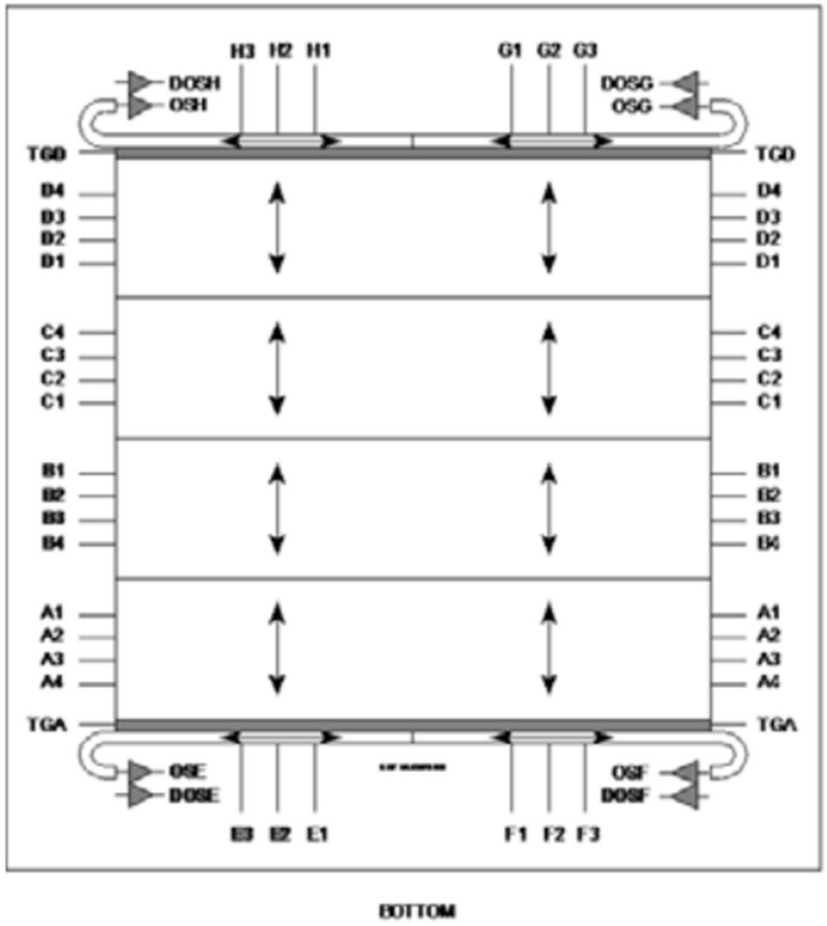
- Transfer charges to horizonal direction
- One pin for each phase or electrode used to define the pixels in the horizonal register is required

2. Parallel register clocks

- Transfer charges to vertical direction
- Each register is split into two sections (image section and store section)

3. Reset transistor clock

- Acquire a single, periodically recurring voltage pulse to reset the CCD output amplifier or more accurately the capacitor



Important voltages on CCD

DC bias (usually shown by data sheet)

1. Substrate voltage
   Reference for other voltages, usually kept at 0V
2. Reset drain voltage
   Applied to the drain terminal of the on-chip reset field effect transistor at the CCD output
3. Output drain voltage
   Applied to the drain terminal of the on-chip output amplifier
4. Output gate voltage

Pulse voltage

Corresponding to individual charge packets
(depends on output transistor)

Safe handling

CCDs can withstand substantial illuminations, and they are robust mechanically. However, CMOS (contains integrated circuits) can't stand with static electricity.

