Data Provided: List of useful equations (attached at the end of the paper)

The University Of Sheffield.

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2014-15 (3.0 hours)

EEE123 Introduction to Electric and Electronic Circuits

Answer **FOUR** questions. **No marks will be awarded for solutions to a fifth or a sixth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1.

a. A 24V lorry battery is connected to the engine starter motor. When the motor is running it draws a current of 200A and the voltage across the terminals of the battery drops to 21.5V. Calculate the internal resistance of the battery, the power dissipated within the battery and the overall system efficiency. **(3)**

b. The same battery is then used to power a heating element in the lorry cab (the starter motor is no longer connected). When the heater is first switched on the current flowing is 12A. After a long period of time the current has dropped to 9A and remains at this level.

(i) Calculate the final temperature of the heating element if initially it was at an ambient temperature of 15°C. You may assume the following: **(4)**

Temp. coefficient = $\alpha_0 = 12.5 \times 10^{-3}$ /°C
$R_T = R_0\,(1+\alpha_0 T)$
R_T = Resistance at temperature T°C
R_0 = Resistance at temperature 0°C

(ii) Calculate the power dissipated in the heating element at the final temperature, and hence calculate the system efficiency at this temperature. **(2)**

(iii) If the driver entered the cab on a morning when the ambient temperature was 15°C and switched on the heater and operated the starter motor at the same time, what would be the initial current drawn from the battery. (Assume the heating element remains at 15°C for the duration of starting). **(2)**

c. An ideal transformer has a turns ratio of 1:5 (primary:secondary) and an input voltage of $200V_{rms}$ at 50Hz.

(i) Calculate the secondary voltage, the current in the primary winding and the **(3)**

power dissipated if a resistive load of 40Ω is connected across the secondary.

(ii) Calculate the current in the primary winding and the power dissipated if the load across the secondary now comprises a resistance of 40Ω in series with an inductance of 150mH. **(3)**

(iii) For the case described in part **(ii)** above, what would be the input power factor and the required VA rating of the transformer? **(1)**

(iv) If the maximum core flux of the transformer is 5mWb calculate the actual number of turns on the primary winding. **(1)**

(v) If the transformer were to be operated in a country where the supply frequency is 60Hz, what is the maximum permissible supply voltage without the maximum core flux of 5mWb being exceeded? **(1)**

2.

a. The coil of an electromagnet can be modelled as a resistance, R = 30Ω in series with an inductance, L = 100mH. The electromagnet is connected to a 400V_{rms}, 50Hz sinusoidal supply, V_S, as shown in Figure 2.1.

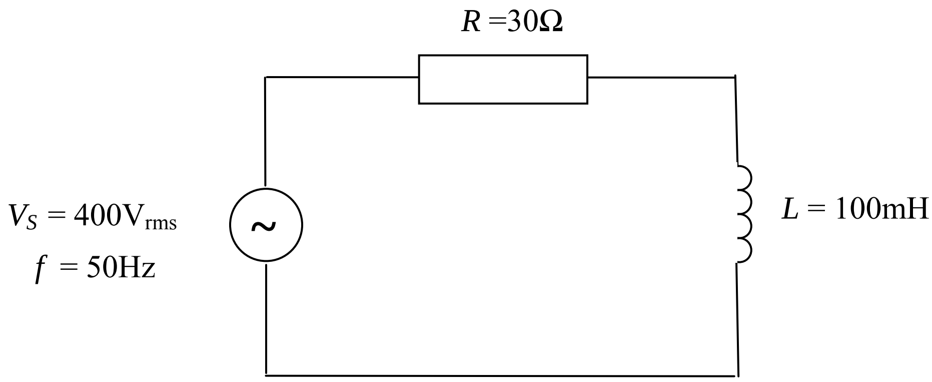


Figure 2.1

(i) Calculate the magnitude and phase angle of the impedance of the electromagnet. **(2)**

(ii) Calculate the magnitude and phase angle of the current flowing in the coil. **(1)**

(iii) What is the real power drawn from the supply and the input power-factor of the circuit? State whether the power-factor is leading or lagging. **(2)**

b. An existing factory is connected to a 3300V_{rms}, 50Hz supply and consumes 160kW of power at a 0.8 power factor lagging.

