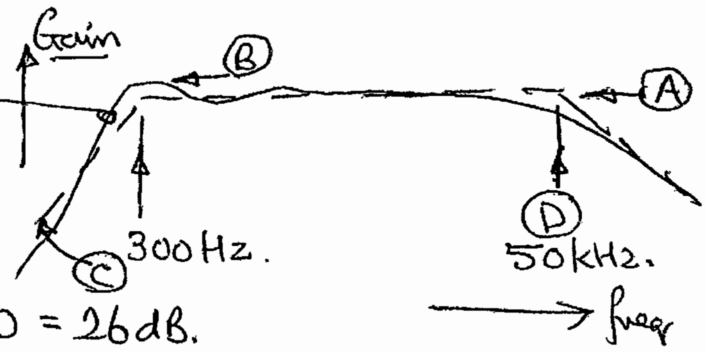
2008 IIB 4B8 ELECTRONIC SYSTEM DESIGN

Q1. Gain against freq response shown on left. Dotted is the straight line approximation, & note



(A) Gain in passband = $20\log_{10}20 = 26$dB.

(B) Chebyshev "ripple" will give +1dB or 27 dB gain at ~ 300 Hz

(C) With ω_0^2 in formulae, Attenuation of ÷100 for ~~frequencies~~ each decade of frequency ~~change~~ reduction below ω_0. as $\text{Gain} = -20\Big/\left(1 + 1.1\frac{\omega_0^2}{(j\omega)^2} + \frac{1.1\,\omega_0}{j\omega}\right)$

When ω = small so $\frac{\omega_0}{\omega}$ is large & $\gg 1$.

(D) At high frequency, the gain of 20 in the passband will be limited at f_2 where $20f_2 = 10^6$ — so $f_2 = 50$kHz

— || —

When $\omega = \omega_0$, $\text{Gain} = -20/(1 - 1.1 - 1.1j) = \frac{-20}{-0.1 - 1.1j}$

$$= \frac{20}{\sqrt{0.1^2 + 1.1^2}}\angle\phi \quad \text{or} \quad \left|\frac{20}{1.104}\right|$$

This is NOT $20/\sqrt{2}$ which would be the half power condition for simple Butterworth response at turnover. The "Ripple" in the passband causes "this increase" — as shown.

Compare formulae: $\frac{-20s^2}{s^2 + 1.1s\omega_0 + 1.1\omega_0^2} = \frac{-Y_1Y_3}{Y_5(\quad) + Y_3Y_4}$

We ONLY get the s^2 term in numerator if ~~$Y_1 = Y_3$ capa~~

$Y_1 = j\omega C_1$ or sC_1
$Y_3 = j\omega C_3$ or sC_3 } ie both Capacitative

With Y_3 a capacitor, we ONLY get a real term in denominator with Y_5 (a resistor) $= 1/R_5$. so real.

Then $Y_4 = j\omega C_4$ or sC_4 to get the s^2 term in Denominator and this leaves

Y_2 = a resistor to get the real term (from $Y_2 Y_5$)

$$\text{So Gain} = -sC_1 . sC_3 \Big/ \left\{ \frac{1}{R_5}\left(sC_1 + \frac{1}{R_2} + sC_3 + sC_4\right) + s^2 C_3 C_4 \right\}$$

To get the desired expression with s^2 in denominator, divide all terms by $C_3 C_4$ to get

$$\text{Gain} = -s^2 (C_1/C_4) \Big/ \left\{ \frac{1}{R_5 R_2 C_3 C_4} + s\frac{(C_1 + C_3 + C_4)}{R_5 C_3 C_4} + s^2 \right\}$$

so Numerator terms give. $20 = C_1/C_4$ —— (a)

Denominator s term : $1.1\omega_0 = (C_1 + C_3 + C_4)/R_5 C_3 C_4$ —— (b)

" Real term : $1.1\omega_0^2 = 1/R_5 R_2 C_3 C_4$ —— (c).

—— " ——

Clearly R_5 is $10^5 \Omega$ and C_1 is 200nF. ←

Equation (a) :- $20 = 200\text{nF}/C_4$ - so $C_4 = 10\text{nF}$ ←

Equation (b) :- $$1.1 . 2\pi . 300 = \frac{(200 + C_3' + 10) . 10^{-9}}{10^5 . C_3' . 10^{-9} . 10 \times 10^{-9}}$$

where C_3' is in nF.

