Question 1

Calibration is done as: $D = MV_o + B$

$$MV_o = D - B$$
$$V_o = \frac{1}{M} D - \frac{B}{M}$$

In this case $M = 1.67821 \ mm/V$

$$\frac{1}{M} = 0.59587 \ V/mm$$

$$B = -4.2131 \ mm$$

$$\frac{B}{M} = -2.51047 \ V$$
$$V_o = 0.59587 \ V/mm \ D + 2.51047 V$$

① Range:

DVRT $I_{MIN} = 0mm$
$I_{MAX} = 8mm$

DVRT $O_{MIN} = 0mm \times 1 \ V/mm = 0V$
$O_{MAX} = 8mm \times 1 \ V/mm = 8V$

DEMOD-DC $O_{MIN} = 0V$
$O_{MAX} = 5V$

2 Span:

DVRT Input: 8 mm
DVRT Output: 8V

DEMOD-DC output: 5V

3 Ideal Straight Line:

Ideally I'd have a straight line with the points

$$A(I_{MIN}, O_{MIN}) \Rightarrow A(0_{mm}, 0V)$$

$$B(I_{MAX}, O_{MAX}) \Rightarrow B(8mm, 5V)$$

$$V_o = mD + c$$

$$m = \frac{5V - 0V}{8mm - 0mm} = 0.625\ V/mm$$

$$0 = (0.625\ V/mm)(0) + C \qquad \therefore C = 0$$

$$\therefore V_{O_{IDEAL}} = 0.625\ V/mm\ D_{IDEAL}$$

4 Hysteresis

$$\text{Hysteresis \% FSD} = \frac{1\,\mu m}{8\,mm} \times 100\%$$

$$= 0.0125\%$$

5 Non-linearity

Accuracy $\pm 1\%$

~~Assuming non-linearity is negligible.~~

a) Table: Static Specifications of the System

Characteristic	Value
DVRT input range	-4mm to 4mm
DVRT output range	0.126994V to 4.89395V
DEMOD-DC Saturation	0V to 5V
DVRT input span	8mm
DVRT output span	8V
DEMOD-DC output span	5V
DVRT temperature range	$-55°C$ to $175°C$
System temperature range	$0°C$ to $40°C$
DEMOD-DC temperature range	$-40°C$ to $85°C$
DVRT Accuracy	$\pm 1\%$
DVRT Sensitivity	1 V/mm
DVRT Signal-to-noise (SNR)	4200
DVRT Resolution (% FSD)	0.025 %
Temperature Span	0.03% /°C
Temperature Offset	0.002% /°C
Hysteresis (% FSD)	0.0125%
System Characteristics	
Input Range	-4mm to 4mm
Output Range	0V to 5V

Input Span	8mm
Output Span	5V

b.) @ 40°C $\quad \Delta T = 40° - 22°C = 18°C$

Temperature Span Error $= (0.03\%/°C)\Delta T$
$= 0.54\%$

Temperature Offset Error $= (0.002\%/°C)\Delta T$
$= 0.036\%$

DVRT-Demod Accuracy $= 1\%$

SNR error $= 0.0238\%$

Hysteresis $= 0.0125\%$

Resolution Error $= \frac{0.025\%}{2} = 0.0125\%$

* The specifications and errors for the DVRT are given using the DEMOD-DC system so these errors are applied to the output of the system other than the error due to the resolution.

So the error in the input is given as

$$I_E(I) = I(1 + \underbrace{0.000125}_{\text{resolution}}) = I(1.000125)$$

Now the error in the system

$$V_o(I)\Big|_{T=40^\circ C} = \Big\{\Big(0.59587\,V/mm\,(1+\underbrace{0.0054}_{\text{temperature moderating}})\Big) I_E(I) + 2.51047V + 5V(\underbrace{0.00036}_{\text{Temperature interfering}})\Big\}\Big(1+\overset{\text{Accuracy}}{0.01}+\underset{\text{SNR}}{0.000238}+\overset{\text{Hysteresis}}{0.000125}\Big)$$

$\cancel{V_o(-4mm)\Big|_{T=40^\circ C} = 0.1168V}$ $E(-4mm) = \dfrac{V_o(-4mm)\Big|_{T=40^\circ C} - V_o(-4mm)}{V_o(-4mm)}$

NOT FULL SCALE (OPPOSITE)

