THE “ARC-LITE” Torque Pendulum THRUST BALANCE with latest Mach-Effect Data from Several PZT-Stacks Presented --Preliminary--

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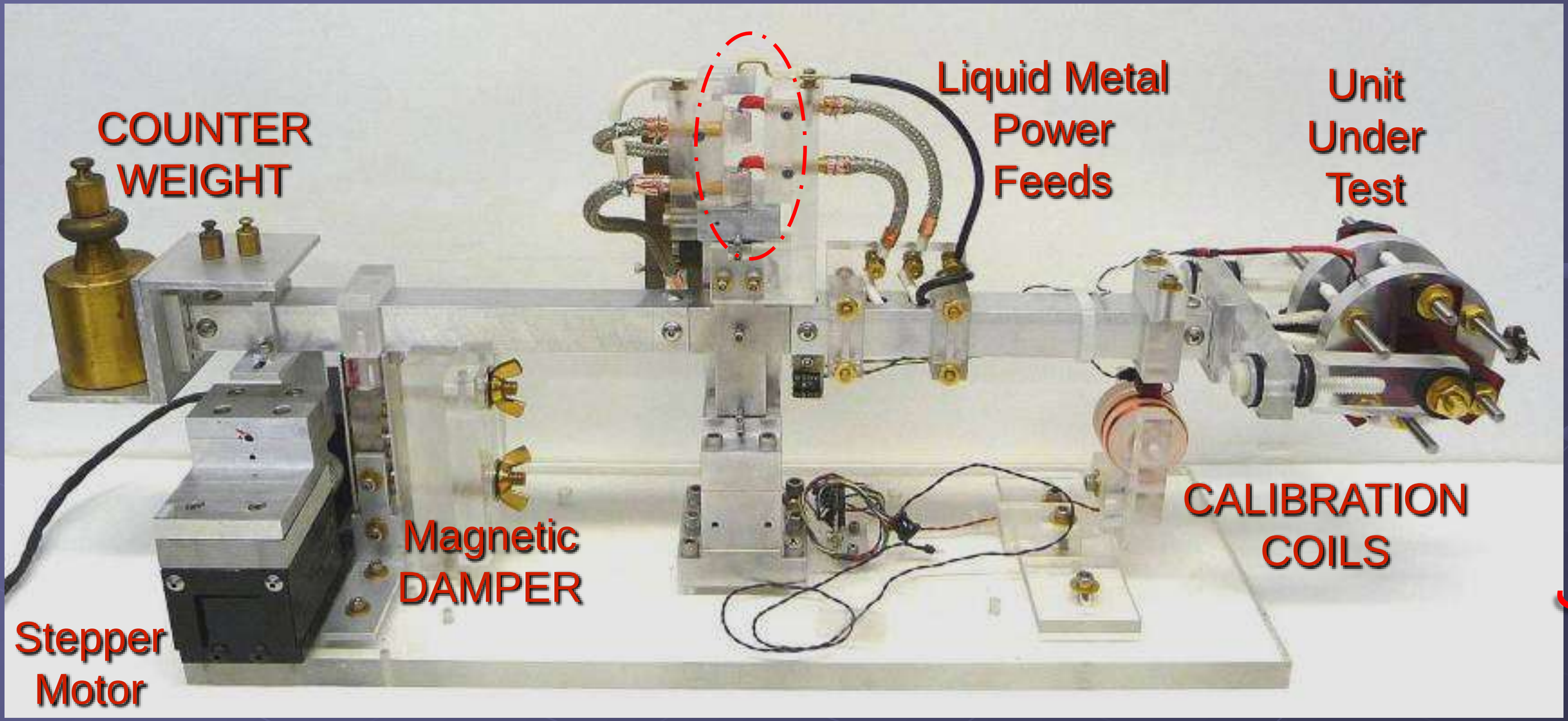
Editor: Paul March

Woodward's "**ARC-Lite**" Thrust Balance



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The "**ARC-Lite**" thrust balance chiefly built by **Tom Mahood** based on a thrust balance at the Austrian Research Center that was, in turn, based on a thrust balance built at **USC** by **Andrew Ketsdever** and colleagues. **C-Flex** flexural bearings support the beam at its center and the horizontal position of the beam is monitored with a **Philtec optical displacement sensor** whose probe is attached to the stepper motor at the left. The **coils at the right** are used to calibrate the thrust response of the balance. Power to the device is fed through **galinstan contacts** mounted coaxially above the flexural bearings to eliminate torques on the beam arising from currents and voltages in the electrical circuit.

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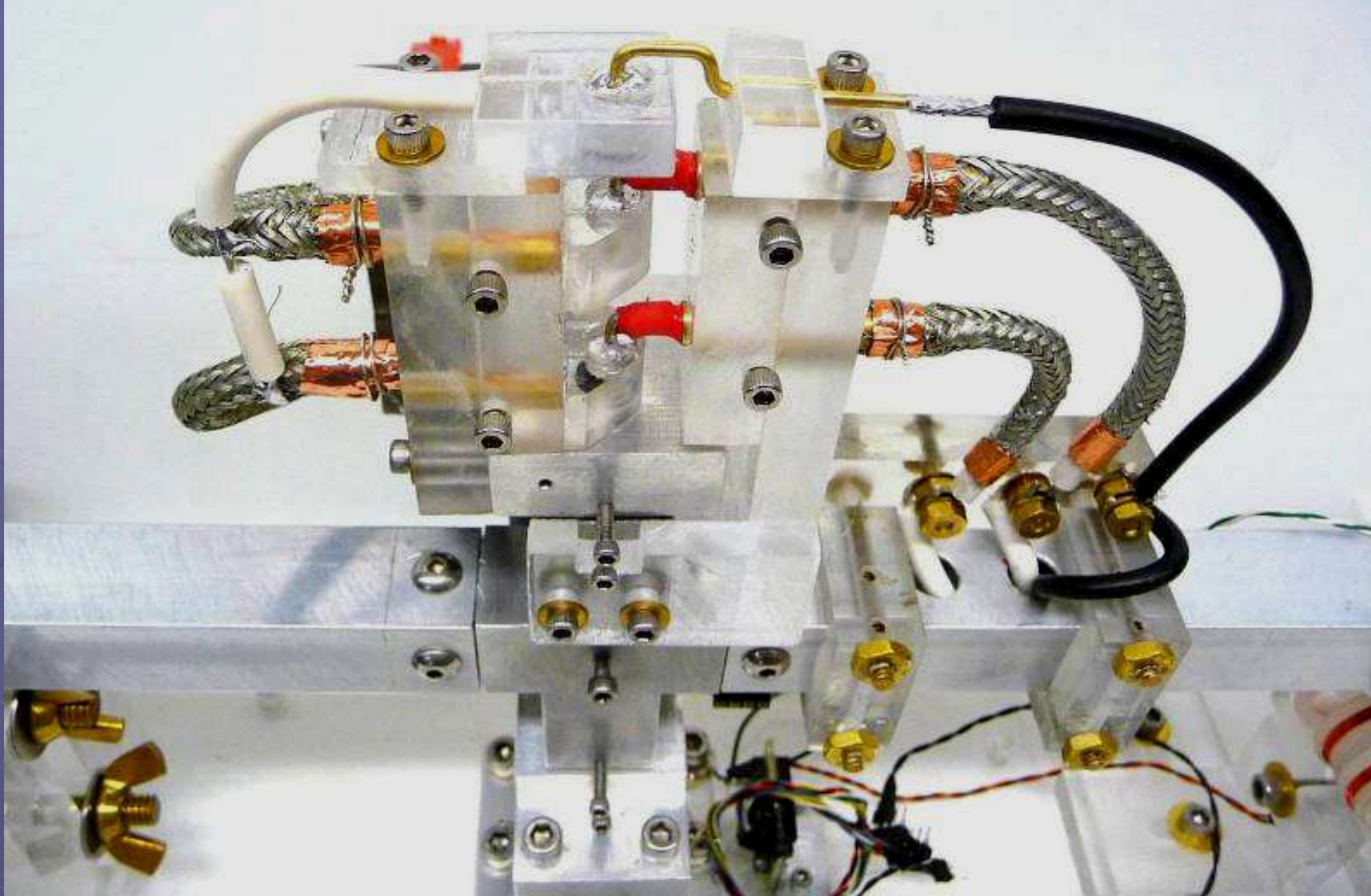
Galinstan Liquid Metal Contacts for RF Power Feeds



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Two views of one of the C-Flex flexural bearings that support the beam of the ARC-Lite thrust balance.