This gives $2.073\, C_3' = 210 + C_3'$ or $C_3' = 195.6\text{nF}$ ←

Equation (c) gives

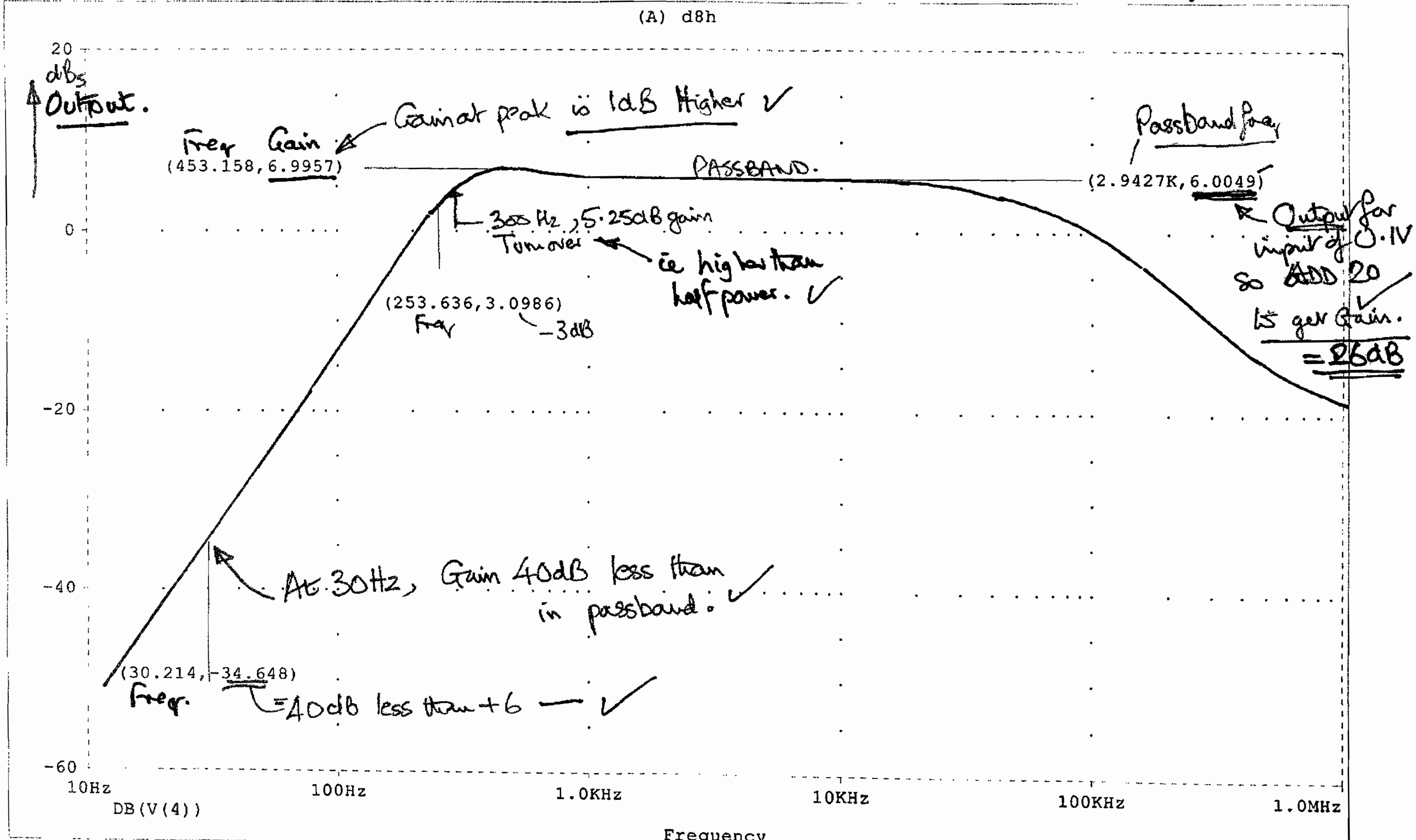
$$1.1(2\pi \times 300)^2 = 1/10^5 . R_2 . 195.6 \times 10 \times 10^{-18}$$

so $R_2 = 1308\,\Omega$. ←

Values put into a PSpice circuit and values checked to give Gain & turnover correctly.

