Chapter 1

$°C = \frac{(°F-32)}{1.8}$

$P = 10\log_{10}\frac{P}{P_0}$ Power, Power Density, Energy

$V = 20\log_{10}\frac{V}{V_0}$ Voltage, Current, Force, Pressure

Chapter 2

Dynamic Range: $\frac{\text{Span}}{\text{resolution}}$ (dB)

Digital Sensors/Actuators: Dynamic Range $= 20\log_{10}\left(\frac{2^N}{1}\right)$ # of bits

Failure Rate (FR) $= \frac{\text{Failures}}{\text{time} \times \text{\# Components}}$

Mean Time Btwn Failures (MTBF) $= \frac{1}{FR}$

Failure-in-time (FIT) $= FR \cdot 10^9$

Chapter 3

RTDs: $R = \frac{L}{\sigma s}$

L: Length (m)
σ: conductivity
S: Cross-Section Area (m^2)

$\sigma = \frac{\sigma_0}{1+\alpha(T-T_0)}\left(\frac{S}{m}\right)$ reference

Resistance as function of Temp

$R = \frac{L}{\sigma_0 s}(1+\alpha(T-T_0))$ °C or K

or

$R = R_0(1+\alpha(T-T_0))$

Transfer Function

1) $R = R(0°c)(1+\alpha T)$ (approx) $\alpha = 0.00385, 0.003926, 0.003916, 0.003902$

2) $T \geq 0°c$ $R(T) = R(0°c)(1+aT+bT^2)$

$T < 0°c$ $R(T) = R(0°c)(1+aT+bT^2+c(T-100)T^3)$

$a = 3.9083\times10^{-3}$ $b = -5.775\times10^{-7}$ $c = -4.183\times10^{-12}$

Thermistors: $R(T) = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)}$ Kelvin

Silicon Resistive: $R(T) = R(0°c)(1+a(T-T_{ref})+b(T-T_{ref})^2+HOT)$ Higher Order Terms

$emf_a = \alpha_a(T_2-T_1)$

$emf_b = \alpha_b(T_2-T_1)$

$emf_T = emf_a - emf_b = \alpha_{ab}(T_2-T_1)$

P-N Junction: $I = I_0 e^{qV/2kT}$ Saturation Current, Kelvin

$V_s = \frac{E_g}{q} - \frac{2kT}{q}\ln\left(\frac{c}{I}\right)$ Temp independent Constant

1.602×10^{-19}, 1.38×10^{-23}, q · bandgap energy

Cold Junction Compensation

$emf = \alpha_{ba}T_2 - \alpha_{ba}T$

$emf_{comp} = V_{BA}$ emf_{comp}

$= \frac{V^+}{R_2+R_0(1+\alpha T)}R_0(1+\alpha T) - \frac{V^+}{R_1+R_2}R_1$

R_1 = RTD @ 0°C, denoted as RT ($R_1 = R_0$)

Acoustical: $V_s = 331.5\sqrt{\frac{T}{273.15}}$ (m/s)

Bimetal: $d = r\left(1-\cos\left(\frac{180L}{\pi r}\right)\right)$ (m)

$r = \frac{2t}{3(\alpha_u-\alpha_l)(T_2-T_1)}$ (m)

Thermal Expansion:
$\Delta V = \beta V \Delta T$ (m^3)
$V = V_0(1+\beta(T-T_0))$ (m^3)
$\Delta l = \alpha l \Delta T$ (m)
$l = l_0(1+\alpha(T-T_0))$ (m)

Chapter 4

$\lambda = \frac{3\times10^8}{f}$ (c)

$h = 6.62620\times10^{-34}$ J·s
$= 4.1357\times10^{-15}$ eV·s
$k = 1.381\times10^{-23}$ $kgm^2/s^2/K$

Photoelectric Effect

$e = hf$ $hf - e_0 = k$ Work Function, Max Ek Outside Material

$\eta = \frac{N_e}{N_{ph}}$ # elec. released / # photon absorbed

Photoconducting Effect

$\sigma = e(\mu_e n + \mu_p p)$ $\left[\frac{S}{m}\right]$

$e = 1.602\times10^{-19}$ coulomb
μ_e: mobility of electrons
μ_p: " " of holes

Luminous Intensity: [cd] $= \frac{W}{sr}$

Luminous Flux: $\left[\frac{cd}{sr}\right] = W$

Illuminance: $\left[\frac{cd \cdot sr}{m^2}\right] = \frac{W}{m^2}$

Luminance $\left[\frac{cd}{m^2}\right] = \frac{W}{sr\,m^2}$

Photomultipliers

gain $G = n^k$ # dynodes, avg # electrons/dynode

$I_0 = aAT^2e^{-E_0/kT}$ Cathode constant, $A = 120.173\times10^4$ A/m^2, E_0 = Cathode Work function