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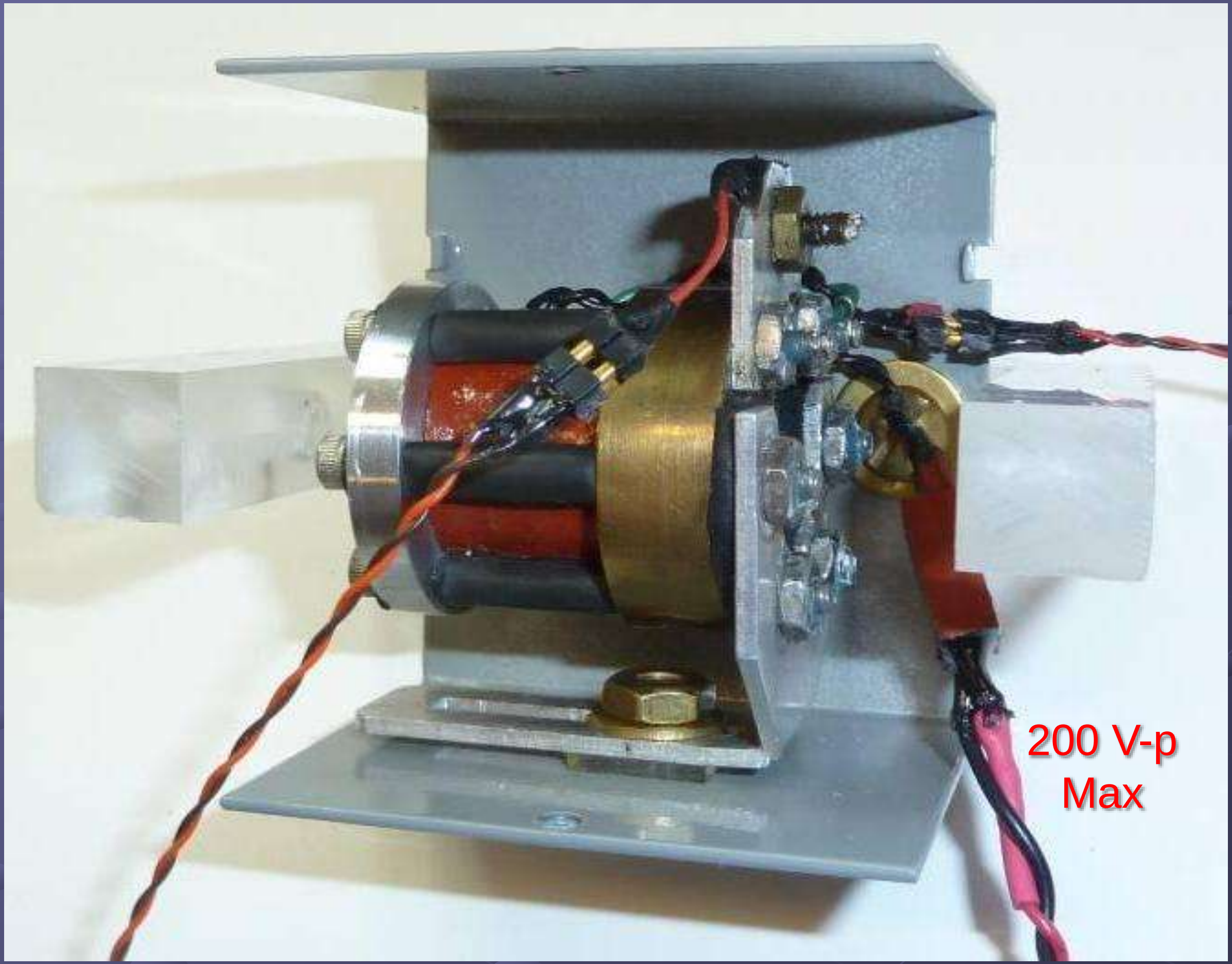
Woodward's PZT Stack Unit Under Test (**UUT**)



One of the PZT-Stack devices mounted in half of the Faraday cage used with the ARC-Lite thrust balance.

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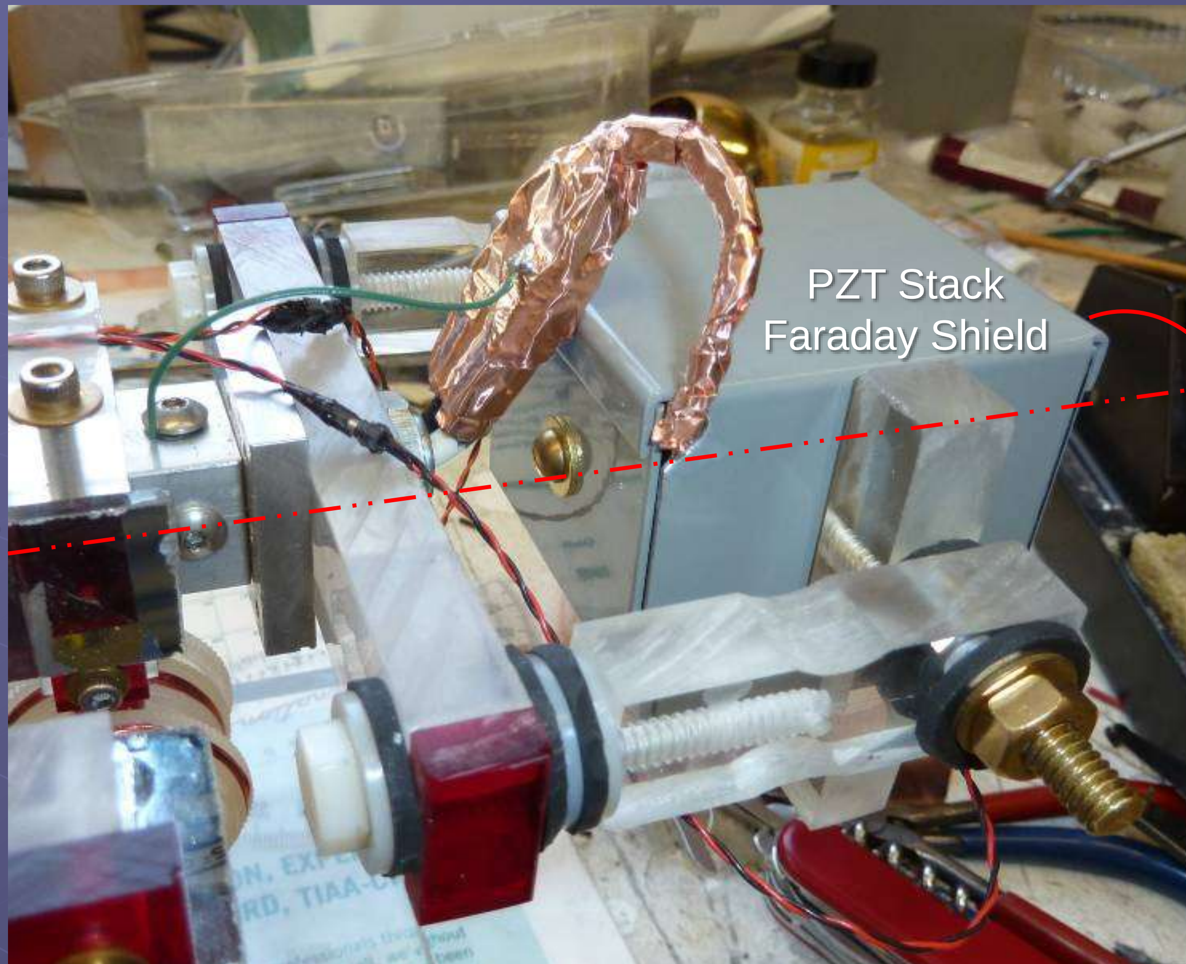
Woodward's PZT-Stack in Aluminum Faraday Shield at end of ARC-Lite Pendulum with copper foil power feed shield

