

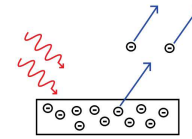
Optical sensors

- Photodiode, phototransistor
- PSD sensors
- CCD sensors
- CMOS sensors
- Color sensors
- Optical distance sensors

6.1. CCD prvky fotoelektrický jav



Hertz: observed in 1887

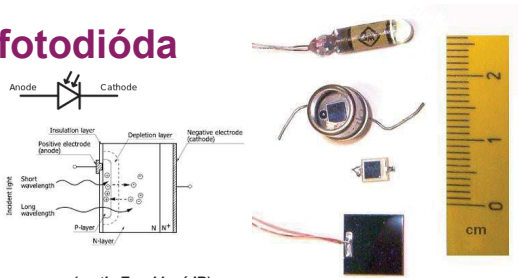


Einstein $E = \frac{hc}{\lambda}$

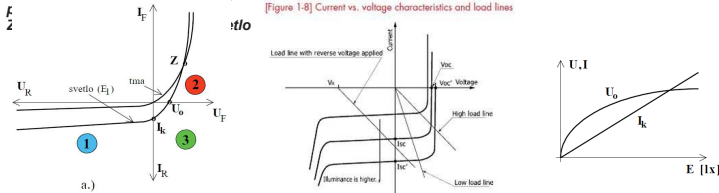
- For silicon, need ≈ 1.14 eV to release an electron
- So need $\lambda < 1100$ nm

Detektory: fotodióda photodiode

rýchle, málo citlivé

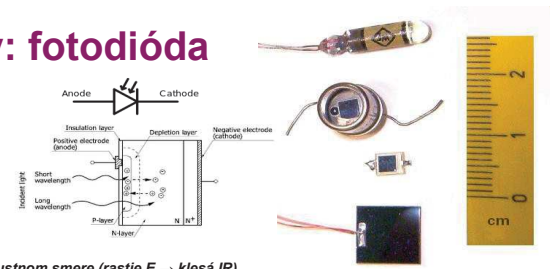


2 - odporový režim v priepustnom smere (rastie E → klesá IR) päťte naprázdno, Ik je výst.

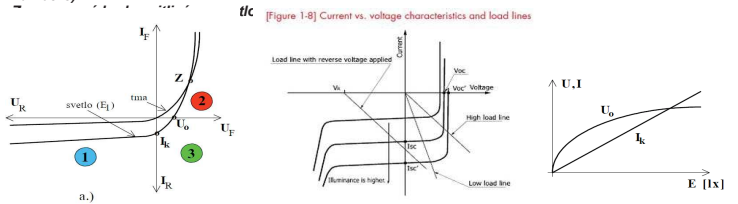


Detektory: fotodióda photodiode

rýchle, málo citlivé



2 - odporový režim v priepustnom smere (rastie E → klesá IR) 3 - hradlový režim (U0 je výst. napätie naprázdno, Ik je výst. prúd nakrátko)

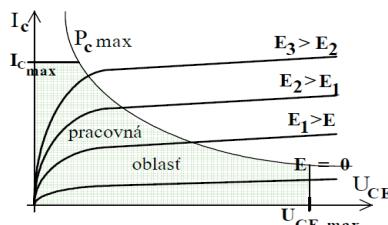
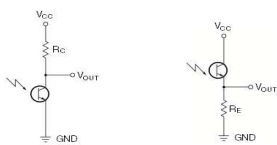


Detektory: fototranzistor phototransistor

- 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).

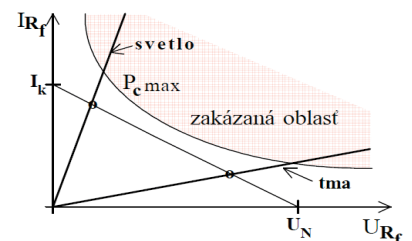


Detektory: fotoodpor, fotorezistor photoresistor

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

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

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



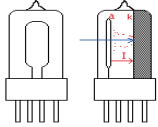
V - A charakteristika

Detektory: fotónka, fotonásobič

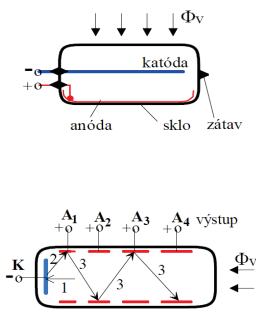
photocell, photomultiplier tube (PMT)

vákuová súčiastka

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



- 1 foton
- 2 elektrón
- 3 sekundárny elektrón



Detektory: integrované

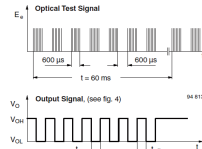
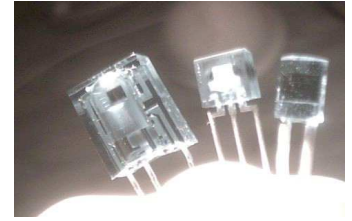
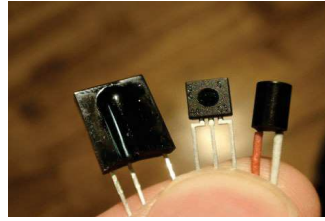