$\cancel{= 8.024\%}$

$V_o(4mm)\Big|_{T=40^\circ C} = 4.9598V$ $E(4mm)\Big|_{T=40^\circ C} = \dfrac{V_o(4mm)\Big|_{T=40^\circ C} - V_o(4mm)}{V_o(4mm)}$

$= 1.346\%$ FSD

@ $0^\circ C$ $\Delta T = -22^\circ C$

Temperature span error $= (0.03\%/^\circ C)(-22^\circ C)$
$= -0.66\%$

Temperature offset error $= (0.002\%/^\circ C)(-22^\circ C)$
$= -0.044\%$

$$V_o(I)\Big|_{T=0^\circ C} = \Big\{\Big(0.59587\,V/mm\,(1-0.0066)\Big) I_E(I) + 2.51047V + 5V(-0.00036)\Big\}(1+0.01+0.000238+0.000125)$$

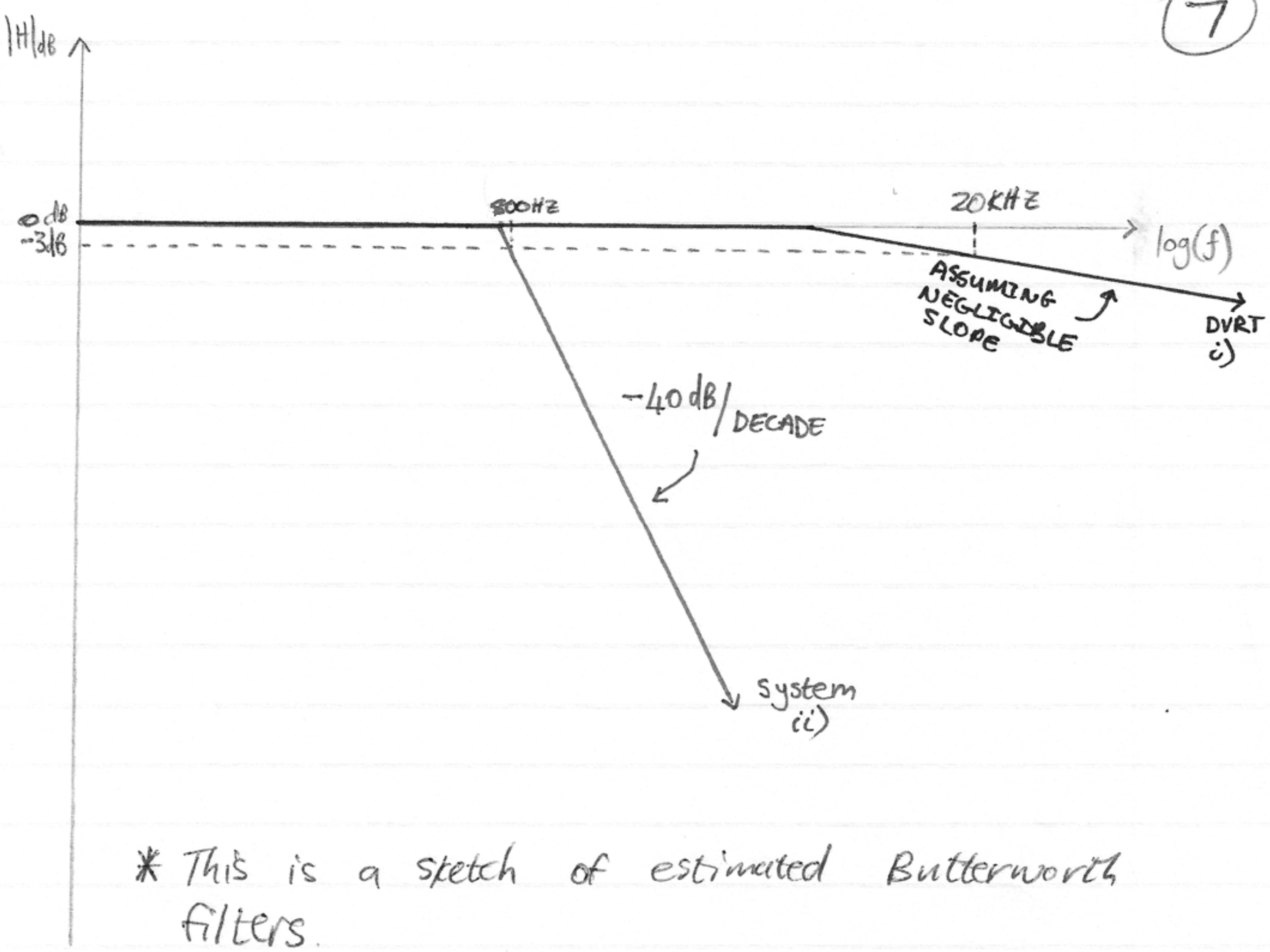
$V_o(4mm)\Big|_{T=0^\circ C} = 4.92725V$ $E(4mm)\Big|_{T=0^\circ C} = 0.6815\%$

