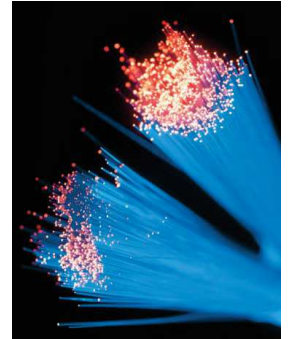


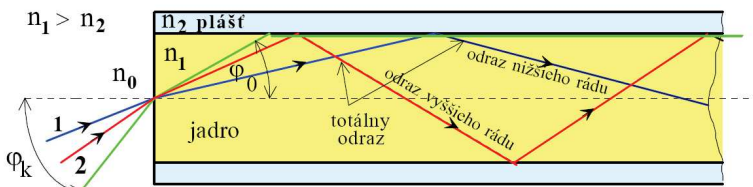


Vláknová optika fiber optics

- prenos obrazu zväzkom elementárnych svetlovodov
- prenos analógových signálov (náročné)
- prenos digitálnych signálov
- **optovláknové senzory**



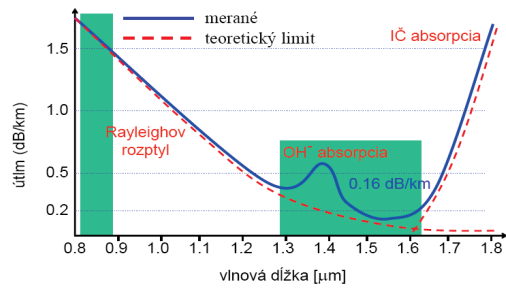
Elementárny svetlovod



absolútny odraz od rozhrania dvoch prostredí

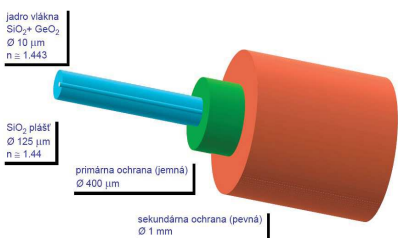
- MM – multimódové / mnohovidové
- SM – jednovidové / monomódové
-
- Materiál: SiO₂ (sklo), plastové

Vláknová optika – útlm



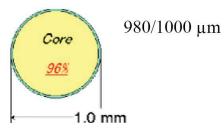
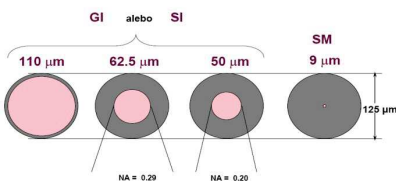
- $\lambda = 1 \mu\text{m}$ (min. straty pre $1,2 \mu\text{m}$ – perspektívne $1,5 \mu\text{m}$)
- $\alpha = 0,3 \text{ dB / km}$
- IČ absorpcia, Rayleighov rozptyl, OH absorpcia
(optické vlákna sú citlivé na vlhkosť, potreba zabaliť do ochranného obalu)

Konštrukcia optovlákien



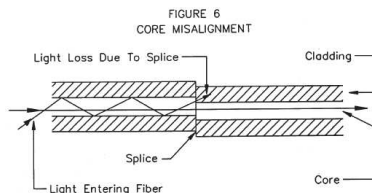
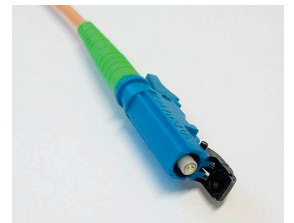
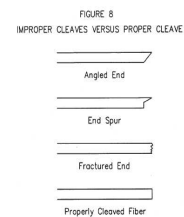
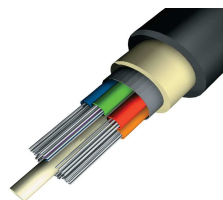
konštrukcia Single-Mode (SM) vlákna

konštrukcia plastového MM vlákna



Štandardné prierezy komunikačných optických vlákien

Konštrukcia optovlákien





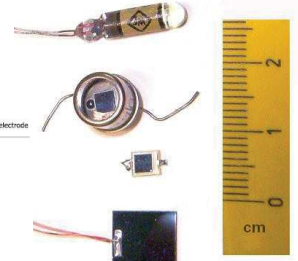
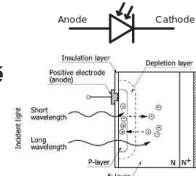
Optické systémy

Zdroje svetla
Optická cesta
Snímače

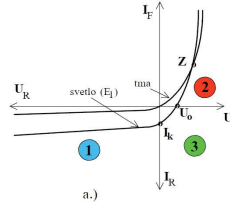
Detektory: fotodióda

photodiode

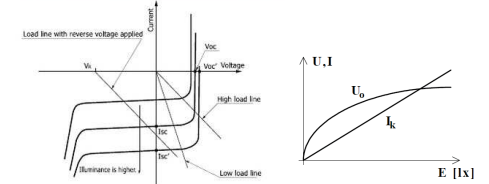
rýchle, málo citlivé



2 - odporový režim v prepustnom smere (rastie $E \rightarrow$ klesá IR)
3 - hradlový režim (U_0 je výst. napätie naprázdno, I_k je výst. prúd nakrátko)
Z - pracovný bod necitlivý na svetlo