Fig. 3 - Output Function

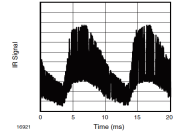
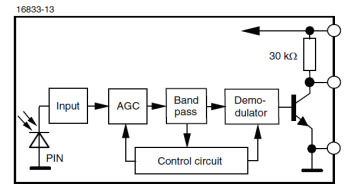
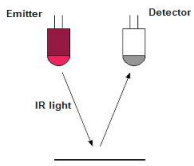


Fig. 14 - IR Disturbance from Fluorescent Lamp

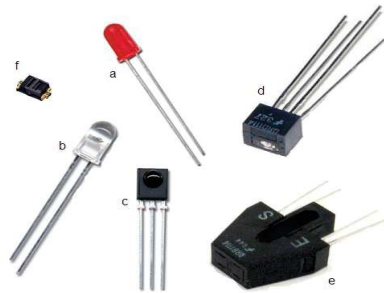


Black = no reflection (0)
= reflection (1)

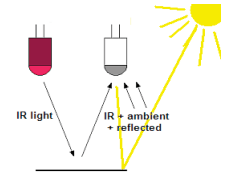
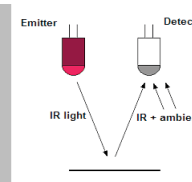
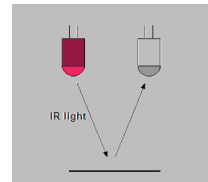
Output
DIGITAL 0 and 1
ANALOGUE 0-100%

Sources of failures

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



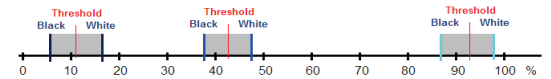
Sensors and detectors:
a) red LED b) Infra red LED c) Infra detector
d) combination emitter + sensor e) larger version
f) miniature SMD version of E+S



Sensor output

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

- Shields!
- Calibrate!



Optical line sensor principle

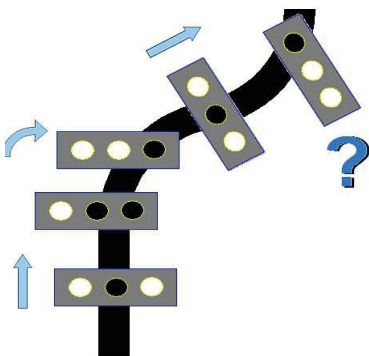
9

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	???

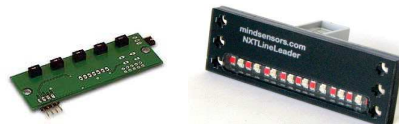


Algorithms

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More sensors?

Adds more reliability
Different width of line

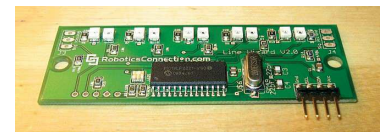


Proportional control

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



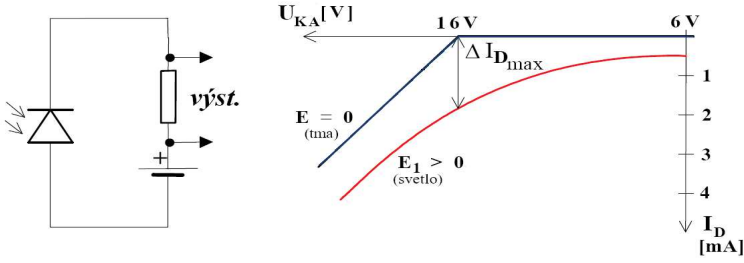
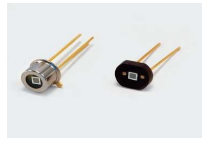
Different shapes enable to determine sharp turns in advance.



