Example circuit for charge sensitivity type shock sensor.

In this manual, it is explained the procedure how to calculate characteristics of the circuit for charge sensitivity type shock sensor, for example of PKGS-00NB-R.
All results in this procedure are calculated by typical values of components. If you have to know influence of their tolerance, please verify equations in this manual by yourself.

◆**Step.1** Charge to voltage transformation, setting HPF

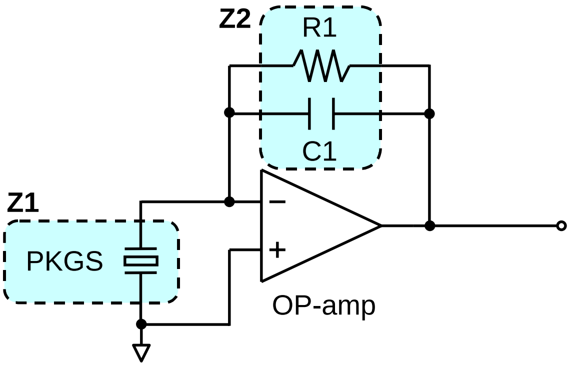


Figure 1

Table 1

Symbol	Constant
Charge sensitivity of PKGS-00NB-R: Qg	0.153pC/G
Capacitance of PKGS-00NB-R: Cf	480pF
C1	390pF
R1	20MΩ

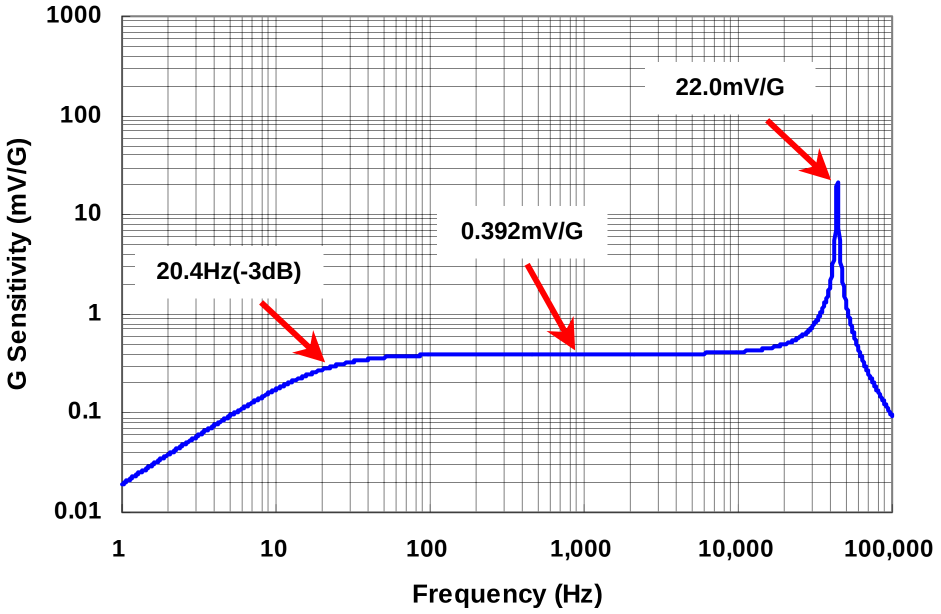
Z1: Impedance of shock sensor PKGS.
Z2: Combined impedance of R1//C1

Characteristics of circuit as Fig.1 are expressed by next equations.

Cut-off frequency of HPF: $\mathbf{fcl1} = \dfrac{1}{2\pi \times C1 \times R1} = \dfrac{1}{2\pi \times 390\text{pF} \times 20\text{M}\Omega} \cong 20.4\text{Hz}$

Output of circuit within the flat band: $\text{Vout} = -\dfrac{Qg}{C1} = -\dfrac{0.153\text{pC/G}}{390\text{pF}} \cong -0.392\text{mV/G}$

Attention, the polarity at output terminal of circuit is inverted to output charge from shock sensor.
PKGS-00NB-R has 44kHz **fr** (resonance frequency) and about +35dB(about ×56) mechanical **Qm** (steepness of resonance). Therefore frequency characteristics of circuit output voltage per 1G(= 9.80665m/s^2) is shown as Graph 1. “Circuit output voltage per 1G” is called “acceleration sensitivity” or “G sensitivity” hereafter.
Caution: To work this circuit correctly, open loop gain of operational amplifier must be enough larger than $1 + \dfrac{Z2}{Z1}$.



