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VI.5 Power spectral bias sources and quantization levels

In seismic data acquisition systems there are three main sources of non-seismic noise (system noise) causing various kinds of limitations in resolution and dynamic range:

1. The seismometer/amplifier system

2. The transmission system (modulators/demodulators, telemetry equipment, telephone lines, etc.)

3. The recording system, for digital systems mainly quantization errors.

A typical problem associated with the Type 1 noise source is given a seismometer/amplifier system with a certain dynamic range, to find a gain level that gives a reasonable tradeoff between the conflicting needs for resolving the seismic background noise and at the same time avoiding clipping of strong signals. This is a particular problem with regional and local earthquake data as the necessary dynamic range for these signals is significantly larger than for teleseismic events.

We have at times experienced significant problems associated with the Type 2 noise source when using leased telephone lines for data transmission on analog form. This applies in particular to systems 9, 13 and 14 described in Section III.2, where we have found (for the particular amplifier gain used there) that the system noise is approximately white and that it reaches the level of the ambient background noise at a frequency of 4-5 Hz, causing an increasing amount of spectral bias for higher frequencies.

For many seismic systems the main limiting factor with respect to dynamic resolution is the limitations within the recording system (Type 3 errors) more than those of the seismometer/amplifier system. For digital systems, the main limitation is the number of bits available for representation of signal level. This problem is sometimes 'solved' by gain-ranging (increasing the quantization step with increasing signal level), which works well as long as the signal spectrum is reasonably white and/or band-limited in frequency. However, the real situation with seismic signals (including earth noise) is that weak high-frequent signals are superimposed on strong low-frequent ones, and quantization errors are therefore dependent upon the shape of the noise and signal spectra (for a discussion of quantization errors under simpler conditions, see Oppenheim and Schafer, 1975).

We have addressed the problem of quantization errors in a strictly empirical way, starting with the unbiased earth noise spectra presented in Section VI.4. Three different power spectra were selected, where the main difference was that they were based on data sampled at 125, 62.5 and 40 Hz, with filters at 50, 25 and 12.5 Hz, respectively (corresponding to systems 16, 12 and 17 in Section III.4). Each of the (integer) time series were then scaled down successively by factors of two, and the power spectra calculated. The results are given in Fig. VI.5.1, where four power spectra are calculated:

1) Scaling factor 2^0, with 0.000334 NM/QU at 1 Hz
2) Scaling factor 2^8, with 0.0855 NM/QU at 1 Hz
3) Scaling factor 2^{10}, with 0.342 NM/QU at 1 Hz
4) Scaling factor 2^{12}, with 1.37 NM/QU at 1 Hz

It is seen from the figure that the power spectra for 1) and 2) overlap almost completely (all possible effects of the PDR-2 gain-ranging have been removed by a scaling of 2^7), at quantization level 3) there is a clear bias extending in the worst case almost down to 10 Hz, while for level 4) the bias extends to about 5 Hz. For these and similar curves we have derived the relationship shown in Fig. VI.5.2, which shows the minimum quantization level that is required for resolving earth noise at a particular frequency, provided that the anti-aliasing filter is above the frequency considered. It must be emphasized here that this relationship is dependent upon the earth noise power spectrum as well as upon the system response function. If used as a guideline for choosing quantization levels, it would be wise of course to select a level a factor of two better than the minimum requirement.

The results presented above can be used also for investigating the limits in resolution for the standard NORSAR system, which (see also Section III.4) have the following very severe gain-ranging:

1) Sample range 1-127, quantization 0.0427 NM/QU
2) Sample range 128-511, quantization 0.171 NM/QU
3) Sample range 512-2047, quantization 0.683 NM/QU
4) Sample range 2048-8191, quantization 2.73 NM/QU

We find at NORSAR that the peak amplitudes of the seismic background noise are usually at sample range 2) but occasionally at range 3), which means that the quantization is either 4 or 16 times poorer than indicated by the usually quoted value of 0.0427 NM/QU. In order to test this on real data we have in Fig. VI.5.3 computed three noise power spectra covering the same time interval, with 1) unbiased PDR-2 data, 2) NORSAR data filtered at 8 Hz, and 3) NORSAR data filtered at 4.75 Hz. These filters are very sharp (24 dB/octave), and we can never recover unbiased data above the cutoff frequency. In fact, from Fig. VI.5.3 we see that the bias in the worst case may extend down to between 3 and 4 Hz. However, the data used in Fig. VI.5.3 are taken from different channels causing some level differences also for lower frequencies, and it is therefore not possible to find a more exact 'bias frequency' from such tests (there are also some instabilities in time).

Another implication of the results presented here is that an even stronger bias should be expected for earthquake and explosion signals with peak amplitudes in sample range 3) and a sharp rolloff in the spectrum towards higher frequencies.