[Figure 1-8] Current vs. voltage characteristics and load lines



Detektory: fototranzistor

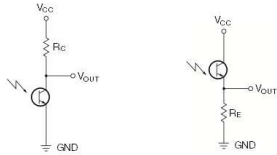
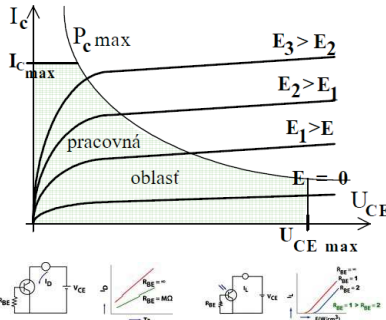
phototransistor

- citlivejšie, ale i zotrvačnejšie ako fotodiódy.
- v obvodoch samostatne, alebo s diódami, prípadne Darlington.



Hodnotu P_{Cmax} treba dodržať, kritická pri "polootvorenom" tranzistore.

Spektrálne skôr v IR oblasti (800 ÷ 1000 nm).



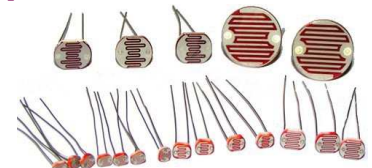
Detektory: fotodpor, fotorezistor

photoresistor

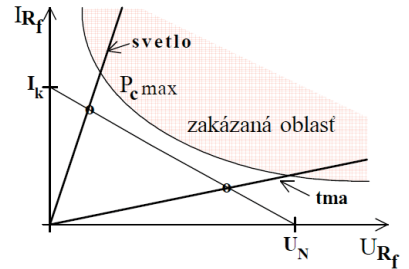
najcitlivejšie, ale aj najzotrvačnejšie spektrálne skôr do viditeľnej oblasti (500 ÷ 600 nm).

U_{Rf} a I_{Rf} sú napätie a prúd fotodporu priamka – obvod, v sérii je R s fotodporom, napájanie sústavy U_N , $I_k = U_N/R$

časovo a teplotne závislé. odpor sa mení v rozsahu cca 100 ÷ 10 M (úplná tma)



V - A charakteristika

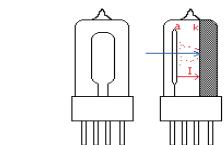
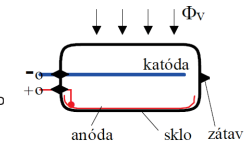


Detektory: fotónka, fotonásobič

photocell, photomultiplier tube (PMT)

vákuová súčiastka

svetlo po dopade na katódu vyrazí niekoľko elektrónov (červené body), tie sú priťahované anódou, elektrónko tečie prúd



- 1 fotón
- 2 elektrón
- 3 sekundárny elektrón

Detektory: integrované

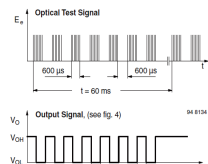
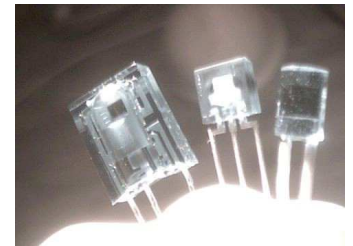
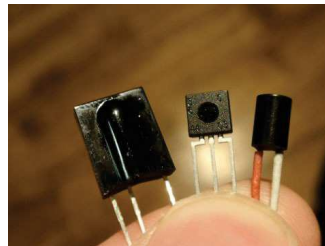


Fig. 3 - Output Function

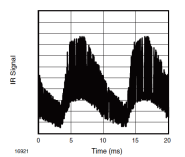
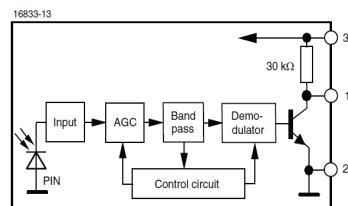
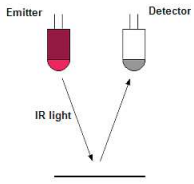


Fig. 14 - IR Disturbance from Fluorescent Lamp

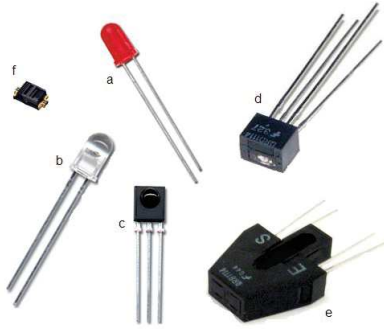
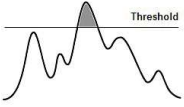


Black = no reflection (0)
= reflection (1)

