

# The Inyo Force-Balance Vertical Seismometer

## Circuit Description

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### Introduction

The Inyo Force-Balance Broad Band vertical seismometer was designed to provide an excellent balance between cost/complexity and performance. Its mechanical design is relatively simple and rugged and can be duplicated by anyone who has some basic metalworking equipment and the skill to use it. The electronics are contained on a single PC board using a circuit which is adequate to give excellent performance, though no more complex than required.

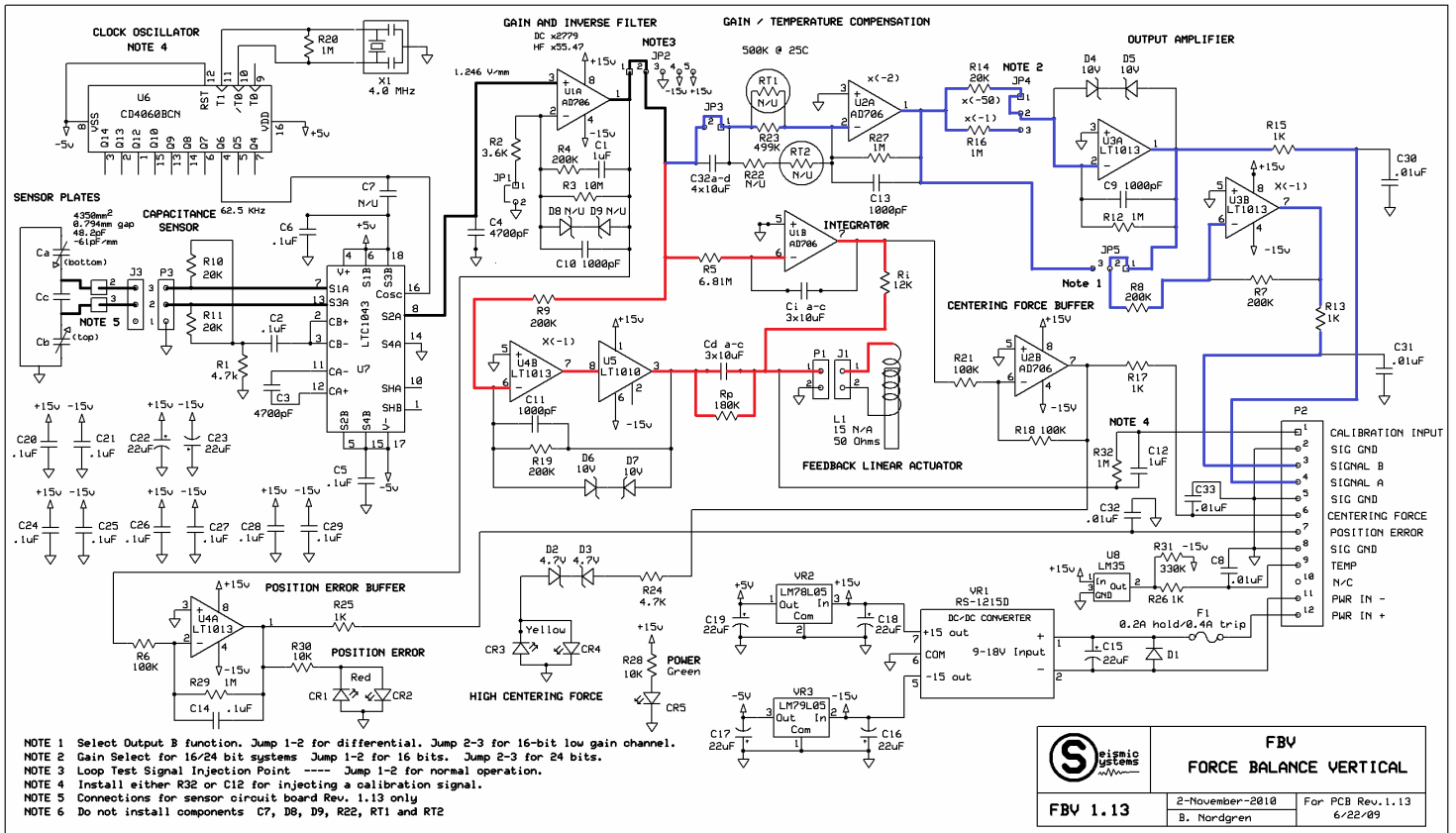
The mechanical design uses an astatic spring configuration, but unlike the most elegant commercial instruments the spring is made from stainless steel rather than from an exotic low TC of Elasticity alloy. This means that the instrument response to the rate of temperature change will be perhaps 10x larger than the best sensors of equivalent bandwidth, but still quite reasonable. In addition, by removing a jumper, the output can be passed through a 1/125 Hz single-pole high-pass filter, which will hide essentially all temperature variation effects. In addition the design is such that it should not need to be mechanically re-balanced over its full operating temperature range.