Important points for handling CCD:

- Stored in electrically conducting containers
- Tie earthing straps to the wrist
- Wear no nylon clothing
- The work performed in a clean, ionized airflow room

With these precautions, CCD cameras can last a long time

8.1.1 The analog signal chain

Analog signal chain contains

- Pre-amplifier
- Post-amplifier
- Noise removal circuits
- ADC
- Low-noise dc power supplies

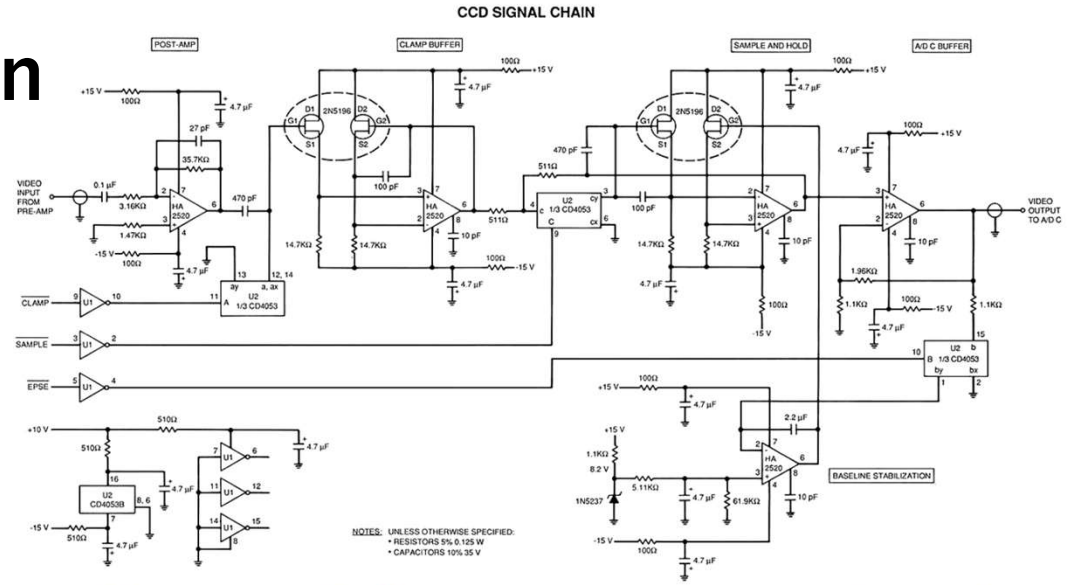
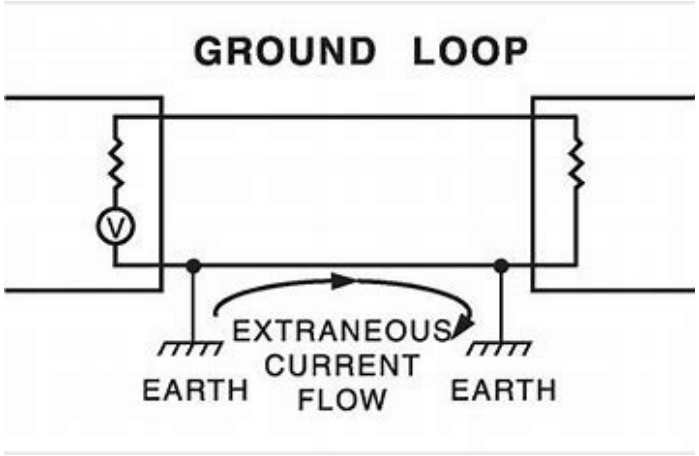


Figure 8.2. Part of the analog signal chain. This is a practical correlated double-sampling circuit used at JPL. Credit: Jim Janesick.

The heart of the system is a signal-processing unit designed to sample and filter noise, but proper grounding and optimum control timing are also important

Cause of noise

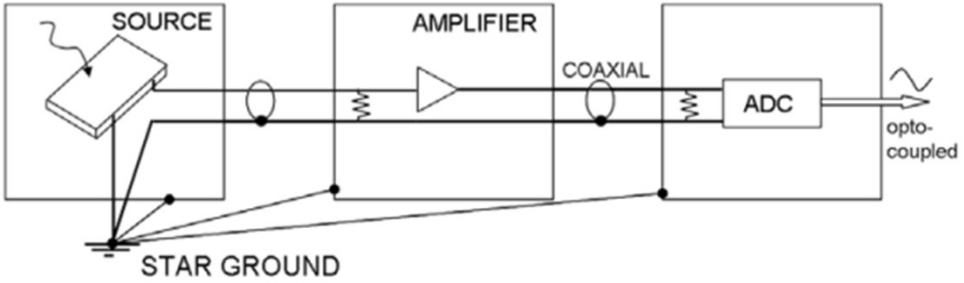
Ground-loop



- Most common cause of noisy CCD system
- Forms when two interconnecting parts of an electronic system are separately connected to ground via different impedance path

