To: Gabriela Gonzalez
From: ponslet@rt66.com (Eric Ponslet)
Subject: BSC seismic isolation transfer functions
Cc: Robbie Vogt, Fred Raab, Lisa Sievers, Bill Miller, Stan Whitcomb

Gabriela,

I have just put on the LIGO FTP site 3 matlab M-files with the latest simulation results for the BSC stacks (support structure dynamics not included). These files contain the whole matrix of complex transfer functions from floor motion along X, Z, and Pitch to the motion of the pendulum suspension point in the X, Z, Pitch and Yaw directions. The pendulum suspension point is assumed to be at (0,20cm,-15cm) from the center of the optics table (the axis system is: Z vertical up, X aligned with internal support beams, Y transverse). The rotations around these axes are labeled 'a' for roll (around X), 'b' for pitch (around Y) and 'c' for yaw (around Z). I use the notation Txz for example to denote the transfer fct from floor Z motion to X motion of the suspension point.

The transfer functions reflect the effect of random stack imperfections that were included in the model: small variability in spring stiffnesses (3 to 5%) and stack element masses (0.1%) and downtube mass (1%), crooked and/or misaligned springs (order of magnitude 1 mm and 5 degrees), misaligned stack elements (1 to 3 mm) and downtube (4 mm). Each file contains the results from a Monte Carlo simulation with those imperfections, using 20 random realizations of the stack (the same 20 for all transmissibilities).

| | |
|---|---|
| vito_sis.mat | BSC stack with viton springs (on STIFF support) |
| coil_sis.mat | " " " coil " " " " |
| leaf_sis.mat | " " " leaf " " " " |

The results included in the files are:

| | |
|---|---|
| f | frequency vector (100 pts logarithmic from 1 to 1000 Hz |
| Txx_nom | Txx for nominal stack (ideal, perfect) |
| Txx_all | Txx's of all 20 random imperfect realizations |
| Txx_min | Envelope of Txx_all showing lower limit VS frequency |
| Txx_max | Envelope of Txx_all showing upper limit VS frequency |

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[Tzx,Tbx,Tcx,Txz,Tzz,Tbz,Tcz,Txb,Tzb,Tbb,Tcb]_[nom,all,min,max]
(the same for all other transfer fcts)

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Keep in mind that for many of those coupling terms (Tzx,Tcx,Txz,Tbz,Tcz,Tzb,Tcb) the nominal value (perfect stack) is zero by symmetry (plus numerical noise) while the min and max envelopes are both non-zero.
As these new results were obtained with slightly modified modeling assumptions, please discard any previous simulation results and replace them with these.
Hope this will help.

Eric.

## Modeling of Stack Imperfections

Imperfections must be accounted for in the simulations because they create asymmetries that result in vertical-horizontal coupling transmissibilities which do not appear in a perfect, symmetric stack. Imperfections in stack element masses and alignment, spring stiffnesses and loss factors, and spring verticality and alignment are accounted for in this analysis. The support structure is assumed ideal (symmetric). Monte Carlo simulations are used to evaluate Min-Max ranges for the various transmissibility terms.

Each imperfect parameter is given a random value $p$ in a uniform distribution, centered around the nominal values $p_o$ and with deviation $\Delta p$, i.e.

