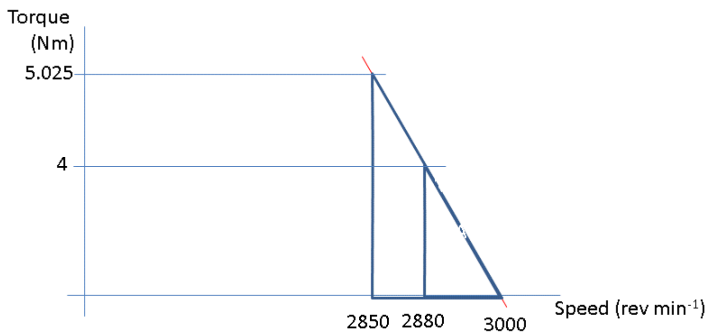
SECTION A
Answer ALL the questions

1. Various ways to tackle of which the easiest is to assume formula for potential divider: $V_A = 10\times118/(118+119) = 4.979$ V [2], $V_B = 10\times120/(122+120) = 4.959$ V [2], $V_{AB}= V_A – V_B=4.979-4.959 = 0.02$V [1]

   Alternative method: $I_A = 10/(118+119)=0.042$A [1] so $V_A = 0.042\times118=4.979$ V [1] etc.

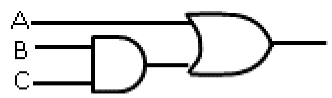
2. MMF = NI = 1000×2 = 2000 A turns [2]
   $H = NI/l = 1000\times2/0.005 = 4\times10^5$ A m^{-1} [2]
   $B=\mu_0\mu_rH = 4\pi\times10^{-7}\times1\times4\times10^5 = 0.5$ T [2]
   $F = B^2A/(2\mu_0)=0.5^2\times200\times10^{-6}/(2\times4\pi\times10^{-7}) = 19.9$ N [2]

3. Synchronous speed at 50 Hz must be 3000, 1500, 1000, 750… nearest above rated speed is 3000 rev min^{-1} [2]
   Similar triangles: Running speed at 4 Nm = 3000 – (3000–2850)$\times$4/5.025=2880 rev min^{-1}



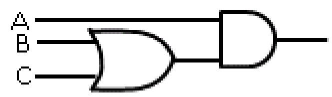
4.

(a) A.A + A.C + B.A + B.C = A +

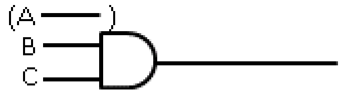


B.C

(b) A(B+C)



(c) A.B.C + B.C = B.C



5. $Log_2(15/0.001) = 13.8$ bits [2] which in practice means 14 bits [1]. Accept alternative trial and error approach by which 2^{14} is found to be just more than 15000.

6. It is the current gain, or the ratio of collector current to base current. [2] It is obtained by varying base current, measuring the resulting collector current [1], and finding the slope of the resulting graph of collector current vs. base current [1].

SECTION B
Answer ONE question

7. (a) Expect a description based on that given in notes, mark allocation is guideline only:
   - Squirrel-cage rotor consists of two rings joined by conductors so that structure forms a grid of closed loops of conductors. [1]
   - Encased in iron (actually iron laminations) – didn't really explain why [1]
   - Shaft is attached to cage [1]
   - Relative movement between field and cage induces emf [1] which causes current to flow around shorted-out loop [1]
   - Current flowing in field causes force on conductor [2]
   - Force results in torque on shaft when there is relative movement between field and cage [1] which drags cage around [1] providing torque to shaft [1].