How to solve:

- To have only a single ground point in the system (usually use copper ground plane)



Electrical noise

- Radiative coupling, capacitive coupling, and inductive coupling are happened by motors, computer parts
- Shielded wires or components is important to protect weak signals (usually use optical fibers and co-axial cables)

同軸ケーブル断面

Co-axial cables
https://www.to-conne.co.jp/about-connector-cable.html

Some telescopes work on cold, high-altitude environment
⇒careful component selection and packaging is required

8.1.2 CCD sequencer and clock drivers

CCD camera & imaging systems:

Numerous events like

- Check instruction status
- Flush the CCD of trapped charge
- Open, close the shutter
- Readout the CCD

must occur in strict time order and at precise time intervals.

CCD sequencer is responsible for these activities

Design of sequencer

1. **Hard-wired designs**
   - Electronic functions are carried out by circuitry, and cannot be altered by typing instruction on computer
   - Possible to make compact, rugged system
   - Used for space telescope or small telescope
2. **programmable**
   - Electronic functions can be changed by computer commands
   - Digital signal processor and programmable read-only memories (PROMS) are representative example

CCD controller

CCD controller: manage CCD process like

- Slow or fast readout
- Bi-directional charge shifting
- overscanning

Design of CCD controller: usually use modular design (remain room for expansion and change to provide for new instrument)

Example of CCD controller

Generic example: ARC controller

- Modular system intended to be tailored to individual systems
- Establish original voltage for detectors, and number of circuits

Exclusive example: controller used by Pan-STARRS

- Designed to operate multiple orthogonal transfer CCD

8.2 Dark current and cooling

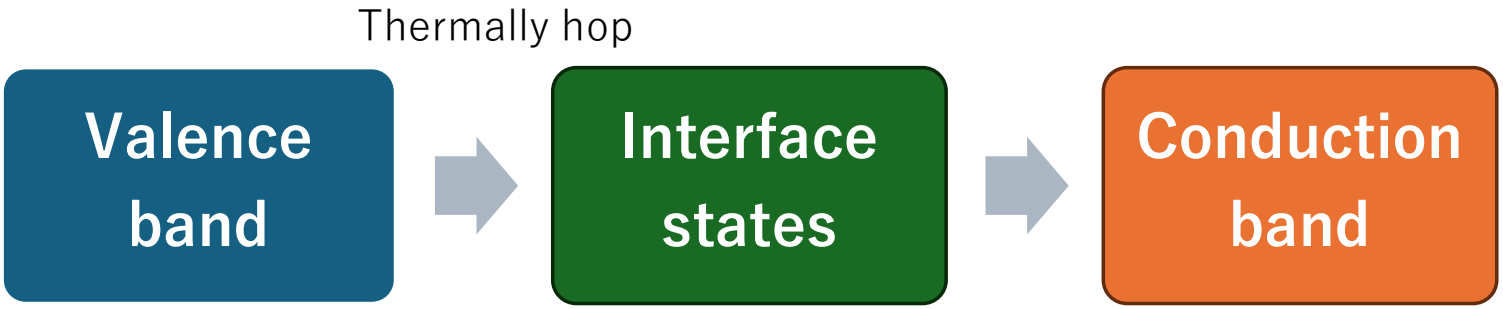
Dark current: flow of electron-hole pairs produced by Brownian motions of atoms within the silicon lattice

Dark current of CCD: 100,000 electron/s/pix (room temperature)
⇒needs to be cooled to use CCD for observation

Main sources of dark current:

1. neutral bulk silicon
2. depletion region
3. junction between the silicon and the silicon dioxide insulation layer

Dark current at the Si-SiO2 interface:
Depends on density of ① interface states ② free carriers



Classical CCD: maximize dark current(S7.2.1)
Inversion mode of CCD (like MPP CCD): Reduce dark current(S7.3.6)
⇒possible to operate CCD under the condition of high temperature (improve charge transfer efficiency)