$$p = p_o + \text{uniform}[-\Delta p....+\Delta p], \qquad (1)$$

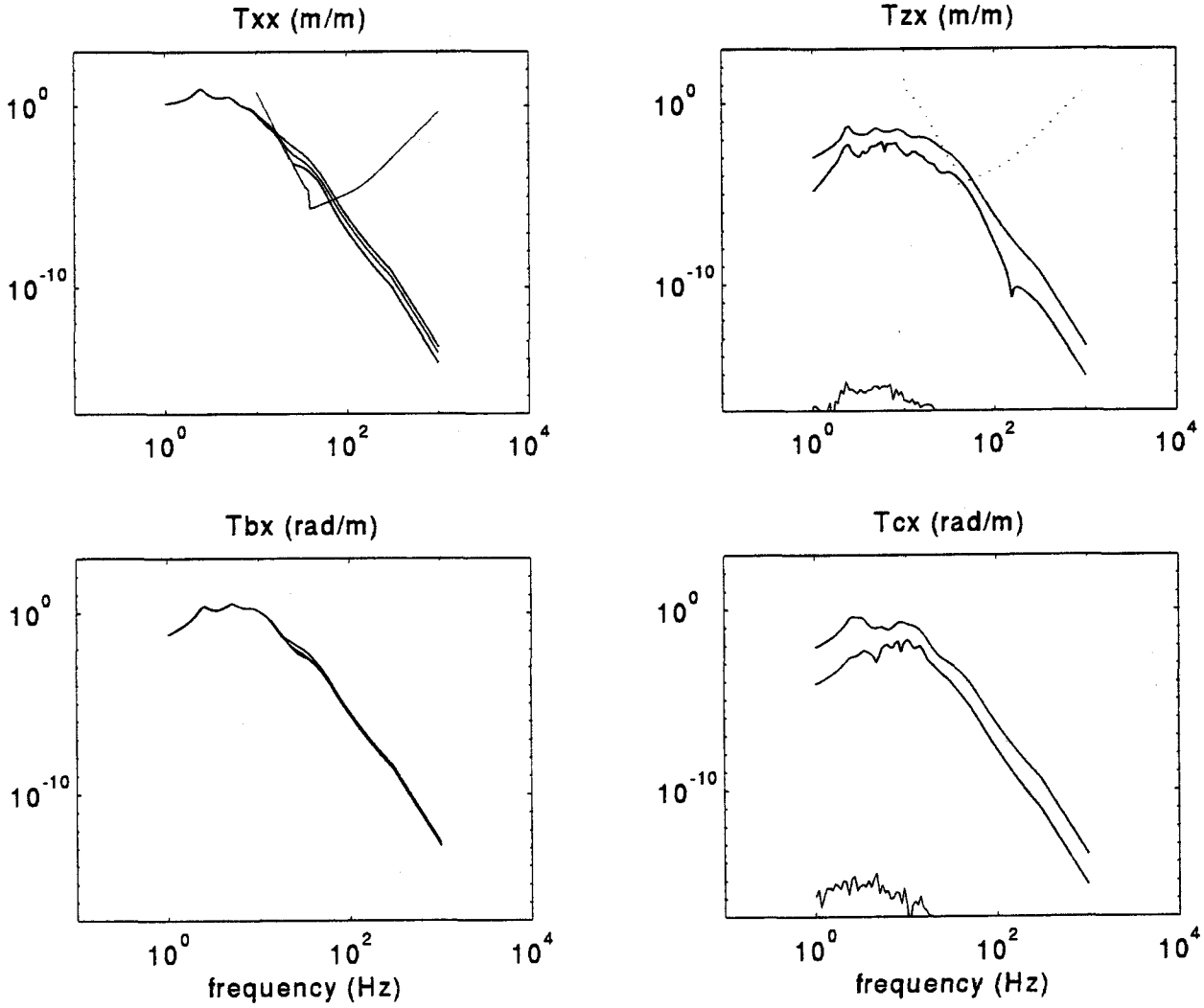
where uniform[$-\Delta p...+\Delta p$] is a uniformly distributed random number between $-\Delta p$ and $\Delta p$. Table 1 lists all imperfections assumed in the model and the corresponding nominal values and deviations. Note that all values are nothing more than engineering estimates and that, for a fair comparison, the same relative deviations on stiffness, damping, and verticality have been assumed for all 3 types of springs.

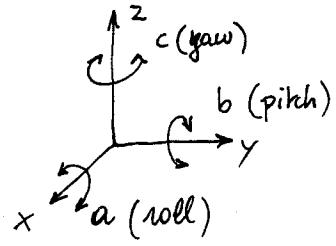
| Parameter | Nominal value $p_o$ | Deviation $\Delta p$ or $\Delta p/p_o$ (%) |
|---|---|---|
| leg element $X$ and $Y$ position, stage 1 | $X_{leg}$ , $Y_{leg}$ | 1 mm |
| " " " " stage 2 | " | 2 mm |
| " " " " stage 3 | " | 3 mm |
| spring $X$ and $Y$ position, stage 1 | uniform on circle | 2 mm |
| " " " stage 2 | " | 3 mm |
| " " " stage 3 | " | 4 mm |
| " " " stage 4 | " | 5 mm |
| downtube $X$ and $Y$ position | $X = Y = 0$ | 5 mm |
| leg element mass | see tables 2, 3, and 4 | 0.1 % |
| downtube mass (incl. payload) | 605.6 kg | 1 % |
| spring stiffnesses $K_x$, $K_y$, $K_z$ | table lookup VS freq. | 3 % |
| spring loss factors $\eta_x$, $\eta_y$, $\eta_z$ | table lookup VS freq. | 5 % |
| spring verticality | vertical | 2° |
| spring orientation (leaf springs only) | radial | 5° |

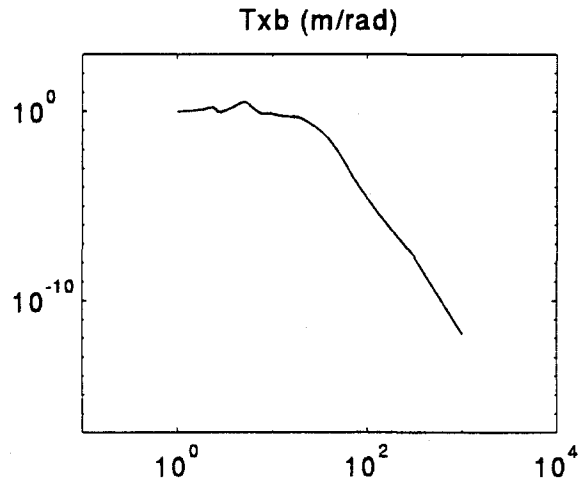
**Table 1: Assumed imperfections in isolation stacks.**

— nominal (perfect) stack
— min & max, imperfect stacks
— direct requirement
..... related requirement.