Output
DIGITAL 0 and 1
ANALOGUE 0-100%

Sources of failures

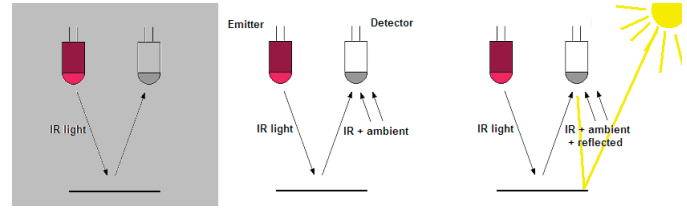
- Ambient light
- Shadows
- Sun, lamps
- Sources of IR
- Dust, dirt
- Distance!
- Speed



Sensors and detectors:
a) red LED b) Infra red LED c) Infra detector
d) combination emitter + sensor e) larger version
f) miniature SMD version of E+S

Optical line sensor principle

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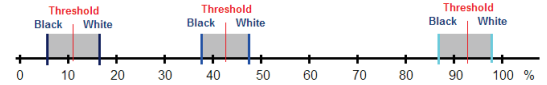


Sensor output

Sensor detector measures not only the reflected IR light, but also the amount of the ambient light

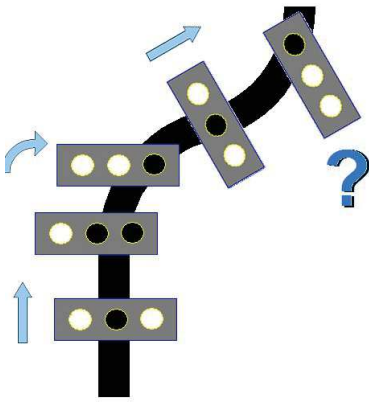
• Shields!

• Calibrate!



Sensor calibration

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Three sensors

Sensor	Action
010 (line)	go.forward
011 (right)	turn.right
001 (right)	sharp.right
100 (left)	sharp.left
110 (left)	turn.left
111	???
000	???
101	???

Algorithms

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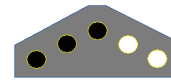
More sensors?

Adds more reliability
Different width of line

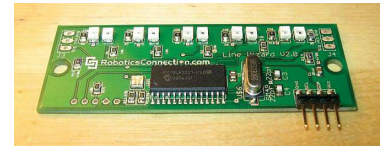


Proportional control

controller output is **proportional** to the error, which is the difference between the desired and actual positions.



Different shapes enable to determine sharp turns in advance.



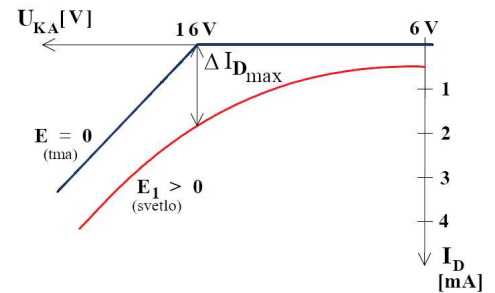
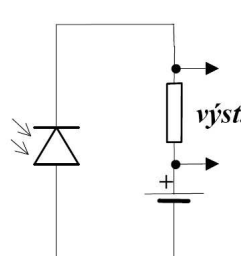
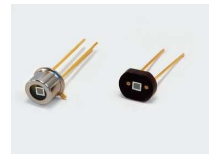
Algorithms

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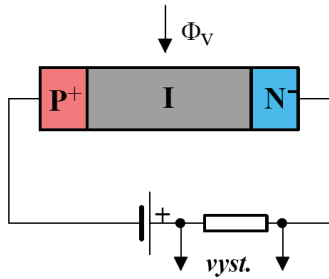
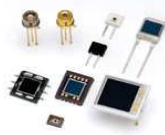
Špeciálne optické snímače

- Lavínová fotodióda
- PIN fotodióda
- PSD prvky
- CCD prvky
- CMOS prvky
-

lavínová fotodióda avalanche photodiode

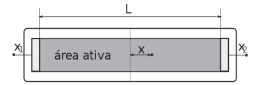
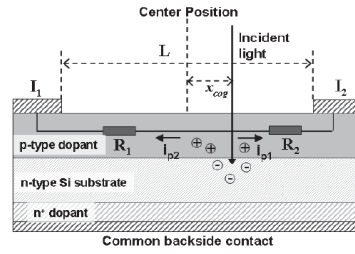
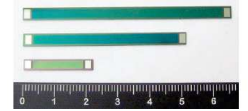


PIN fotodióda avalanche photodiode



- I – intrinzická časť
 - prijíma fotóny, izolácia
 - vysoké U → rýchlosť $10^{-12} - 10^{-15}$ s

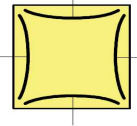
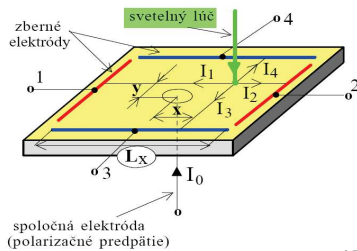
PSD prvky position sensitive device



$$x = \frac{L}{2} \frac{I_2 - I_1}{I_2 + I_1}$$

- informácia o POLOHE, nie o intenzite
- celkový prúd (cez spoločnú el.) $I_0 = 1\mu A$
- rozlíšenie $12\mu m$, chyba $\pm 0,9\%$
- obvykle laser, modulovaný – lepšie SNR

