Magnetic Noise at LIGO-Livingston

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- We have made some systematic measurements of the magnetic noise at the LIGO Livingston Observatory.
- **Good News** 1: The fundamental physics of this source is simple, and the complications can probably be handled, because it is possible to measure B-fields and B-gradients down nearly to the levels required for LIGO I.
- **Good News** 2: It is pretty quiet at the Yarm endstation.
- **Bad News** 1: It is noisy at the corner station (LVEA), where there is large "broad-band" magnetic noise from 40 to 100Hz. This noise is probably LIGO equipment, and does not go away when we shut off non-essential equipment.
- **Bad News** 2: The B-Gradients at the power line frequencies are large, and vary rapidly with position, so they will be hard to balance out.

Magnetic Coupling

- Attached to each mirror are 6 small dipole magnets for alignment and control

- Here we mostly ignore the pure torque $\vec{\Gamma}$ on each magnetic dipole $\vec{\mu}$, which is $\vec{\Gamma} = \vec{\mu} \times \vec{B}$

- And concentrate on the magnetic force $\vec{F}$ on each dipole, which is proportional to the B-gradient

$$\vec{F} = \left(\vec{\mu} \cdot \vec{\nabla}\right)\vec{B}$$

- Most the dipoles are aligned with the optic axis, call it *x*, so the most important gradient is $\nabla_x B_x$ which determines the force parallel to the axis

$$F_x = \mu_x\left(\nabla_x B_x\right)$$

- Since the mirror reacts like a free mass *m*, the resulting displacement $\tilde{x}(\omega)$ due to a single magnet is

$$\tilde{x}(\omega) = \frac{\mu_x\left(\nabla_x B_x\right)}{m\omega^2}$$

Measurement Technique

- A coil of wire, with N = # turns , A =area, oriented so that x is the coil axis, will have an induced voltage of

$$V_I(t) = NA\frac{dB_x}{dt} \rightarrow NAi\omega\tilde{B}_x(\omega)$$

so we can measure field $B_x(\omega)$ this way.

- If two coaxial coils are connected in series opposition, with seperation $x_2 - x_1$ then the net voltage is

$$V_{net}(t) = NA\frac{d}{dt}\left(B_x(x_2) - B_x(x_2)\right) \cong NA(x_2 - x_1)\frac{d}{dt}(\nabla_x B_x)$$

So we can measure field gradient $\nabla_x B_x$ this way

- Most often we have used 3 coils, to get field and field gradient simutaneously.

Experimental Details

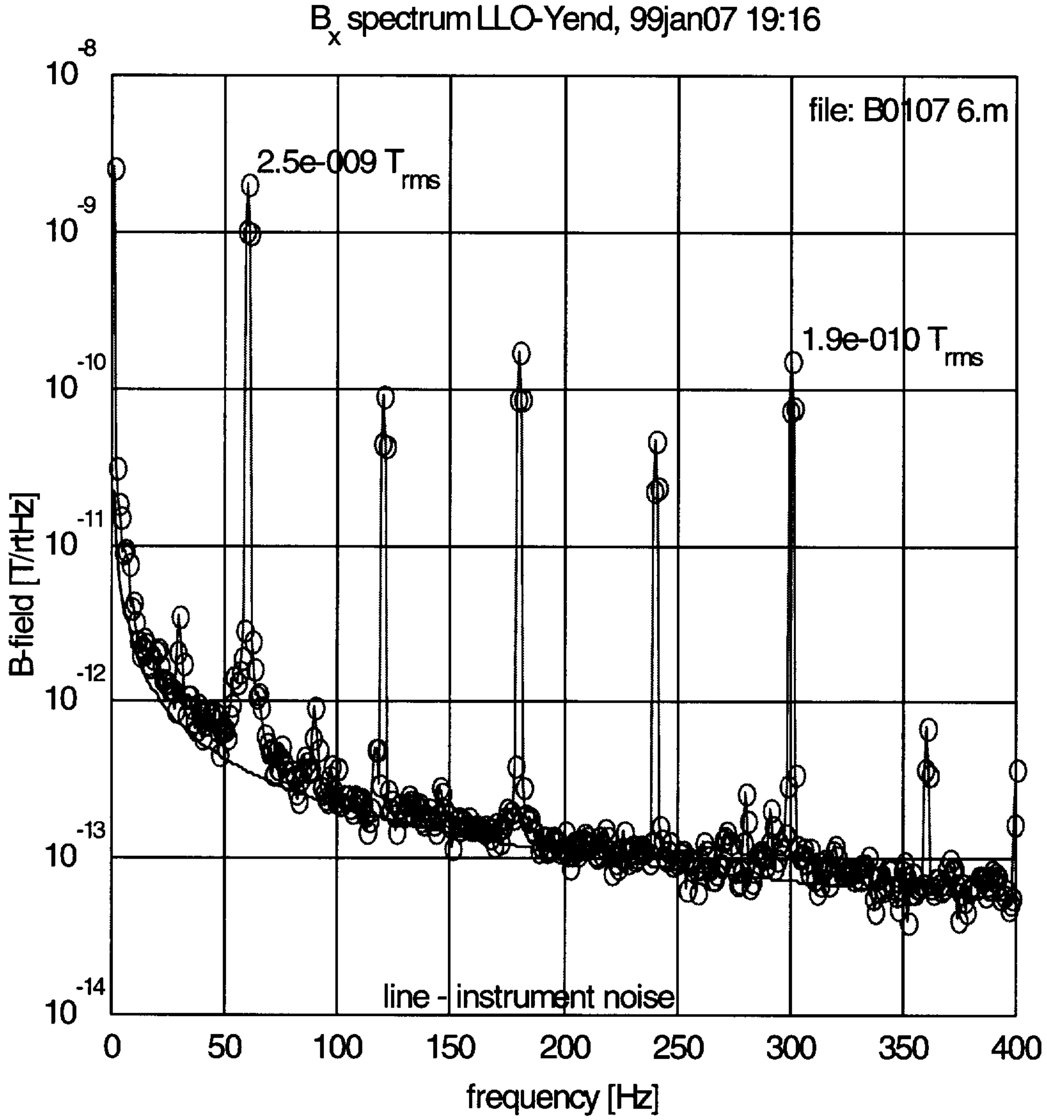
- The coils were solenoids of copper wire which are 20 cm long, have a mean diameter of 10.5 cm, and are wound on a plastic bobbin. They have 3400 turns, so the 'coupling coefficient' NA = 29.4 m^2 . They have a resistance of 60 Ω, and an inductance of 0.9 H.