Graph 1

◆**Step 2.** Amplify signal

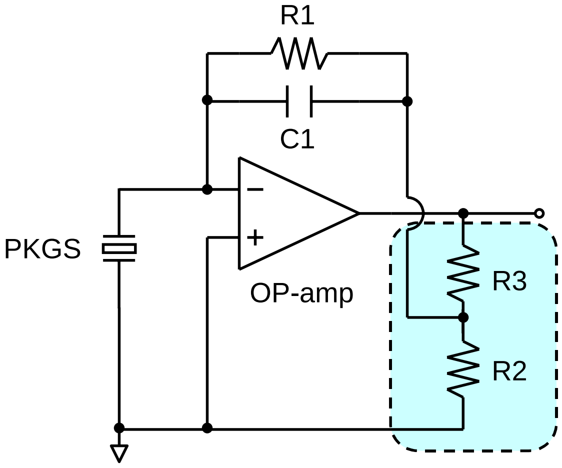


Figure 2

Table 2

Symbol	Constant
R2	1kΩ
R3	12kΩ

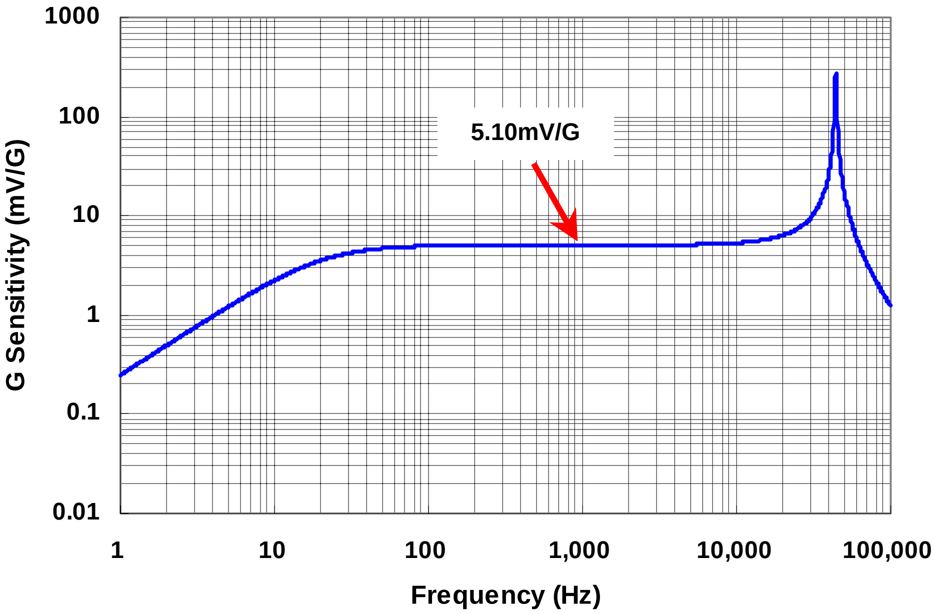
If Op-Amp has enough open loop gain, it is possible to amplify signal at the first stage as follows.
In case of R2 impedance is enough smaller than combined impedance of R1 and C1, the signal is amplified by inserting R2 and R3 as Fig.2.

$$\mathrm{Vout} \cong -\frac{Qg}{C1}\times\left(1+\frac{R3}{R2}\right)=-0.392\mathrm{mV/G}\times\left(1+\frac{12\mathrm{k}\Omega}{1\mathrm{k}\Omega}\right)\cong -5.10\mathrm{mV/G}$$

As Graph 2, G sensitivity is amplified about $\left(1+\frac{R3}{R2}\right)$ times within condition of R2<<(R1//C1).

