# Question 1

AMC1021S static characteristics:

| | |
|---|---|
| Operating temperature | -55°C to 150°C |
| Input Range | -6 gauss to 6 gauss |
| Linearity | ± 1.6 % FS |
| Hysteresis | ± 0.08% FS |
| Bridge Offset | 11.25 mV |
| Sensitivity | 1.25 mV/V/gauss |
| Noise Density | 48 nV/√Hz |
| Resolution | 85 μgauss |
| Sensitivity Temperature Coefficient | -0.32% / °C |
| Bridge Offset Temperature Coefficient | ±0.05% / °C |
| Bridge Ohmic Temperature Coefficient | 0.25 % / °C < no effect |
| Cross-Axis effect | 0.3 % FS |

LMV324N static characteristics

| | |
|---|---|
| Offset Voltage (input) | 9mV |
| Bias Current | 500 nA |
| Offset current (input) | 150 nA |
| CMRR | 65 dB |
| PSRR | 60 dB |
| Output Swing | 400mV |

* There is a fundamental error with the circuit shown in Figure 6 in that it can only have an input range of ±2.5 gauss. There are two ways I could address this problem:

1) Limit the system specifications to ±2.5 gauss.
2) Change resistors R5 and R6 to reduce the gain to allow for ±5 gauss.

I'll go with option 2 ∴ $R5 = R6 = 10k\Omega \pm 0.5\%$
∴ Gain = 100

System Input Range ±5 gauss
System Operating Temperature 15°C to 25°C

## Error Due to HMC1021S:

Resolution = 85μgauss ⇒ $\frac{85\mu}{5} \times 100\% = 0.0017\%$ FS

Bridge Offset = 11.25mV ⇒ $\frac{11.25\,mV \times \overset{gain}{100}}{5V} = 22.5\%$ FS

~~Sensitivity error = $\frac{1.25-1}{1} \times 100\% = 25\%$ FS~~ Calibration table shows 1mV/V/gauss

Noise density = $48\times10^{-9}V \times \sqrt{10000} = 4.8\times10^{-6}V$ ⇒ 0.0096 % FS

Linearity = 1.6 % FS

Hysteresis = 0.08 % FS

Sensitivity Temperature coefficient: $\Delta T = 25°C - 15°C = 10°C$

$= -0.32\%(10) = -3.2\%$

Bridge offset temperature coefficient: $0.05\%(10) = 0.5\%$

Cross-Axis effect $= 0.3\%$ FS

~~$V_{error} = 1 + \underbrace{0.225}_{\text{bridge offset}}\underbrace{(1.005)}_{\text{temperature drift}} + \underbrace{0.000017}_{\text{resolution}} + \underbrace{0.0000048}_{\text{noise}} + \underbrace{0.016}_{\text{linearity}} + \underbrace{0.0008}_{\text{hysteresis}}$~~

Ideal straight line:

$$V_o = 5V \times 1\ mV/V/gauss\ (\gamma)$$

Introducing error

$$V_o(\gamma) = \left[\left(5V \times 1\ mV/V/gauss\,\overbrace{(1-0.032)}^{\text{temperature coeff}}\right)\left(\gamma\,\overbrace{\left(1+\frac{0.000017}{2}\right)}^{\text{resolution}}\right) + \overbrace{11.25mV}^{\text{bridge offset}} + \overbrace{4.8\times10^{-6}V}^{\text{noise}}\right] \times \left\{\left(1 + \overbrace{0.016}^{\text{linearies}} + \overbrace{0.0008}^{\text{hysteresis}} + \overbrace{0.003}^{\text{cross-axis}}\right)\right\}$$

FS @ $\gamma = 5$ gauss

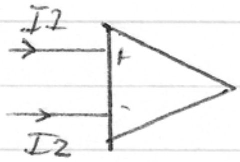
ideally $V_o = 25mV$

Actually:

$V_o(5mm) = 36.16$ mV

error $= 44.63\%$

## Error due to Amp:

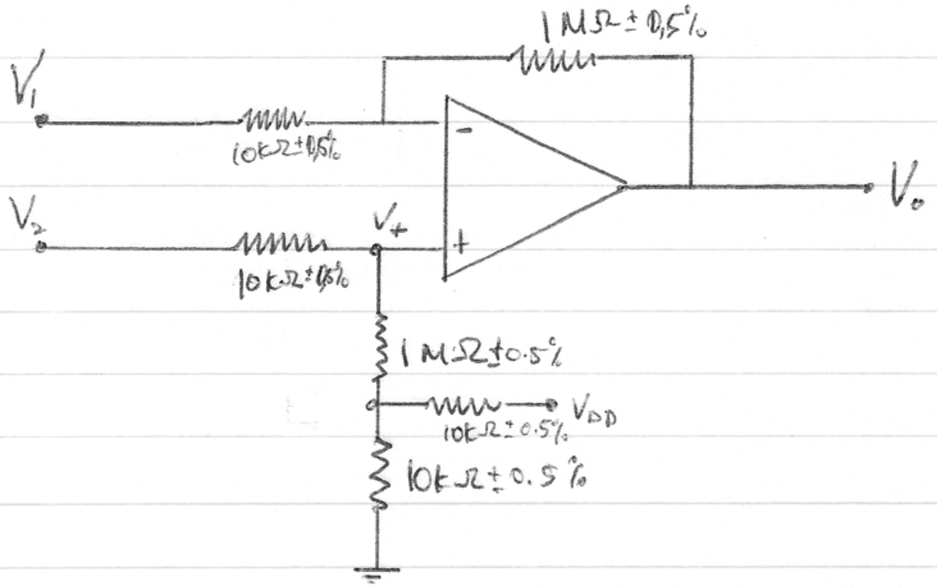



$$I_{Bias} = \frac{I1 + I2}{2} \qquad I_{offset} = I1 - I2$$

$$\therefore I1 = I_{BIAS} + I_{offset}/2$$

$$I2 = I_{BIAS} - I_{offset}/2$$

$I1 = 575\ nA$
$I2 = 425\ nA$ } considering we're working with mV these may be significant.



Super position

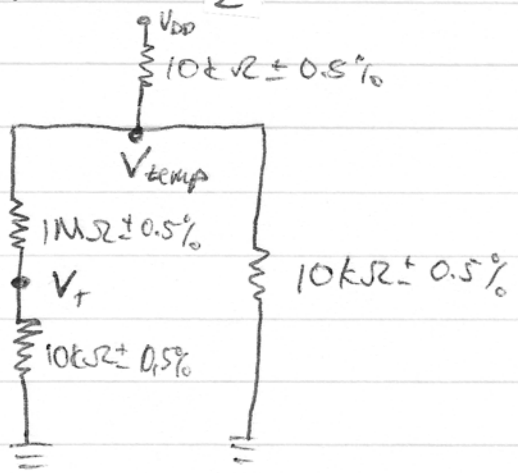
1. Short $V_{DD}$:

$$V_+ = V_2 \left( \frac{1M\Omega + \frac{10k\Omega \, 10k\Omega}{10k\Omega + 10k\Omega}}{1M\Omega + \frac{10k\Omega \, 10k\Omega}{10k\Omega + 10k\Omega} + 10k\Omega} \right)$$

$$= 0.990167\ldots V_2$$

$$= 0.99 V_2$$

2. short $V_2$:




$$R_{\parallel} = 9902\,\Omega$$

$$\therefore V_{temp} = V_{DD} \left( \frac{9.902k\Omega}{10k\Omega + 9.902k\Omega} \right)$$

$$V_+ = \frac{1M\Omega}{1M\Omega + 10k\Omega} V_{DD} \left( \frac{9.902k\Omega}{10k\Omega + 9.902k\Omega} \right)$$

$$= 0.493\, V_{DD}$$

$$\therefore V_+ = 0.99 V_2 + 0.493\, V_{DD}$$

this is using ideal resistors...