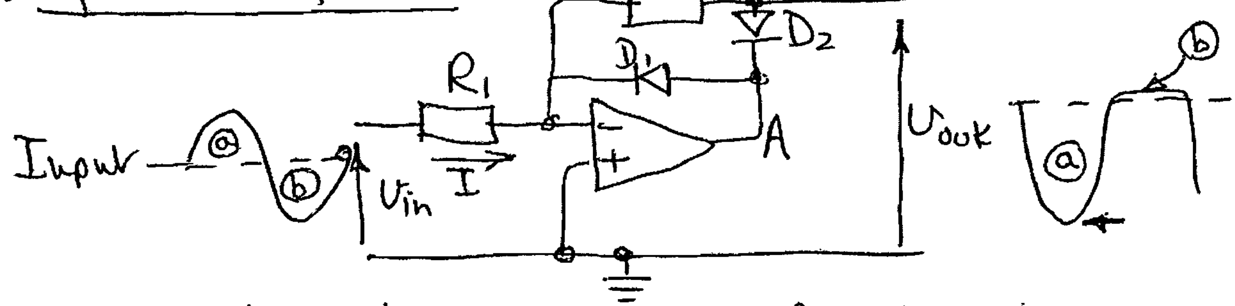
* C:\Documents and Settings\Toshiba\My Documents\Pspice\d8h.sch

Date/Time run: 01/08/108 17:17:55 Temperature: 27.0



Date: January 08, 2008 Page 1 Time: 17:30:30

Q2. Half Wave Rectifier Circuit



ⓐ For ⊕ half cycle of input, current I flows into (−) input of op amp (inverting), making the output at A to swing negative (below the no signal voltage. Hence D_1 is off & draws leakage I_{off} and D_2 is ON and drops its forward voltage E_{on}.

So current $I = \frac{V_{in}}{R_1}$ & it flows on in R_2 but D_1 passes I_{off}

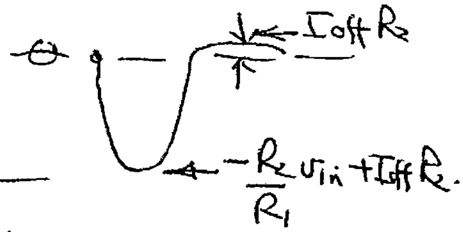
So current in $R_2 = I - I_{off} = V_{in}/R_1 - I_{off}$.

And Output $= V_o = -\frac{R_2}{R_1} \cdot V_{in} + I_{off} \cdot R_2$ ← Error.

ⓑ For ⊖ half cycle of input, current I reverses making A tend to swing ⊕ causing D_1 to be ON and D_2 OFF (½ v drop and drawing I_{off} leakage respectively). Now V_{OUT} will be defined by the current I_{off} flowing in R_2 and, as the (−) input to the op amp is a virtual earth.

V_o is $+ I_{off} R_2$

and waveform is



———— || ————

(i) Now input resistance desired is 40KΩ

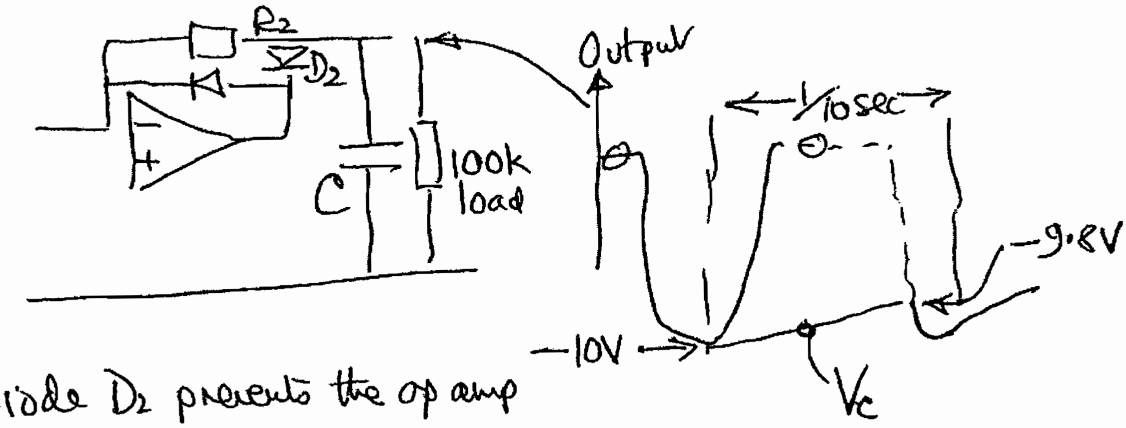
so $40k\Omega = R_1$ for virtual earth amp