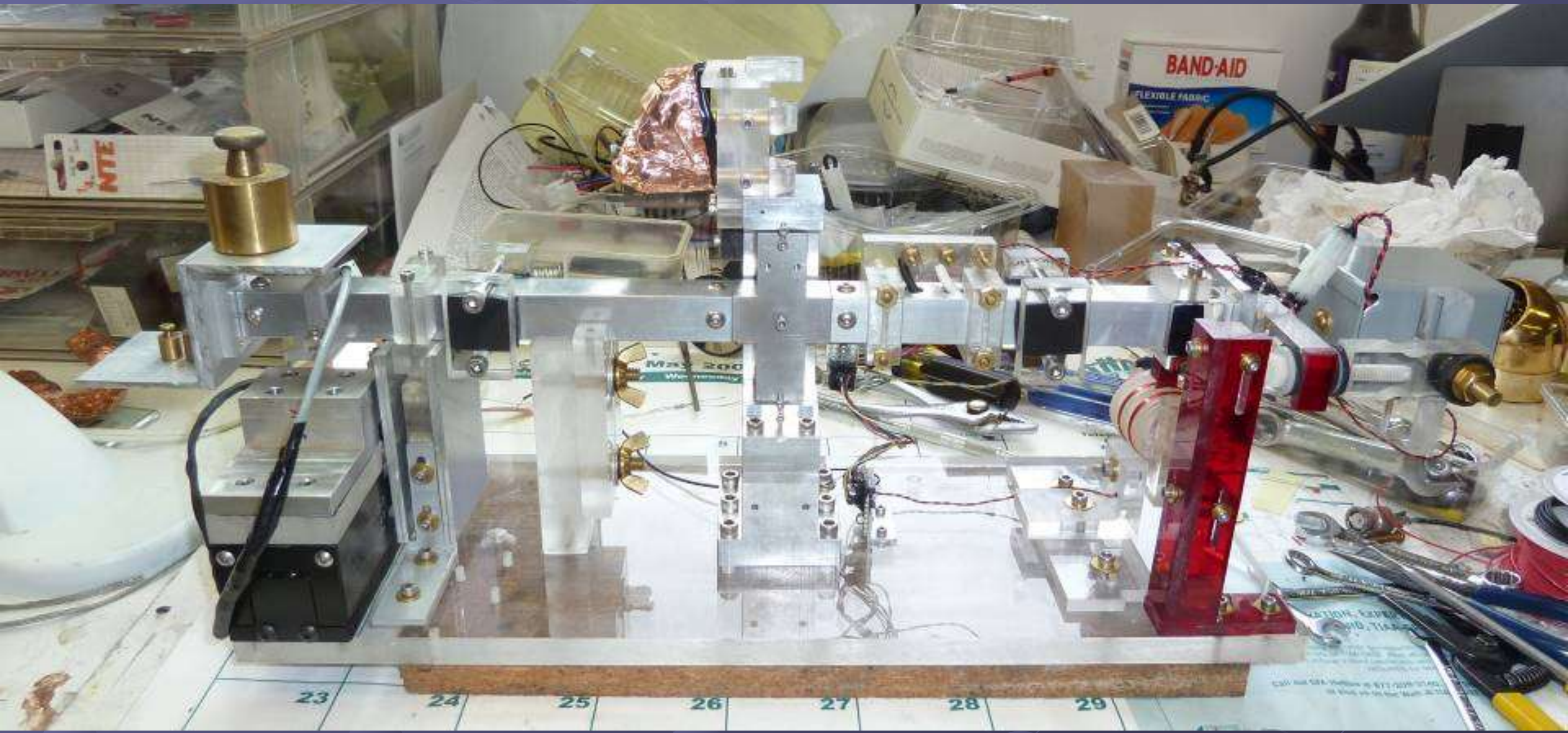


UUT Axis
of Rotation
needed for
Thrust
Reversals

Preliminary

PZT-Stack Faraday Shield and copper power feed shield were added to minimize any EMI effects and possible coronal induced sonic winds. Since the PZT stack's peak drive voltage does not exceed 200V-p, the likelihood of these effects occurring are very small even without these shields in place.

The current version of the ARC-Lite Torque Pendulum with mounted PZT-Stack in Faraday Shield partially reassembled.



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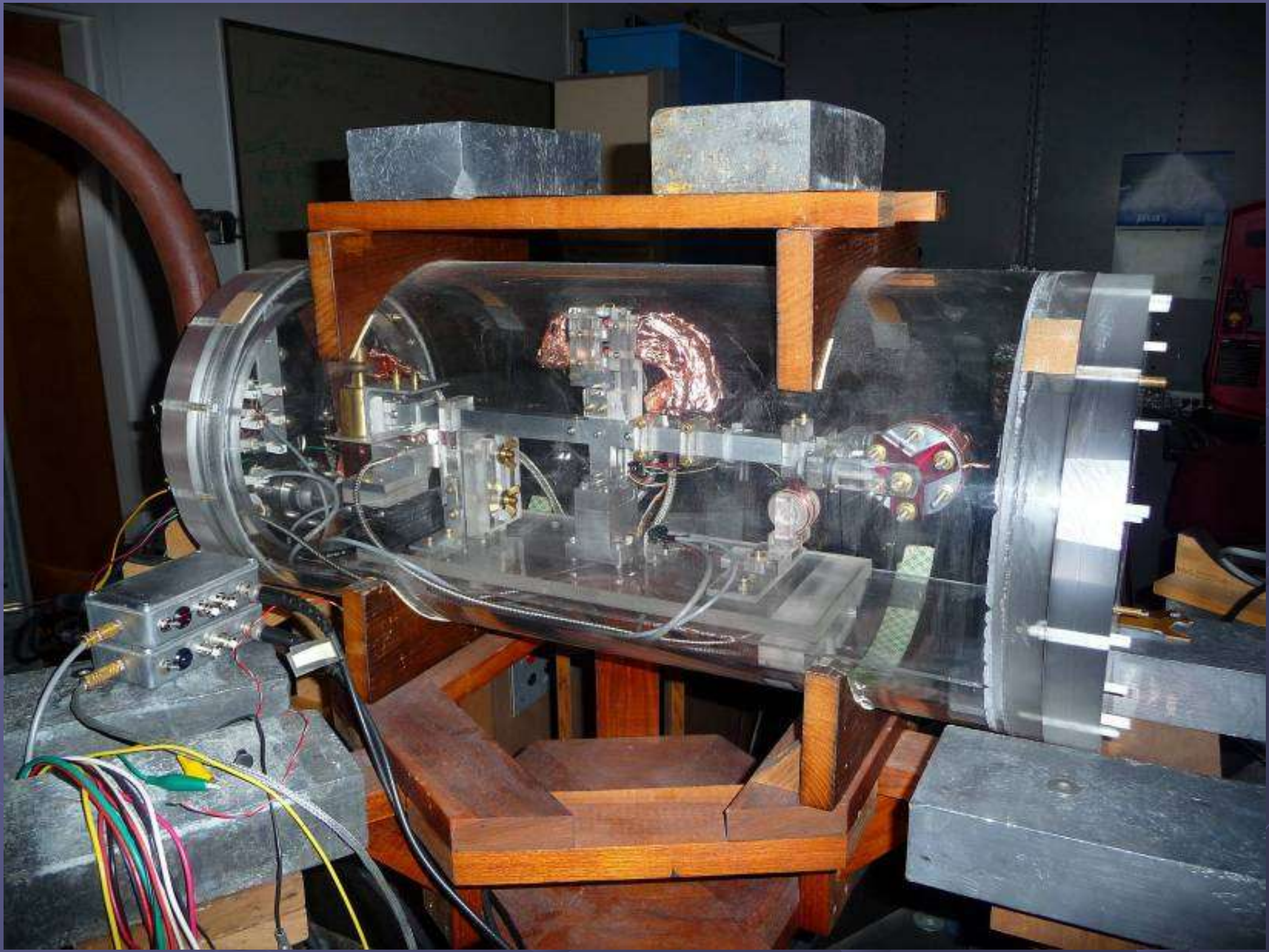