- Possible stray coupling to electric fields was eventually eliminated by building a electrostatic sheilding box out of printed circuit board, which has a layer of copper for an electrostatic sheild.

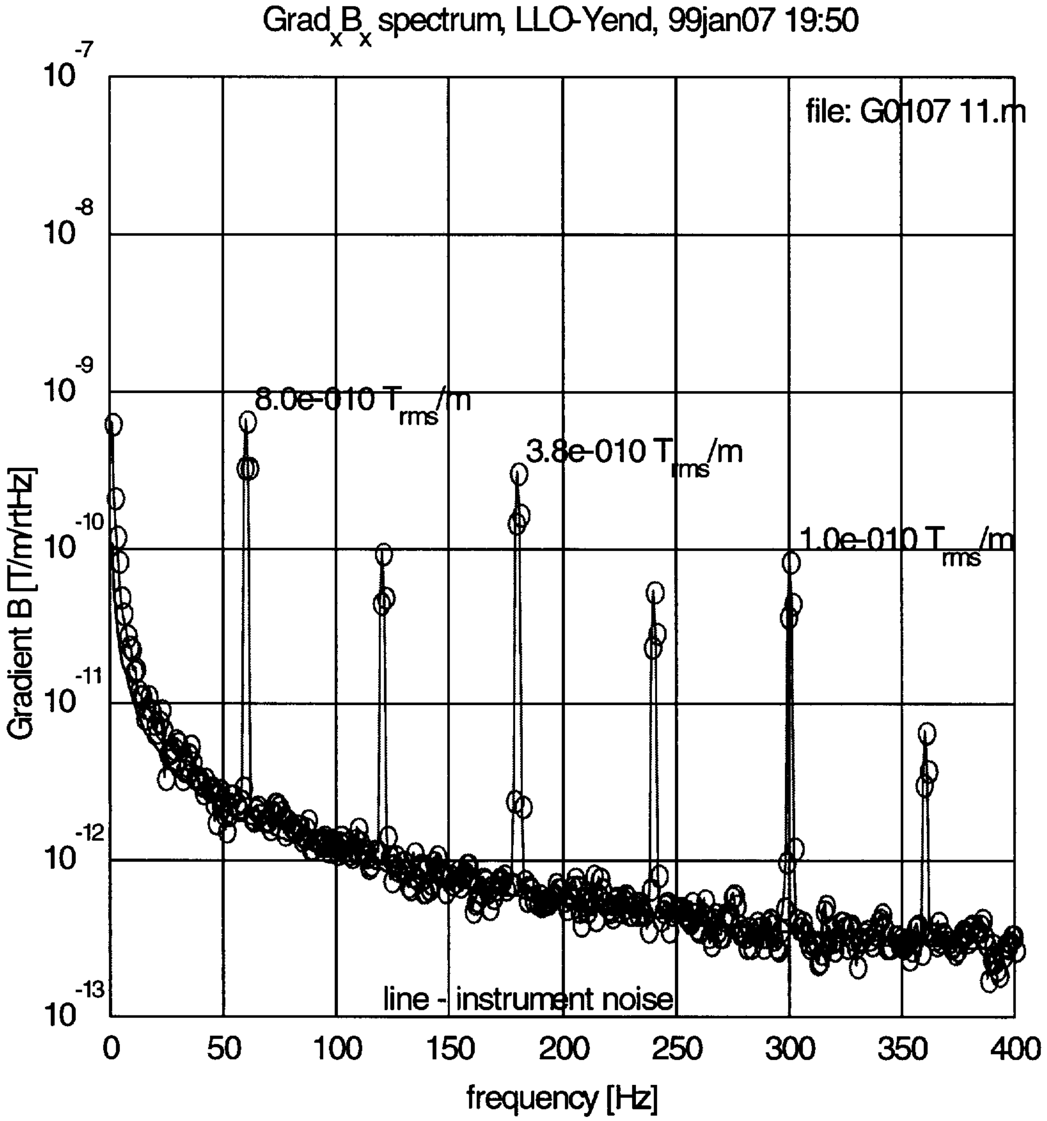
- An amplifier with a measured voltage noise of ~4 nV/rtHz was used. It is the main source of instrumental noise, which translates into a B-field noise of

$$|\delta B| = \frac{|\delta V_{net}|}{NA\omega} \cong \frac{4\times 10^{-9}\,\frac{V}{\sqrt{Hz}}}{29.4m^2(2\pi 60)} = 3.6\times 10^{-13}\,\frac{Tesla}{\sqrt{Hz}}$$