(i) Calculate the kVA rating of the factory. **(1)**

(ii) Calculate the reactive power in kVAr. **(1)**

(iii) Calculate the magnitude and phase of the current drawn from the supply. **(1)**

c. The factory is enlarged and the following loads are added:

- Heating ovens with a total rating of 50kW (assume these are purely resistive)
- A motor load of 100kVA at 0.75 power factor lagging

(i) Calculate the new kVA rating of the factory. **(5)**

(ii) Calculate the new overall power factor and state whether it is lagging or leading. **(1)**

d It is decided to use a capacitor to correct the power-factor of the enlarged factory (original factory + additional loads) to 0.96 lagging.

(i) Draw a diagram to show where you would connect the capacitor. **(1)**

(ii) Find kVAr rating of the capacitor, the magnitude of the current drawn by the capacitor, and the value of the capacitor in Farads. **(4)**

(iii) What is the peak voltage the capacitor must withstand under normal operating conditions? **(1)**

3.

a. For the network shown in Figure 3.1, find the value of the current through the 10Ω resistance using the method of superposition. Indicate the direction of the current. **(6)**

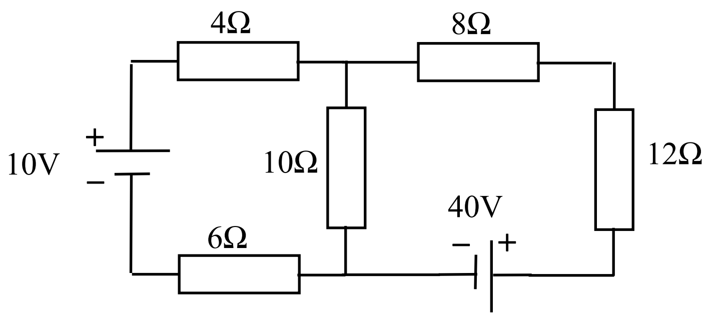


Figure 3.1

b. The network of Figure 3.1 is to be used as a source for a load resistor of 20Ω, as shown in Figure 3.2. Derive the Thevenin equivalent circuit for the source and hence calculate the power dissipated in the load resistor. **(6)**

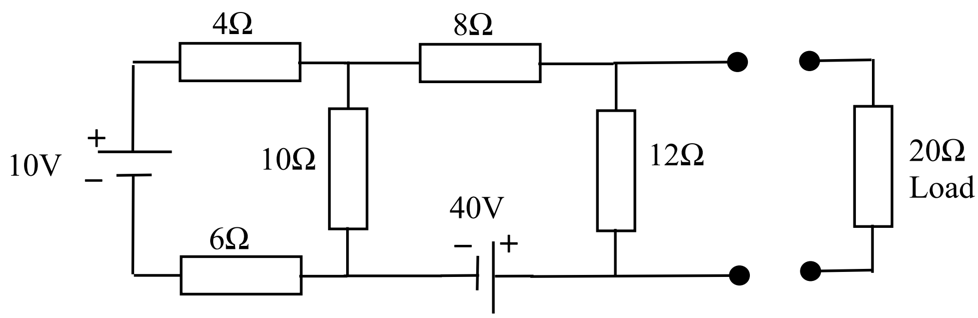


Figure 3.2

c. Calculate the Norton equivalent circuit for the source network shown in Figure 3.2 (i.e. not including the load resistor). **(3)**

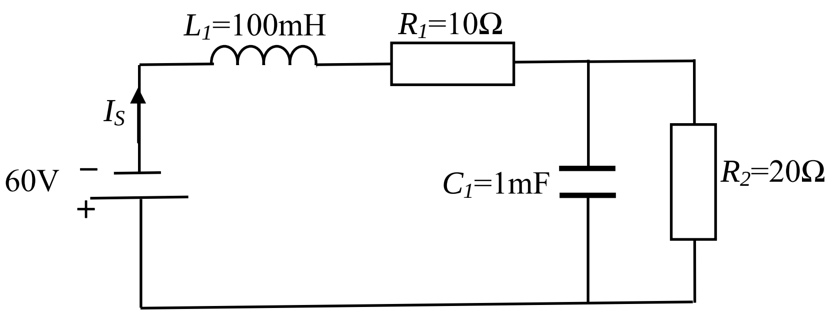


Figure 3.3

d. The network shown in Figure 3.3 has been connected for some time and has reached steady-state. Calculate:

(i) The current I_S **(2)**

(ii) The energy stored in L_1 and C_1 **(2)**

(iii) The total power dissipated in the circuit **(1)**

4. Figure 4.1 shows a BJT transistor which is used as a switch to control a lamp, which can be regarded as a pure resistive load. The transistor has a static current gain h_{fe} of 125.