MONTE CARLO SIMULATION
20 REALISATIONS




Txb (m/rad)
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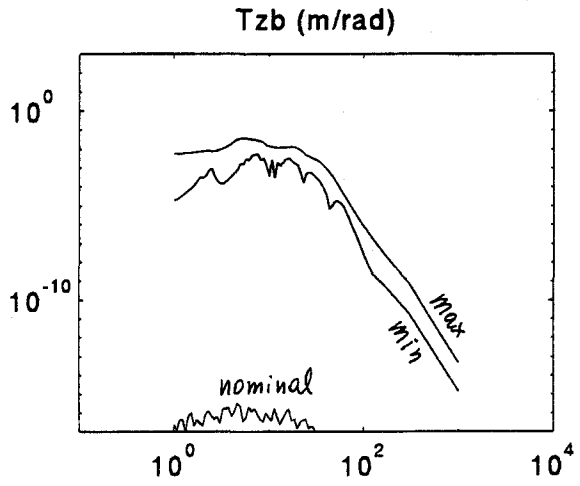
$10^{-10}$
$10^{0}$
$10^{2}$
$10^{4}$


Tzb (m/rad)
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max
min
nominal
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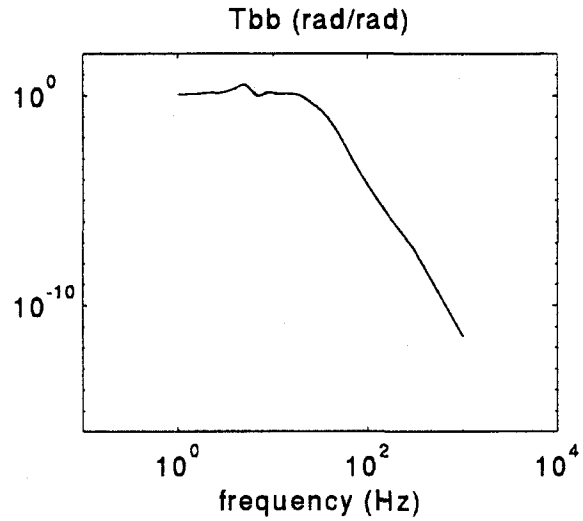
$10^{2}$
$10^{4}$


Tbb (rad/rad)
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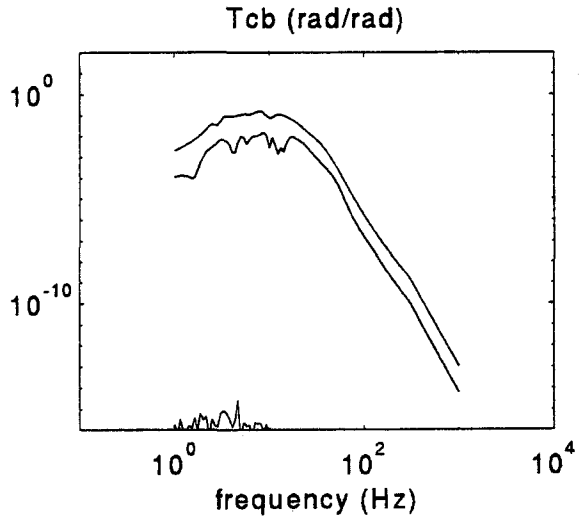
$10^{-10}$
$10^{0}$
$10^{2}$
$10^{4}$
frequency (Hz)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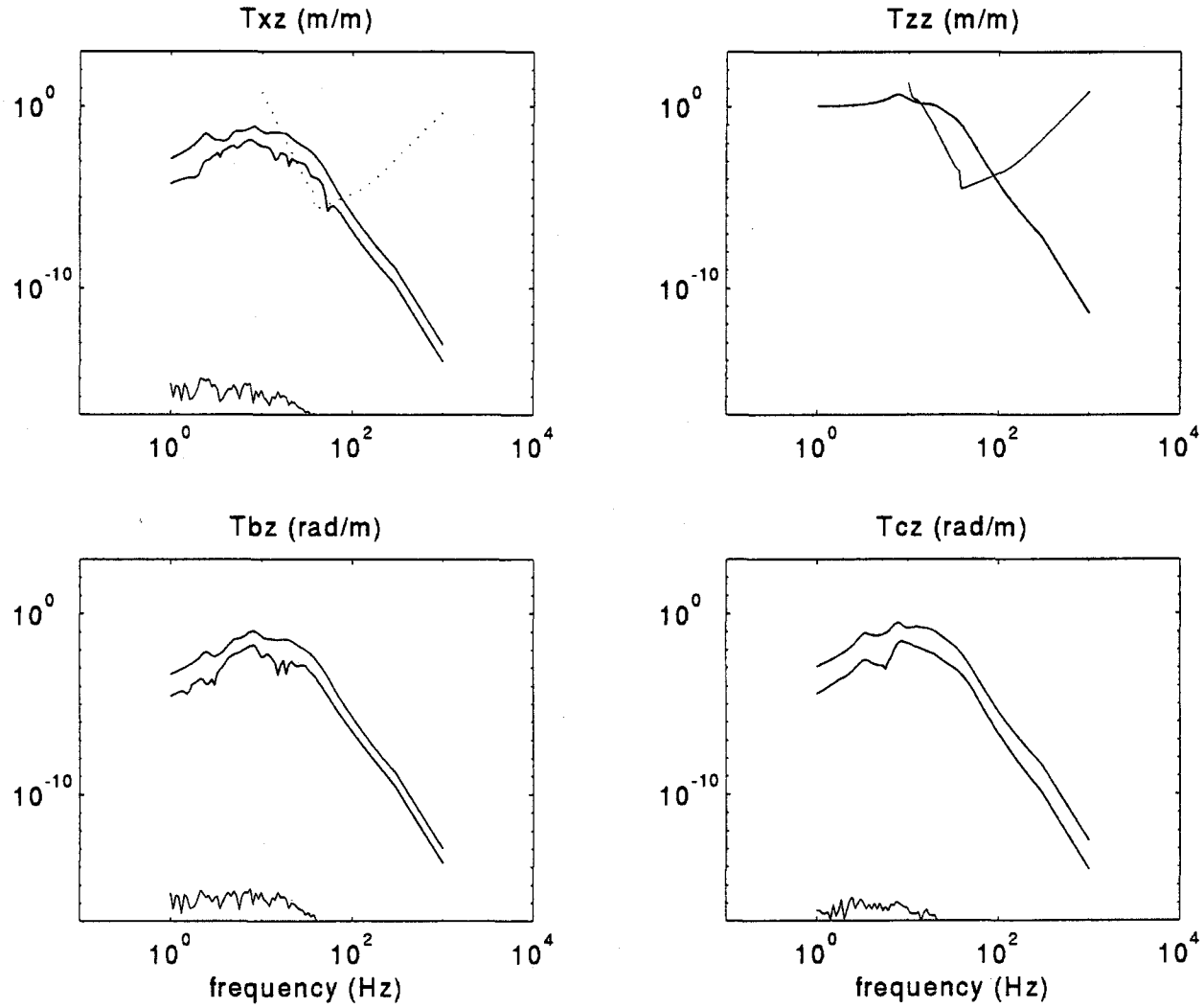
$10^{4}$
frequency (Hz)