The internal noise of the Inyo FBV is somewhat higher than the expensive commercial verticals, but in all but the quietest locations will not be seen above the seismic background. Side-by-side tests against a high quality instrument (Trillium Compact 120) show virtually identical waveforms, both when displaying seismic background signals as well as larger seismic events.

The mechanical elements are designed to be field-reparable, requiring only tools which can be obtained at any small hardware store. And all parts, mechanical and electronic are readily constructed or are available from on-line sources.

# Circuit Overview

Following is an overview schematic which shows the major signal paths. The heavy black lines trace the forward, 'A', portion of the loop, starting at the capacitive position sensor and ending at the output of the feedback loop. The red lines trace the feedback branches of the loop, the 'B' path, starting at the loop output and ending at the force feedback coil. The blue lines trace the signal from where it exits the loop, through several alternative stages of amplification to the output terminals.



## Capacitive Sensor

The capacitive sensor consists of two sensor plates, copper foil layers, on opposite sides of a stationary printed circuit board. Above and below the PC board are two moving, grounded plates which form capacitors  $C_a$  and  $C_b$ , and which change value as the moving plates change position. As the boom moves up,  $C_a$  increases in value while  $C_b$  decreases. The difference in capacitance is detected and amplified by U7 and its associated circuits.  $C_c$  is a stray capacitance of about 130 pF formed by the circuit board dielectric between the driven electrode plates of  $C_a$  and  $C_b$ .