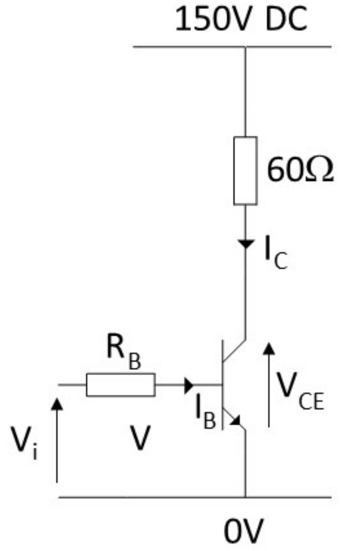


Figure 4.1 BJT transistor switching circuit

a. For the case of the transistor being switched on and hence conducting current, calculate the load current and load power (you may assume that the voltage across the transistor (V_{ce}) in the 'on' state is << DC supply voltage). **(4)**

b. Assuming that a typical value of the base-emitter voltage for a BJT (V_{BE}) is 0.7V, calculate the maximum value of the base resistor R_B which could be used to ensure that the switch is fully turned when supplied with an input voltage (V_i) of 5V. **(6)**

c. Comment on why a smaller value of resistor than that calculated in part (b) might be adopted in practice. **(2)**

d. When the BJT transistor in Figure 4.1 is fully turned on and conducting the load current calculated in part (a), the voltage across the device (V_{ce}) is 1.15V. Calculate the power loss in the BJT transistor for this operating condition. **(3)**

e. In order to reduce the power loss in the switch, the manufacturer plans to replace the BJT transistor with a MOSFET transistor. Calculate the maximum allowable value of the on-state resistance of this MOSFET in order for it to demonstrate an efficiency benefit over the BJT option. **(3)**

f. List another benefit of using a MOSFET as the switch element. **(2)**

5.

a. Using appropriate calculations, determine whether the diode D1 in Figure 5.1 is conducting current. **(7)**

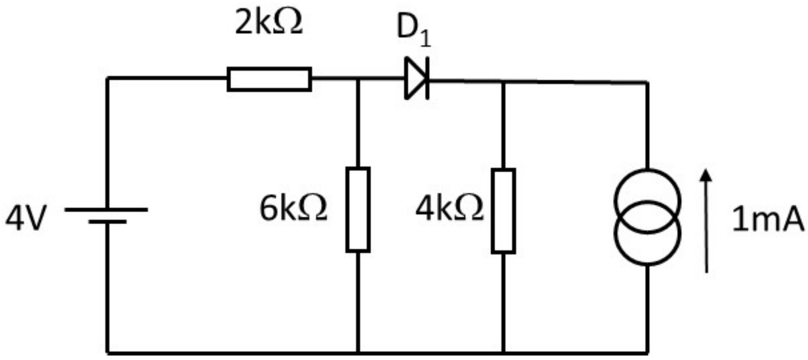


Figure 5.1 DC circuit containing diode D1

Figure 5.2 shows a full-wave bridge rectifier connected to a 40Ω resistive load. The rectifier is supplied by a 115Vrms, 400Hz sinusoidal AC supply from a small aircraft auxiliary supply generator.

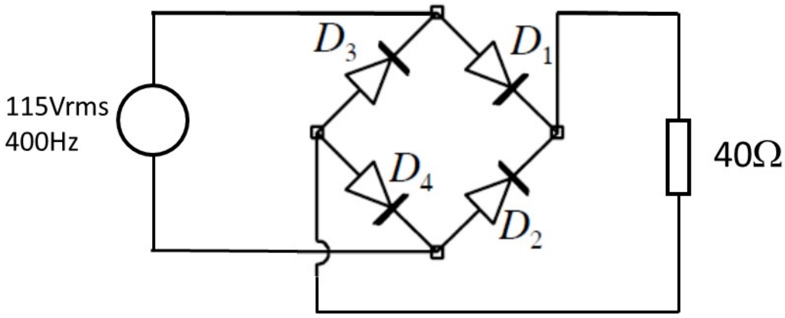


Figure 5.2 Full-wave bridge rectifier circuit

b. Calculate the average DC voltage applied to the load. **(3)**

c. Calculate average power delivered to the load. **(3)**

d. In order to reduce the ripple voltage applied to the load, a capacitor is introduced between the rectifier and the load. Calculate the minimum value of capacitance which required to reduce the ripple voltage to <6V. **(4)**