(ii) $\frac{\text{Maximum Output}}{\text{Peak input}} = \frac{-10}{+1} = -\frac{R_2}{R_1}$ gives $400K = R_2$.

(iii) Error $= I_{off} R_2 = 10^{-4} \times 10$ gives $I_{off} = 2.5 \times 10^{-9}$ or 2.5 nA.

(So some care needed in selecting diode so that even at a reverse voltage of 10V, leakage is below this)

(iv)



Diode D_2 prevents the op amp discharging C so the negative potential V_c on the capacitor is as shown with an exponential discharge, the equation being

$$V_c = -10 e^{-t/CR'} = 9.8 \quad \left\{ \begin{array}{l} \text{ie 2\% less when} \\ t = \frac{1}{10}\text{s for 10Hz.} \end{array} \right.$$

So $0.98 = e^{-t/CR'}$

or $-t/CR = \ln 0.98 = -0.0202$

So $C = t/R' \times 0.0202$ where $R' = 400k // 100k$ $= 80k$ and $t = \frac{1}{10}$ s

$= 6.19 \times 10^{-5}$

or $62 \mu F$. or next size bigger (say $100 \mu F$).

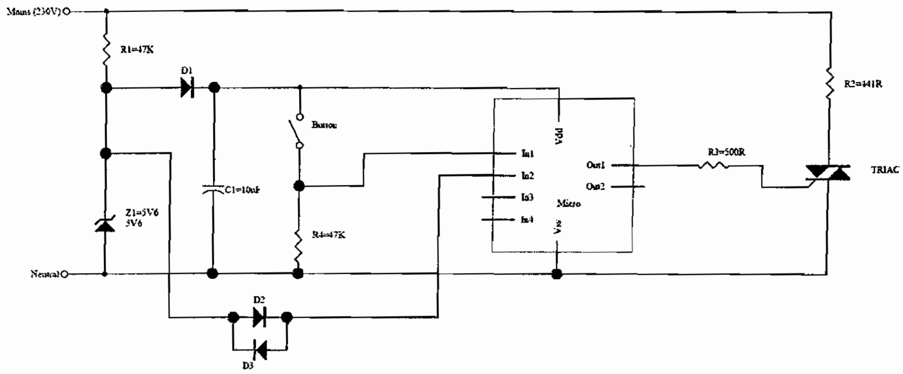
<u>Applications</u> (a) <u>Instrumentation</u> on <u>tape</u> recorders to show peak signal level on a meter so signal levels can be adjusted to avoid <u>saturation</u> or <u>for ALARMS</u>

(b) General display of ac amplitudes as DC meters and A→D converters are usually unipolar.

3. a)

	Harvard	Von Neumann	Marks
Memory	Program and data have separate memory maps.	Program and data shares same memory space	5%
Errors	No instruction/data mixups	Data can be erroneously read as an instruction and vice versa	5%
Bottleneck	Bottleneck as instructions and data share the same bus	Separate buses for instructions and data means no bottlenect	5%

b)



[10%] for power supply for microcontroller. Choose Z1=5.6V to give a 5V Vdd after D1. At worst case, this circuit must deliver 2.4mA (=2mA for triac+0.4mA for micro). Since it is a half wave rectifier, assume we need 4.8mA to supply enough current through R1 to power the micro+triac combo.
So $R_1 = V/I = (230-5.6)/4.8mA = 47K$

[10%] for triac, lamp ($R_2=V^2/R=230^2/120=441\Omega$) and calculation of the triac's drive resistor ($R_3=V/I=(5-2.5)/0.002=1250\Omega$).

[10%] for zero crossing circuit. At the 5V6 zener, we see a 'square wave' with 5.6V and -0.6V. The 2 diodes (D2 and D3) remove the 0.6V overvoltages, thus In2 essentially sees a 'square' wave of peak voltages of 5V and 0V. Acceptable variations is to use separate 5V1 Zener with a big resistor (eg. 560K).

