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Charge Amplifiers for Piezo Electric Accelerometers

Introduction

Piezo electric accelerometers are widely used for measuring shock and vibration and offer several well documented benefits over other technologies such as small size, wide bandwidth, large dynamic range and low cost.

In most applications the best performance will be achieved if a charge amplifier rather than a voltage amplifier is used to buffer the signal from the piezo electric element. Several manufacturers offer accelerometers with built in charge amplifiers as well as a range of perfectly acceptable (but often expensive) external amplifiers.

In many applications these readily available off the shelf solutions are not suitable and you may need to design your own charge amplifier. The most common reason is to reduce costs but increasingly important is the need to reduce power consumption in battery operated equipment.

This paper discusses the design of charge amplifiers for use with piezo electric accelerometers, presents a simple low cost circuit and explores the issues involved in more demanding applications.

Simple Charge Amplifiers

A charge amplifier produces an output which is a function of the electrical charge flowing into the input. While directly coupled charge amplifiers are possible we are concerned here with charge amplifiers for use with piezo electric accelerometers and these are invariably ac coupled.

The basic circuit is:

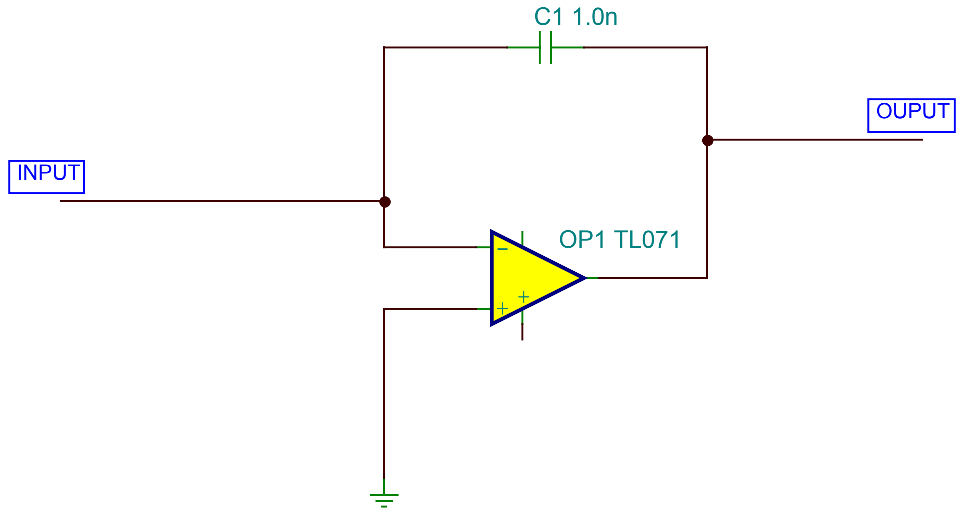

figure 1, basic charge amp

The feedback arrangement attempts to keep the net flow of charge into the inverting input of the amplifier to zero. If charge flows into the input then charge flows from the output into C1 to keep the voltage at the inverting input at zero. The amplifier output voltage must therefore be:

$$V = Q/C1$$

This simple circuit will not work in practice because amplifier bias current will act as an additional source of charge and result in the output saturating at one of the power rails.

A useable circuit is not too complicated:

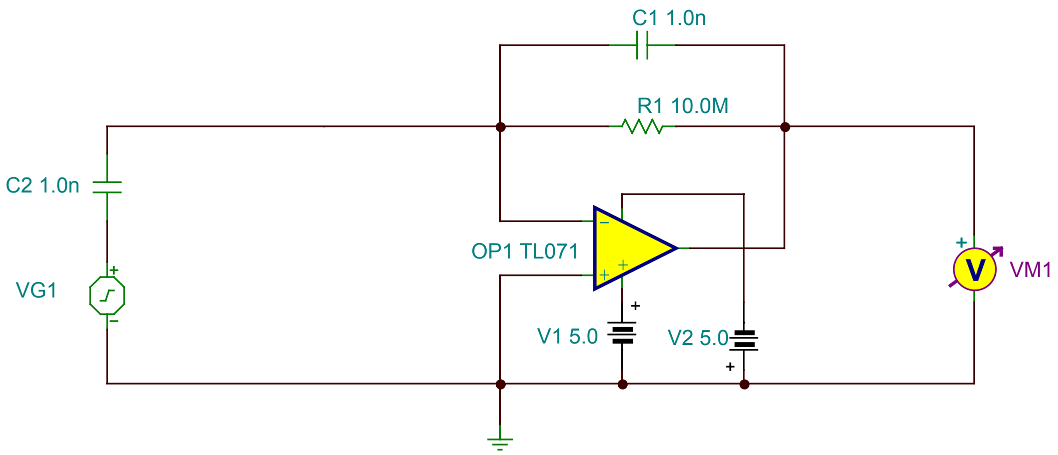

figure 2, practical charge amplifier

The piezo electric accelerometer is represented by C2 and VG1. C2 is the internal source capacity of the piezo electric sensor and 1nF is a fairly typical value.