(b) (i) p = pairs of poles = 4/2 = 2 so $n_s = 60f/p = 60\times50/2 = 1500$ rev min^{-1}

(ii) $V_P = V_L/\sqrt{3} = 400/\sqrt{3} = 230.9$ V

(iii) s = (1500-1445)/1500 = 0.0367 [2]

a = 4/20 = 0.2 [2]

$$T = \frac{3p}{2\pi f} \times \frac{V^2 as}{X_R(a^2+s^2)} = \frac{3\times2}{2\pi\times50} \times \frac{230.9^2\times0.2\times0.0367}{20(0.2^2+0.0367^2)} \quad [4]$$
$$= 9.06 \text{ Nm}$$

Power = Tω = 9.06×1445×2π/60=1371 W [2]

(c) (i) $\phi = -\cos^{-1} 0.7 = -45.6°$ [1 for angle, 1 for sign]

Hence the current is 3.8 A $\angle -45.6°$ [1] = 2.66–j2.71 A [2]

(ii) $I_P = I_{motor} + j2\pi fCV_P$ = 2.66–j2.71 + j2π×50×30×10^{-6}×230 [2]
= 2.66–j0.54 A [1] = 2.71A $\angle -11.5°$[2]. (3.8–2.71)/3.8 = 28.7% [1]

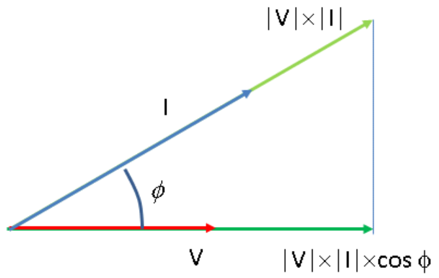
8. (a) $V_P = V_L/\sqrt{3} = 415/\sqrt{3} = 239.6$ V [3 marks]

(b) $Z = R+jX_L = R+j2\pi fL = 20 + j2\pi\times50\times100\times10^{-3}$ [2] $= 20+ j31.4\ \Omega$ [1] $= 37.24\Omega\ \angle57.5°$ [3]

(c) $I = V/Z$ [1] $= 239.6/(37.24\ \angle57.5°)$ [3] $= 6.43$ A $\angle-57.5°$ [3]

(d) Power per phase
$= |V_P|\ |I_P| \cos\phi$ [1] $= 239.6 \times 6.43 \times \cos(-57.5°)$ [2] $= 827.7$ W [2]
Total power $= 3 \times 827.2 = 2483.3$ W [2]

(e) Apparent power for a single phase system is $|V|\times|I|$ [1] in VA [1]; it is a measure of the capacity required (in terms of supply voltage and current capability) of the power supply[1]. Active power is $|V|\times|I|\times\cos\phi$ [1] in watts [1]; it is the electrical power drawn from the supply [1]. Unless the power factor $\cos\phi$ is 1, the active power is less than the apparent power because the voltage and current are out of phase, with power being drawn for some of the cycle and a small amount of power being returned to the supply during other parts of the cycle [2]. [2 marks for a fair attempt at a phasor diagram, or a diagram showing power being drawn and returned over each cycle].



Note: no marks for mentioning beer glass, beer and head!

(f) Houses are typically connected between neutral and successive phases e.g.first house to phase 1, second to phase 2, third to phase 3, fourth to phase 1 etc. [1] So if one phase (only) suffers an outage, only around a third of the houses will be affected. [1] (IN practice of course there might be some voltage change to imperfect balancing of the load but this is not sought here).

Turn over

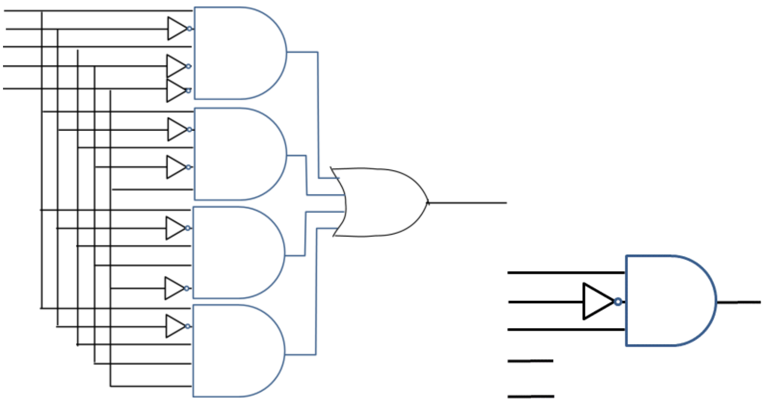
SECTION C
Answer ONE question

9. (a)