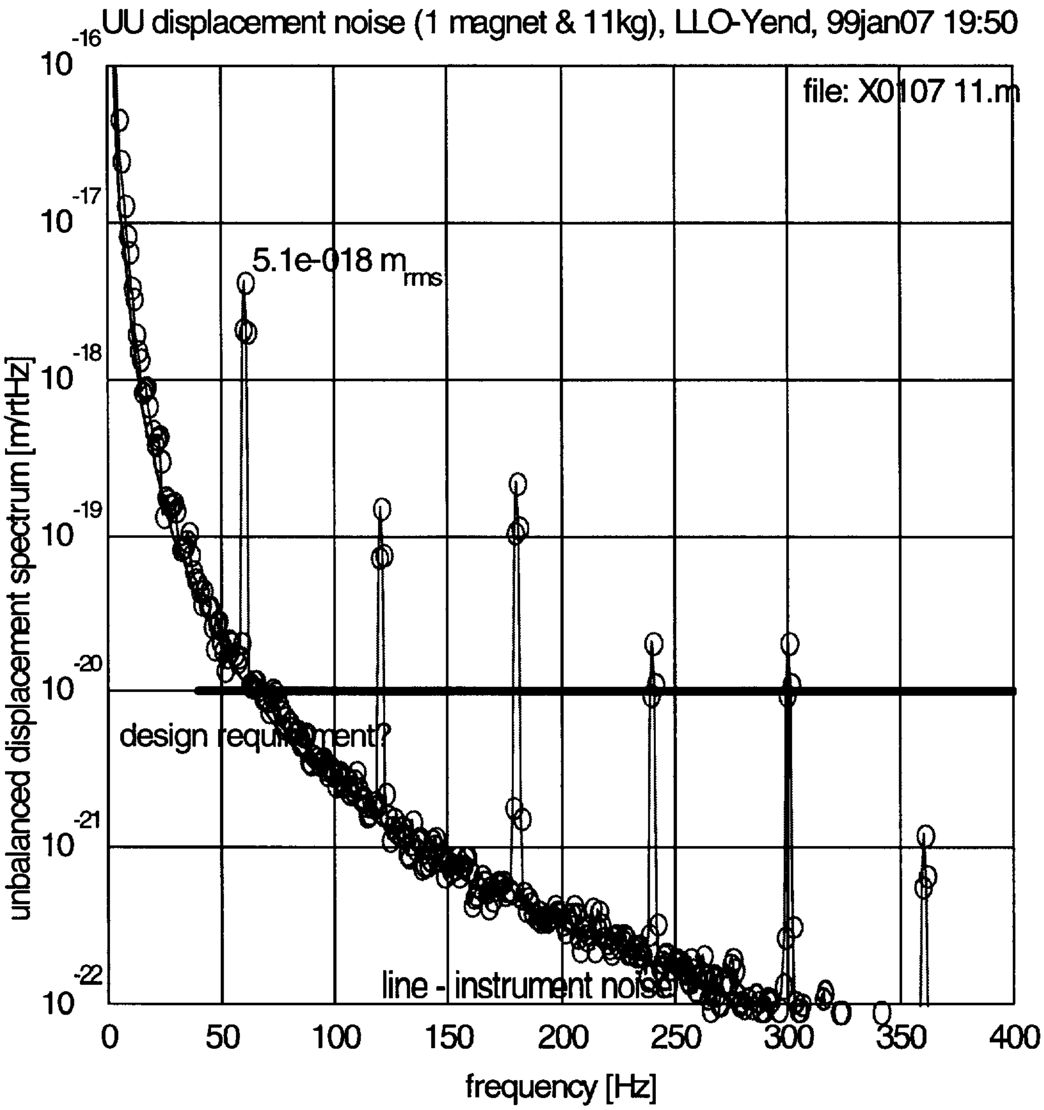
Good News : B-field noise is fairly low at Yarm endstation