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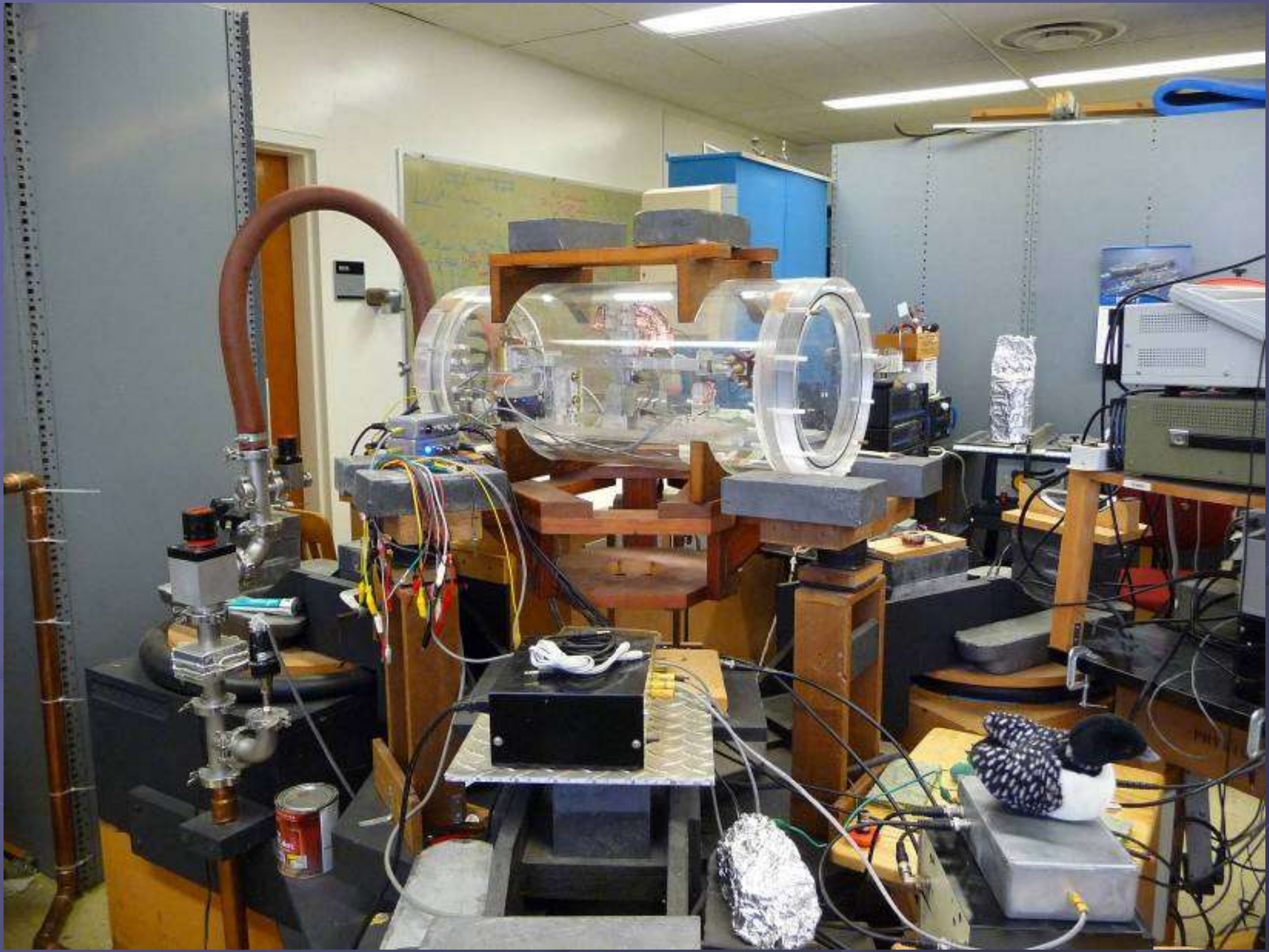
The Arc-Lite balance in the vacuum chamber during a previous test. Normal operating conditions were vacua of a few milli-Torr as only a rotary vane pump was used.

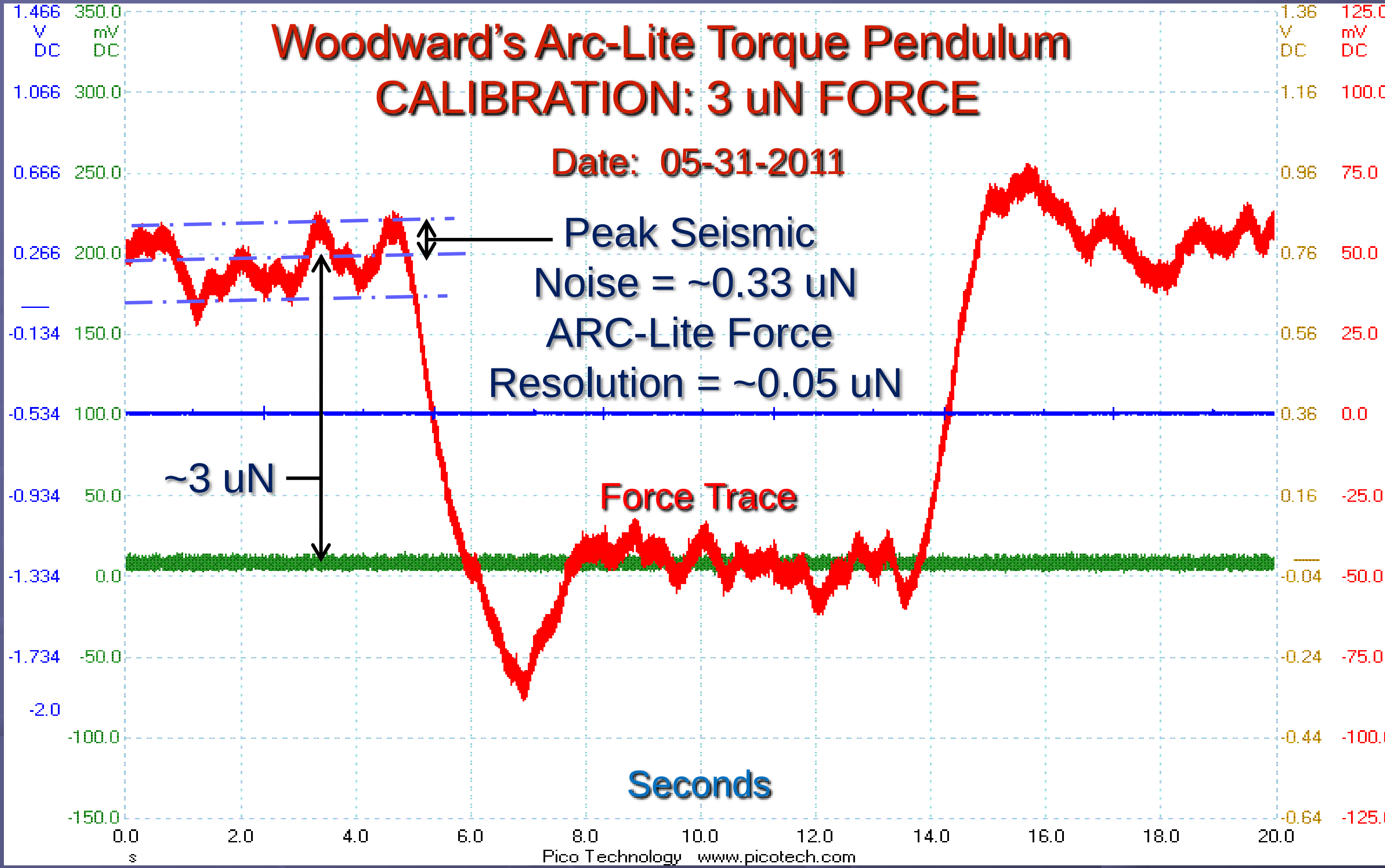


The ARC-Lite Pendulum & vacuum chamber on its vibration isolation table surrounded by sundry electronics in Woodward's CSUF Laboratory.