So the output would be:

$$\frac{V_1 - V_+}{10k\Omega} = \frac{V_+ - V_o}{1M\Omega}$$

$$100(V_1 - V_+) - V_+ = -V_o$$

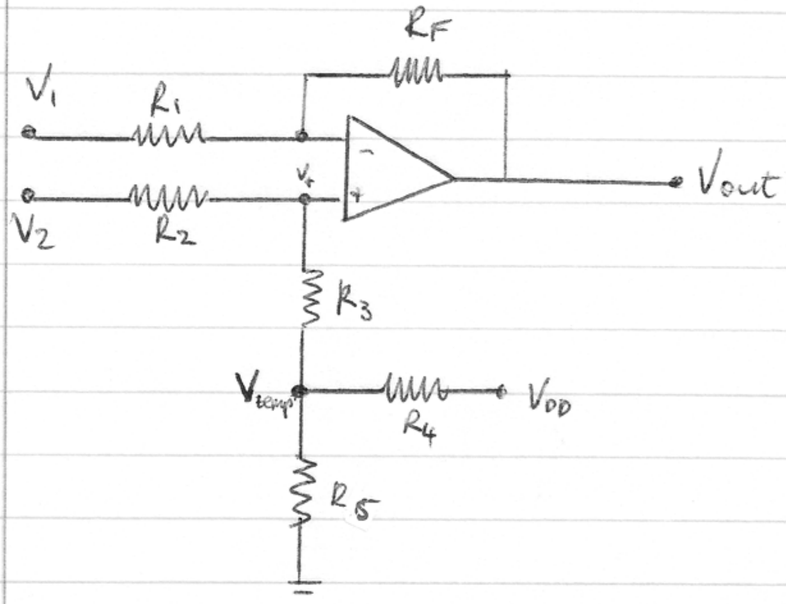
$$\therefore V_o = 100(V_+ - V_1) + V_+$$

$$= 101V_+ - 100V_1$$

$$= 99.99\,V_2 + 49.793\,V_{DD} - 100V_1 \quad \text{(Ideally)}$$

So at full scale we have $V_1 = 5mV$ and $V_2 = 0mV$

$$\therefore V_o =$$




If $R_4 = R_5 \ll R_3$ assume $V_{temp} = V_{DD}/2$

~~Superposition for $V_+$:~~

Now $V_+ = (V_2 - V_{temp})\left(\frac{R_3}{R_2+R_3}\right)$

$= (V_2 - V_{DD}/2)\left(\frac{R_3}{R_2+R_3}\right)$

$$V_{out1} = \left(1+\frac{R_F}{R_1}\right)(V_2 - V_{DD}/2)\left(\frac{R_3}{R_2+R_3}\right)$$

$$V_{out2} = -\frac{R_F}{R_1}V_1$$

$$V_{out} = (V_2 - V_{DD}/2)\left(1+\frac{R_F}{R_1}\right)\left(\frac{R_3}{R_2+R_3}\right) - \frac{R_F}{R_1}V_1$$

$$= 100(V_2 - V_{DD}/2) - 100\,V_1$$

From A.3.10 TI Op amps for everyone

$$V_o = V_2\left(\frac{R_F+R_1}{R_1}\right)\left(\frac{R_3}{R_2+R_3}\right) + V_{temp}\left(\frac{R_F+R_1}{R_1}\right)\left(\frac{R_2}{R_2+R_3}\right) - V_1\frac{R_F}{R_G}$$

$$= 100V_2 + V_{temp} - 100V_1$$

$$= 100(V_2 - V_1) + V_{temp}$$

$$= 100(V_2 - V_1) + V_{DD}/2$$

I know max difference is 25mV

$\therefore V_2 - V_1 = 25mV$ (ideally)

$V_{DD} = 5V$ ideally

$\therefore V_o = 100(25mV) + 2.5V = 5V$ ideal

Introducing errors

Make $R_F$ big

$R_1$ small

$R_2$ small

$R_3$ big

Assuming we're at 15°C and resistors have zero temp drift @ 25°C

~~$R_F = 1M\Omega(1.005)(1+25\times10^{-6}$~~

$$R_F = 1M\Omega(1 + \underbrace{0.005}_{\text{tolerance}} - \underbrace{25\times10^{-6}\times 10}_{\text{temp drift}})$$

$$= 1.00475\,M\Omega$$

$$R_1 = 10k\Omega(1 - 0.005 - 25\times10^{-6}\times10)$$
$$= 9.9475\,k\Omega$$

$$R_2 = 9.9475\,k\Omega$$

$$R_3 = 1.00475\,M\Omega$$

Now

$$V_o = 101.005V_2 + V_{temp} - 101.005V_1$$

$$= 101.005(V_2 - V_1) + V_{temp}$$

Introduce amp errors

$$V_o = 101.005(V_2 - V_1) + V_{temp}(1.01) + \underbrace{9mV}_{\text{offset}} \times 101.005$$