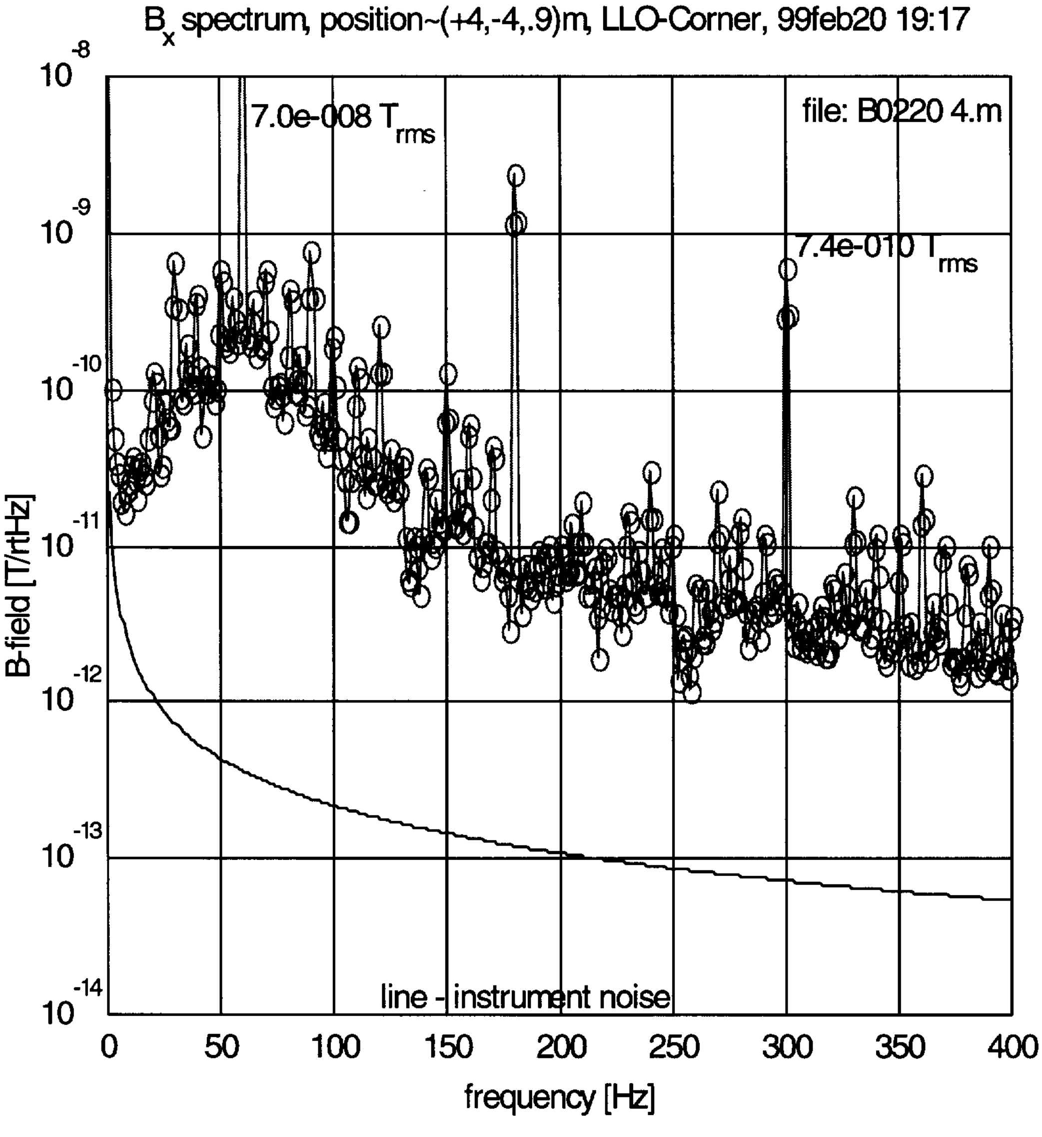
And the gradient is pretty small



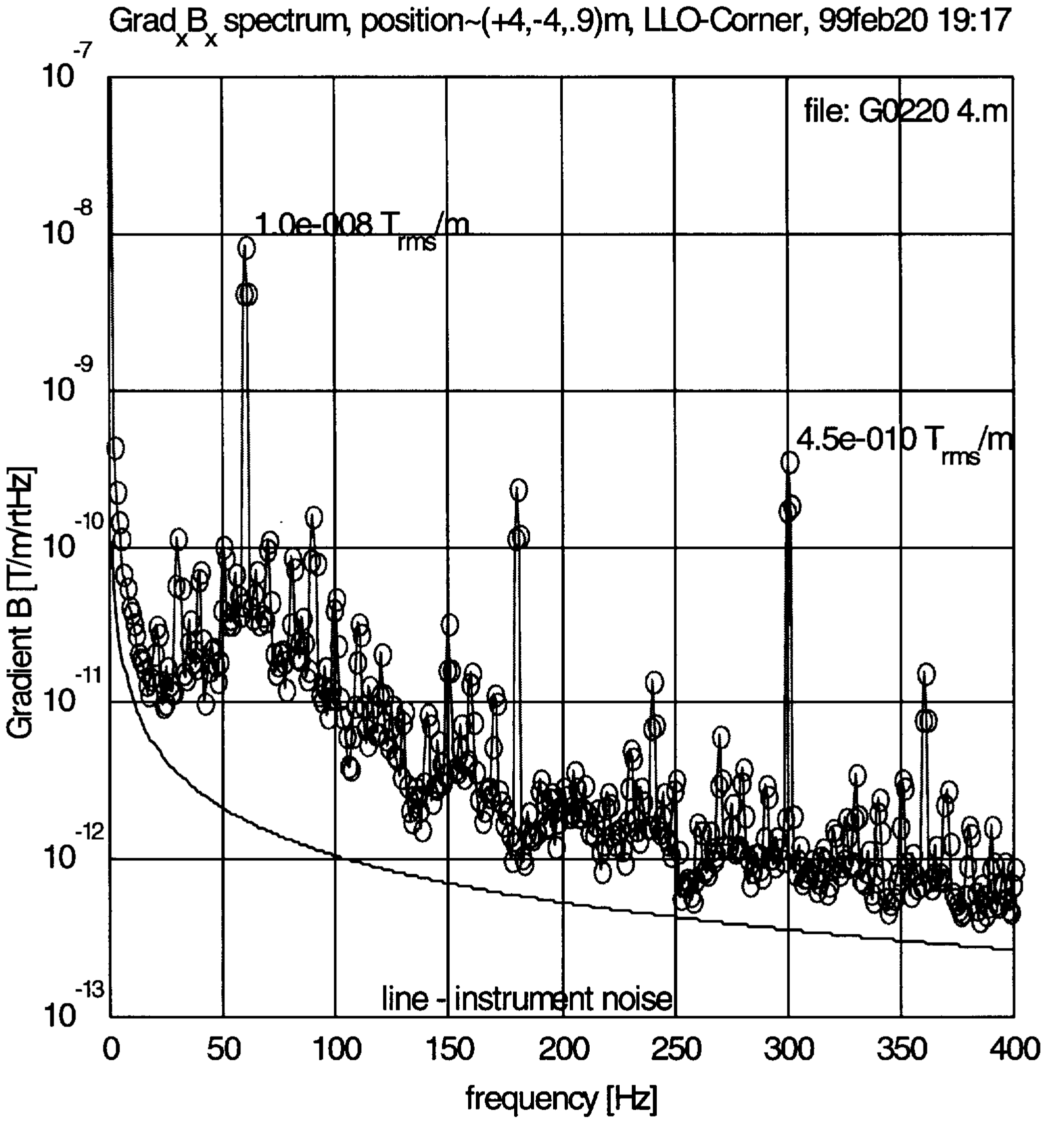
which translates into an Unsheilded, Unbalanced (UU)displacement noise