Txz (m/m)
Tzz (m/m)
Tbz (rad/m)
Tcz (rad/m)
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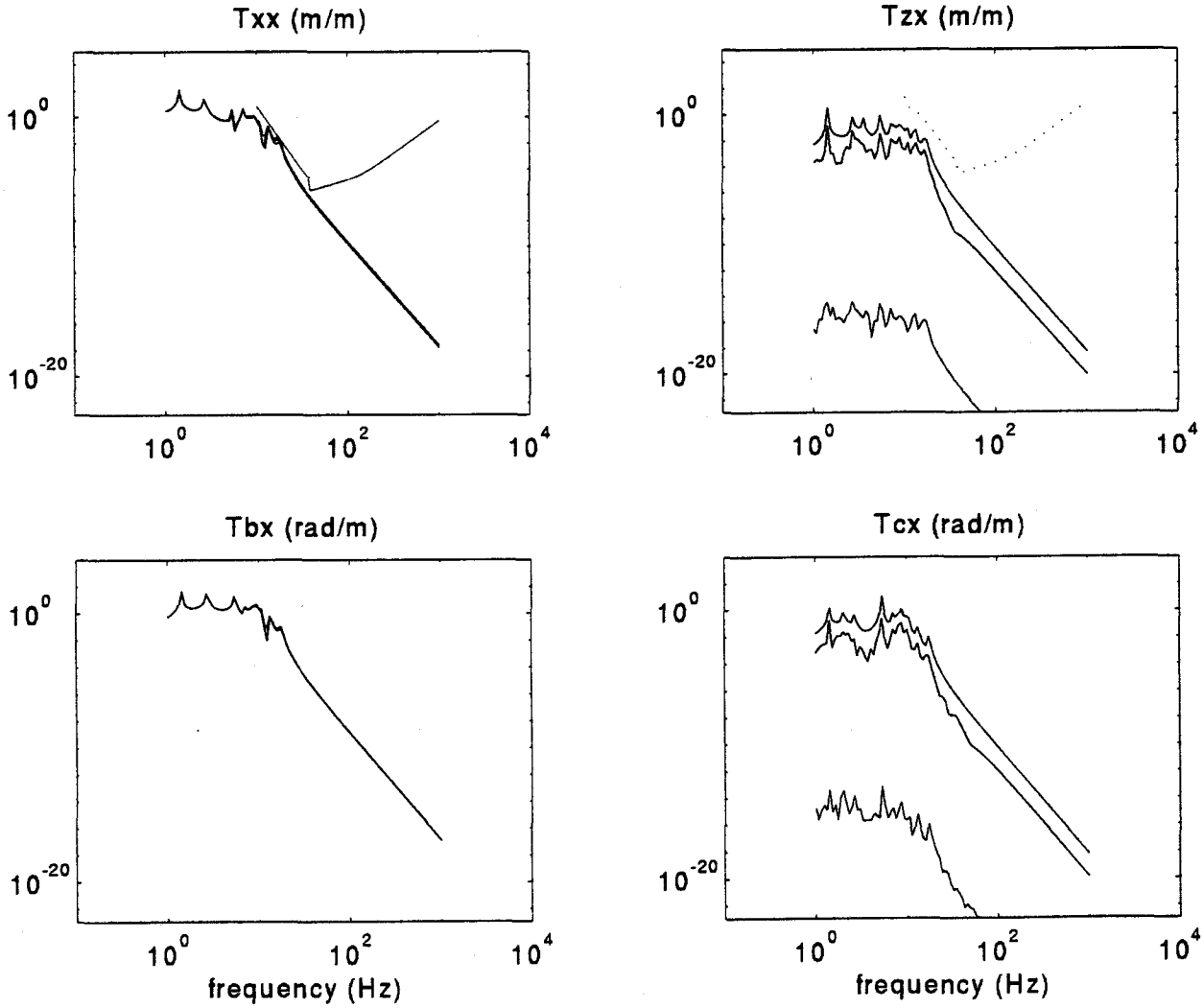
$10^4$
frequency (Hz)


