Songyu

- Batteries [figure]
  - macro primary: Zinc-Air, Lithium, Alkaline
  - macro secondary: Lithium-Ion, NiMHd, NiCd
  - micro & flex
- Capacitors
  - electrolytic capacitors,
- Energy harvesting:
  1. micro thermoelectric generators (TEG)
     - ① Seebeck effect
     - ② {in-plane configuration (IPC) / cross-plane configuration (CPC)} [47]
     - ③ theroelectric efficiency: $zT = \frac{\alpha^2 \sigma}{k} T$
  2. mechanical vibration energy harvesters
     - ① electromagnetic generator
     - ② electrostatic generator
     - piezoelectric vibration energy harvesters
       - cantilever beams
  3. radio frequency (RF) micro harvesters
     - ① non-radiative RF energy transfer [84]
     - ② radiative RF energy transfer (Friis equation)
       - HF power transfer (smart contact lens)
- Human eye:

spherically-shaped organ, cornea, iris, pupil, crystalline lens, retina (rods, cones)

Artificial Iris:

① autonomic response to light

② depth of field (DOF)

③ pin hole effect

- Transistors:

① $I_B = \frac{I_S}{\beta} e^{\frac{V_{BE}}{V_T}}$ $\quad I_C = \beta I_B$ $\quad I_E = (\beta+1) I_B$ $\quad I_B$ depends on V_{BE}

$I_S = I_{SO}(1+\frac{V_{CE}}{V_A})$ $\quad \beta = \beta_0(1+\frac{V_{CE}}{V_A})$ $\quad I_C$ slightly depends on V_{CE} (early effect)

② small signal model: $r_e = \frac{V_T}{I_E}$

1. current mirrors:

① $I_O = \frac{I_{ref}}{1+\frac{2}{\beta}}$ $\quad R_i \approx \frac{V_A}{I_{ref}}$ [131]

② MOSFET current mirror: $I_O = I_{ref}$ [132]

③ with base current compensation: $I_O \approx \frac{I_{ref}}{1+\frac{2}{\beta(1+\beta)}}$ [133]

④ Wilson mirror: $I_O = \frac{I_{ref}}{1+\frac{2}{\beta(1+\beta)}}$ $\quad R_i \approx \frac{\beta}{2} r_o(Q_3)$ [134]

⑤ Widlar mirror: $\times I_O$ $\quad R_E = \frac{V_T}{I_O} \ln(\frac{I_{ref}}{I_O})$ [135]

2. operational transconductance amplifier: $i_o = \frac{(V_+ - V_-) I_{ABC}}{2V_T}$

- Interfacing photodiodes:

transimpedance amplifier (TIA) [142]

$\frac{V_o}{I_S} = \frac{-Z_F}{1+\frac{A}{\beta}} \triangleq Z_T$

- LED:

① Buck converter [172]

② Boost converter [178]

③ capacitive voltage divider [181]

- Microdisplays:

1. Poly-Si [184] 2. DLP [189] 3. LCOS [209]

4. others: ① OLED on silicon ② x-Si ③ Pico projectors

- Radiometric & Photometric quantities:

① photopic response curve [216]

② lumens per watt

③ flux (light power): F_e (W), F_v (lm)

④ flux density (incoming light): E_e (W/m²), E_v (lm/m² = lx) $E = \frac{dF_i}{dA}$

⑤ exitance (outgoing light): M_e (W/m²), M_v (lm/m²) $M = \frac{dF_o}{dA}$

⑥ intensity: I_e (W/sr), I_v (lm/sr = cd)

⑦ luminance: L_e (W/m²sr), L_v (cd/m² = nit)

Etendrue: $G = n^2 \int_S \int_\Omega \cos(\theta)\, dA\, d\omega$ (m²sr)

- CCD:

1. characteristics:

① pixel count ② dynamic range ③ speed ④ physical size

2. architectures:

① full frame ② interline transfer ③ frame transfer

- Static characteristics: [figure]
  - static transfer function & range
  - accuracy & precision (noise) & resolution, systematic & random errors
  - (non-) linearity & hysteresis
- Dynamic characteristics:
  - bandwidth (zero, first, second order)
- Other characteristics:
  - input & output impedance, power supply, cross-influences, sensitivity distribution, reliability, efficiency
- Primary sensors:
  - temperature: bimetal
  - pressure: U-tube [85], Bourdon-tube [86], diaphragm [87], capsule & bellows [89]
  - flow: orifice plate & diaphragm [93], nozzle, Ventrui-tube [94]
    (Bernoulli's theorem: $p + \rho g h + \frac{\rho v^2}{2} = \text{constant}$)
- Signal conditioners:
  1. amplitude: voltage & current
  2. frequency: demodulation ($f \rightarrow V + ADC$)
  3. linearization:
     ① non-linear sensor: using parallel resistor [112]
     ② current driven [117]
     ③ small-signal [118]
     ④ push-pull [120]

⑤ feedback [122]

⑥ afterwards numerically

- Signal transmission:

  voltage & current transmission, frequency modulation

  digitizing, digital transmission

- Digital:

  inertion switch (airbag trigger), tilt switch, reed switch

  position-encoder: absolute, incremental/decremental,

  Moiré encoder, photodetector

- EMF (self-generating)

  1. thermocouple: Peltier & Thomson, thermopile
  2. electret microphone
  3. Piezo-electric sensor
  4. Pyro-electric sensor
  5. photovoltaic sensor
  6. photodiode { photovoltaic / photoconductive

① noise { Johnson noise / Shot noise / Flicker noise

$\sim \sqrt{\text{bandwidth}}$

$\sim \sqrt{A_D}$

$I_N = \sqrt{I_J^2 + I_S^2 + I_F^2}$

② NEP (Noise Equivalent Power) $NEP = \frac{I_{N(dark)}}{S_R} (W)$

③ detectivity $D = \frac{\sqrt{B}}{NEP} \left(\frac{\sqrt{Hz}}{W}\right)$

④ response speed $T_R = \sqrt{T_{CC}^2 + T_{DIF}^2 + T_{RC}^2}$

④ photodiode circuits [125]

- Resistive:
  1. ① potentiometers ② strain gauge ③ push-pull
  2. temperature sensors:
     ① RTD (compensation of wires)
     ② thermistor: NTC, PTC
  3. photoconductor (LDR)
  4. humidity sensor
- Capacitive:
  1. plate separation
  2. pressure & strain
  3. level of liquid
  4. permittivity
  5. plate area: liquid level, position, rotation, tilt angle
  6. interfacing capacitive sensors
  7. capacitive accelerometer
- Inductive:
  1. reluctance & self-inductance: N, μ, Z_0 (eddy current)

  2. LVDT
- Other:
  1. Hall sensor [237]

2. optical fiber sensor : intrinsic & extrinsic

3. fiber Bragg grating sensor

- Actuators:

  electrostatic actuators :

  interdigitated comb capacitor & parallel plate capacitor