e. In order to further reduce the ripple voltage and produce a regulated DC voltage output, a Zener diode regulator is added to the circuit. Draw a complete circuit diagram which includes the rectifier, the smoothing capacitor and Zener regulator, and discuss the role of the series resistor which forms part of the Zener regulator. **(3)**

6.

Figure 6.1 shows a circuit diagram of an inverting amplifier based on an op-amp (the power supply connections to the op-amp have been omitted).

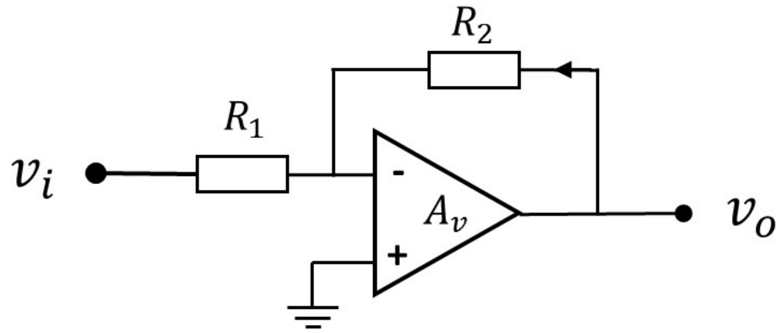


Figure 6.1 Inverting amplifier

a. Starting from the circuit diagram of Figure 6.1, derive an expression for the gain of the amplifier in terms of the circuit resistors. You may assume that the op-amp gain $\rightarrow \infty$. **(6)**

b. Calculate values of R_1 and R_2 to give an overall gain of -100 and an effective input impedance of 10kΩ. **(2)**

c. The input voltage v_i is produced by a source with an output impedance of 2kΩ. Calculate the change in the effective voltage gain between the source voltage and the inverting amplifier output which is introduced by this combination of source impedance and the inverting amplifier input impedance of 10kΩ. **(2)**

d. Suggest one means of overcoming the problem highlighted in part (c) which does not involve changing the values of resistor. Draw the additional circuit elements that would be introduced into the system. **(3)**

e. If the gain of the op-amp is in fact 5×10^4, calculate the effective gain of the inverting amplifier stage of Figure 6.1. **(3)**

f. The circuit of Figure 6.1 is to be modified to include another input voltage, v_2, with the overall amplifier output now given by:

$v_o = -(100v_i + 50v_2)$

Draw a circuit for this modified amplifier arrangement and calculate the value of any additional resistors introduced. **(4)**

KM/GWJ/MH

USEFUL EQUATIONS – EEE123

Electric Circuits

Resistance (*R*) – units Ohms (Ω)

Resistors in series $R_{TOT} = R_1 + R_2 + R_3 + \cdots R_n$

Resistors in parallel $\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \frac{1}{R_n}$

Resistance (Ohms law) $R = \frac{V}{I}$

Resistance $R = \frac{\rho l}{A} = \frac{l}{\sigma A}$

(*l=length, m; A = cross-sectional area, m^2; ρ = resistivity, Ω m; σ = conductivity, S/m)*

Temperature dependence of resistors $R_{T1} = R_0(1 + \alpha_0 T_1)$

α_0 = temperature coefficient of resistance
R_0 = Resistance (Ω) at 0°C
R_{T1} = Resistance (Ω) at T_1°C
T_1 = Temperature in °C
For temperatures T_1 and T_2 use ratio

$$\frac{R_{T1}}{R_{T2}} = \frac{(1 + \alpha_0 T_1)}{(1 + \alpha_0 T_2)}$$

Voltage across a resistor $V_R = IR$

Power dissipated in a resistor $P = I^2 R = \frac{V^2}{R} = V \cdot I$

Energy dissipated in a resistor $E = I^2 Rt = \frac{V^2 t}{R} = V \cdot I \cdot t$

Capacitance (*C*) – units Farads (F)

Charge (*Q*) $Q = I \cdot t$ (Constant current , I)