Photodiodes

Forward-Bias: $I_d = I_0(e^{eV_d/kT}-1)$ K

Reverse-Bias: $I_d = 0$

PC Mode

$I_p = \frac{\eta PAe}{hf}$ W/m^2, m^2

$I_L = I_d - I_p$

ηPA = Power absorbed by junction

PV Mode (No Bias)

$I_{sc} = -I_p = -\frac{\eta PAe}{hf}$

$I_0(e^{eV_{oc}/kT}-1) = \frac{\eta PAe}{hf}$

$eff = \frac{P_{out}}{P_{in}} = \frac{V^2/R_L}{P_d \times S}$ Area, $\frac{mW}{cm^2}$

Photoconducting Sensors

$\Delta\sigma = e(\mu_e\Delta n + \mu_p\Delta p)$

n-type => $\sigma = e(\mu_e\Delta n)$
p-type => $\sigma = e(\mu_p\Delta p)$

$\Delta\sigma = eg(\mu_n\tau_n + \mu_p\tau_p)$ (Steady-State) # carriers generated per sec. per unit Vol., Lifetimes

$R = \frac{L}{\sigma wd}$ Power Density, % absorbed

$G = \frac{V}{L^2}(\mu_n\tau_n + \mu_p\tau_p)$ [V/V]

Excess Carrier Density

$\Delta N = \eta\frac{P\tau wL}{hf}$

$\Delta n = \eta\frac{P\tau}{hfd}$

Thermopile PIR

Heat Absorb $W = P_{in}Ae t$ time, efficiency

$C_f = Cm$ $T = \frac{W}{C_f}$

Sensitivity of thermopile, # pairs

$V_{out} = SN\Delta T$

Sensitivity of sensor

$S = \frac{V_{out}}{P_{in}}$

Bolometers

$\beta = \frac{\alpha\varepsilon_s}{2}\sqrt{\frac{Z_T R_0 \Delta T}{(1+\alpha_0\Delta T)(1+(\omega\tau)^2)}}$

Pyroelectric Sensors

$\Delta Q = P_Q A \Delta T$

$\Delta V = P_V h \Delta T$

$\frac{P_Q}{P_V} = \frac{dP_s}{dE} = \varepsilon_0 \times \varepsilon_r$

$C = \frac{\Delta Q}{\Delta V} = \varepsilon_0\varepsilon_r\frac{A}{h}$

ΔQ: Charge
P_Q: Table
P_V: Table
A: Area
ΔT: Temp Grad.
h: Thickness
$\varepsilon_0 = 8.852\times10^{-12}$
ε_r: Table
C: Capacitance

Phototransistors

Normal BJT: $I_C = \beta I_B$ $I_E = I_B(\beta+1)$

Dark: $I_C = \beta I_0$ $I_E = I_0(\beta+1)$

Lit: $I_B = I_p = \frac{\eta PAe}{hf}$ $I_C = \beta I_p$ $I_E = I_p(\beta+1)$

Chapter 5

Capacitance

$$C = \frac{Q}{V} = \frac{\varepsilon_0 A}{d} = \frac{\varepsilon A}{d} = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

air

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

Inductance

$$L = \frac{n\phi}{I} \qquad L = \frac{\mu_0 \mu_r n}{2\pi r}$$

Hall Effect Sensors

$$E_H = \frac{F_m}{q} = VB\sin\theta_{VB}$$

$$V_{out} = \frac{IB\sin\theta}{qnd} \quad @90^\circ \quad V_{out} = \frac{IB}{qnd}$$