PSD prvky position sensitive device



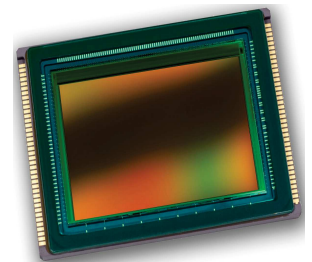
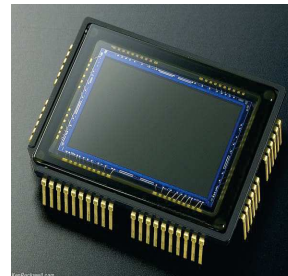
vyhodnotenie 4 prúdov voči zbernej elektróde

$$x = \frac{L_x}{2} \frac{I_2 - I_1}{I_2 + I_1} \quad y = \frac{L_x}{2} \frac{I_4 - I_3}{I_4 + I_3}$$

x a y sú vzdialenosti od stredu

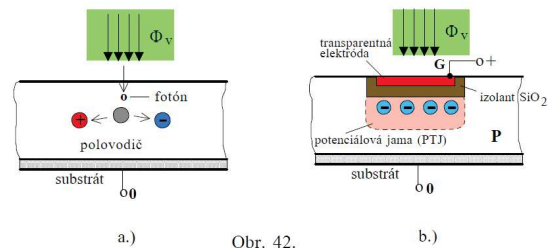
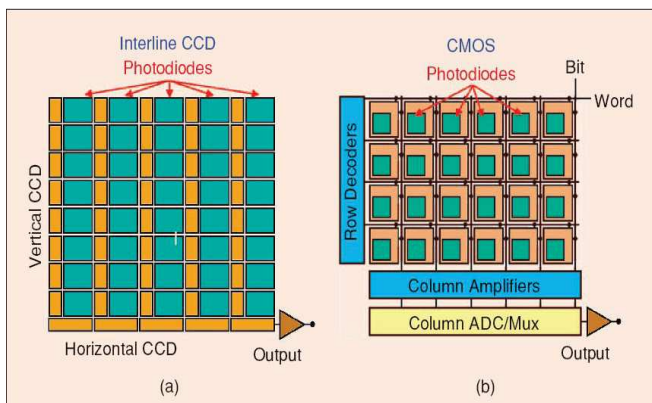
6. Optické snímače

CCD a CMOS



6. Optické snímače

6.1. CCD prvky charge coupled device



- Uchovávame tzv. menšinové náboje, teda v P polovodiči elektróny. Tieto môžu vzniknúť :
- tepelnou generáciou - parazitný jav (sum)
 - injekciou svetlom - vlastný snímací efekt
 - injekciou z blízkeho PN prechodu - odovzdanie výstupného signálu

6.1. CCD prvky základná CCD bunka

Metal Oxide Semiconductor (MOS) Capacitor

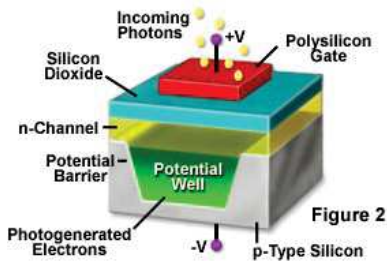


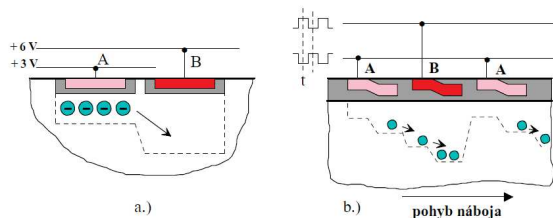
Figure 2

Charge-Coupled Device

- Invented at Bell Labs in 1970
- 2009 Nobel Prize in Physics
- Widely used in TV, medical, astronomy cameras
- Array of light sensitive MOS capacitors (pixels)
- Incoming light generates electrons which are captured in a potential well
- Electrodes, or gates, move the charge

From <http://learn.hamamatsu.com/articles/quantumefficiency.html>
Image from <http://www.microscopy.com/articles/digitalimaging/ccdintro.html>

6.1. CCD prvky prenos náboja



Obr. 43.