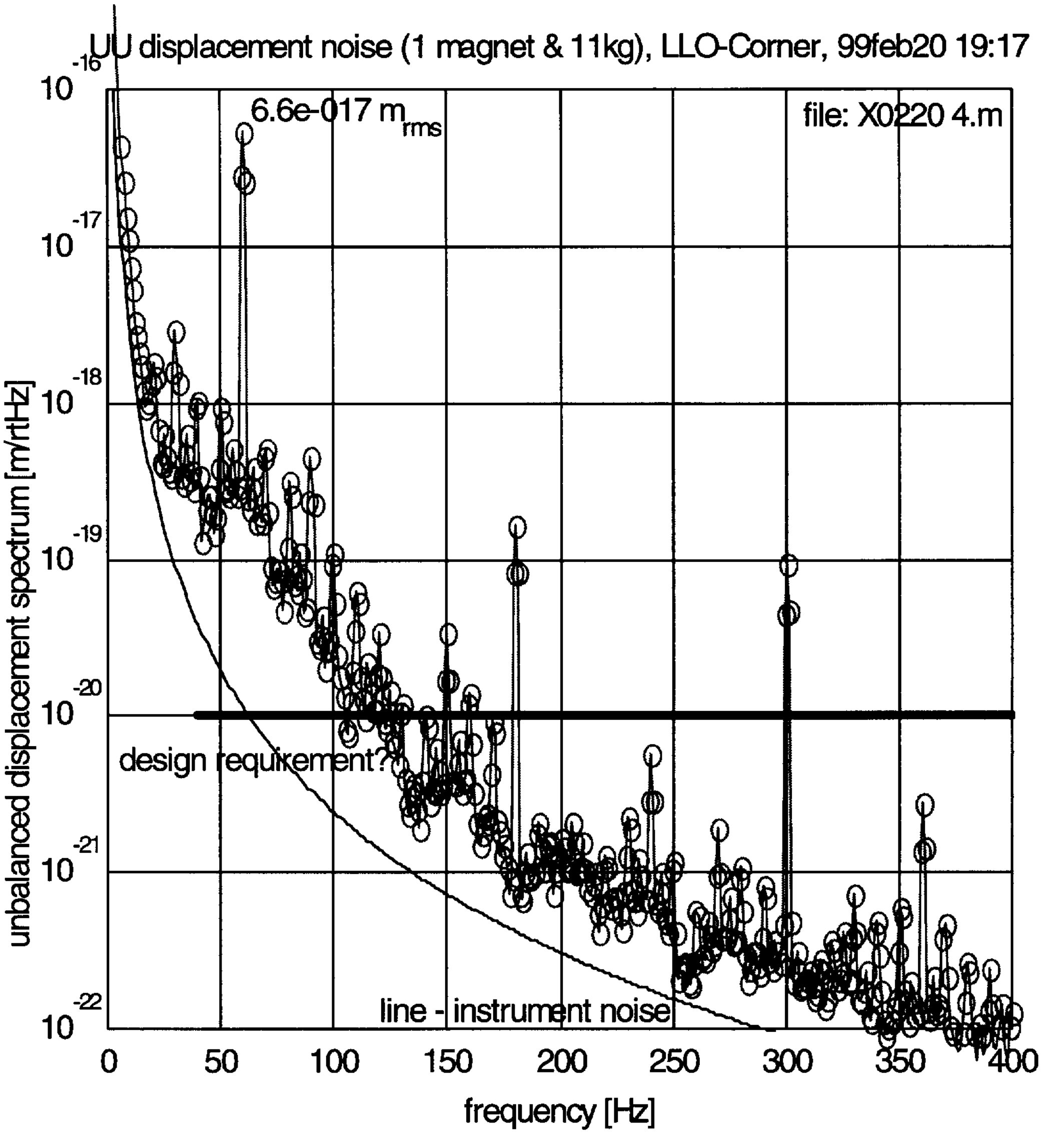
Bad News : much noiser in the Corner Station