$@ V_2 - V_1 = 25mV \times 1.4463$

$V_o = 101.005 \times 25mV \times 1.4463 + \frac{5 \times 101}{2} + 9mV \times 101.005$

$= 7.086\ V$ (Assuming the amp doesn't saturate which it would)

$$\text{error} = \frac{7.086 - 5}{5} \times 100\%$$

$$= 41.72\%$$

Entire system is 41.72 %

just amp we use $V_1 - V_2 = 25mV$

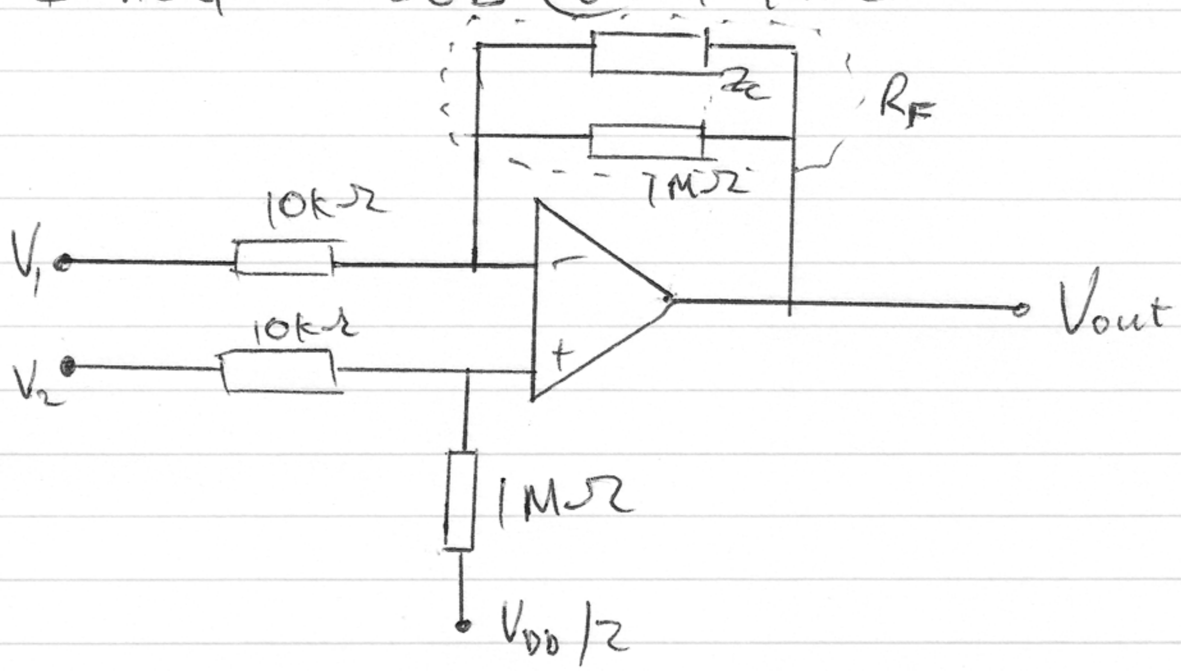
$\therefore V_o = 101.005 \times 25mV + \frac{5 \times 1.01}{2} + 9mV \times 101.005$