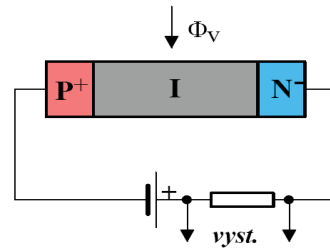
Algorithms

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lavínová fotodióda avalanche photodiode

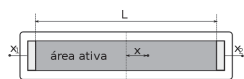
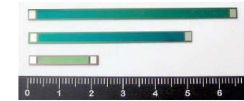
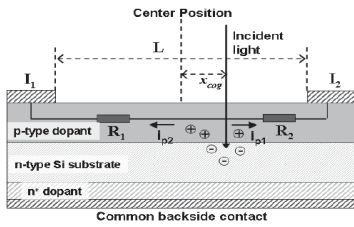


PIN fotodióda avalanche photodiode



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

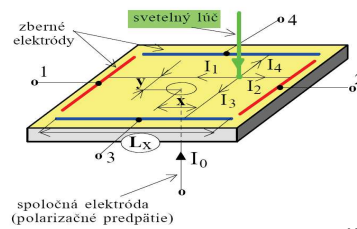
PSD prvky position sensitive device



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

- 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



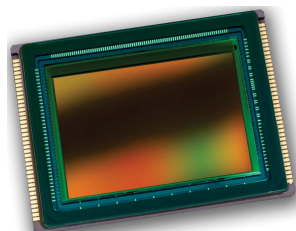
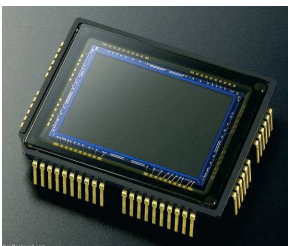
$$x = \frac{L_x}{2} \frac{I_2 - I_1}{I_2 + I_1} \quad y = \frac{L_x}{2} \frac{I_4 - I_3}{I_4 + I_3}$$

vyhodnotenie 4 prúdov voči zbernej elektróde

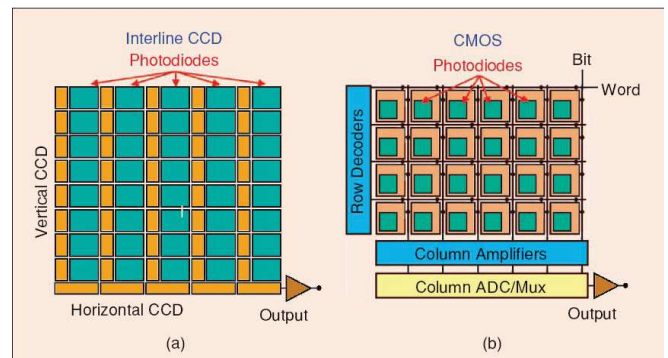
x a y sú vzdialenosti od stredu

6. Optické snímače

CCD a CMOS



6. Optické snímače

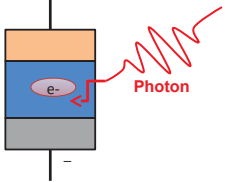


6.1. CCD prvky

1 pixel

Photodiodes

- Photons will generate electron (photoelectron)

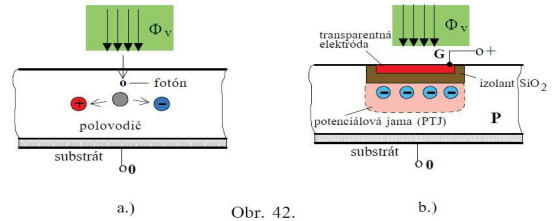


- But detecting few electrons is hard
- Need way to amplify the signal



6.1. CCD prvky

charge coupled device

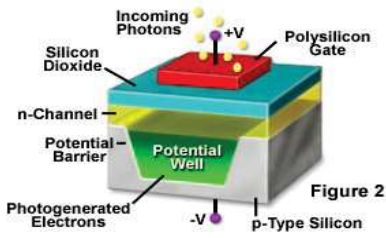


- Uchovávame tzv. menšinové náboje, teda v P polovodiči elektróny. Tieto môžu vzniknúť:
- tepelnou generáciou - parazitný jav (šum)
 - injekciou svetlom - vlastný snímací efekt
 - injekciou z blízkeho PN prechodu - odovzdanie výstupného signálu

6.1. CCD prvky

základná CCD bunka

Metal Oxide Semiconductor (MOS) Capacitor

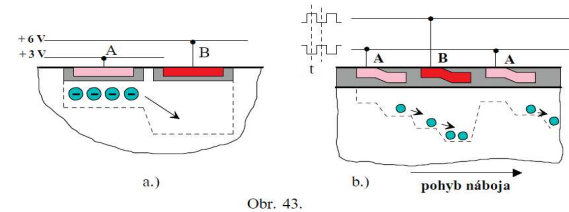


Charge-Coupled Device

- 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

6.1. CCD prvky

prenos náboja



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

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

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)