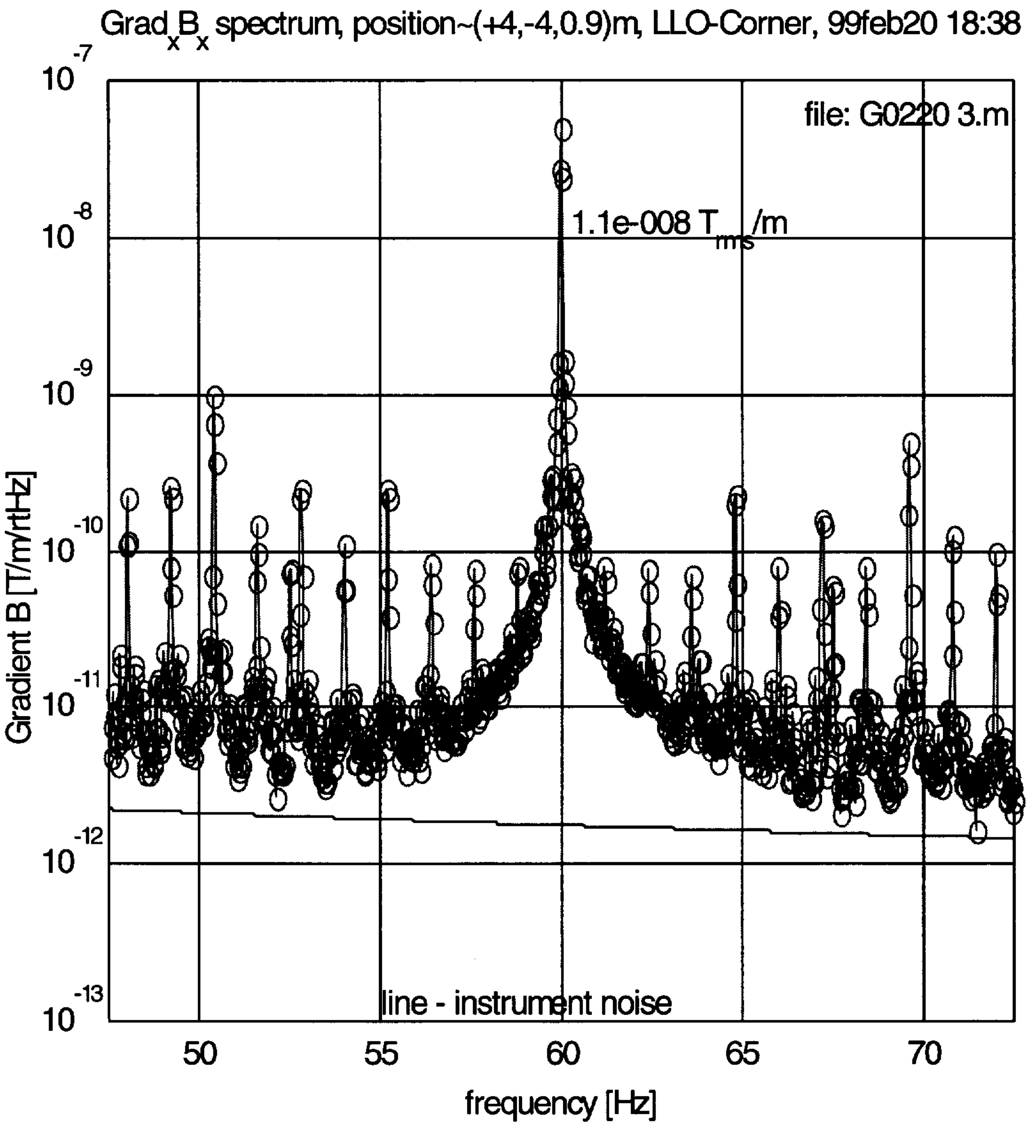
and a large gradient noise



which translates to an Unshielded Unbalanced (UU) displacement noise of

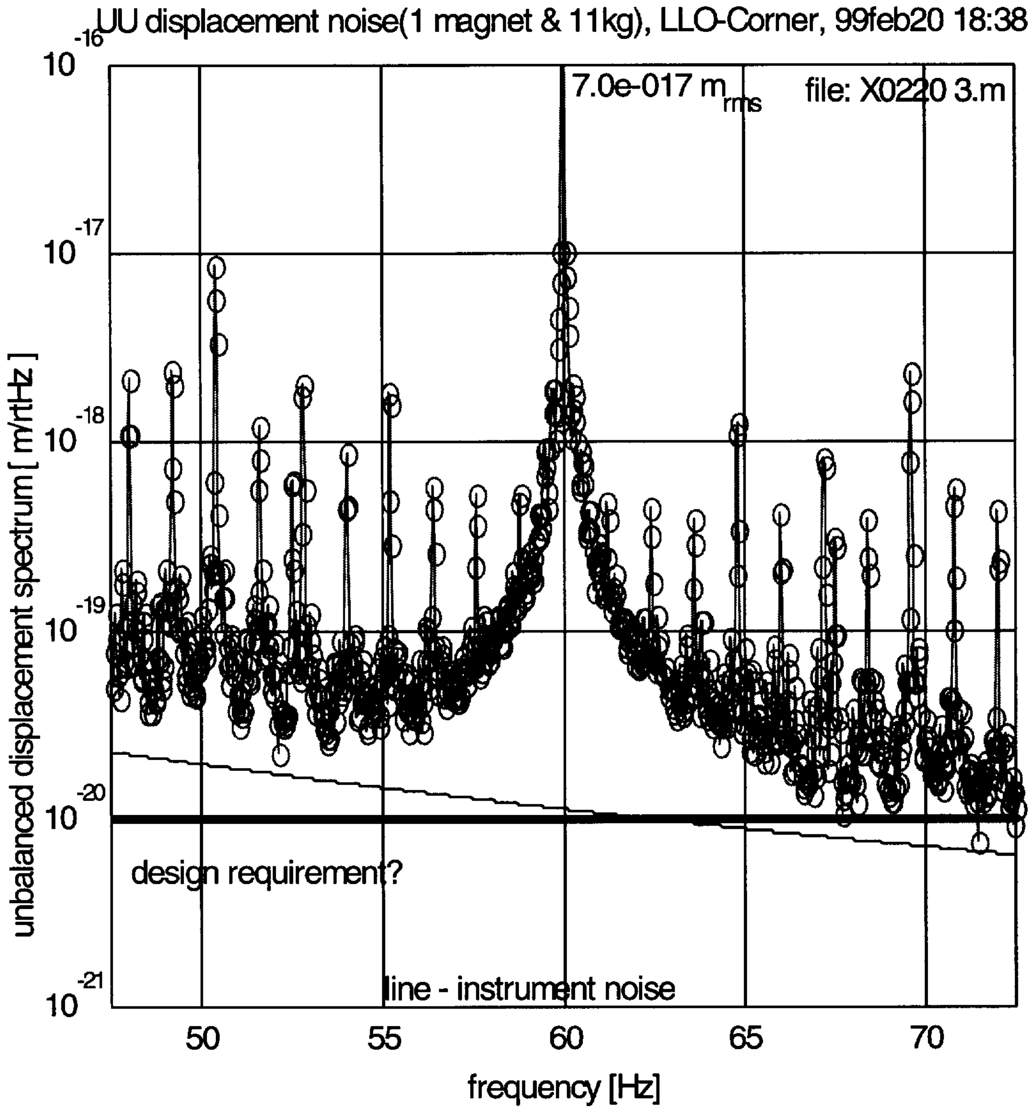