$= 5.95917\ V$

error = 19.18 %

# Question 2

I need $-3dB$ @ $10kHz$




$$\frac{1}{R_F} = \frac{1}{Z_c} + \frac{1}{1M\Omega}$$

$$\frac{1}{R_F} = \frac{1M\Omega + Z_c}{1M\Omega Z_c}$$

$$R_F = \frac{1M\Omega \times Z_c}{1M\Omega + Z_c}$$

I need $-3dB$ @ $10kHz$

$$-3dB = 20\log(x)$$

ie when $\text{Gain} = \frac{1}{\sqrt{2}}$

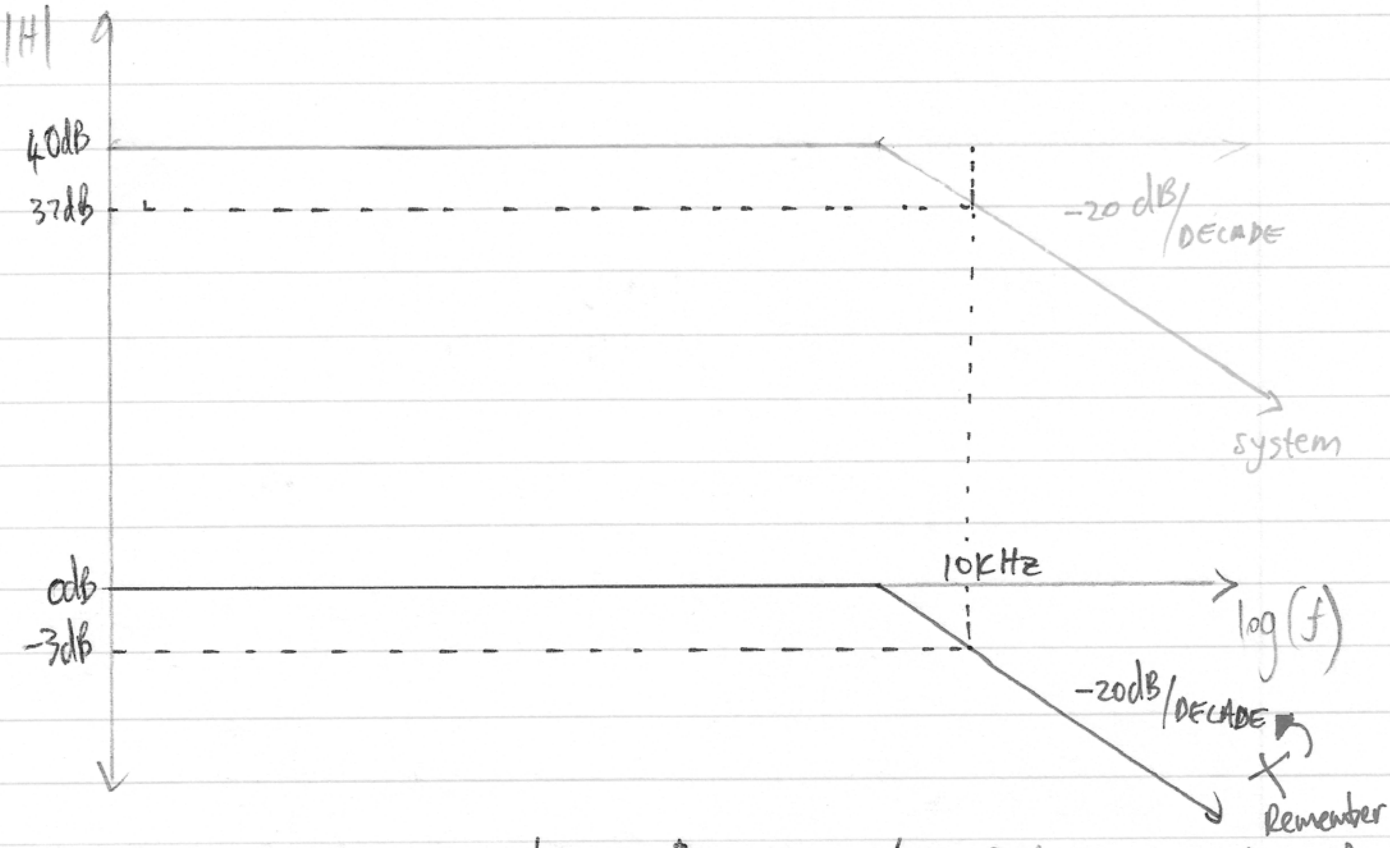
$$\frac{R_F}{10k\Omega} = \frac{1}{\sqrt{2}}$$

$$\frac{1M\Omega \times \frac{1}{2\pi f C_{IN}}}{10k\Omega\left(1M\Omega + \frac{1}{2\pi f C_{IN}}\right)} = \frac{1}{\sqrt{2}}$$

$$\therefore C_{IN} = 2.25 \times 10^{-9} \text{ F}$$

$$= 2.25 \text{ nF}$$

ii)




* ~~Assuming~~ 1st order Butterworth filter because that's what it is in figure 6.

Remember the amp is not the sensor

the sensor has a bandwidth of 500MHz