Caution: If R2 impedance is not enough smaller than (R1//C1), circuit does not work correctly.

Of course you don't have to insert R2 and R3, if it is not necessary to amplify signal.



Graph 2

◆**Step.3** Amplify signal, setting BPF

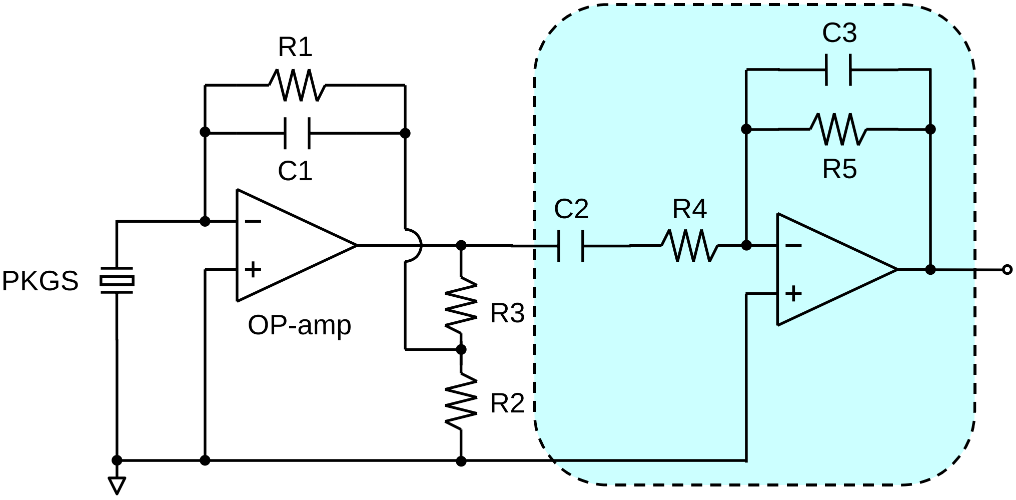


Figure 3

Table 3

Symbol	Constant
R4	27kΩ
R5	560kΩ
C2	1μF
C3	120pF

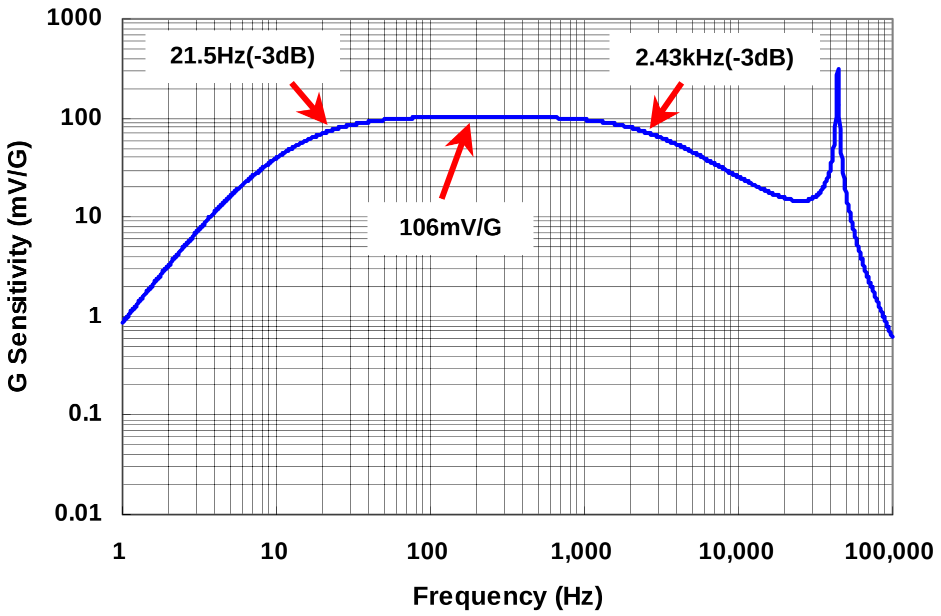
Fig.3 shows inverting amplifier at the second stage.