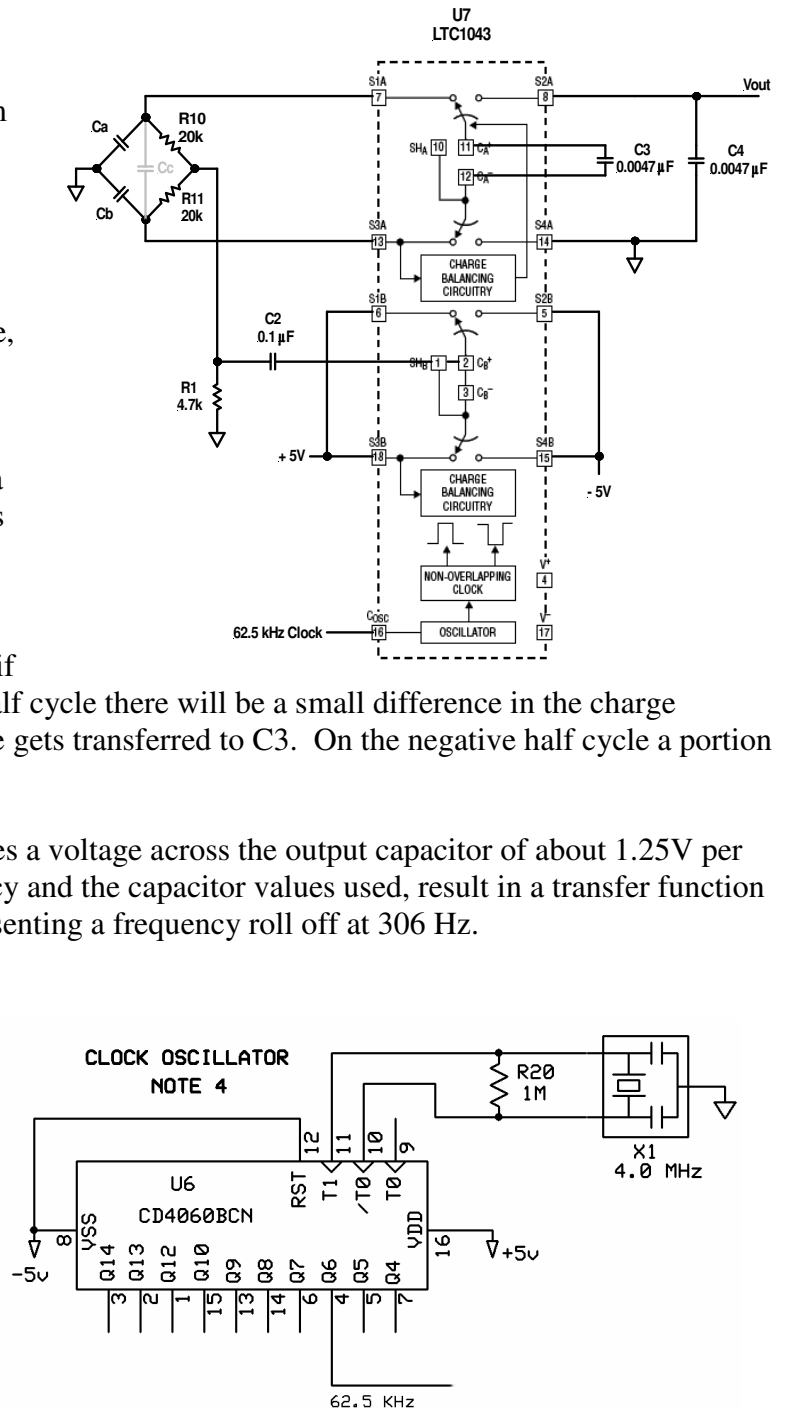
The area of each capacitor plate is approximately 4350 mm<sup>2</sup> and when centered, their separation from the grounded plates is about 1/32" or 0.79mm, making the capacitance of each about 48.2 pF. As the boom moves a small distance from its rest position, the capacitor values change at a rate of 61pF/mm of motion, one increasing and one decreasing, though in practice, with feedback active, that motion will only be few micrometers or even less.

Although  $C_a$ ,  $C_b$ , R10 and R11 may be viewed as a half-bridge circuit, they are more easily analyzed as a switched-capacitor, charge transfer problem. U7, via C2, R10 and R11, applies a 62.5kHz, 5V peak square wave to both  $C_a$  and  $C_b$ . Each half cycle of 8.0  $\mu$ s is sufficient to fully charge  $C_a$  and  $C_b$ . But if their values are slightly different, on the positive half cycle there will be a small difference in the charge transferred to each, and therefore a small net charge gets transferred to C3. On the negative half cycle a portion of that charge is transferred to output capacitor C4.

The result is that any unbalanced capacitance creates a voltage across the output capacitor of about 1.25V per mm of sensor motion. The 62.5kHz clock frequency and the capacitor values used, result in a transfer function pole having a time constant of about 0.52ms, representing a frequency roll off at 306 Hz.

## External Clock

Since the gain of the sensor circuit is proportional to frequency it is desirable to maintain close control of the clock frequency. Therefore provision was made to install a higher stability clock in place of the LTC1043 internal oscillator. The clock is obtained by dividing down a 4MHz ceramic resonator to obtain the 62.5kHz signal.