Vyšší potenciál vytvorí hlbšiu PTJ, nosiče do nej prepadávajú.
Tvarované elektródy - tvarovaná PTJ
Elektródy A a B - výstupný register

6.1. CCD prvky

Množstvo nosičov závisí od intenzity osvetlenia E a od času t :

expozícia (osvit) e : (e býva označené tiež H)

$$e = E \cdot t \quad [lx \cdot s; lx; s;]$$

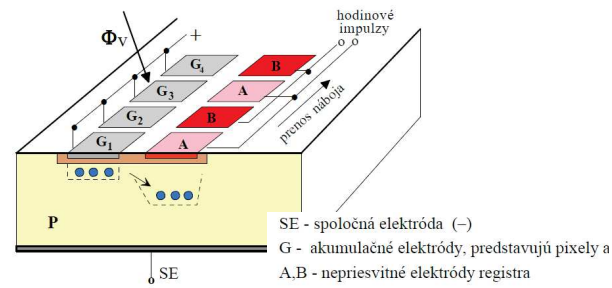
(6 - 2)

Poznámka: Doba existencie náboja v PTJ je asi $100 \text{ ms} + 10 \text{ s}$. (vyrovnanie tepelnou generáciou). Dlhé časy - problém, už cca $5 + 10 \text{ s}$ vyžadujú chladienie prvkov, napr. polovodičové, resp. softwérové potlačenie. (následné zosnímanie bez obrazu a odčítanie)

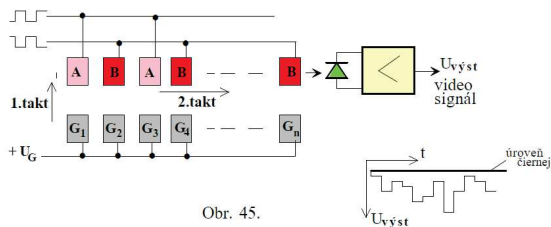
6.1. CCD prvky riadkový CCD senzor

Riadkový CCD senzor

1. Svetelný tok $\Phi_v \rightarrow$ náboj pod G_1, G_2 , atď.
2. Po dobe expozície presun náboja pod A,B
3. Fázovo posunuté impulzy na A,B - vysívanie nábojov



6.1. CCD prvky riadkový CCD senzor



Obr. 45.

Video signál:

- poloha bodu - čas od začiatku prenosu
- osvetlenie bodu - amplitúda.

Počet pixelov - 128 (termovízia), po 6 - 10 tis. (profi scannery...)
Rozmery: od $6 \times 6 \mu\text{m}$ do $17 \times 8 \mu\text{m}$.

6.1. CCD prvky riadkový CCD senzor

Princíp elektronickej uzávierky

Doba snímania (pre 1728 pixelov) \rightarrow hodinové impulzy:

10 kHz \rightarrow doba snímania = 86 ms (1/12 [s])

10 MHz \rightarrow doba snímania = 86 μs (1/12000 [s])

Optimálne cca 10 ms (1/100 [s]), čomu zodpovedá 86 kHz.

Výhody: netreba mechanickú uzávierku - cena

Nevýhody: pomalé vysívanie - akumulujú svetlo aj počas vysívania (náchylnejšie na smearing, blooming)
rýchle vysívanie - nekvalitné (rýchle) odčítanie náboja

T/2 spôsobí posun o jedno miesto, resp. T vysunie polovicu pixelov (párne - nepárne)

$E = 10 \text{ lx}$ dáva 0,2 V na výstupe.

Citlivosť na svetlo: ASA (DIN) a je $100 + 3200 \text{ ASA}$ ($21 + 36 \text{ DIN}$).

Poznámka: Horná hranica je už 6000 - 12000 ASA, diskutabilná je kvalita (malé snímače)

Rozlíšenie úrovni šedej 8 - 32 bitov $\rightarrow 256 - 4,295 \cdot 10^9$ úrovni. (štand. 24 bit)

6.1. CCD prvky riadkový CCD senzor

Použitie riadkových CCD :

- nepohyblivé obrázky (scannery...) - snímání po riadkoch
- snímání polohy (ako PSD)
- iné, napr. zaostrovací systémy - vyhodnotenie kontrastu (križový senzor, hrany)

Ako zobrazovacie systémy potrebujú vysokokvalitnú optiku s vysokým rozlíšením pre malé ohniskové vzdialenosti (3 - 8 mm)

6.1. CCD prvky Front or Back Illuminated

Frontside and Backside Illuminated CCDs

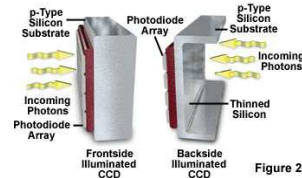
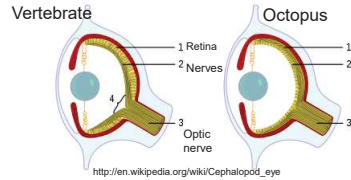
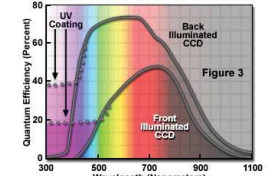


Figure 2

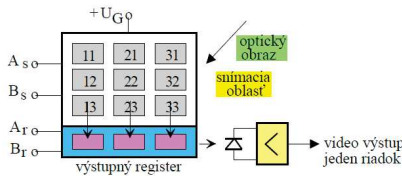
- Traditional, front-illuminated have wiring in front of photosensitive region
- This blocks some light, reducing QE
- Back-illuminated CCDs:
- Back side of the CCD is etched to 10-15 microns
- More fragile and costly, but higher QE



From <http://learn.hamamatsu.com/articles/quantumefficiency.html>
Image from <http://www.microscopyu.com/articles/digitalimaging/ccdintro.html>



6.1. CCD prvky maticový CCD senzor: Full frame



Obr. 46.