$Q = \int_0^t i(t)dt$ (Time varying current, $i(t)$)

$Q = CV$ (Capacitance × Voltage)

Capacitors in series $\frac{1}{C_{TOT}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \cdots \frac{1}{C_n}$

Capacitors in parallel $C_{TOT} = C_1 + C_2 + C_3 + \cdots C_n$

Voltage across a capacitor $V_c = \frac{Q}{C}$

Energy stored in a capacitor $E = \frac{1}{2} CV^2$

Inductance (*L*) – units Henrys (H)

Inductors in series $L_{TOT} = L_1 + L_2 + L_3 + \cdots L_n$

Inductors in parallel $\frac{1}{L_{TOT}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \cdots \frac{1}{L_n}$

Voltage across an inductor $V_L = L\frac{dI}{dt}$

Energy stored in an inductor $E = \frac{1}{2} LI^2$

A.C. Circuits

Power dissipated in a resistance $P = I_{rms}^2 R = \dfrac{V_{rms}^2}{R}$

For other circuits having capacitance and/or inductance, there is a phase shift, ϕ, between the current and voltage waveforms.

Real Power (*P*) (*Watts*) $P = V_{rms} I_{rms} \times \cos\phi$

Reactive Power (*Q*) (*VARs*) $Q = V_{rms} I_{rms} \times \sin\phi$

Power factor (p.f. or cos ϕ) $0 < \cos\phi < 1$

Power = Energy s^{-1} $Watts(W) = Js^{-1}$

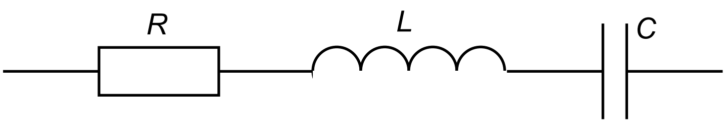
Capacitive reactance $X_C = \dfrac{1}{j\omega C} = \dfrac{1}{j2\pi f C} = \dfrac{-j}{\omega C} = \dfrac{-j}{2\pi f C}$

(ω = electrical frequency in rad/s (= $2\pi f$); f is the electrical frequency in Hz)

Inductive reactance $X_L = j\omega L = 2\pi f L$

(ω = electrical frequency in rad/s (= $2\pi f$); f is the electrical frequency in Hz)

Series Resonant Circuit

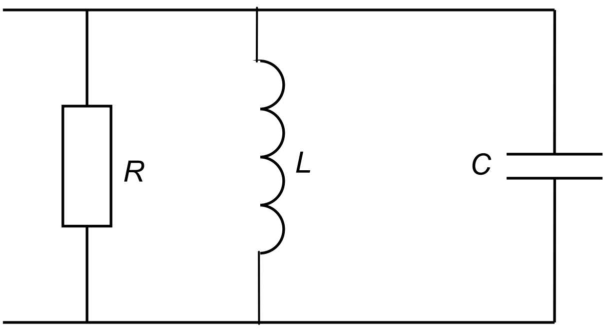


At resonance $X_C = X_L$ and $Z = R$

Frequency for resonance $\omega_r = \dfrac{1}{\sqrt{LC}}$ or $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

Q factor $Q = \dfrac{\omega_r L}{R} = \dfrac{1}{\omega_r CR} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$

Parallel Resonant Circuit



At resonance $X_C = X_L$ and $Z = R$

Frequency for resonance $\omega_r = \dfrac{1}{\sqrt{LC}}$ or $f_r = \dfrac{1}{2\pi\sqrt{LC}}$

Q factor $Q = \dfrac{R}{\omega_r L} = \omega_r CR = R\sqrt{\dfrac{C}{L}}$

Transient Circuits

Current growth in an inductive circuit containing inductance and resistance:

Instantaneous current $i = I_0(1-e^{-t/\tau})$ where $\tau = L/R$

Current decay in an inductive circuit containing inductance and resistance:

Instantaneous current $i = I_0 e^{-t/\tau}$ where $\tau = L/R$

Charging a capacitor through a resistor:

Instantaneous voltage $v = V_0(1-e^{-t/\tau})$ where $\tau = RC$

Instantaneous current $i = I_0 e^{-t/\tau}$ where $\tau = RC$

Disharging a capacitor through a resistor:

Instantaneous voltage $v = V_0 e^{-t/\tau}$ where $\tau = RC$

Instantaneous current $i = -I_0 e^{-t/\tau}$ where $\tau = RC$

Magnetic Circuits

Reluctance (S) – units H^{-1} $S = \dfrac{l}{\mu_0 \mu_r A}$

(*l=length, m; A = cross-sectional area, m^2; μ_0 = permeability of free space (Hm^{-1}); μ_r = relative permeability)*

Inductance (L) $L = \dfrac{N^2}{S}$

(*N = number of turns on the coil*)

Flux density (B) – units Tesla (T) $B = \mu_0 \mu_r H = \dfrac{\phi}{A}$

(H = magnetic field strength(A/m); φ = flux (Wb))

MagnetoMotive Force – MMF $F = H \cdot l = N \cdot I = \phi S$

Induced EMF (E) – units Volts (V) $E = N \dfrac{d\phi}{dt}$

Transformers (ideal)

Voltage ratio $\dfrac{V_{in}}{V_{out}} = \dfrac{N_1}{N_2} = turns \quad ratio$

Current ratio $\dfrac{I_{in}}{I_{out}} = \dfrac{N_2}{N_1} = \dfrac{1}{turns \quad ratio}$

Impedance ratio $\dfrac{Z_{in}}{Z_{out}} = \left(\dfrac{N_1}{N_2}\right)^2 = (turns \quad ratio)^2$

V_{in} = voltage across primary winding; *I_{in} = current through primary winding;*

V_{out} = voltage across secondary winding; *I_{out} = current through secondary winding;*

Induced voltage $V_{rms} = 4.44f \cdot N \cdot \phi_{max}$

(ϕ_{MAX} = maximum flux in the transformer core (Wb); f = frequency (Hz))

Mechanics

Mechanical Power (W) $P_{mech} = \omega_{mech} \cdot T$

(T = torque (Nm); ω_{mech} = rotational speed (rad/s))

Rotational speed (rad/s) $\omega_{mech} = \frac{2\pi}{60} \cdot n$

(n = speed in revs per minute)

Torque $T = F \cdot r$

(F = force(Nm); r = radius (m))

Gearbox (no losses) $\omega_{in} T_{in} = \omega_{out} T_{out}$

DC motors

Force on a current carrying conductor $F = B \cdot I \cdot l$

(B = flux density (T); I = current (A); l = length (m))

DC motor armature voltage $V_A = E_A + I_A R_A$

(E_A = induced emf (V); I_A = armature current (A); R_A = armature resistance (Ω))

Induced voltage, E_A is proportional to the speed of rotation, ω (rad/s), and the flux, ϕ (Wb).
Torque, T is proportional to the armature current, I (A) and the flux, ϕ (Wb).

For a wound field machine:

Induced emf (V) $E_A = K I_F \omega$

Torque (Nm) $T = K I_F I_A$

(I_F = field current (A); K = constant)

For a permanent magnet machine:

Induced emf (V) $E_A = K_E \cdot \omega$

Torque (Nm) $T = K_T \cdot I_A$

(K_E (V/rad/s) and K_T (Nm/A) are constants with the same numerical values)

Electronic Circuits

$$g_m = \frac{eI_C}{kT} \qquad r_{be} = \frac{\beta}{g_m} \qquad h_{FE} = \frac{I_C}{I_B} \qquad \beta = \frac{\Delta I_C}{\Delta I_B} = \frac{i_c}{i_b} \qquad \tau = RC$$

$$I = C\frac{dV}{dt} \qquad \omega = 2\pi f \qquad V(t) = \left(V_{START} - V_{FINISH}\right)\exp\left(\frac{-t}{\tau}\right) + V_{FINISH}$$

$V_{AVE} = \frac{V_P}{\pi}$ for a half-wave rectified sinusoid $\qquad V_{rms} = \frac{V_P}{\sqrt{2}}$ for a sinusoid

$$v_0 = A_v\left(v^+ - v^-\right) \qquad \frac{kT}{e} = 0.026\,\mathrm{V}$$

All the symbols have their usual meanings

Standard Unit Multipliers

$p = \times 10^{-12},\ n = \times 10^{-9},\ \mu = \times 10^{-6},\ m = \times 10^{-3},\ k = \times 10^{3},\ M = \times 10^{6},\ G = \times 10^{9}$