Txx (m/m)
Tzx (m/m)
Tbx (rad/m)
Tcx (rad/m)
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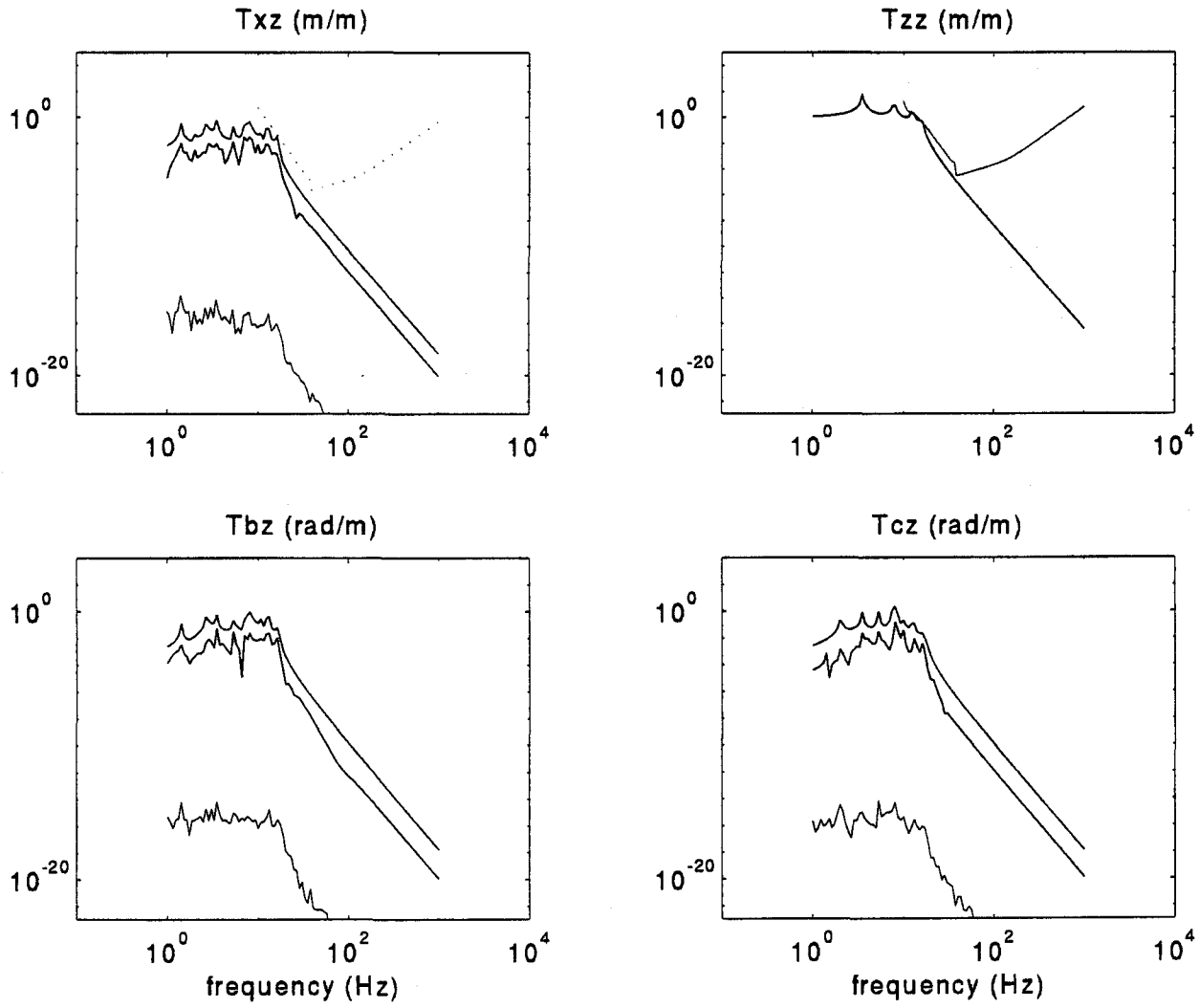
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$
frequency (Hz)


Txz (m/m)
Tzz (m/m)
Tbz (rad/m)
Tcz (rad/m)
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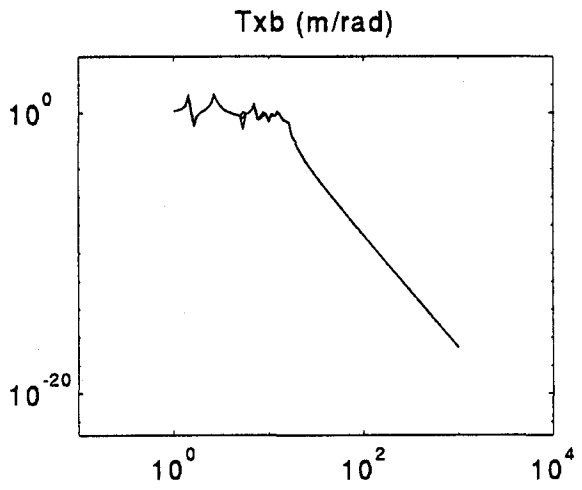
$10^{-20}$
$10^0$
$10^2$
$10^4$
frequency (Hz)