we can zoom in on the gradient noise



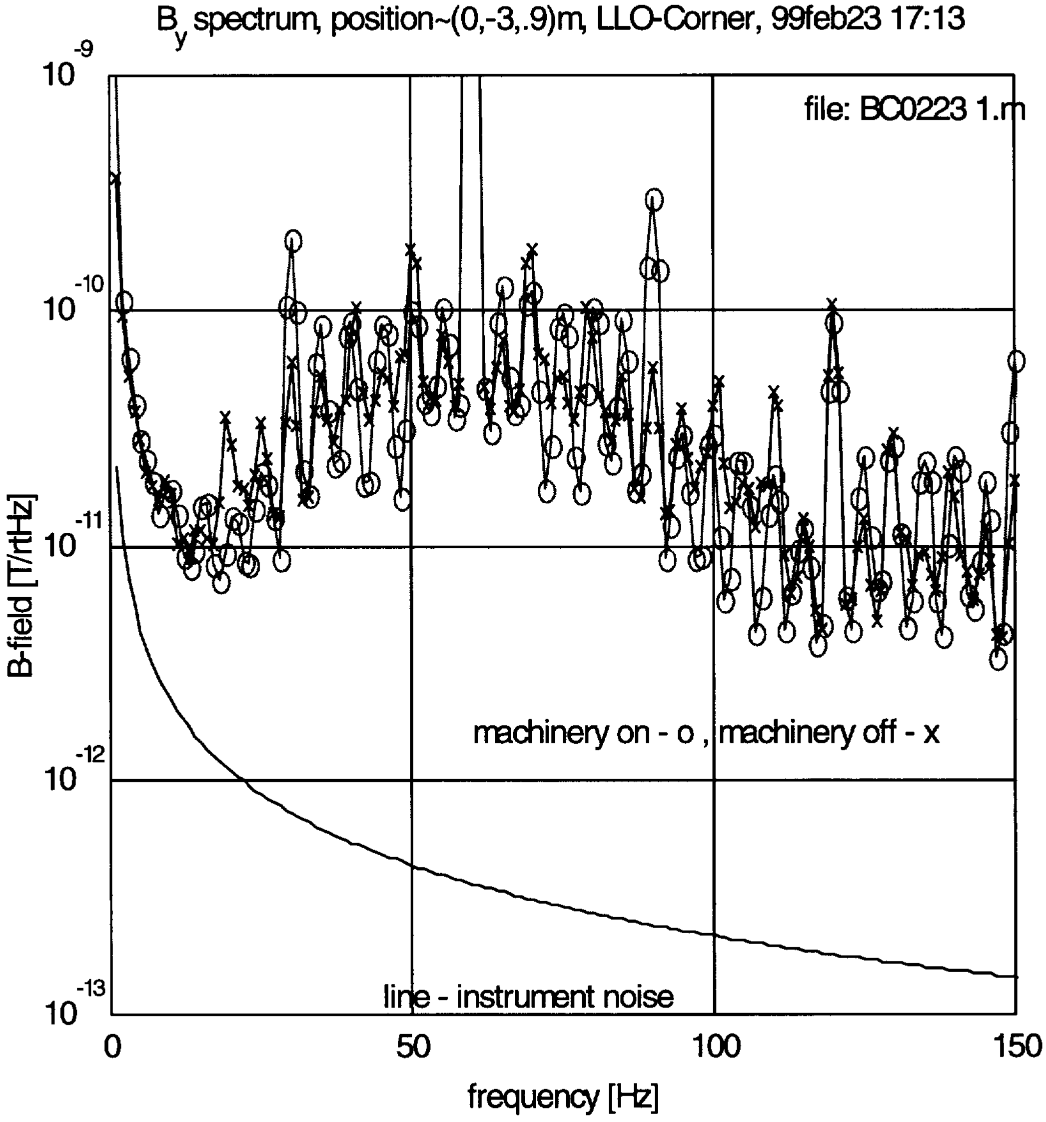
to see the broadband noise is mostly symmetric sidebands of 60 Hz, and therefore caused by some kind of electrical equipment