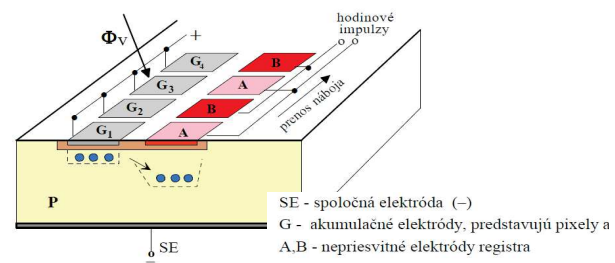
Poznámka: Doba existencie náboja v PTJ je asi 100 ms + 10 s. (vyrovnanie tepelnou generáciou). Dlhé časy - problém, už cca 5 + 10 s vyžadujú chladienie prvkov, napr. polovodičové, resp. softwérové potlačenie. (následné zosnímanie bez obrazu a odčítanie)

6.1. CCD prvky

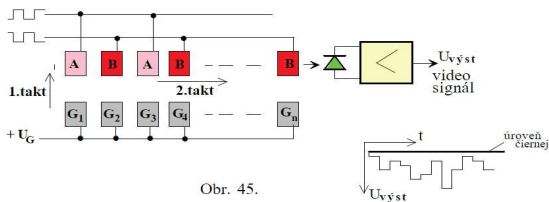
riadkový CCD senzor

Riadkový CCD senzor

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



6.1. CCD prvky riadkový CCD senzor



Video signál:

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

Počet pixelov - 128 (termovízia), po 6 - 10 tis.(profi scannery...)
Rozmery : od 6 x 6 μm do 17 x 8 μm .

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 vysvitvanie - akumulujú svetlo aj počas vysvitvania (náchyľnejšie na smearing, blooming)
rýchle vysvitvanie - nekalitné (rýchle) odčítanie náboja

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

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

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

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)

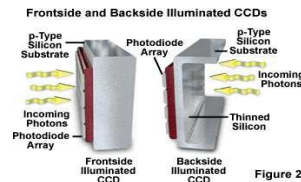
6.1. CCD prvky riadkový CCD senzor

Použitie riadkových CCD :

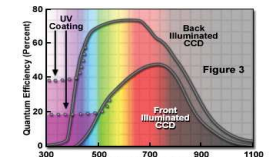
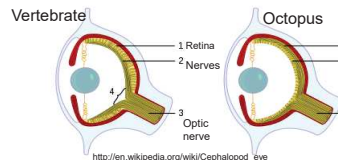
- nepohyblivé obrázky (scannery...) - snímanie po riadkoch
- snímanie polohy (ako PSD)
- iné, napr. zaostrovacie systémy - vyhodnotenie kontrastu (križový senzor, hrany)

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

6.1. CCD prvky Front or Back Illuminated

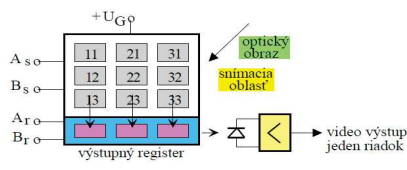


- Traditional, front-illuminated have wiring in front of photosensitive region
- This blocks some light, reducing QE
- Back-illuminated CCDs:
- Back side of the CCD is etched to 10-15 microns
- More fragile and costly, but higher QE



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

6.1. CCD prvky maticový CCD senzor: Full frame

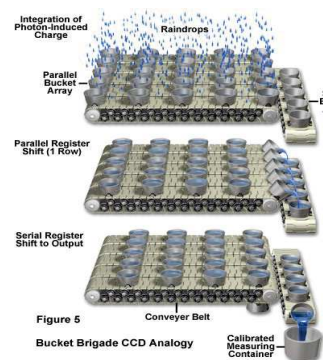


Činnosť :

- obraz sa premietne na snímaciu časť \rightarrow pod elektródami náboj
- hodinové impulzy na A_1, A_2 (1 fáza), a B_1, B_2 (2 fáza) \rightarrow jeden riadok do výstupného registra.
- hodinové impulzy na A_2, B_2 \rightarrow obsah registra po pixeloch do výstupu.

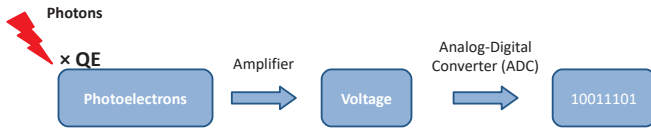
- častejšie pre väčší formát (24 x 36 mm) - pridaný "bočný register"
- pri vysvitvaní by nemal reagovať na svetlo - zakrytie (mechanic, uzávierka)
- lacnejší

Bucket brigade analogy for read out



- 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

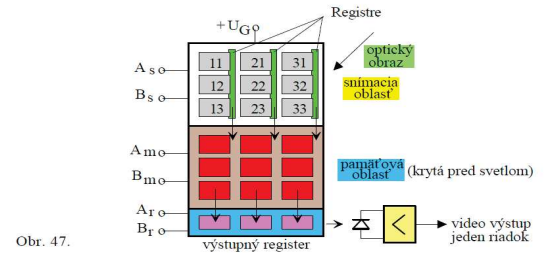
6.1. CCD prvky vyčítanie obsahu...