Output Amplifier Gain Following Loop					
Mode	JP4	JP5	Signal A	Signal B	Differential
16-bit	1-2	2-3	100.2	2.004	---
16-bit differential	1-2	1-2	100.2	-100.2	200.4
24-bit	2-3	2-3	2.004	2.004	---
24-bit differential	2-3	1-2	2.004	-2.004	4.008

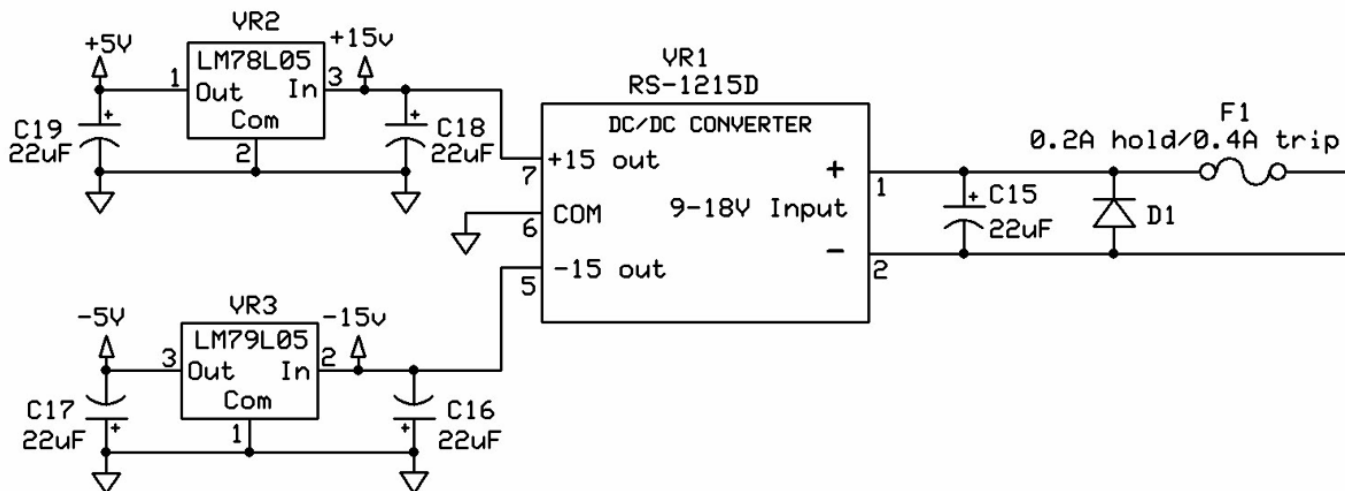
Instrument Generator Constant V / m/s					
Mode	JP4	JP5	Signal A	Signal B	Differential
16-bit	1-2	2-3	75,150	1,503	---
16-bit differential	1-2	1-2	75,150	-75,150	150,300
24-bit	2-3	2-3	1,503	1,503	---
24-bit differential	2-3	1-2	1,503	-1,503	3,006

Peak clipping Velocity for given digitizer clipping voltage - m/s					
Mode	JP4	JP5	Signal A	Signal B	Differential
16-bit	1-2	2-3	1.3307E-04	6.6534E-03	---
16-bit differential	1-2	1-2	---	---	1.3307E-04
24-bit	2-3	2-3	6.6534E-03	6.6534E-03	---
24-bit differential	2-3	1-2	---	---	6.6534E-03

## Power Supply

The power supply uses a voltage regulated DC/DC converter, VR1, to provide DC isolation from the external power source, whose voltage may vary over a range which includes the voltage range of a 12V lead-acid battery. The converter provides supply voltages of + and - 15 Volts, which are also regulated by regulators VR2 and VR3 down to + and - 5 Volts for those circuits which require the lower, better regulated voltages.