Preliminary

PICOSCOPE TRACES OF CALIBRATION TRACE

Preliminary



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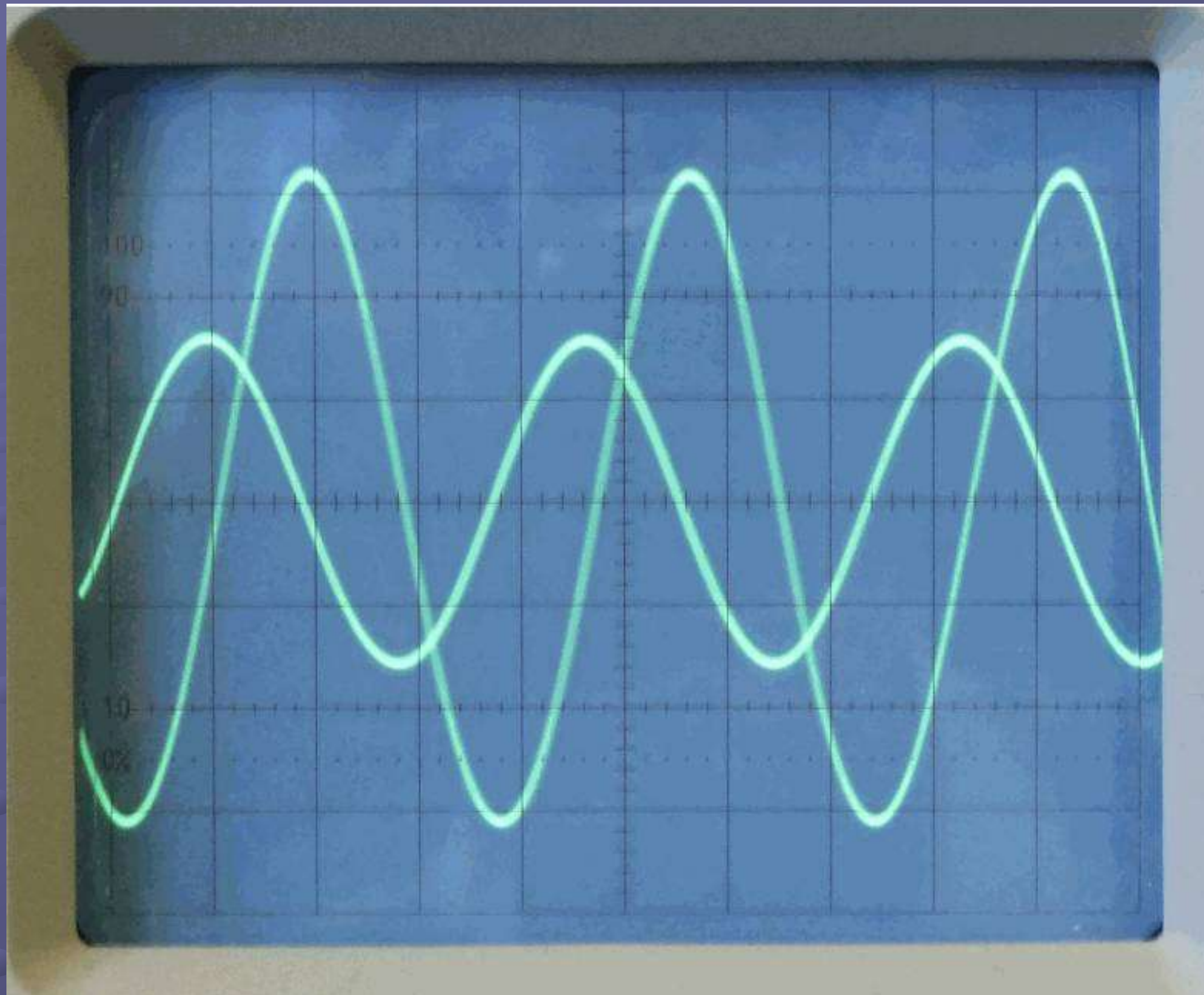
A thrust calibration trace. The voltage signal to the calibration coils is simply switched on, and then after several seconds, switched off. The shift in the red thrust trace – about 100 mV (note the same scale as the preceding cycle plots) – is produced by a current of 100 milli-amp in the calibration coils, each having 10 turns with a diameter of 3.0 cm, and the coils being separated by a distance of 1.2 cm. This returns about 3 uN for a 100 mV thrust signal. Note that while the beam is not quite critically damped, there is only slight overshoot and no bounce in the thrust signal.

1 OMEGA RESULTS

Preliminary



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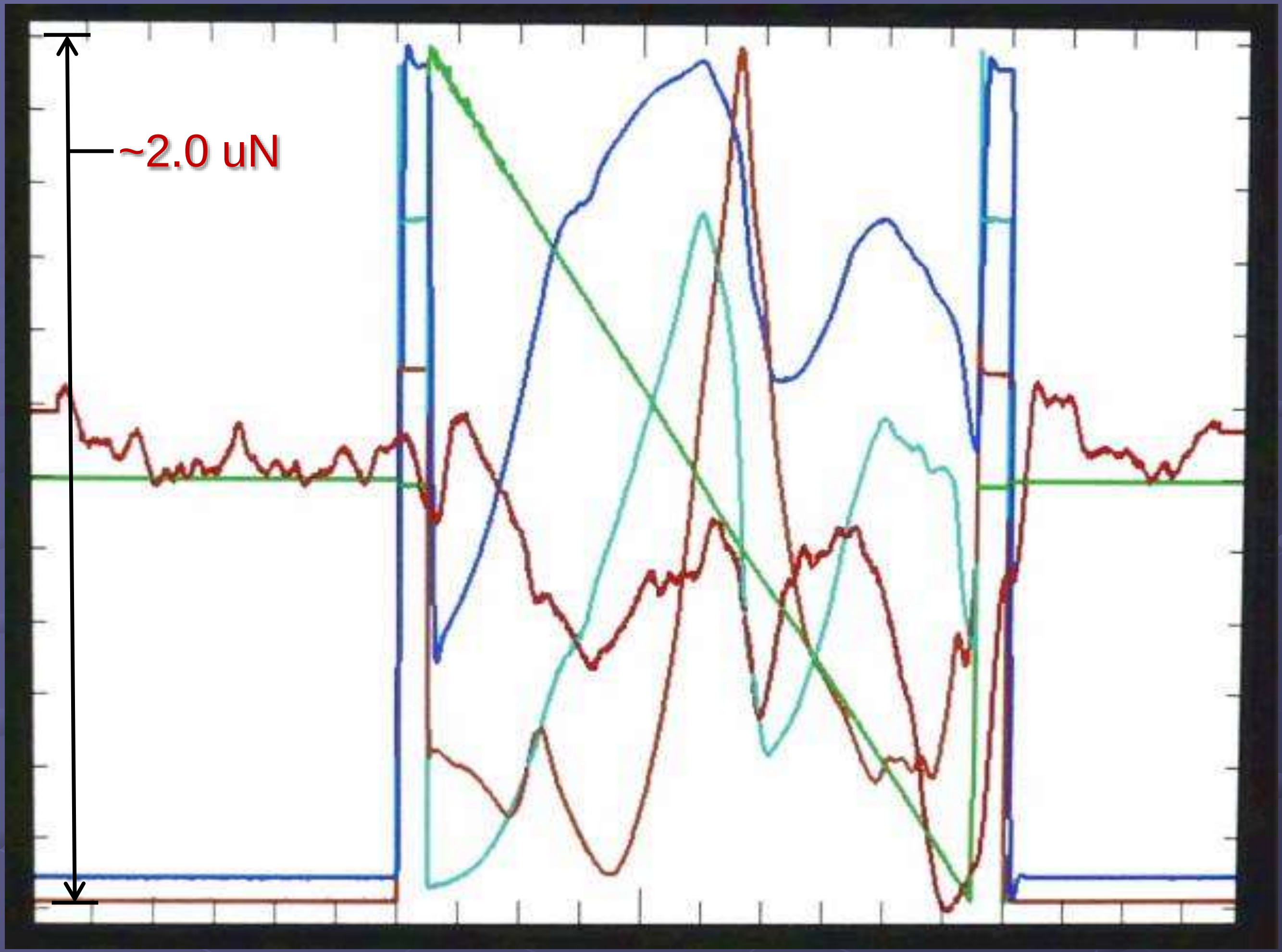
The generator signal (low amplitude) and voltage signal applied to the PZT stack (high amplitude). Note that both are pretty clean sine waves that do not exceed **200 Volts-p** between 75 kHz and 45 KHz for the 1-ω mass fluctuation signal.