Txb (m/rad)
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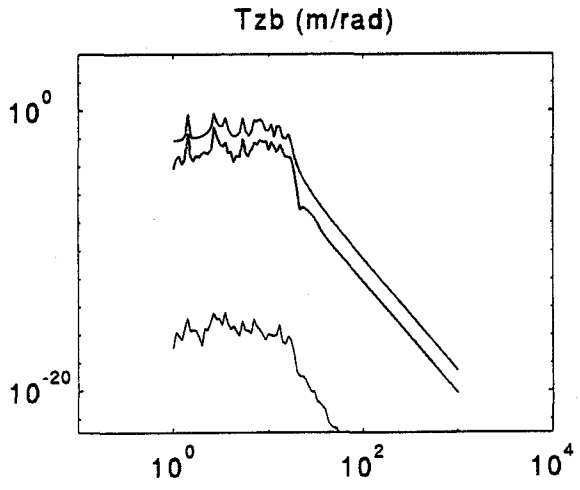
$10^{-20}$
$10^0$
$10^2$
$10^4$


Tzb (m/rad)
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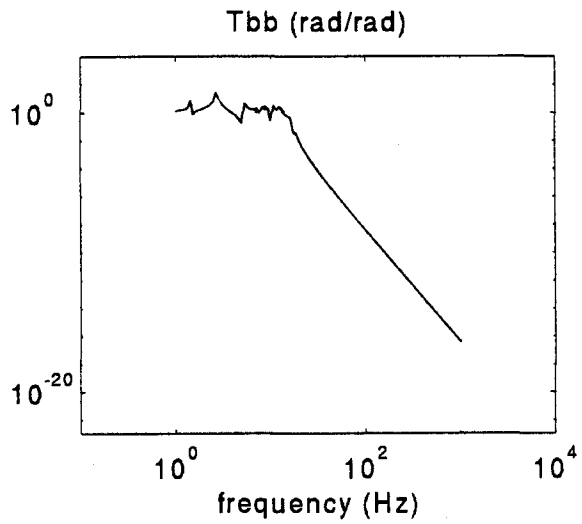
$10^0$
$10^2$
$10^4$


Tbb (rad/rad)
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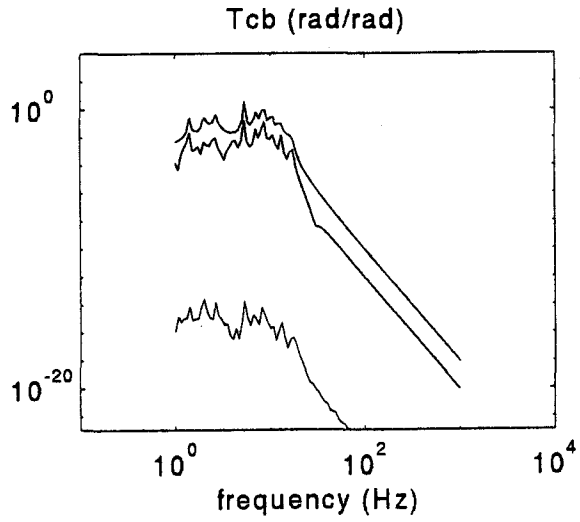
$10^{-20}$
$10^0$
$10^2$
$10^4$
frequency (Hz)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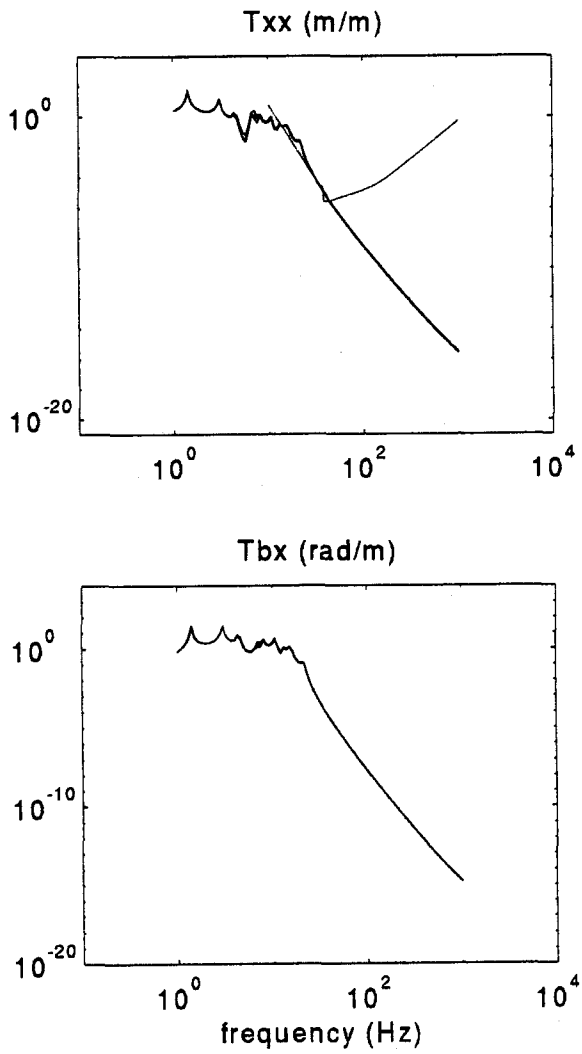
$10^2$
$10^4$
frequency (Hz)