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 stĺpcom v sn. časti (Al elektródy, krytý pred svetlom)
- úbytok plochy (citlivosť) – nad pixelom mikrošošovka (HAD)



Obr. 47.

6.1. CCD prvky snímanie farby

RGB systém

tri základné farby:

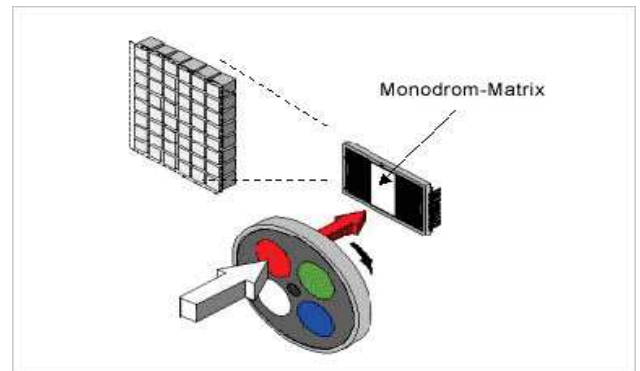
R (Red - červená), G (Green - zelená), B (Blue - modrá)

Poznámka: Jedna sa o aditívne miesanie farieb - svetiel.

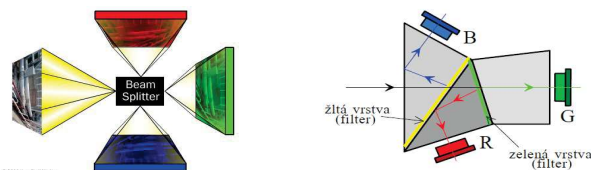
Možnosti:

- 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

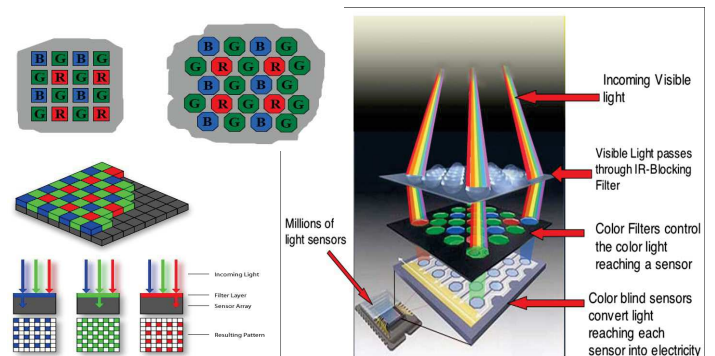


RGB prizma

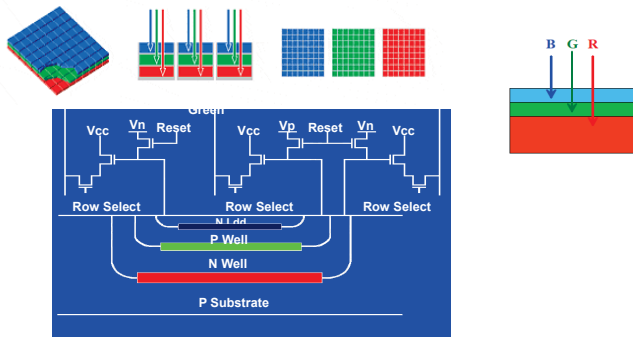
Obr. 48

- kvalitné zobrazenie
- náročné na presné nastavenie

6.1. CCD prvky snímanie farby – mozaikový filter

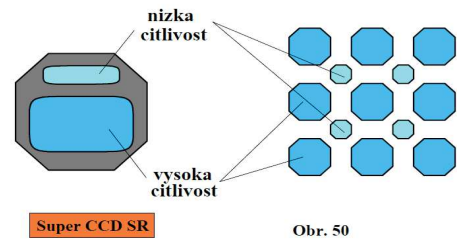


6.1. CCD prvky snímanie farby – trojvrstvový FOVEON



6.1. CCD prvky snímanie farby – dynamický rozsah

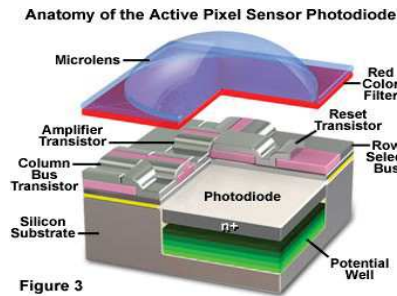
Zväčšenie dynamického rozsahu.