q: electron charge n: carrier density

d: thickness of hall plate

Conductors

$$qn = K_H \Rightarrow V_{out} = K_H \frac{IB}{d}$$

K_H is hall coefficient

Semiconductors: $K_H = \frac{p\mu_h^2 - n\mu_e^2}{q(p\mu_h + n\mu_e)^2}$

$$K_H = \frac{q(p\mu_h + n\mu_e)^2}{\sigma^2}$$

Capacitive Fluid

$$C_f = \frac{\varepsilon_f h w}{d} \qquad C_0 = \frac{\varepsilon_0 (l-h) w}{d}$$

$$C = C_f + C_0 = h\left(\frac{(\varepsilon_f - \varepsilon_0) w}{d}\right) - \frac{\varepsilon_0 l w}{d}$$

$$C_{min}(h=0) = \frac{\varepsilon_0 l w}{d} \qquad C_{max}(h=l) = \frac{\varepsilon_f l w}{d}$$

$$S = \frac{dC}{dh}$$

h: fluid height l: Capacitor height

w: plate width d: plate distance

Inductive Proximity

Reluctance, length, Permeability, Area

$$\mathcal{R}_m = \frac{l_m}{\mu S} \qquad \phi = \frac{\Sigma NI}{\Sigma \mathcal{R}_m}$$

MHD Sensors & Actuators

Sensor:

$$F = qV \times B = qE$$

Width

$$V_{BA} = -\int_a^b E\,dI = -\int_a^b (V \times B)\,dI = VBw$$

height

$$Q = awV \Rightarrow Q = \frac{aV}{B}$$

Vol., Length

$$F = VI \times \frac{B}{A} = B_0 \frac{I}{bd} abd = B_0 I a$$

Coaxial Fluid

$$C_0 = \frac{2\pi\varepsilon_0 d}{\ln(b/a)} \qquad C_f = \frac{2\pi\varepsilon_0}{\ln(b/a)}(h\varepsilon_r + d - h)$$

$$S = \frac{dC_f}{dh} = \frac{2\pi\varepsilon_0}{\ln(b/a)}(\varepsilon_r - 1)$$

b = outer radius a = inner radius

d = length ε_r = relative permeability

Induced Current

$$L = \mu n^2 \pi r^2 \qquad emf = -N\frac{d\phi}{dt}$$

Eddy Current Sensors

$$B = B_0 e^{-d/\delta} \text{ or } J = J_0 e^{-d/\delta}$$

B_0: Flux Density J_0: Eddy Current Density

d: Depth in medium

B & J: Densities @ depth d

$$\delta = \frac{1}{\sqrt{\pi f \mu \sigma}}$$

σ: Conductivity

μ: Permeability

Magnetoresistive Sensors

$$\frac{\Delta R}{R_0} = kB^2$$

k is calibration function

$$R = R_0 + \Delta R_0 \cos^2\alpha$$

Capacitive Actuators

$$F = QE = \frac{kq_1 q_2}{r^2}$$

Parallel plate: $F = \frac{CV^2}{2d} = \frac{\varepsilon_0 \varepsilon_r A V^2}{2d^2}$

Transformers

$$V_2 = \frac{N_2}{N_1} V_1 = \frac{1}{a} V_1$$

$$I_2 = \frac{N_1}{N_2} I_1 = aI_1$$

Variable Inductance

Movable Core: $R_m = \frac{l_m}{\mu S}$

LVDT: $V_{out} = K \frac{N_1}{N_2} V_{ref}$

Magnetostrictive Sensors

$$\left(\frac{\Delta L}{L}\right)_B = \left(\frac{\Delta L}{L}\right)_{B_m} \times \left(\frac{B}{B_m}\right)$$

Magnetics Theory

$\mu_0 = 4\pi \times 10^{-7}$ H/m

μ_r: From table

H: Field Intensity

Flux Density: $B = \mu_0 \mu_r H$

$$B = \mu_0 \mu_r \frac{I}{2\pi r}$$

r: distance from wire to point

$$B = \hat{z}\mu_0 \mu_r n I$$

n: # turns in Solenoid

$$B = \hat{z}\frac{\mu_0 \mu_r N I}{2\pi r_0}$$

r_0: Avg radius of toroidal coil

$$\phi = \int B\,ds = BS\cos\theta \quad \text{if B constant}$$

$$F = qV \times B = qVB\sin\theta_{VB}$$

$F = BIL$ For long perpendicular wires

Magnetometers

$$emf = -N\frac{\delta\phi}{\delta t} \qquad \phi = \int_S BS \sin\theta_{BS}$$