C1, the charge amp feed back capacitor, is also set to 1nF which gives a charge gain of 1mV/pC – a reasonable value considering that typical sensor sensitivities range from 1 to 50pC/g.

A feedback resistor is added in parallel with C1 to provide a path for the amplifier bias current. Of course this resistor also affects the frequency response of the amplifier – the low frequency –3dB point for the amplifier is:

$f = 1/(2 * \pi * C1 * R1)$

which gives 15.9 Hz for the values shown.

The TL071 op amp shown is quite useable but not necessarily the best choice for any given application as we shall see later on.

The simulated frequency response for the circuit is perhaps not quite what is required:

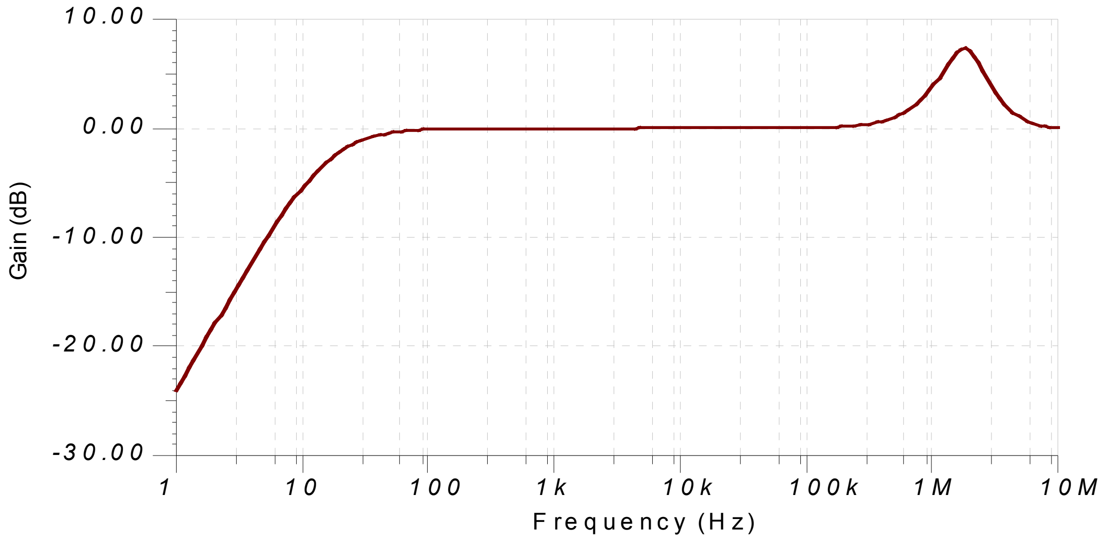

figure 3, simulated frequency response of amplifier in figure 2

The low frequency end behaves well enough, and as we would expect, but the peak at over 1MHz is likely to cause trouble. For most applications it is much better to add another resistor in series with the input to limit the high frequency response to a suitable range.

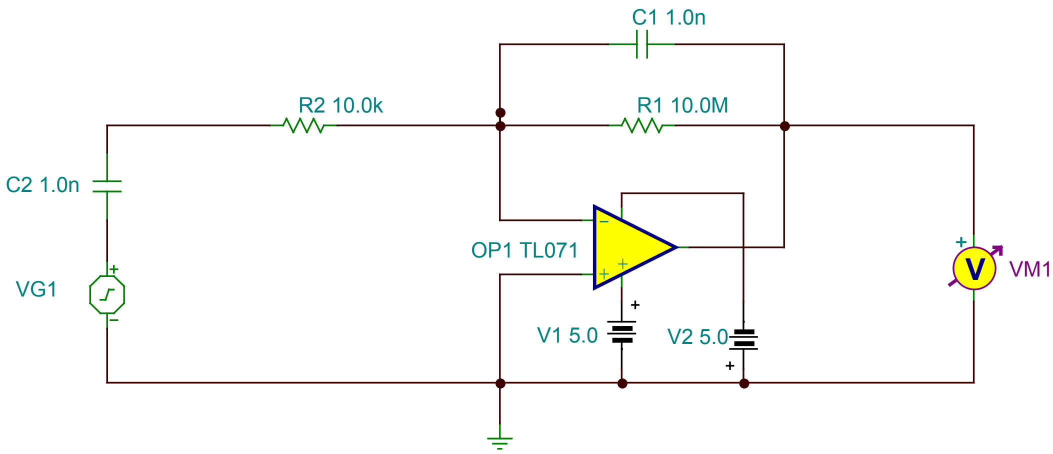

figure 4, high frequency control resistor R2 added

This gives the much better looking simulated frequency response of figure 5.

The high frequency –3dB point is:

f = 1/(2 * π * C2 * R2)

Be careful with this – the frequency response is dependent on the source capacity of the **sensor** once you add the series resistor. This is no problem if the amplifier will always be used with the same type of accelerometer but implies that R2 must be kept small for general purpose amplifier designs.

