

A short history of the Inyo Force-Balance Vertical and its successors

David F. Nelson and Brett M. Nordgren
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The idea of designing a force-balance vertical seismometer came originally from Angel Rodriguez, director of OSOP, the Seismic Observatory of Western Panama. In March of 2008, Angel approached a few of us who had been active on the Public Seismic Network's mailing list, PSN-L, with the specifications for an instrument which he believed could be of use in his seismic observatory and perhaps to others in the region.

The instrument he proposed would be a single-axis force-balance vertical design, which he hoped could be built locally in Panama, which was to be characterized by excellent performance, simplicity and ease of maintenance in the field. After reviewing the goals for the design, Dave Nelson from Los Angeles visited Terry Brown in Tennessee to discuss mechanical approaches. Terry proposed the first configuration for the instrument and Dave went back to California to work on the electronics and mechanical construction. Brett Nordgren in New Jersey provided the analytical tools required to complete and refine the design and helped to document the instrument. As the design progressed, it was decided that it should be shared for construction and use by advanced amateurs. So mechanical drawings, schematics, bare circuit boards and a few unique parts were made available to interested builders.

At that time Brett established a private mailing list, FBV-topics, for all those who were interested in the design. Now with over 35 members, this has proved to be most successful for sharing ideas and experiences and has helped to relieve the designers from having to handle some of the more routine questions coming from new builders.

Dave named his first and largest design, the "Inyo" and there are over a dozen in operation at the time of this writing. Four are in California (one is Dave's), one in Ohio, two in Alabama, and six are operating in Australia. Another in Iowa is also nearing completion, and several others are in earlier stages of construction, including instruments in France and England.

His second instrument, the "Yuma" was somewhat smaller, based on a simpler mechanical design which should be easier to construct by someone having a less-endowed home machine shop. There are presently five of the Yuma models operating, three in California and two in New Jersey. Both the Inyo and Yuma required substantial pressure cases, which were usually mounted on a granite slab.

The third design, the "Napa" is currently in the final stages of prototype testing and is the first design on which we have attempted to make noise PSD measurements. It is also the first to have a self-contained pressure case, though the Yuma design now has one, too. A more complete description of the Napa may be found below.