J1	K1	Q1	notQ1	J2	K2	Q2	notQ2
		1	0			1	0
1	0			1	1		
		1	0			0	1
0	1			1	1		
		0	1			1	0
1	0			0	0		
		1	0			1	0
1	0			1	1		
		1	0			0	1
0	1			1	1		
		0	1			1	0
1	0			0	0		
		1	0			1	0
1	0			1	1		

[11 marks: 3 for setting up valid table with numerous errors, 6 for some correct rows, 11 for all correct]

(b) Two solutions: one rather "pedestrian" which will work but is non-optimal; other relies on students noting that there are two "don't care" lines so only one gate is needed. Either will score full marks, even though second is very easy marks.



[6 marks]

(c)

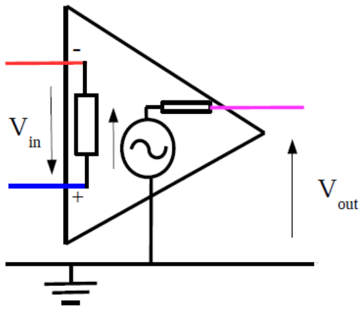
(i) B: NPN bipolar junction transistor (BJT) [2]
C: PNP BJT [2]
D: N-channel MOSFET [2]
E: diode [1]

(ii) The gate is separated by a very thin oxide layer from the rest of the device; this arrangement acts as a capacitor [2], making it difficult to change the gate voltage rapidly as this "capacitor" needs to be charged and discharged[1]

(iii) They connect the gate either to the supply or to ground with minimum of resistance [2], allowing it to be charged and discharged quickly [2]. This configuration is known as a push-pull pair [2].

(iv) E is a diode (known as a flyback or freewheeling diode) which allows the current to continue circulating through the actuator after the MOSFET has ceased conducting [2]. It prevents an “inductive spike” from damaging the MOSFET. [1]

10. (a)

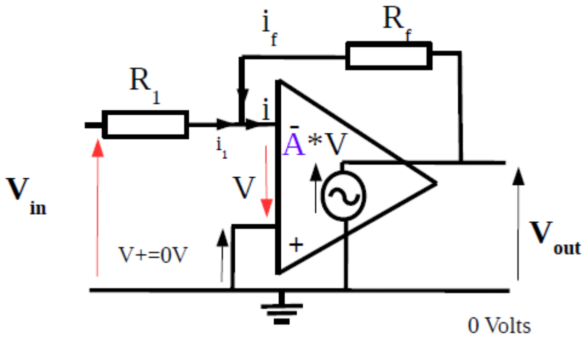


[3]

$V_{out} = A\,V_{in} = A\,(V^+ - V^-)$ where A is the open-loop gain of the op-amp. [2]

Simplifying assumptions: Input impedance infinite [1], output impedance zero [1], gain infinite [1]

(b) Infinite impedance so $i_1 = -i_f$



$V_{in} = i_1 R_1 - V$

V is an unknown so let's get rid of it with $V_{out}=AV$.