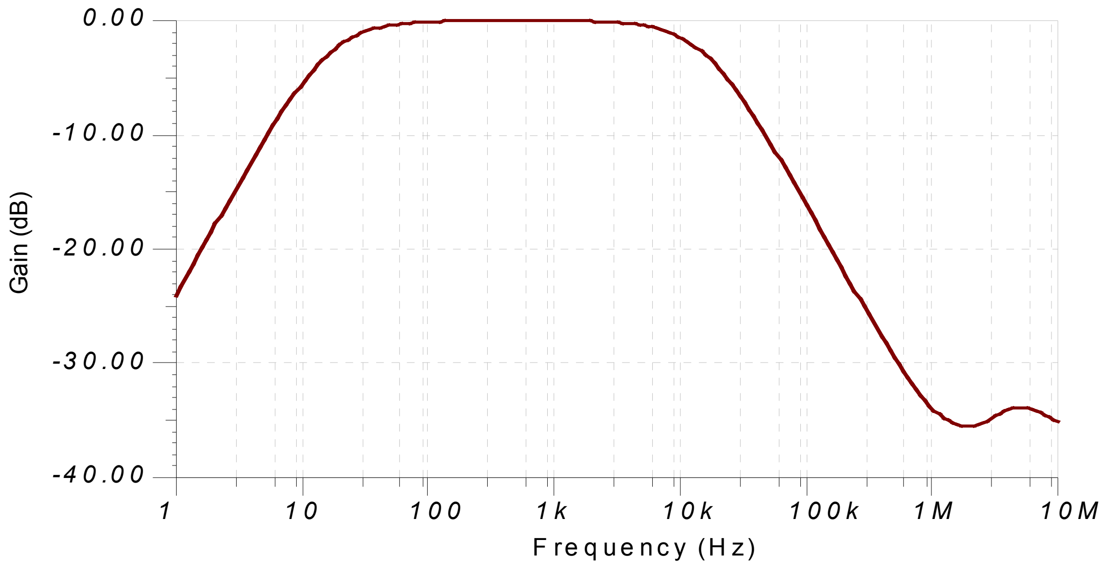

figure 5, simulated frequency response of amplifier in figure 4

The circuit in *figure 4* is useable but it does have several limitations.

The low frequency cut off frequency can be decreased by increasing R1 but the worst case bias current of the TL071 (20nA for the industrial temperature rated part) will cause problems with values of R1 much greater than 50MΩ because of the large offset voltages which will occur.

Of course the low frequency response can be extended by increasing C1 but this has the side effect of reducing the gain and worsening the system signal to noise ratio.

The TL071 needs a total supply voltage of at least 10V (and figure 4 requires split supplies) at a current of as much as 2.5mA – battery operated systems will do better with more modern op amps which can work off 3V total supplies with much lower supply currents.

If the amplifier is to be integrated with the accelerometer in one package no special input protection (other than R2) will be required in many cases. If the sensors will be plugged into the amplifier via leads and connectors then protection against static discharges, electro-magnetic interference and large voltages on the sensor will be required. (Piezo electric accelerometers are all pyro electric to some degree – this means that a charge will build up on the sensor if its temperature is changed. When accelerometers are temperature cycled it is quite common for voltages well in excess of 100V to build up on an open circuit device.)

Optimal Charge Amplifiers

There is no single perfect charge amplifier so optimisation is a matter of fitting the design to the application as well as possible.

For battery powered designs there are many rail to rail input and output op amps available with low bias currents and very low supply current requirements. The gain/bandwidth product of the very low power devices will restrict the frequency range of the amplifier. Many of these amplifiers are much noisier than the traditional ±15V supply J-FET designs like the TL071.

If the frequency range of interest is not too great then the design of *figure 4* can be adapted simply by changing the amplifier to another type (such as TI's TLV2761 which runs from as little as 1.8V at 20uA with bias currents two orders lower than the TL071 – but – four times the voltage noise and only one sixth of the gain bandwidth product).

Input protection can be achieved by adding diodes in various configurations from the input to ground (on the amplifier side of R2 !).

Single supply designs are possible but it is important not to allow the amplifier bias voltage to appear across the accelerometer without due consideration of the effects. The sensor will not be damaged by a few volts DC but the shunt resistance across the sensor is usually unspecified and very noisy. Normal surface contamination of the pcb, connectors or the sensor itself can result in very large low frequency noise signals and make the amplifier/sensor combination quite unusable.

Care must be taken in the choice of passive components, especially C1, which should be stable and low noise. Polystyrene capacitors are capable of very good performance (types vary so careful selection and testing is required) and surface mount NPO or COG ceramics can give acceptable performance. Other ceramic types are not suitable.

Surface mount resistors are available in very high values but may be expensive and hard to obtain. It is sometimes better to use more complex circuit arrangements to allow extended LF performance without the need to use very high value resistors or increase the value of C1.

The best absolute performance in terms of noise, bandwidth and stability is still likely to be achieved with a ±15V J-FET amplifier used in a simple circuit like *figure 4*.

Summary

A simple charge amplifier for use in un-demanding applications can readily be built from standard components. A possible circuit is given in *figure 4*.

To produce a design optimised for a given purpose is more challenging and a great many conflicting factors must be considered.

If you need help with a charge amplifier design or any other low power low frequency analogue design problem please contact me.

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