Question 2

a) It seems that there is a conflict between the calibration results, the DVRT and the DEMOD-DC. The DVRT has a frequency response of 800 Hz, this can be interpreted in two ways: 1) After 800 Hz the magnitude of the transfer function starts to roll-off. 2) The sensor is guaranteed to work according to the spec sheet at frequencies lower than 800 Hz but this does not imply that it won't respond to frequencies higher than that.

I am going to go with the 2nd interpretation, in other words the sensor does not act as a low pass filter at 800 Hz instead I'm going to go with the worst case where the sensor does not attenuate the signal at all around the 800Hz frequency. I can argue this using the fact that a 20kHz sensor also exists so attenuation must only happen at much higher frequencies, so, let's assume the DVRT has a -3dB gain at 20kHz and even at this point let's assume it doesn't roll-off like a first order LPF.

i)
(i)



* This is a sketch of estimated Butterworth filters.

b) Assuming a Butterworth filter

$$|H| = \frac{1}{\sqrt{1 + \left(\frac{w}{w_c}\right)^{2n}}}$$

Butterworth transfer characteristic

I know it's a second order filter $\therefore n=2$

Also W_c @ 800Hz

$\therefore W_c = 2\pi(800)$
$= 1600\pi$

I need an aliasing error 0.1%

$$20\log(0.001) = -60dB$$

The 500Hz is insignificant because we're actually worried about the point where $|H|_{dB} = 20\log(0.001)$ *THIS IS ASSUMING @ 500Hz the system has a ≈ 0 dB gain

@ $f = 500\text{Hz}$
$\omega = 1000\pi$

$$|H(1000\pi)|_{dB} = -10\log\left(1 + \left(\frac{1000\pi}{1600\pi}\right)^4\right)$$

$$= -0.61674 \text{ dB}$$

So I need when $|H(\omega)|_{dB} = -60.61674 \text{ dB}$

$$-10\log\left(1 + \left(\frac{\omega}{1600\pi}\right)^4\right) = -60.61674 \text{ dB}$$

$$\therefore \omega = 164697.98\ldots \text{ rad/sec}$$

$$\therefore f = 26212.49773\ldots \text{ Hz}$$

We need to apply Nyquist's theorem in order to find the sampling frequency:

$$f_s = 2(26212.49\ldots)$$

$$= 52\,424.99547\ldots \text{ Hz}$$

So use a sampling frequency of

$f_s = 53 \text{ kHz}$ to allow for an error of 0.1% or less @ 500 Hz c.) The DVRT has a resolution of $2\mu m$ and a span of $8mm$, the number of steps are, therefore:

$$\text{steps} = \frac{8mm}{2\mu m} = 4000$$

$$\log_2(4000) = 11.965\ldots$$

$\therefore$ A 12 bit ADC is required to match the resolution of the sensor.

Question 3

I would choose the VIBLT1-S24-S12-SMT 12V DC to DC converter. It meets the input range of the DEMOD-DC of 6V to 16V. I chose this over the 9V regulator because it's 1% more efficient with no effect on the circuit. Also it allows for larger drifts compared to the 9V and 15V.

Taking worst case drift into account the drift would be:

$$V_o = 12V\left(\underbrace{0.03}_{\text{accuracy}} + \underbrace{85°C(0.0003)}_{\text{temperature drift}} \underbrace{+0.01}_{\text{regulation}} + 1\right) + \underbrace{20mV}_{\text{output ripple}} + \underbrace{100mV}_{\text{output noise}}$$

$$= 12.906V < 16V$$

This DC to DC converter can take an input of 22.8V to 25.2V.

The circuit diagram would look as follows