Dave's Vault



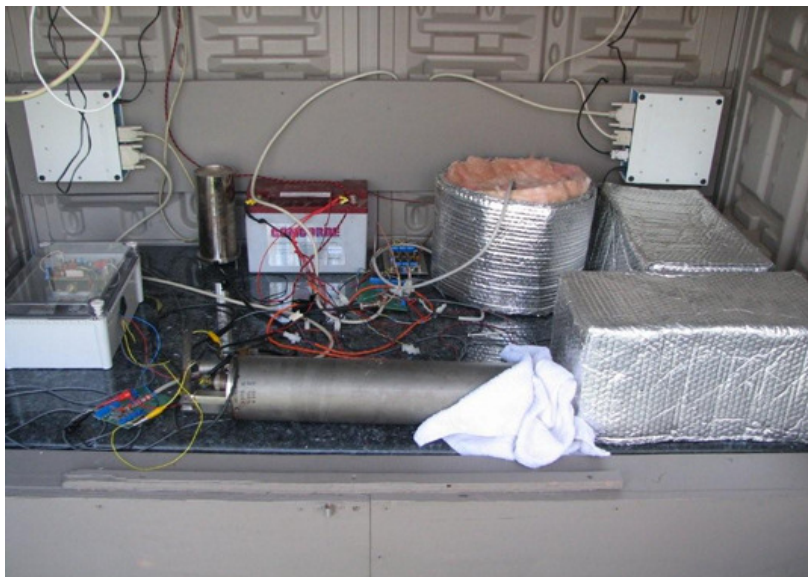
Pier under construction



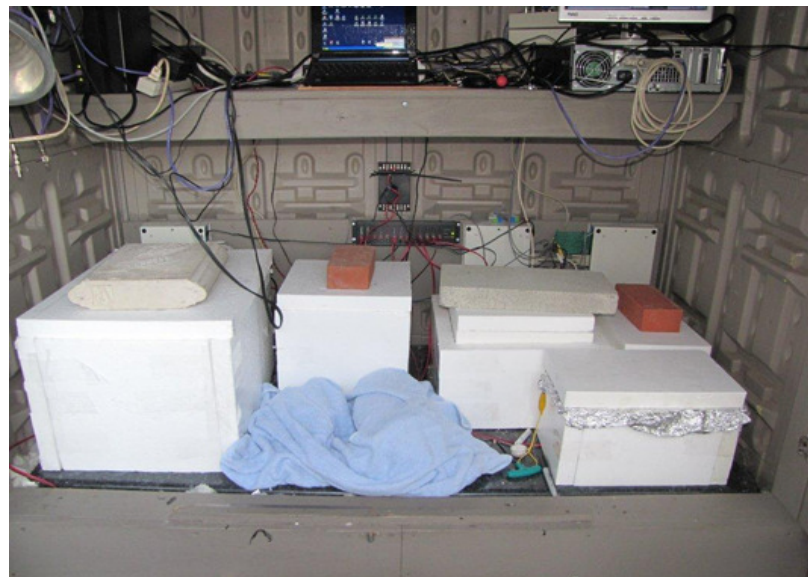
Granite pier top



Barometric pressure sensor



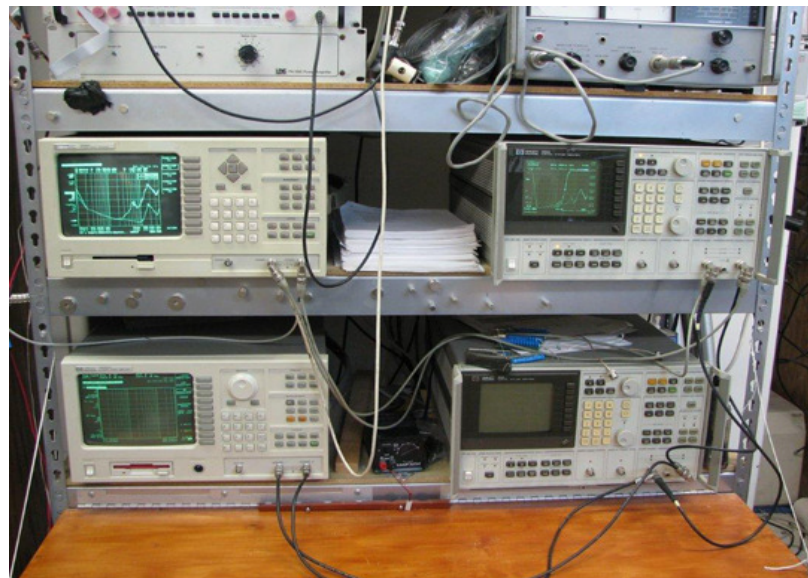
Various instruments



Insulation installed



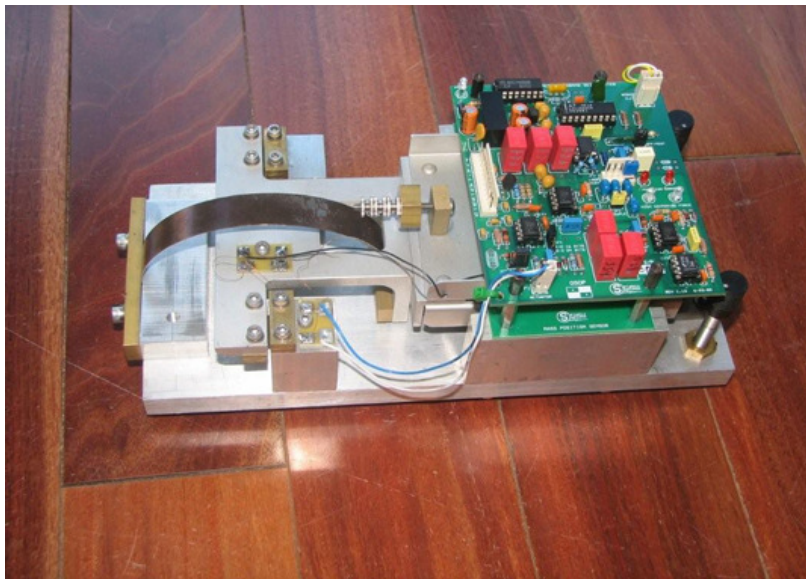
In Dave's Lab



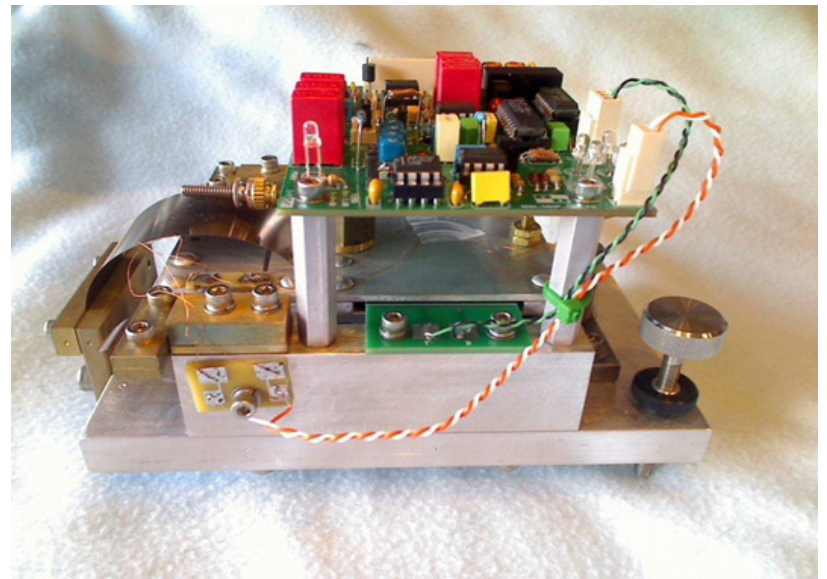
Signal analyzers in Lab

The three Force-Balance Vertical designs

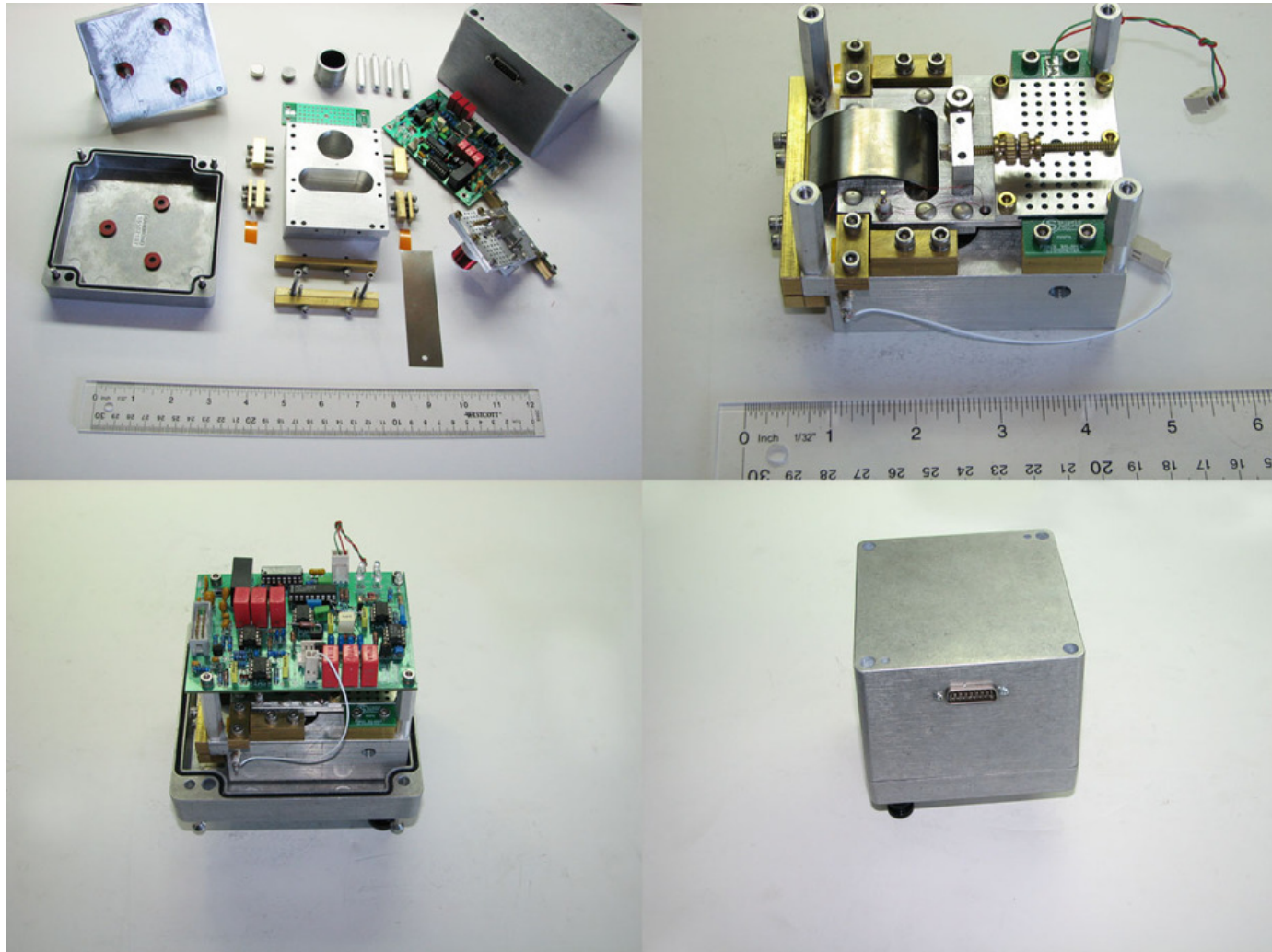
Inyo



Yuma



Napa



Introducing the Napa Force-Balance Vertical Seismometer

David F. Nelson and Brett M. Nordgren
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The Napa is the third design in a series of FBV seismometers, starting with the Inyo, followed by the Yuma. It is intended to be relatively inexpensive and may be constructed and operated by any advanced amateur seismologist who has access to a reasonably well-equipped metalworking shop.

Smallest of the three models, having a mass of about 60g, the Napa incorporates a self contained pressure case, making use of a standard Hammond waterproof aluminum box employing a simplified "warpleless" base design. Like the earlier designs, its broad-band velocity response has a 2-pole low-frequency corner at 50 seconds and a 1-pole high-frequency corner at 30 Hz.

In order to allow the use of a less expensive 16-bit digitizer, the Napa provides two output signals. The high-gain output has a mid-band generator constant of 30,000 V/m/s, clipping at a peak velocity of 333 $\mu\text{m/s}$ and giving it a sensitivity of 10.2 nm/s per count when used with a $\pm 10\text{V}$, 16-bit A/D. A lower-gain output signal continues to provide useful data to a second A/D channel for the occasional large or nearby quake which exceeds the 333 $\mu\text{m/s}$ clipping velocity. The low-gain output has a generator constant which is reduced by a factor of 50, giving 600 V/m/s or 508 nm/s per count, clipping at a peak velocity of 1.7 cm/s.

Instrument internal noise is intended to be sufficiently low so that within its operating frequency band it should be below the local site noise encountered at any amateur installation. In fact, early tests suggest that the instrument self-noise Power Spectral Density may be below the NLNM out to 25 seconds period, rising to around -180dB vs $1\text{m}^2/\text{sec}^4$ per Hz at 50 seconds. At 1mHz, the instrument PSD measured slightly below -150dB. These measurements, shown on the next page, were made by using an H-P/Agilent 35665A Dynamic Signal Analyzer on two prototype Napa instruments, modeling the instrument internal noise by means of coherence measurements. For comparison, the dashed black line represents the median of noise measurements made at ASL on four STS-1 instruments. (Ringler & Hutt 2010)

As in the previous designs, the Napa employs a stainless-steel leaf spring, having a thermoelastic coefficient of approximately -240ppm/ $^{\circ}\text{C}$. This means that for best performance, the Napa must be well insulated so as to have a long thermal time constant to ambient temperature changes. Although its steady-state temperature coefficient approaches zero, the instrument will respond to the rate of temperature change by an estimated 41 $\mu\text{m/s}$ per $^{\circ}\text{C}$ per hour.

Napa 1 RMS acceleration noise PSD

dB vs $1\text{m}^2/\text{sec}^4$ per Hz