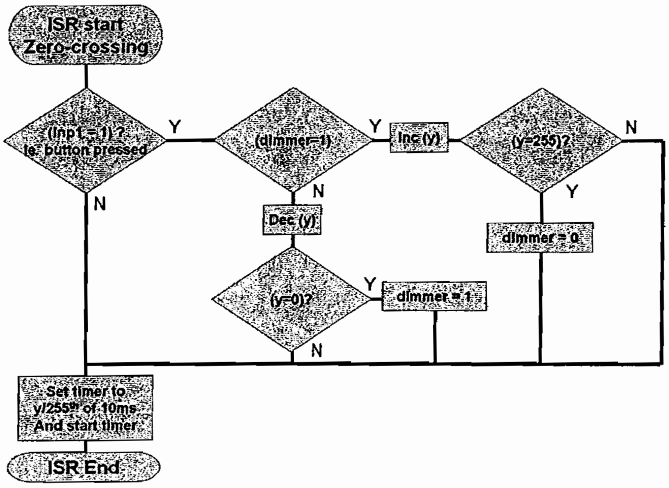
[10%] for button – check that R4 is reasonably large so as not to overload the power supply.

c) Two interrupt service routines are required.

In the below flow diagrams, two variables are used:

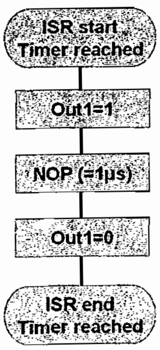
- y is fraction of 'delay' for firing the triac
- dimmer is to indicate whether user button is dimming (ie. increasing the delay) or brightening (ie. decreasing the delay)

Input interrupt set to interrupt on "change" of In2, which is the zero crossing. Hence, every 10ms, the following interrupt service routine (ISR) is executed:



[10%] for checking if the button is pressed
[10%] for increasing the delay (y) if it is dimming and vice versa
[10%] for correctly implementing the change in dimmer when y is 0 and 255.

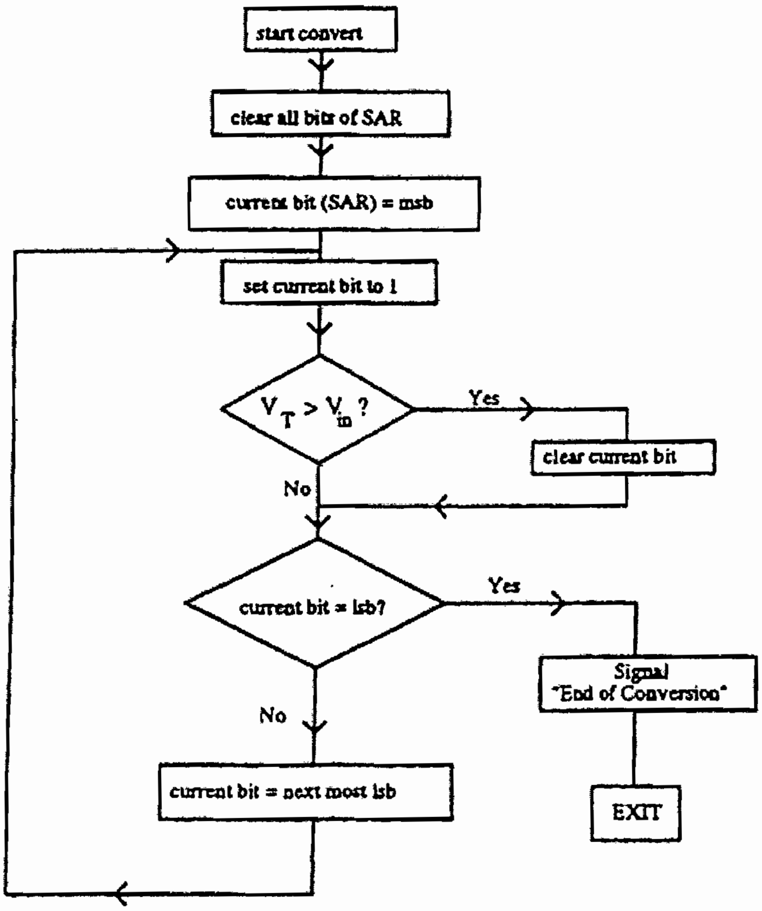
The timer interrupt is set to interrupt when the time (ie. the delay) is reached.