Činnosť :

- obraz sa premietne na snímajúcu časť → pod elektródami náboj
- hodinové impulzy na A_x, A_y (1 fáza), a B_x, B_y (2 fáza) → jeden riadok do výstupného registra.
- hodinové impulzy na A_x, B_x → obsah registra po pixeloch do výstupu.

- častejšie pre väčší formát (24 x 36 mm) - pridaný "bočný register"
- pri vystúvaní by nemal reagovať na svetlo - zakrytie (mechanic. uzávierka)
- lacnejší

Bucket brigade analogy for read out

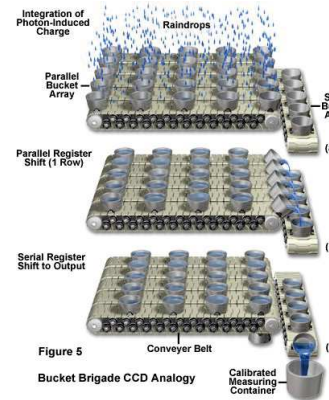
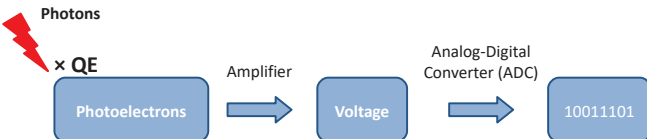


Figure 5

Bucket Brigade CCD Analogy

- Rain accumulates in buckets
- Rows of buckets shifted to readout row
- Readout row shifted bucket-by-bucket to measuring device
- Unless rain stops, last bucket to be read out will have much more water than the first

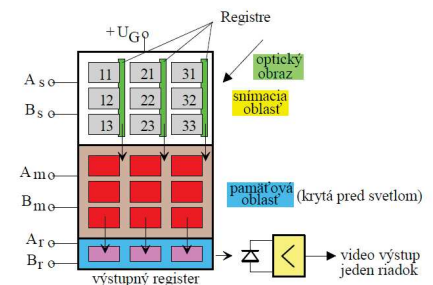
6.1. CCD prvky vyčítanie obsahu...



Bit Depth	Number of gray levels
8	28 = 256
10	210 = 1024
12	212 = 4096
14	214 = 16384
16	216 = 65536

6.1. CCD prvky maticový CCD senzor: frame transfer

- pridaná pamäť (rovnaká)
- pridaný zvislý register k sĺpcom v sn. časti (AI elektródy, krytý pred svetlom)
- úbytok plochy (citlivosť) - nad pixelom mikrošošovka (HAD)



Obr. 47.

6.1. CCD prvky snímanie farby

RGB systém

tri základné farby:

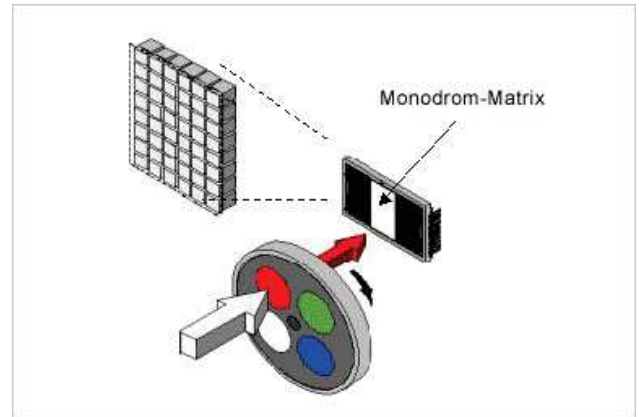
R (Red - červená), G (Green - zelená), B (Blue - modrá)

Poznámka: Jedna sa o aditívne miesanie farieb - svetiel.

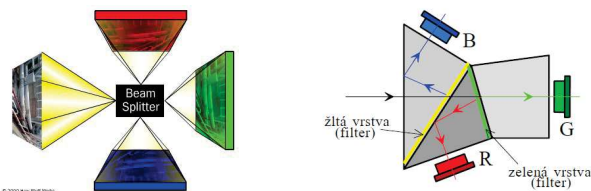
Možnosti:

- postupne tri expozície cez tri filtre
- tri identické obrazy - tri senzory
- jeden "trojitý" maticový senzor + tzv. mozaikový filter.
- systém FOVEON