Obr. 50

CMOS sensors

CMOS Detectors



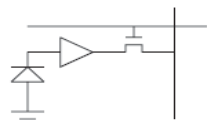
Complementary Metal Oxide Semiconductor

- 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**

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

Active Pixel Image Sensor

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



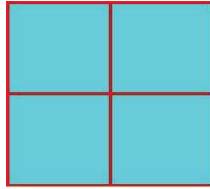
Passive Pixel Image Sensor

- 1 transistor per pixel.
- Small pixel, large fill factor, but
- Slow, low signal to noise ratio (SNR).



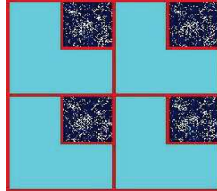
What is a Pixel?

- ◊ 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

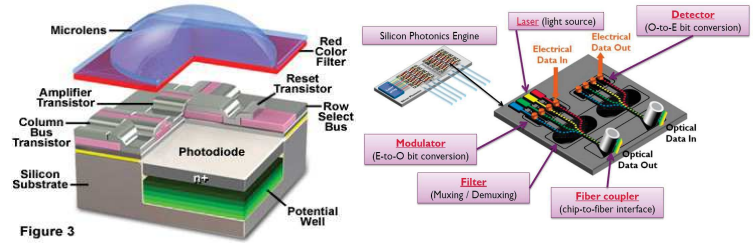
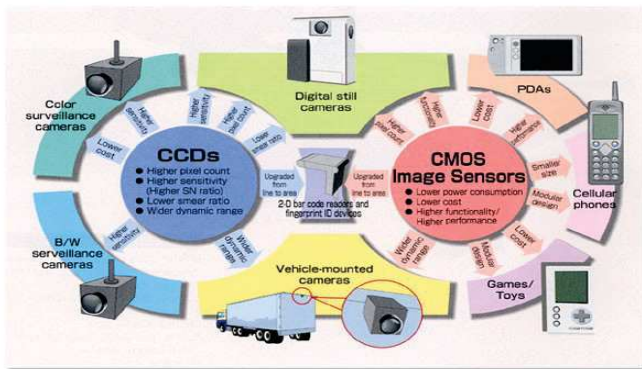


Figure 3

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

6.1. CCD vs. CMOS



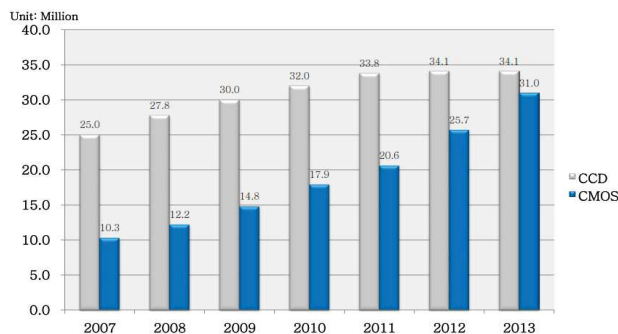
6.1. CCD vs. CMOS

- | | |
|---|---|
| <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

Přiklady



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

Ultrasonic sensors at side:

- Audi active lane assist
- Parking assist

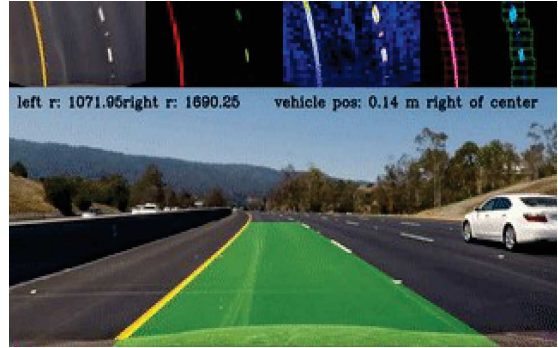
360° cameras:

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

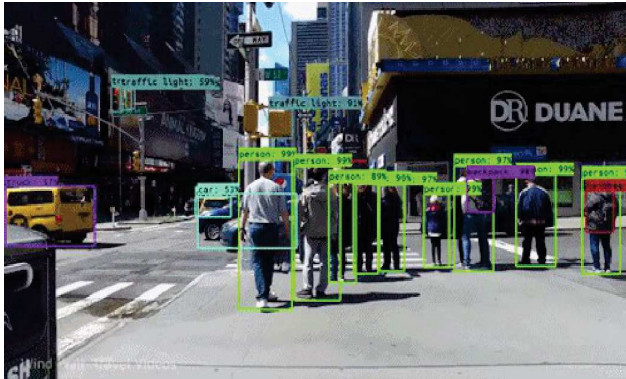
Rear radar sensors:

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

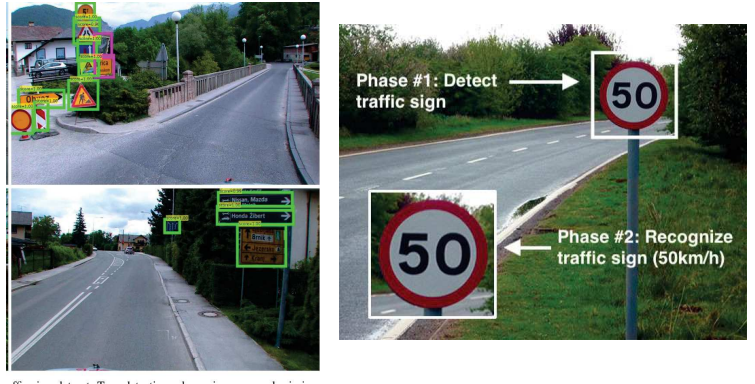
6.1. Kamery v automobiloch case study



6.1. Kamery v automobiloch case study



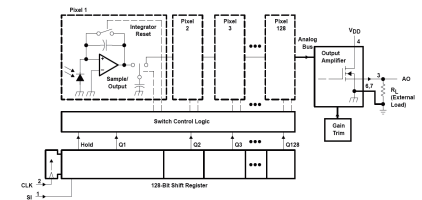
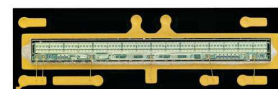
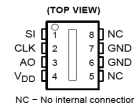
6.1. Kamery v automobiloch case study



6.1. Kamery v automobiloch case study

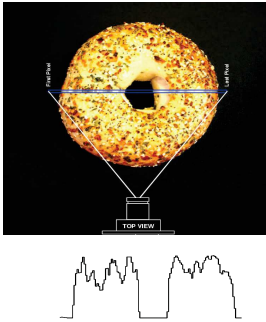


Riadkový CCD snímač TAOS TSL 1401 CL

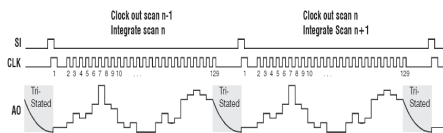


Riadkový CCD snímač

TAOS TSL 1401 CL

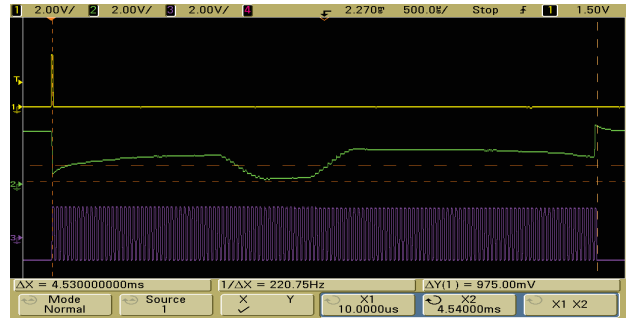


- 1 x 128 pixels
- 0 - 5 V output for each pixel
- 1 pixel / 1 clock pulse



Riadkový CCD snímač

TAOS TSL 1401 CL



6.3. Čiarové kódy

barcode



- lineárne
- dvojrozmerné
- moderné identifikačné prvky

6.3. Čiarové kódy

Lineárne – linear barcode

Lineárne - sústava čiar a medzier

- menšia kapacita (tradičné len čísla, cca 20 znakov)
- jednoduchšia tvorba (tlač)
- jednoduchšie čítanie



Požiadavky:

- presná geometria
- šírka čiar a medzier

- dostatočný kontrast
- ideálny čierny na bielom podklade (**nelesklý !!**)

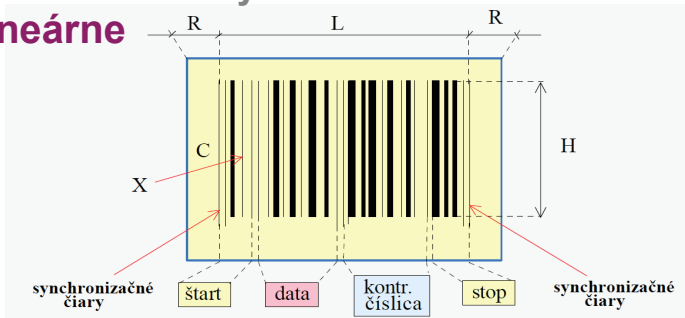
- farebná kombinácia
- ak nemá kód rušiť na obale