Txx (m/m)
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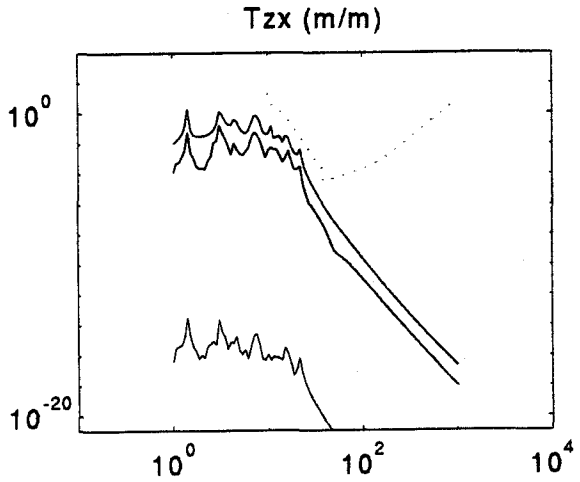
$10^2$
$10^4$


Tzx (m/m)
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$10^{-20}$
$10^0$
$10^2$
$10^4$


Tbx (rad/m)
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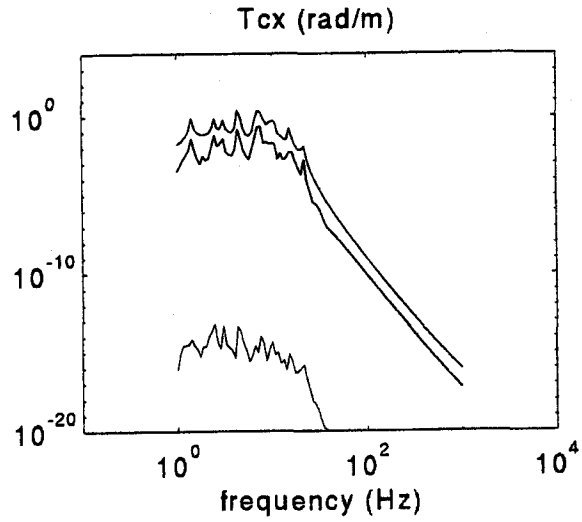
$10^{-10}$
$10^{-20}$
$10^0$
$10^2$
$10^4$
frequency (Hz)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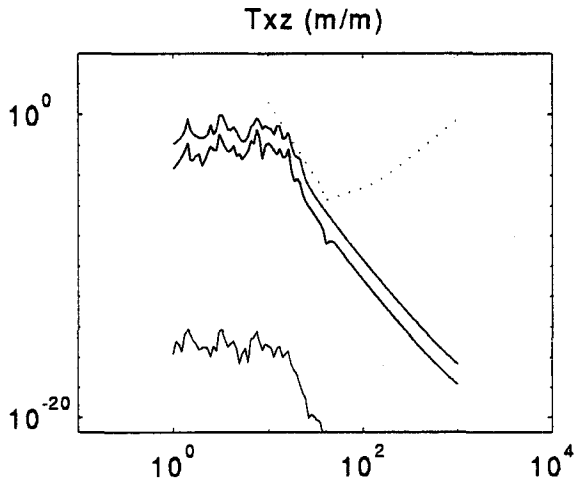
$10^4$
frequency (Hz)


Txz (m/m)
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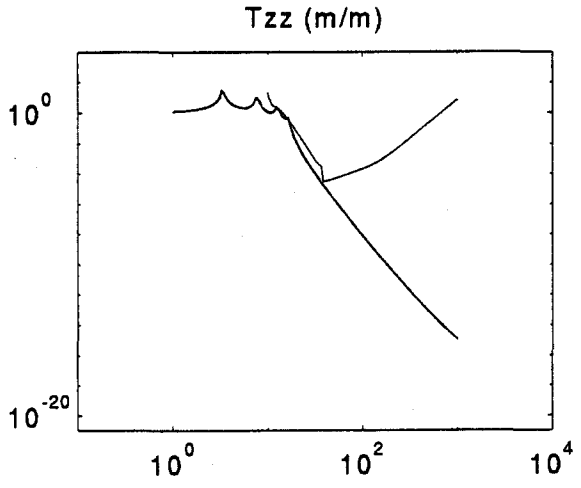
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$


Tzz (m/m)
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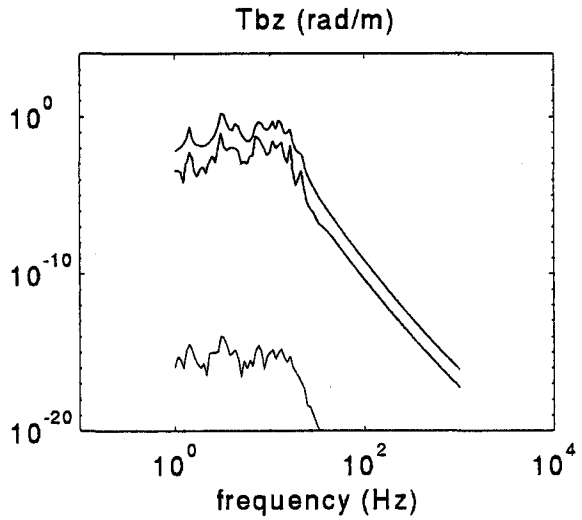
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$