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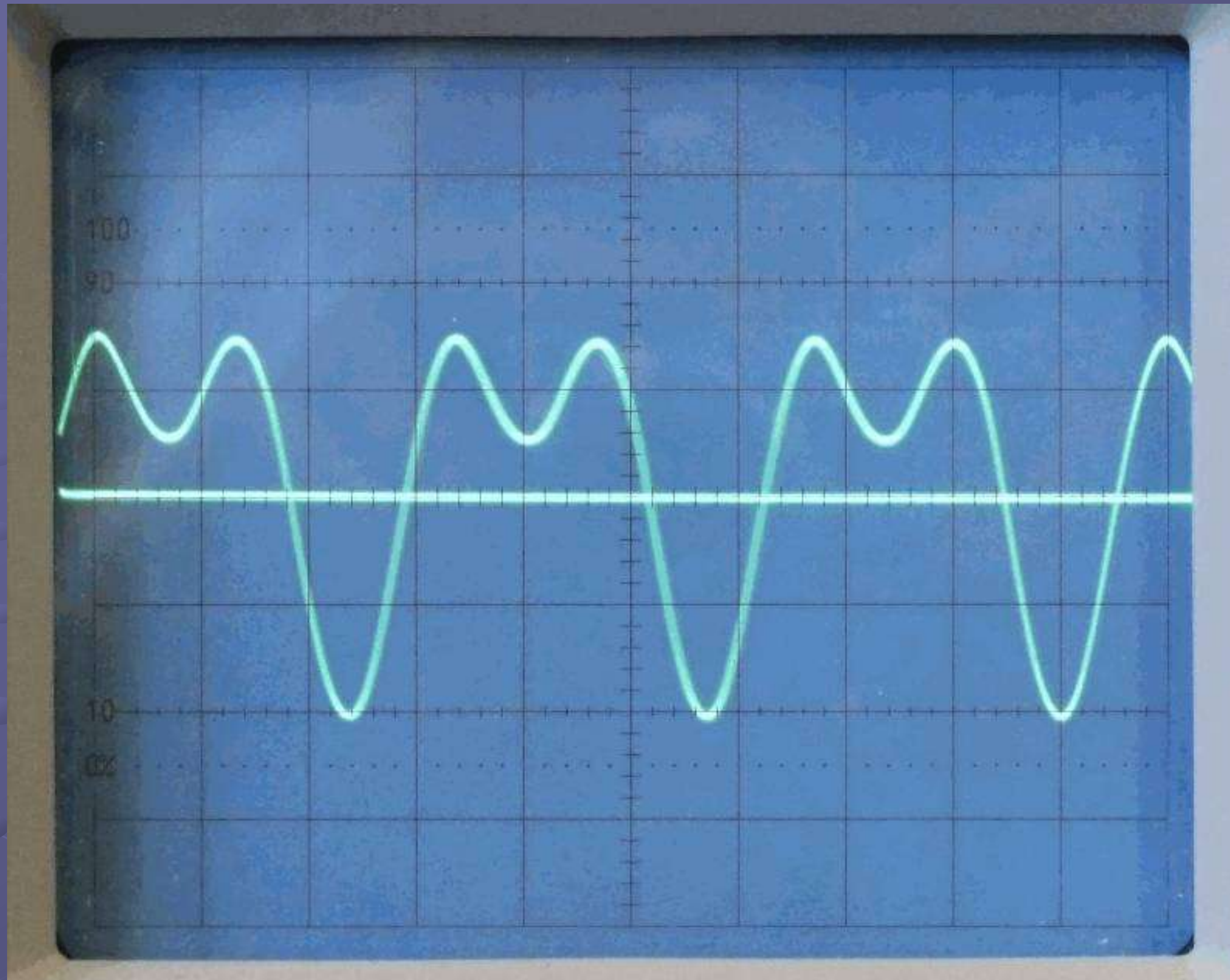
The average of 35 sweep cycles taken in runs on two days. The thrust scale is fixed to one typical of full scale results for two frequency data – about 2 uN full scale. The thrust spikes at resonance and toward the end of the sweep seem to result from the excitation of a second harmonic signal in the PZT material by the single frequency applied signal. The color scheme of the traces is: Red: thrust; Green: frequency; Brown: stack accelerometer; Light blue: applied power (square of the applied voltage measured near the amplifier); Dark blue: applied voltage (measured on the beam of the thrust balance).

1 + 2 OMEGA RESULTS

Preliminary



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Displayed is the two frequency driving signal with phase relationship at 1ω = 60 KHz, which is the center frequency of the 30 KHz sweeps between 75 KHz and 45 kHz and is used in the results described in the following slides. This phase relationship changes markedly as the frequency sweep progresses.

Comments on PZT-Stack Frequency Sweep Responses

- Little or nothing happens above 60 KHz because not much power at either frequency gets through at higher frequencies due the bandwidth limits of the Carvin Amplifiers driving the impedance of the PZT stack.
- The most interesting data are from the PZT Stack accelerometer spectra.
- With only one frequency excitation, the nonlinearity of the PZT stack generates higher harmonics as recorded by the stack accelerometer.
- Even with single frequency excitation, you still get a thrust effect like that seen in the double frequency results, but with smaller amplitude.

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THRUSTS MEASURED WITH THE DEVICE ORIENTED IN ONE DIRECTION ONLY ARE SUSCEPTIBLE TO ARISING FROM SPURIOUS CAUSES. THEY MAY BE ELIMINATED BY REVERSING THE DIRECTION OF THE DEVICE, AND SUBTRACTING THOSE RESULTS FROM THOSE OBTAINED IN THE INITIAL ORIENTATION.