6.1. CCD prvky snímanie farby – trojité snímanie



6.1. CCD prvky snímanie farby – tri CCD prvky

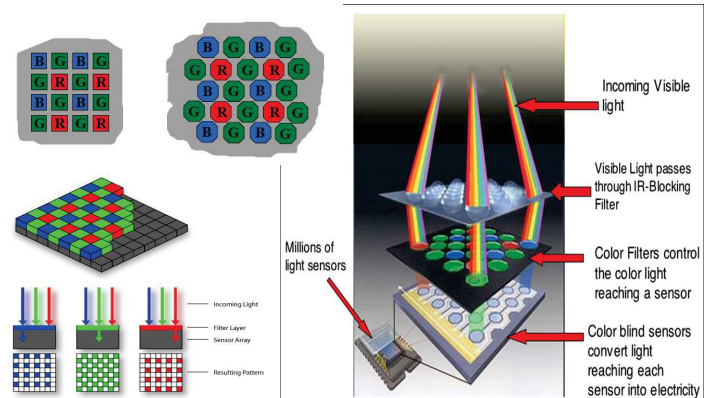


RGB prizma

Obr. 48

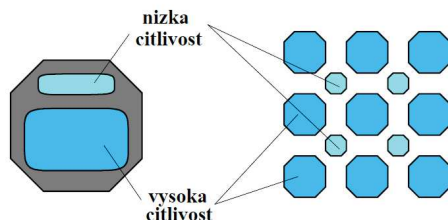
- kvalitné zobrazenie
- náročné na presné nastavenie

6.1. CCD prvky snímanie farby – mozaikový filter



6.1. CCD prvky snímanie farby – dynamický rozsah

Zväčšenie dynamického rozsahu.



Super CCD SR

Obr. 50

CMOS Detectors

Anatomy of the Active Pixel Sensor Photodiode

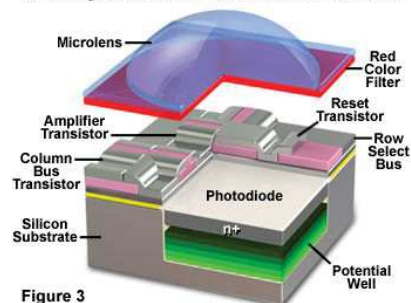


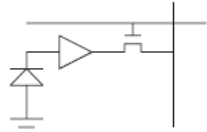
Figure 3

Complementary Metal Oxide Semiconductor

- Transistors in each pixel convert charge to voltage
- More can be done within a pixel meaning **frame read out can be faster**
- Fabricated much like microprocessors and RAM so are **cheaper to make**
- Used in webcams, phone cameras since they use **less power**

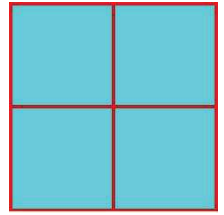
Active Pixel Image Sensor

- 3-4 transistors per pixel.
- Fast, higher SNR, but
- Larger pixel, lower fill factor.
- Lower voltage and lower power.



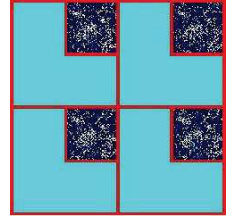
What is a Pixel?

- The smallest discrete component of an image or picture on a CRT screen is known as a pixel.
- Each pixel is a sample of an original image, where more samples typically provide more-accurate representations of the original.



What is Fill Factor?

- Fill factor refers to the percentage of a photo site that is sensitive to light.
- If circuits cover 25% of each photo site, the sensor is said to have a fill factor of 75%. The higher the fill factor, the more sensitive the sensor.



CMOS Detectors

Anatomy of the Active Pixel Sensor Photodiode

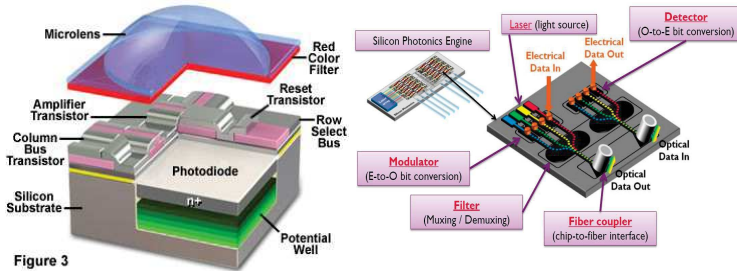


Figure 3

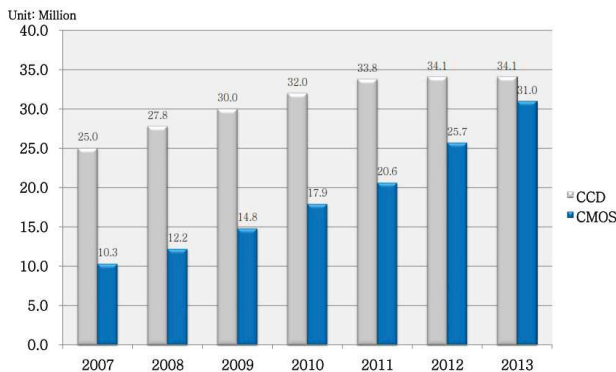
Image from <http://www.olympusmicro.com/primer/digitalimaging/cmosimagesensors.html>

6.1. CCD vs. CMOS

- | | |
|---|---|
| <ul style="list-style-type: none"> • Create high-quality, low-noise images. • Greater sensitivity and fidelity • 100 times more power • Require specialized assembly lines • Older and more developed technology | <ul style="list-style-type: none"> • More susceptible to noise • Light sensitivity is lower • Consume little power • Easy to Manufacture • Cheaper |
|---|---|

Picture quality, sensitivity and cost vs. Cost and battery life.