Tbz (rad/m)
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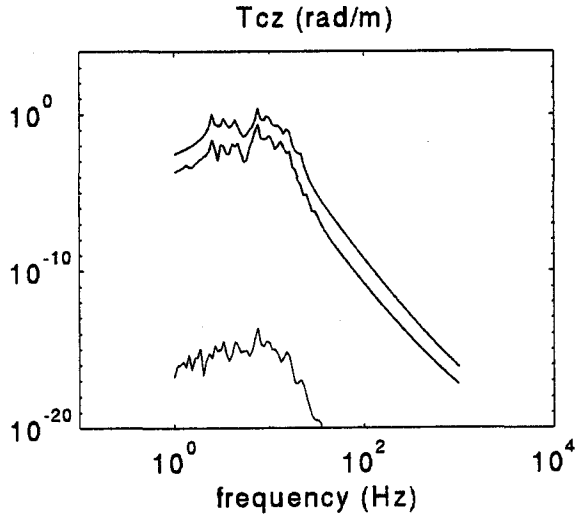
$10^{-10}$
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$
frequency (Hz)


Tcz (rad/m)
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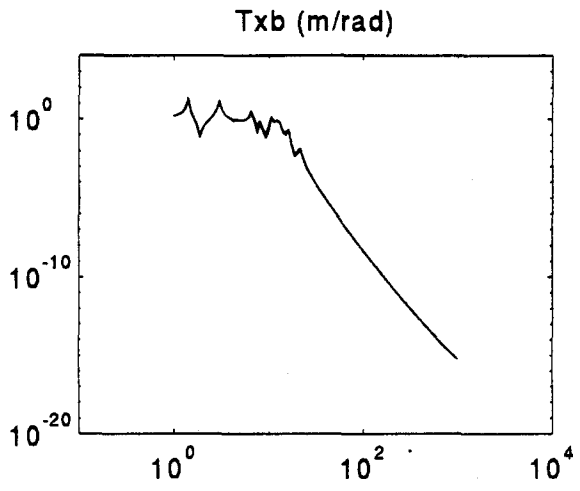
$10^{-10}$
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$
frequency (Hz)


Txb (m/rad)
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$10^{-10}$
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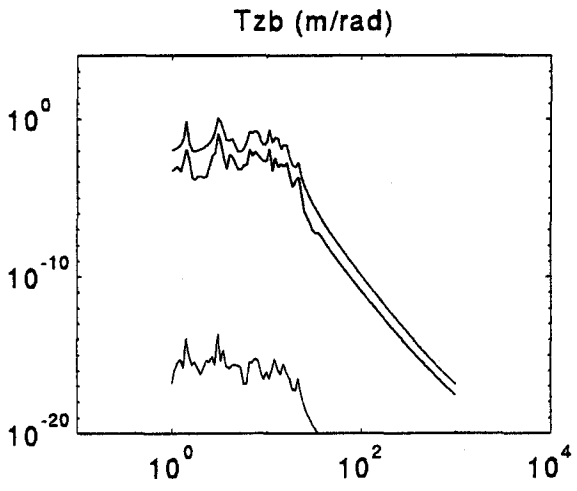
$10^{0}$
$10^{2}$
$10^{4}$


Tzb (m/rad)
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$10^{-10}$
$10^{-20}$
$10^{0}$
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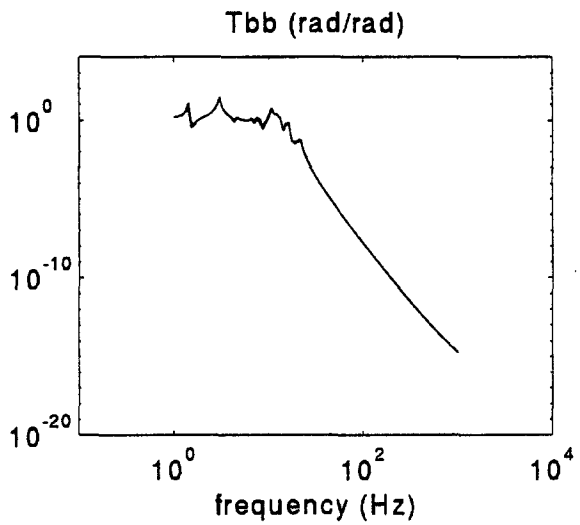
Tbb (rad/rad)
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$10^{-10}$
$10^{-20}$
$10^{0}$
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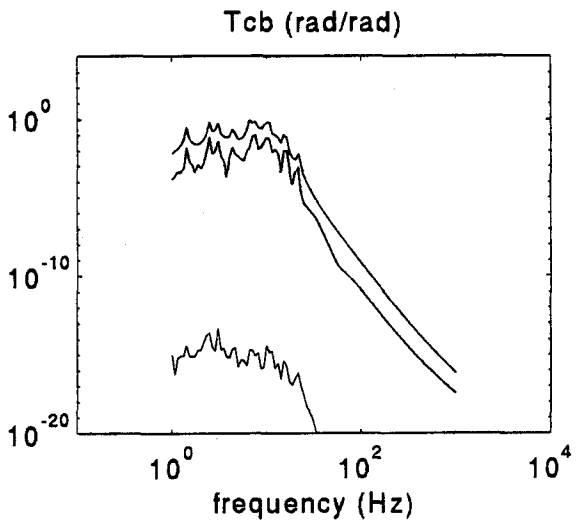
frequency (Hz)


Tcb (rad/rad)
$10^{0}$
$10^{-10}$
$10^{-20}$
$10^{0}$
$10^{2}$
$10^{4}$
frequency (Hz)