G sensitivity: $\text{Vout} = -\frac{Qg}{C1} \times \left(1 + \frac{R3}{R2}\right) \times \left(-\frac{R5}{R4}\right) = -5.10\text{mV/G} \times \left(-\frac{560\text{k}\Omega}{27\text{k}\Omega}\right) \cong 106\text{mV/G}$

Cut-off frequency of HPF: $\mathbf{fcl2} = \frac{1}{2\pi \times C2 \times R4} = \frac{1}{2\pi \times 1\mu F \times 27\text{k}\Omega} \cong 5.89\text{Hz}$

Cut-off frequency of LPF: $\mathbf{fch1} = \frac{1}{2\pi \times C3 \times R5} = \frac{1}{2\pi \times 120\text{pF} \times 560\text{k}\Omega} \cong 2.37\text{kHz}$

Frequency characteristics of G sensitivity is shown as Graph 3.



Graph 3

Usually it is difficult to get enough G sensitivity for application only at the first stage. Therefore it is necessary to amplify signal at second stage. In Fig.3, the first stage is “inverting” amplifying, and the second stage is “inverting” amplifying too. Then polarity of the second stage output is returned to “positive”.

HPF before input of second stage Op-Amp is placed to cut DC offset generated by first stage Op-Amp. To reduce offset, Op-Amp that has “low input offset voltage” and “low input bias current” like as FET or CMOS type are suitable generally.

LPF is placed to attenuate peak sensitivity of resonance frequency. If application requires wide flat G sensitivity band, it may be difficult to get enough attenuation by one-dimensional LPF at resonance frequency. Such as this case, add LPF(s) next stage to attenuate resonance peak to avoid bad influence to applications.

♣Graph 3 shows G sensitivity of circuit as Fig.3. Low cut-off frequency and high cut-off frequency of which level is –3dB to center frequency level, are including effect of HPF of Step 1. **fcl1** is more dominant to total low cut-off frequency of entire circuit, because **fcl2**=5.89Hz is lower than **fcl1**=20.4Hz.

Total high cut-off frequency of entire circuit is shifted higher than **fch1**. It is affected by resonance of shock sensor. Therefore high cut-off frequency of Graph 3 is not equal to **fch1**=2.37kHz.

If cut-off frequencies of HPF and LPF are close to each other, G sensitivity of circuit is attenuated by them.

Note: Mechanical Qm of shock sensor

To confirm resonance characteristics of shock sensor, shock sensor should be measured actually around resonance frequency by precision vibration testing machine. However, it is not available in our technology now.

So we processes this problem by simulation according to equivalent circuit of shock sensor calculated by impedance curve. Equivalent circuit reproduces resonance characteristics (fr, Qm) on circuit simulator for PC.

In this method, mechanical Qm is calculated without actual vibrating. But correlation between Qm by equivalent circuit and Qm by vibrating is not verified. Therefore mechanical Qm in this manual is for reference only.