[15%] for generating the 1 μs pulse-hi on Out1.

Note that the CPU is clocked at 4MHz, and has 4 cycles per instruction. So the NOP essentially wastes 1 μs which is the min gate pulse required for the triac.

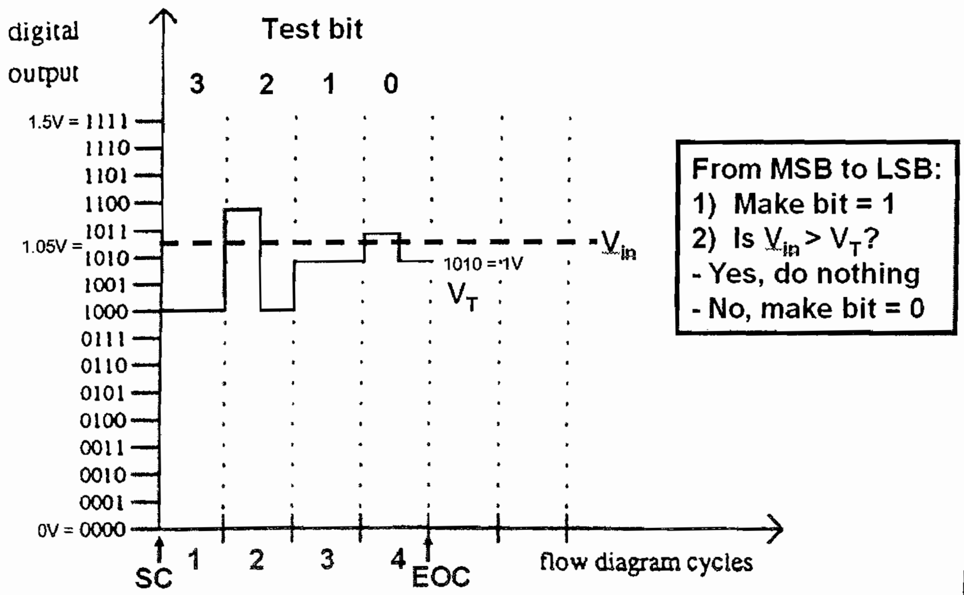
4. (a)



start convert
clear all bits of SAR
current bit (SAR) = msb
set current bit to 1
$V_T > V_{in}$?
Yes
clear current bit
No
current bit = lsb?
Yes
Signal "End of Conversion"
EXIT
No
current bit = next most lsb

[35%]

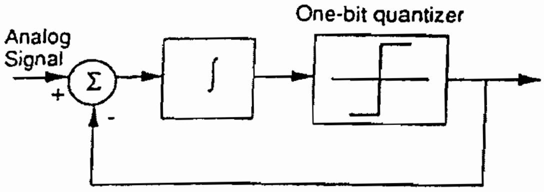
(b)



digital output
Test bit
3 2 1 0
1.5V = 1111
1110
1101
1100
1011
1.05V =
1010
1001
1000
0111
0110
0101
0100
0011
0010
0001
0V = 0000
V_{in}
1010 = 1V
V_T
From MSB to LSB:
1) Make bit = 1
2) Is $V_{in} > V_T$?
- Yes, do nothing
- No, make bit = 0
SC
1
2
3
4
EOC
flow diagram cycles

[30%]

(c)



[10%]

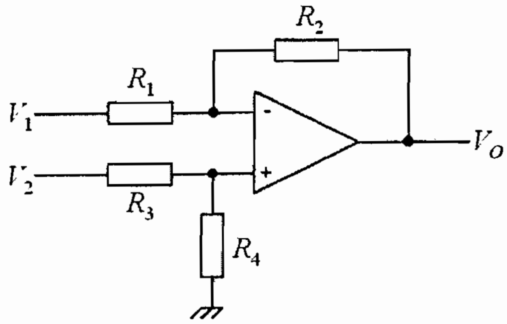
Subtractor	Integrator	Quantiser
=analog(t)-quantiser(t-1)	=subtractor(t)+integrator(t-1)	=level '1' if integrator > 0
		=level '0' if integrator < 0