- utajené kódy
- ňakom neviditeľný číta sa IR žiarením

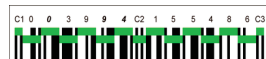


6.3. Čiarové kódy

Lineárne



- X - šírka modulu (najtenšia čiara - medzera)
- R - svetlé pásmo (min 2,5 mm, resp. 10 X)
- H - výška kódu (min. 0,1 L ručné, 0,2L skener.....)
- L - dĺžka kódu (štart - stop)
- C - kontrast (jaspozadia - jasčiary) / jaspozadia
- synchronizačné čiary (okrajové) - určujú štart-stop

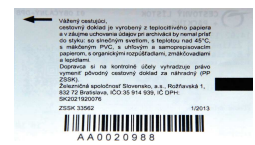


6.3. Čiarové kódy

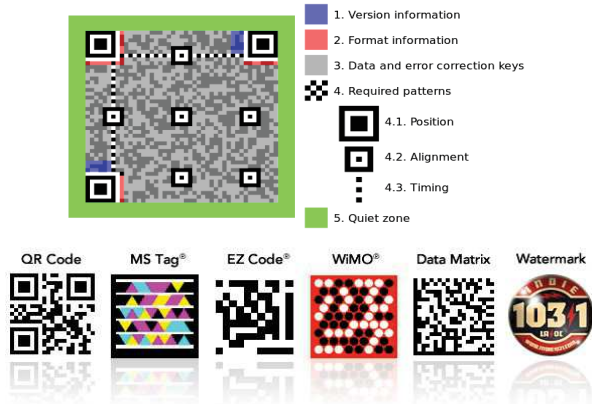
Plošné (2D)

plošné 2D - sústava plošných útvarov (DataMatrix, PDF417, MaxiCode...)

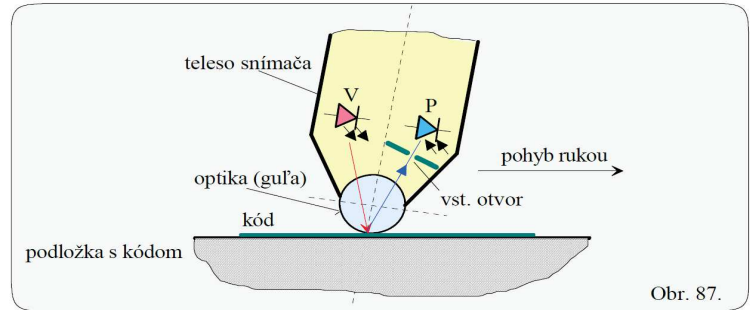
- vyššia kapacita (až 4 kB)
- zložitejšia tvorba a čítanie
- čítanie kamerou (image sensors)



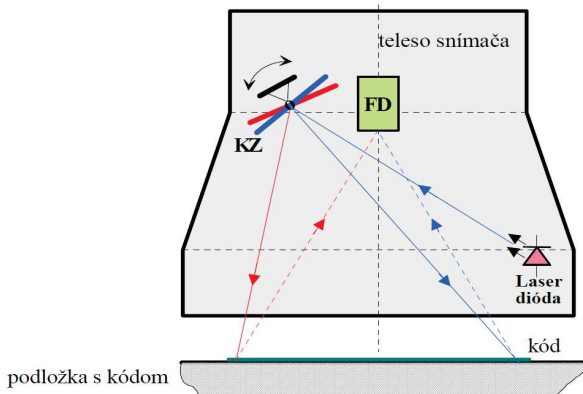
6.3. Čiarové kódy Plošné (2D)



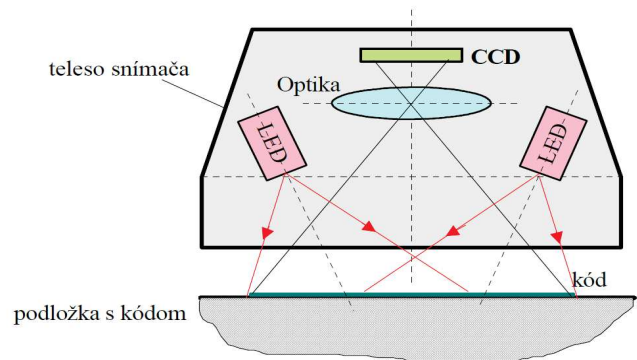
6.3. Čiarové kódy Lineárne – skenery



6.3. Čiarové kódy Lineárne – skenery



6.3. Čiarové kódy Lineárne aj plošné



6.3. Moderné kódy RFID – radio-frequency identification



6.3. Moderné kódy NFC – near field communication