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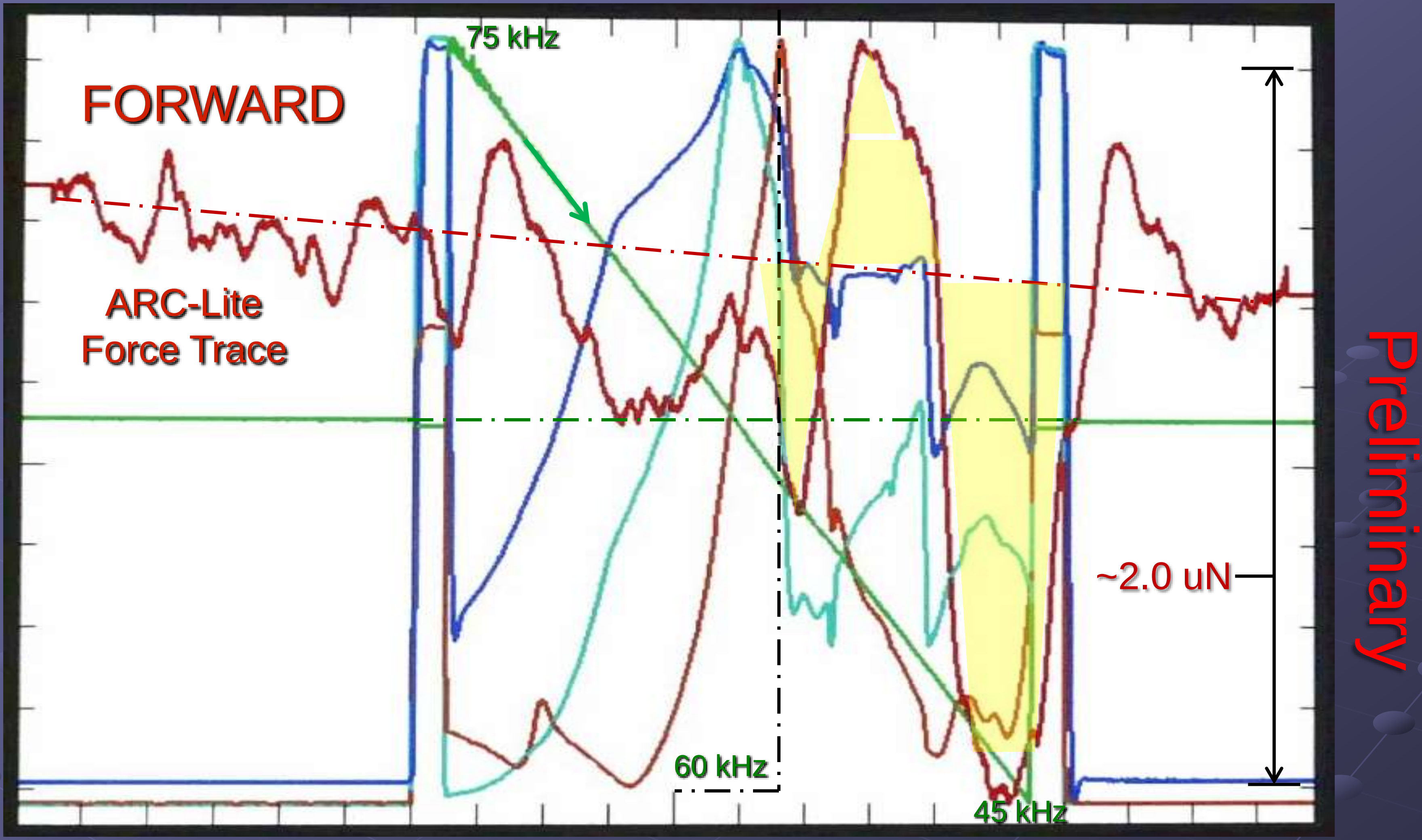
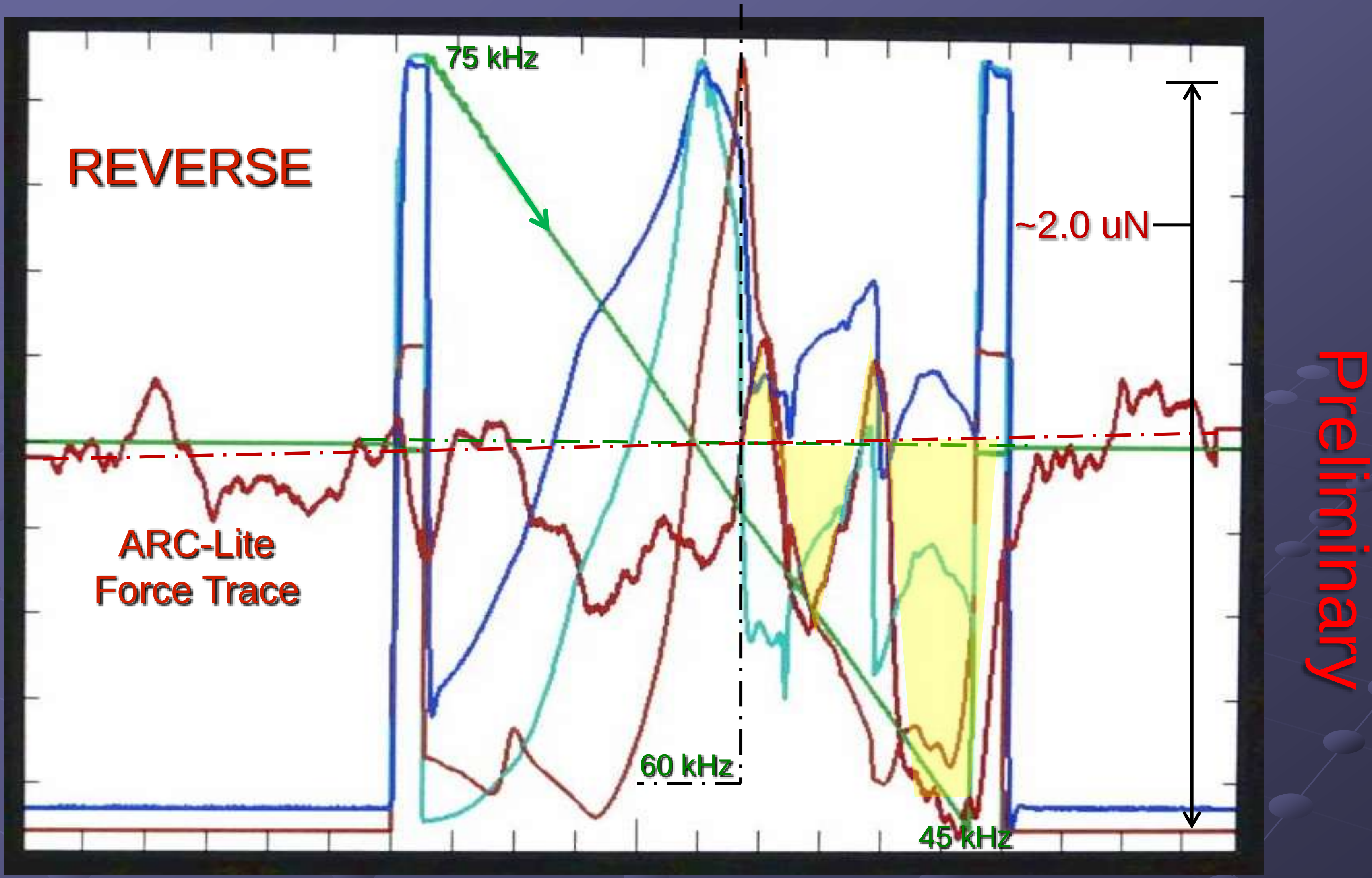
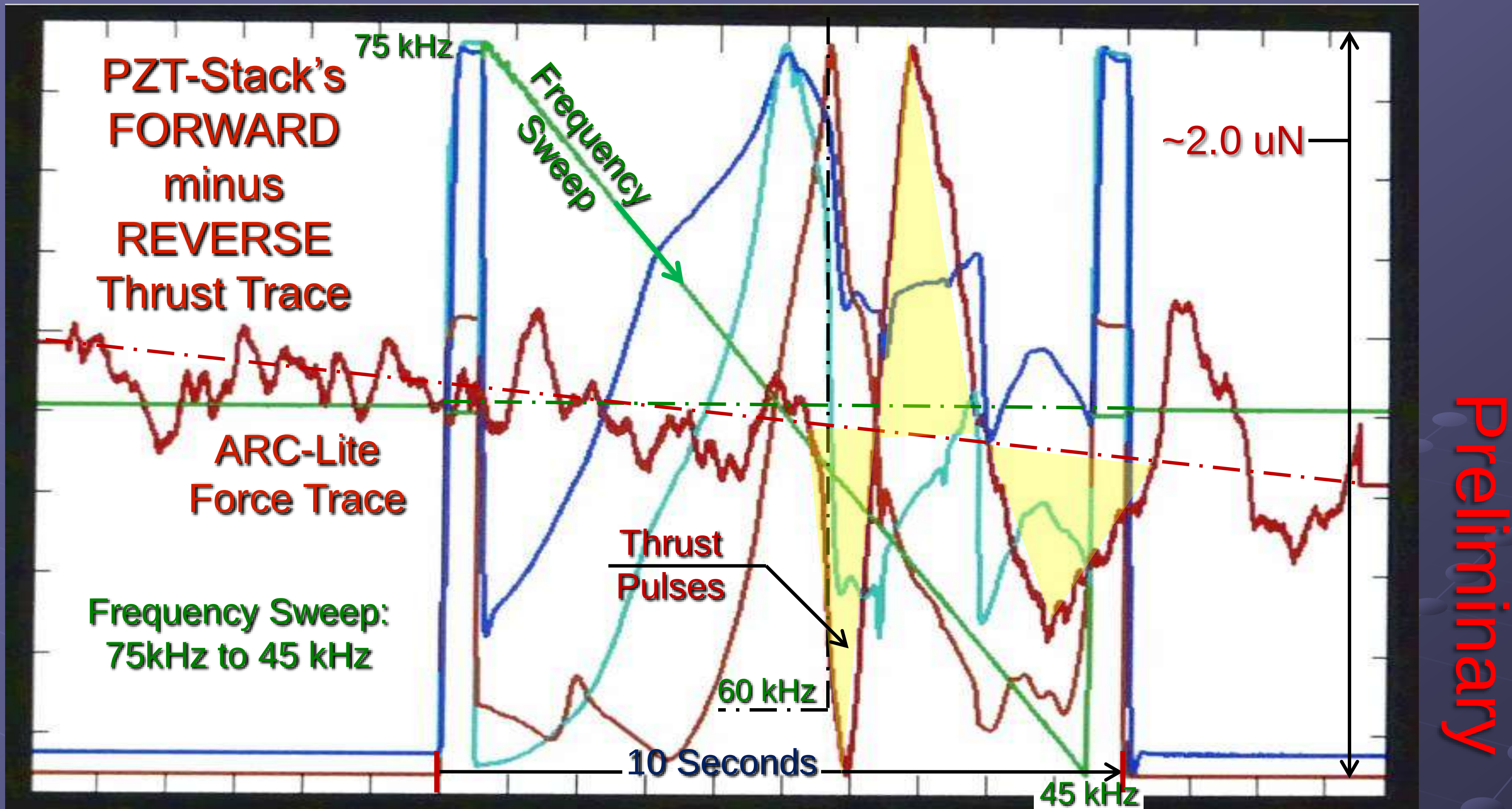


The average of 20 cycles taken with the device oriented to the **"left"** on the ARC-Lite torque pendulum. As in the single two frequency Picoscope trace, <u>thrust signatures appear when the swept frequency falls below 60 KHz</u> – **to the right of the center of the traces.** Half of the cycles were taken before, and half after 20 cycles were taken with the orientation of the device reversed, shown in the next slide.



The averaged results for 20 cycles taken with the device oriented to the **"right"**. Note that the full-scale thrust is the same as in the previous slide. <u>The thrust signature at the resonance is in the opposite direction</u>, and the thrusts for lower frequencies (to the right) also differ. Observations points to 1ω & 2ω phase shifts as the cause for these wild thrust direction swings as the drive frequency descends.



The color scheme of the traces is: Red: thrust; Green: frequency; Brown: stack accelerometer signal; Light blue: applied power; Dark blue: applied voltage (measured on the beam of the thrust balance).