resulting in very large UU displacement noise



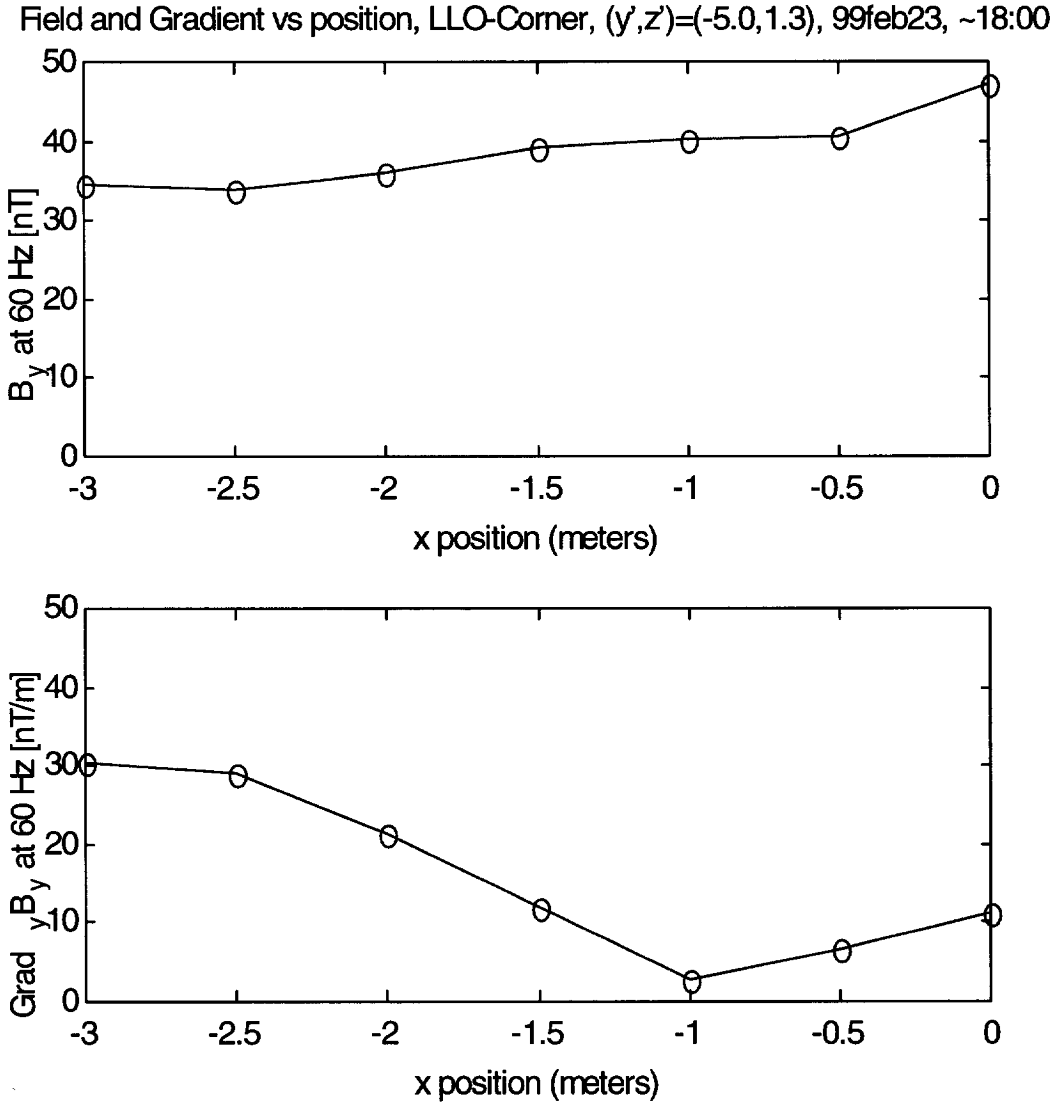
- Shielding and balancing would have to be very good to beat this down to design requirements.

This noise does not go away when nonessential equipment is turned off



- Machinery here was the purge air compressor and the crane lights. No vacuum pumps running. Is the noise the HVAC equipment?

The B-gradient at the power line frequencies is large, and varys with position



- Here, the field becomes smaller, moving to the left, and the gradient becomes bigger.