6.1. CCD vs. CMOS



6.1. Kamery v automobiloch case study

Audi A5 Sportback

Driver assistance systems - overview of sensors

Front camera:

- adaptive cruise control (ACC)
- Stop&Go incl. Traffic jam assist
- Audi active lane assist
- Audi pre-sense front
- Audi pre-sense city
- Camera-based traffic sign recognition
- Collision avoidance assistant
- High beam assist
- Matrix LED headlights
- Predictive efficiency assistant
- Turn assist

Ultrasonic sensors at rear:

- Parking system rear
- Parking system plus
- Parking assist

Ultrasonic sensors at front:

- adaptive cruise control (ACC)
- Stop&Go incl. Traffic jam assist
- Parking system plus
- Park assist

Front radar sensors:

- adaptive cruise control (ACC)
- Stop&Go incl. Traffic jam assist
- Audi active lane assist
- Audi pre-sense front
- Collision avoidance assistant
- Distance display
- Predictive efficiency assistant
- Turn assist

Rear radar sensors:

- adaptive cruise control (ACC)
- Audi active lane assist
- Audi pre-sense rear
- Audi side assist
- Exit warning
- Predictive efficiency assistant
- Rear cross traffic assist

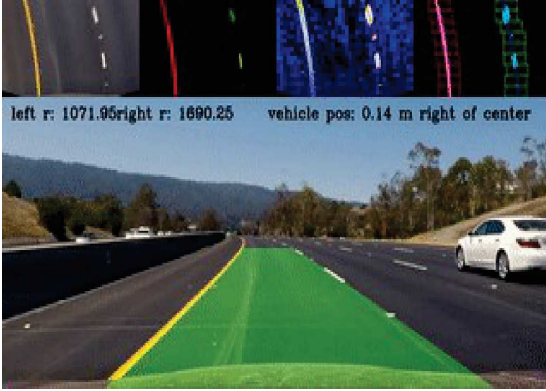
360° cameras:

- Parking system plus
- 360° cameras
- Parking assist with 360° cameras

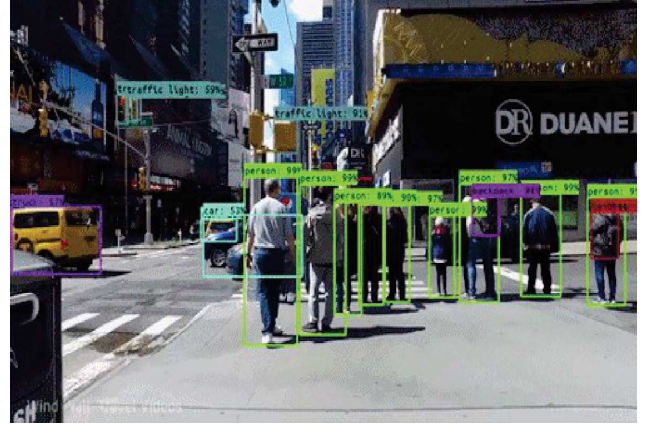
Ultrasonic sensors at side:

- Audi active lane assist
- Parking assist

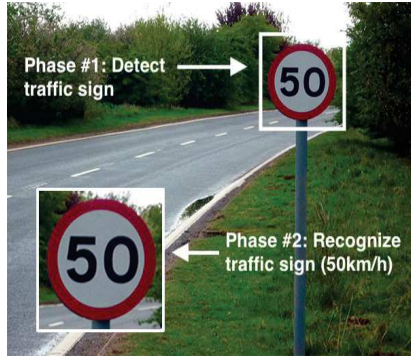
6.1. Kamery v automobiloch case study



6.1. Kamery v automobiloch case study



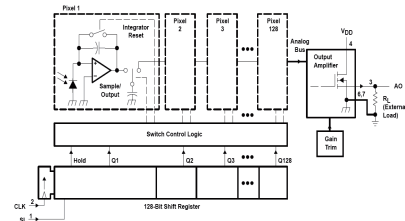
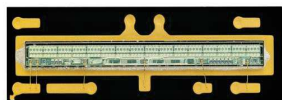
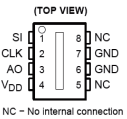
6.1. Kamery v automobiloch case study



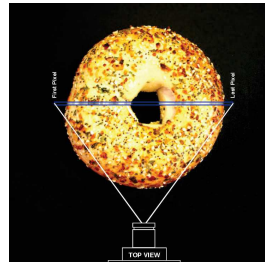
6.1. Kamery v automobiloch case study



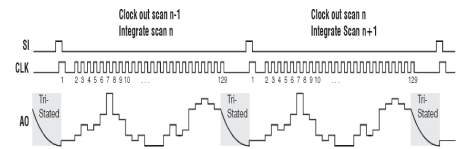
Riadkový CCD snímač TAOS TSL 1401 CL



Riadkový CCD snímač TAOS TSL 1401 CL



- 1 x 128 pixels
- 0 - 5 V output for each pixel
- 1 pixel / 1 clock pulse



Riadkový CCD snímač

TAOS TSL 1401 CL