$V_{in} = i_1 R_1 - V_{out}/A$

$V_{out} = A(i_1 R_1 - V_{in})$

$V_{out} = i_f R_f - V = i_f R_f - V_{out}/A$

Infinite impedance so $i_f = -i_1$

$V_{out} = -i_1 R_f - V_{out}/A$

$V_{out} + V_{out}/A = -i_1 R_f$

$V_{out}\,(1+A) = -i_1 R_f A$

$i_1 = -V_{out}\,(1+A)/\,(R_f A)$

Insert into $V_{in} = i_1 R_1 - V_{out}/A$

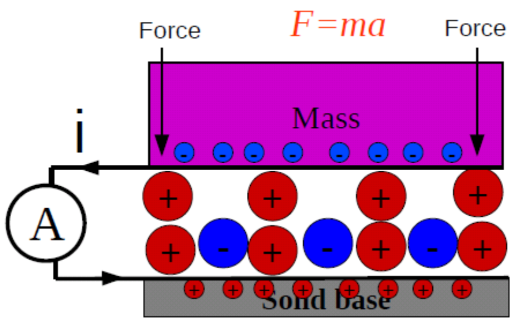
$V_{in} = -V_{out}\,R_1(1+A)/(R_f A) - V_{out}/A = -V_{out}\,(R_1(1+A)+R_f)/(R_f A)$

$V_{out}/V_{in} = -R_f A\,/(R_1(1+A)+R_f)$

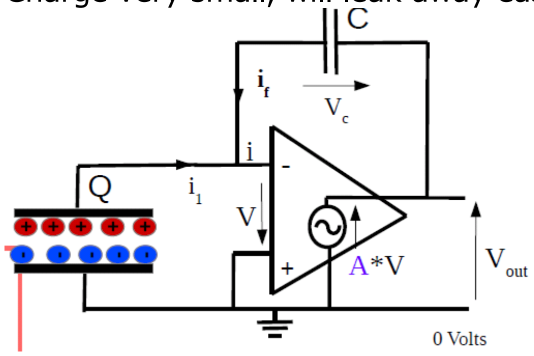
If A>>1, $V_{out}/V_{in} = -R_f/R_1$

[10 for a valid derivation]

(c) Mass mounted on piezoelectric crystal:



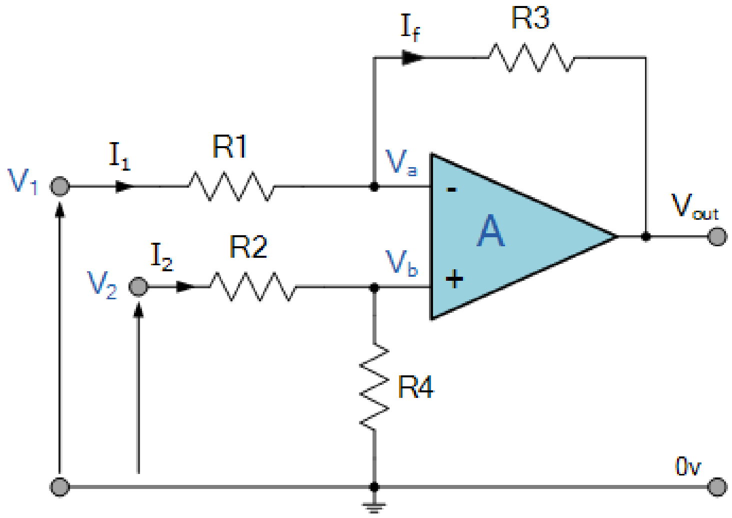
Force ∝ acceleration
Piezoelectric crystal has charged atoms which rearrange under force and cause charge to appear across faces:
Charge ∝ force
Charge very small, will leak away easily, can't measure directly.



Using an integrating circuit, V_{out} is proportional to charge and hence proportional to acceleration.

[10 marks]

(d) Full marks for an argument which covers the following main points in a way which exhibits understanding, not necessarily via the scheme given:
This circuit amplifies the voltage (PD) across the Wheatstone bridge [1], which is very small [1], requiring a differential amplifer i.e. one which amplifies the potential difference between two inputs [1]. This is because neither of the inputs is at earth potential so a simple amplifier will not be sufficient [1].
Formula is
$V_{out} = R_3(V_2 - V_1)/R_1$ when $R_1=R_2$ and $R_3=R_4$ [3]



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