◆**Step.4** setting LPF

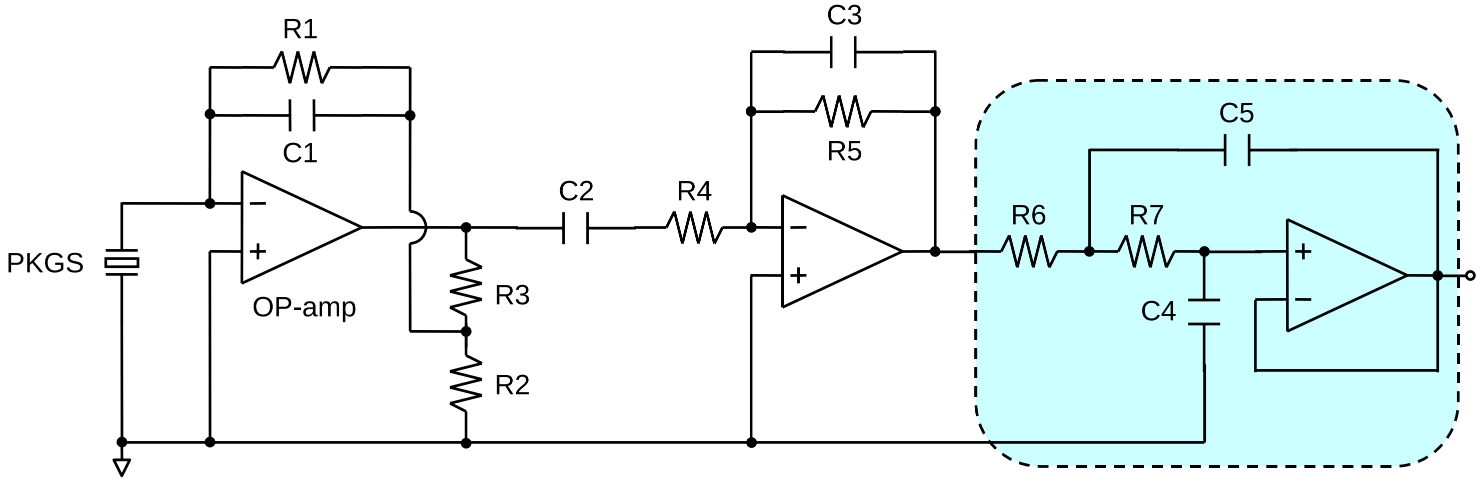


Figure 4

Table 4

Symbol	Constant
R6	240kΩ
R7	240kΩ
C4	150pF
C5	300pF

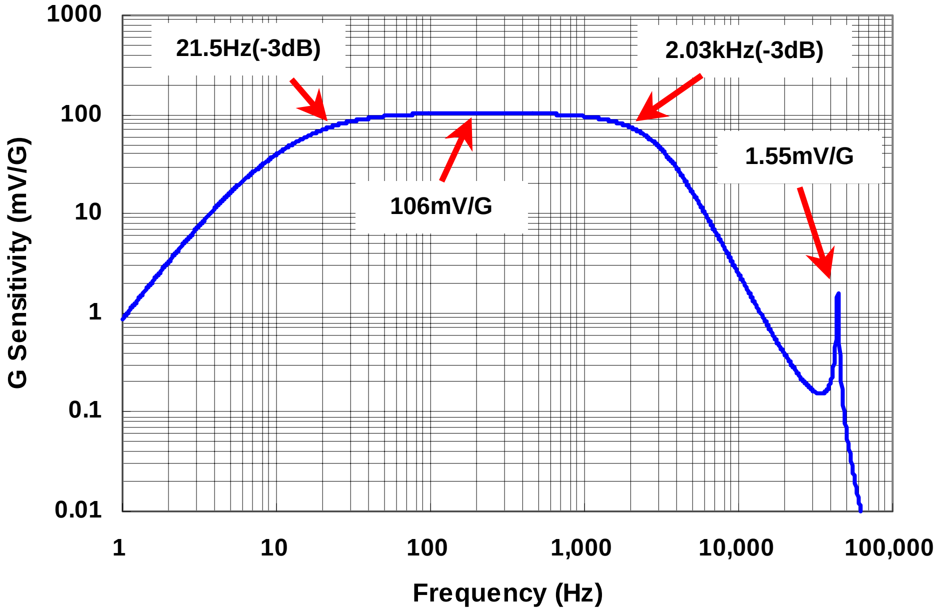
If application needs more attenuation to resonance peak, add LPF.

For example, Fig.4 is connected two-dimensional Butterworth LPF has $Q = \frac{1}{\sqrt{2}}$.

Cut-off frequency of LPF: $\mathbf{fch2} = \frac{1}{\sqrt{2}\,\pi \times C5 \times R6} = \frac{1}{\sqrt{2}\,\pi \times 300\text{pF} \times 240\text{k}\Omega} \cong 3.13\text{kHz}$

(When $R7 = R6$, $C4 = \frac{C5}{2}$)

Graph 4 shows frequency characteristics of G sensitivity at the output of circuit as Fig.4.



Graph 4

Notice

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This application manual is for reference only. Please make sure that your product is evaluated and confirmed against your specifications when shock sensor is mounted to your product.