The difference of the Forward and Reverse slides. The differencing procedure eliminates all thrust signatures that are common to the two orientations of the device – those that may arise from various spurious causes. The Mach effect thrust, if present, should reverse direction when the device's orientation is reversed by rotation on the end of the thrust balance beam. Were there no Mach effect thrust present, there would be no thrust signal in this plot. Evidently, there is a thrust signal – at the level of about **1.0 uN** – that reverses direction as the frequency sweeps down through the stack's mechanical resonance at **60 KHz and below**, (where the second harmonic of the voltage signal is not completely suppressed by the limitations of the power amplifier and low pass characteristics of the power circuit).

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VACUUM VARIATION < 10 mT AND > 200 mT

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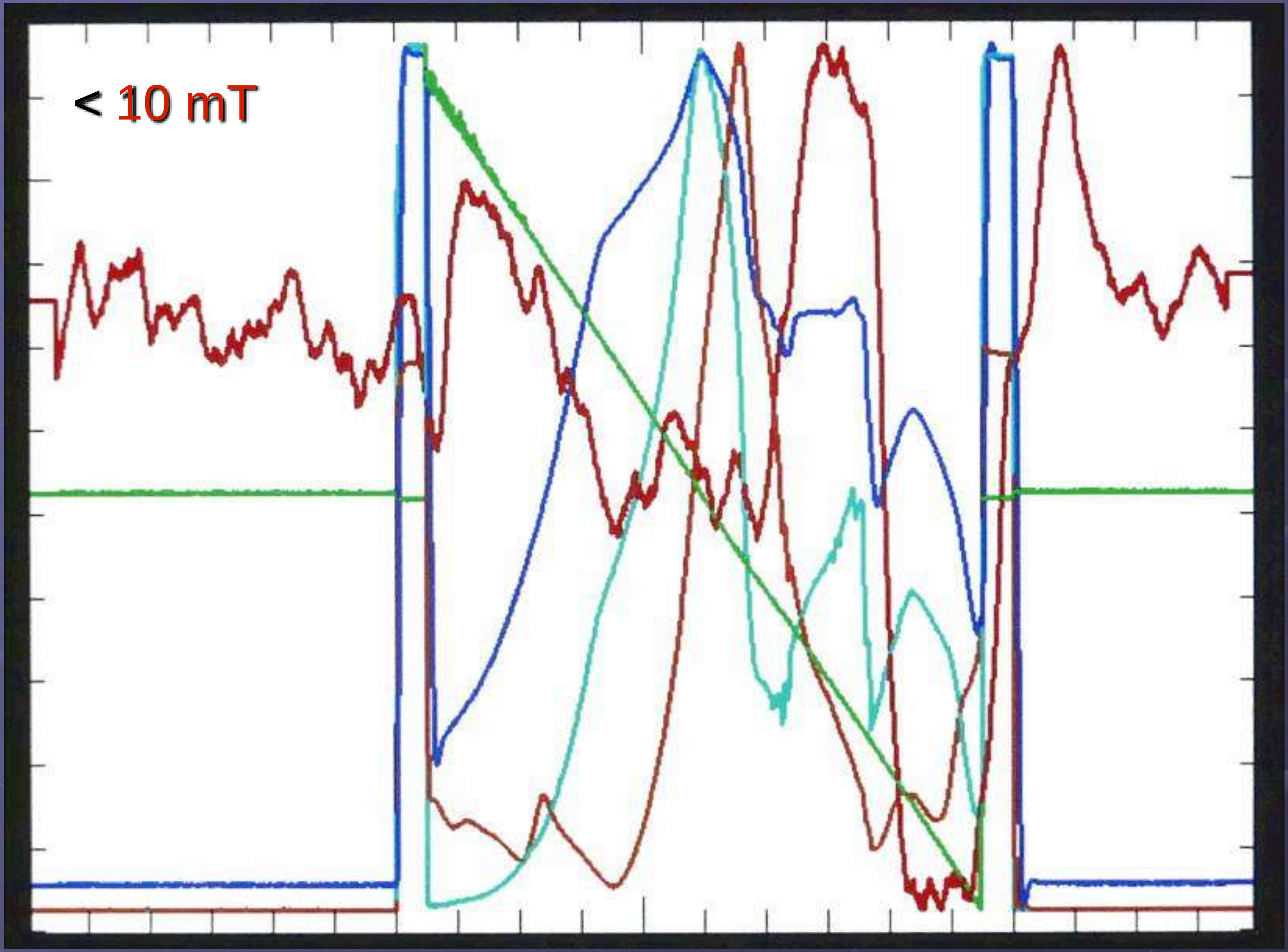

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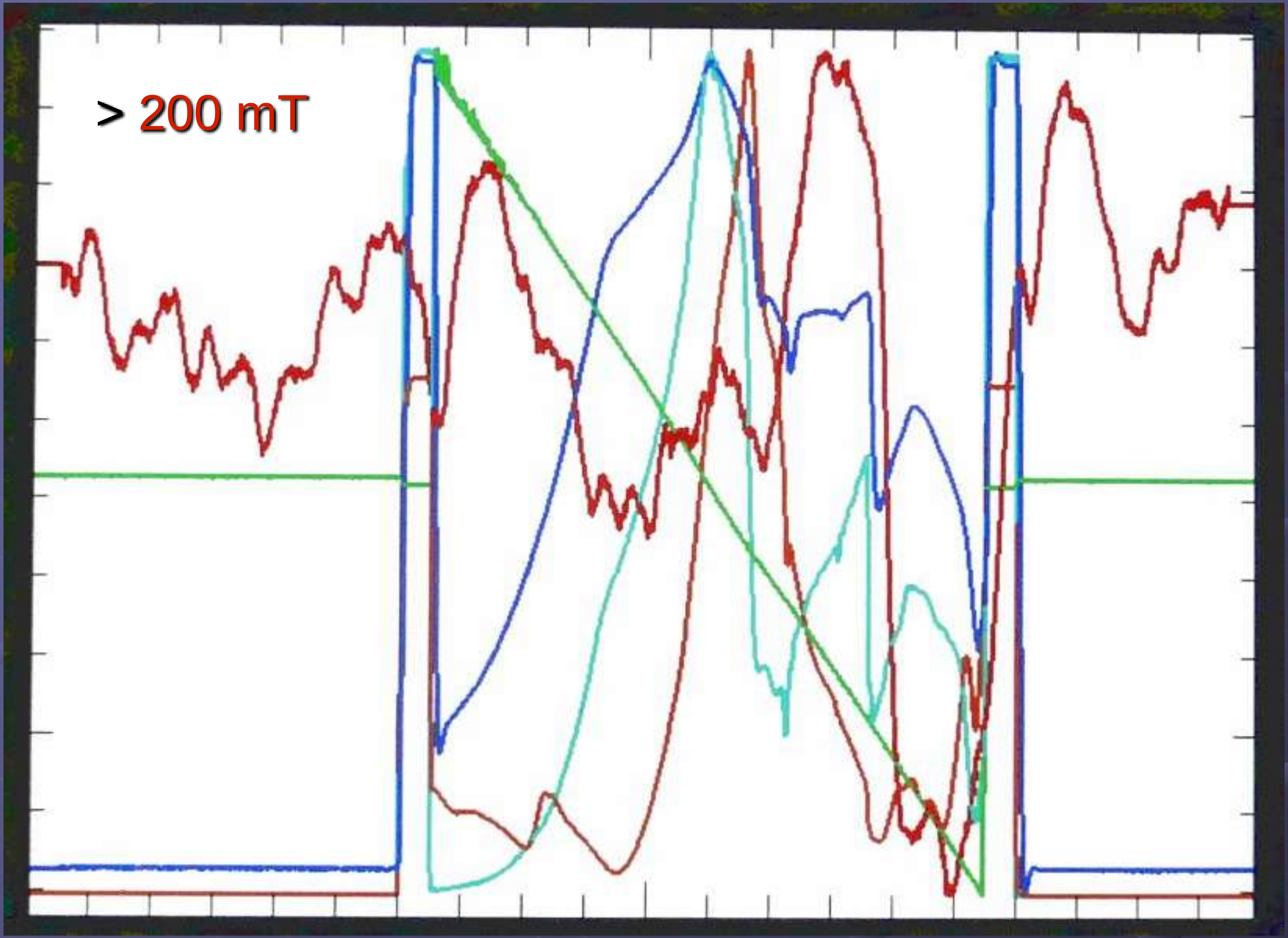

Preliminary

Conclusion: No Sonic Wind contributions to this thrust signature are present.