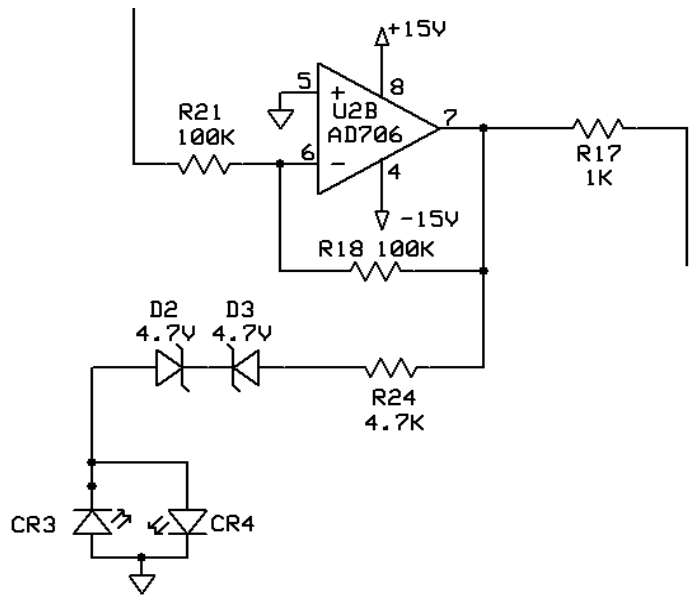
Input protection is provided by resettable PTC device, F1, which has a nominal operating current rating of 0.2A and a trip rating of 0.4A. Diode D1 protects against reversed polarity conditions. Normal input current draw is approximately 60 mA.



## Auxiliary Circuits

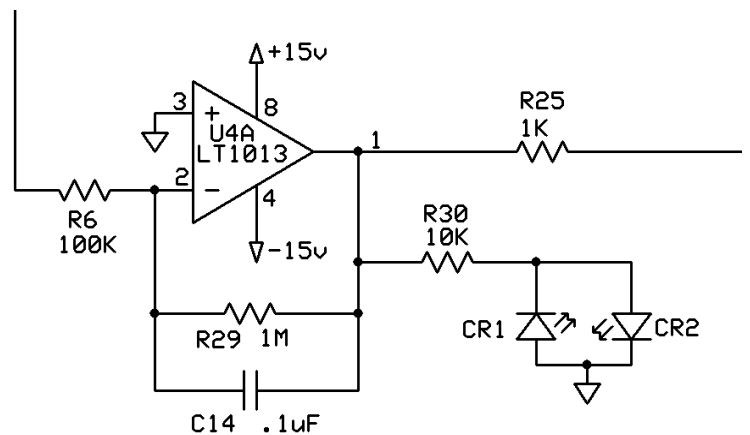
### Centering Force Buffer

The centering force buffer amplifier, U2B is driven by the output of the Integrator circuit. With a gain of -1 it provides a test signal 'CF' to the output connector P2. This signal reflects the amount of mechanical imbalance which is being offset by the integrator. If this signal becomes too large the instrument should be mechanically re-balanced. Also, the circuit board contains two LED's, CR3 and CR4, which indicate when the Centering Force signal exceeds approximately +/- 7V. If the instrument is being operated with the circuit board hidden by a cover, R24 may be lifted to reduce possible current drain.



### Position Error Buffer

The position error buffer amplifier, U4A is driven by the output of the feedback loop. It is useful when initially setting up the instrument, usually with jumper JP1 removed. During normal operation the position error signal 'PE' on the output connector P2, will be a filtered, low-amplitude version of the instrument output. However, it has the advantage of always being DC coupled so that it shows DC errors which would not be visible if the instrument had been AC coupled by removing jumper JP3. If the instrument is being operated with the circuit board hidden by a cover, R30 may be lifted to reduce possible current drain.



### Temperature Sensor

A temperature sensor device, U8, is included, which provides a voltage signal 'T' on the output connector, P2, in order to track the board temperature. This is calibrated for 10 mV/°C, so that 25 °C is indicated by an output of 250mV.