Time	Input	Subtractor	Integrator	Quantiser
0	3	0	0	0
1	3	3	3	5
2	3	-2	1	5
3	3	-2	-1	0
4	3	3	2	5
5	3	-2	0	0

Bitstream (t=1 to 5) **1 1 0 1 0**

[25%]

5. (a)



$$V_+ = V_2\left(\frac{R_4}{R_3+R_4}\right) \qquad \text{(divider at } V_+\text{)}$$

$$V_O = V_-\left(\frac{R_1+R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right) \qquad \text{(KCL at } V_-\text{)}$$

Ideal op - amp, so $V_+ = V_-$, hence

$$V_O = V_2\left(\frac{R_4}{R_3+R_4}\right)\left(\frac{R_1+R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right)$$

[20%]

(b)

If R_1 = 1K, R3 = 1.01K (for 1% error)

R_2 = 100K (for nominal difference gain of 100 = R_2/R_1)

And $R_4 = R_2$ = 100K

$$V_O = V_2\left(\frac{R_4}{R_3+R_4}\right)\left(\frac{R_1+R_2}{R_1}\right) - V_1\left(\frac{R_2}{R_1}\right)$$

$$V_O = V_2\left(\frac{100}{1.01+100}\right)\left(\frac{1+100}{1}\right) - V_1\left(\frac{100}{1}\right)$$

$$V_O = 99.99V_2 - 100V_1$$

$$\therefore A_O = \frac{99.99+100}{2} = 99.995$$

$$\therefore A_{CM} = 100 - 99.99 = 0.01$$

$$\therefore CMRR = \frac{A_O}{A_{CM}} = 9999.5 \quad or \quad 80\,dB$$

[25%]

(c)
Offset current of 200nA flows through both R_2 and R_1, hence 'sees' $R_2//R_1$ = 0.99kΩ.
This generates an offset voltage of 0.99 kΩ x 200nA = 0.2 mV
Total offset voltage = 0.2mV + 0.8mV = 1mV

Quick answer (for 'clever' students who actually remember the lectures):
Error in output voltage = offset voltage x gain = 1mV x 100 = 100mV (full marks)

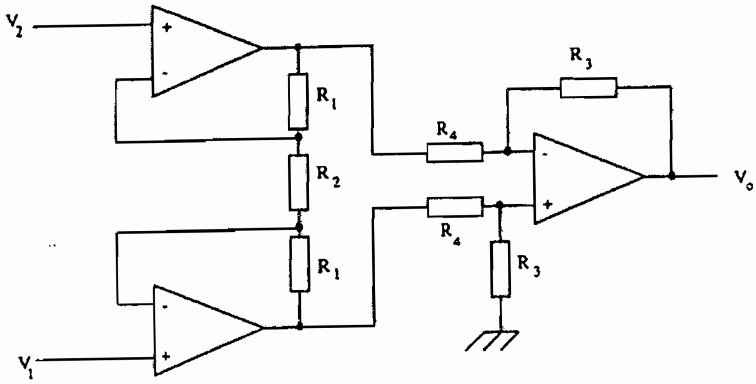
Alternatively, part (a) can be derived again (long answer)with the op-amp inputs as $V_+ = V_- + V_{offset}$ which gives:

$$V_O = (V_2 - V_1)\left(\frac{R_2}{R_1}\right) + V_{offset}\left(\frac{R_1 + R_2}{R_1}\right)$$

The second term is the error in the output voltage, which is = 1mV x 101 = 101mV

[25%]

(d) The differential amp circuit has low input impedance of 1kΩ, hence when connected to a source with higher impedance, the gain of the differential amp is reduced (since gain $= R_2/R_1$). This problem can be solved by using 2 op-amps in front such that the inputs are now of high impedance, for example, as buffers or as an instrumentation amplifier:



(e)
From datasheet, for G=100, CMRR(dc) = 120dB = 10^6
and CMRR(50kHz) = 70dB = 3162

$$\text{CMRR} = \frac{A_O}{A_{CM}}$$

$$A_{CM} = \frac{A_O}{CMRR}$$

$$V_{error} = V_{CM} \times A_{CM} = 2 \times \frac{100}{CMRR(f)}$$

$$= 0.2mV @ dc$$

$$= 63mV @ 50kHz$$

Ken Teo
Peter Spreadbury 2008