The best way to solve these problems would of course be to replace the AD-converter with a more advanced one (increasing significantly the number of bits), but some improvement (for small signals) within the frame of the old system could also be obtained by whitening the uncorrected power spectrum through the introduction of an extra analog high-pass filter (with a reasonably gentle slope).

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Reference

Oppenheim, A.V. and R.V. Schafer (1975): Digital Signal Processing (Chapter 9), Prentice-Hall, New Jersey.

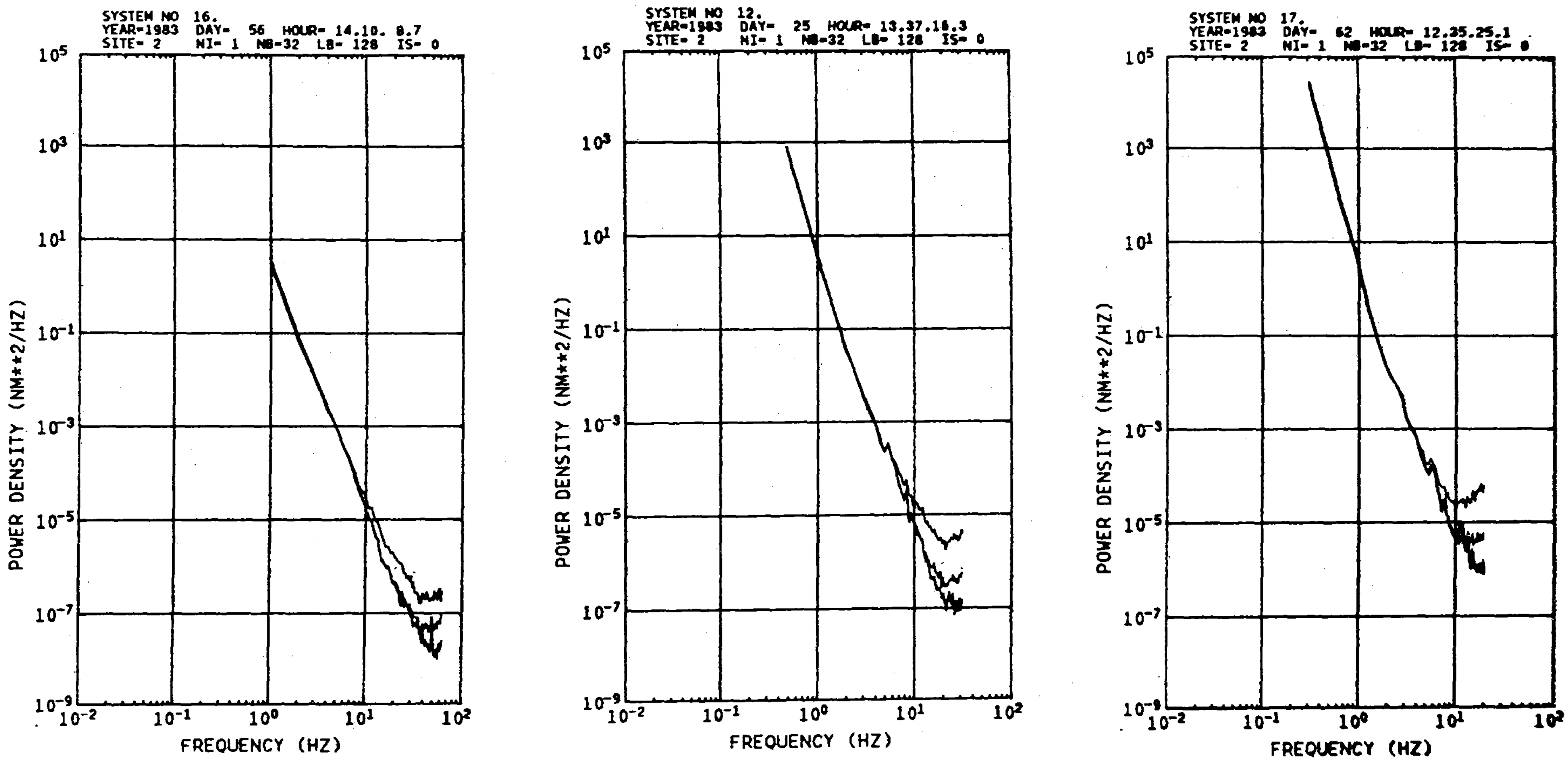

Fig. VI.5.1 Noise power spectral for left: day 56/1983 (125 Hz sampling, 50 Hz filter), center: day 25/1983 (62.5 Hz sampling, 25 Hz filter), right: day 62/1983 (40 Hz sampling, 12.5 Hz filter). For each day, spectra are computed at 4 different quantization levels: 1) original data (PDR-2 recording at NORSAR subarray) with at most 0.000334 nm/Qu at 1 Hz; 2) same data scaled down to 0.0855 nm/Qu (overlapping trace 1); 3) scaled to 0.342 nm/Qu (center trace); and 4) scaled to 1.37 nm/Qu (uppermost trace, strongly biased).

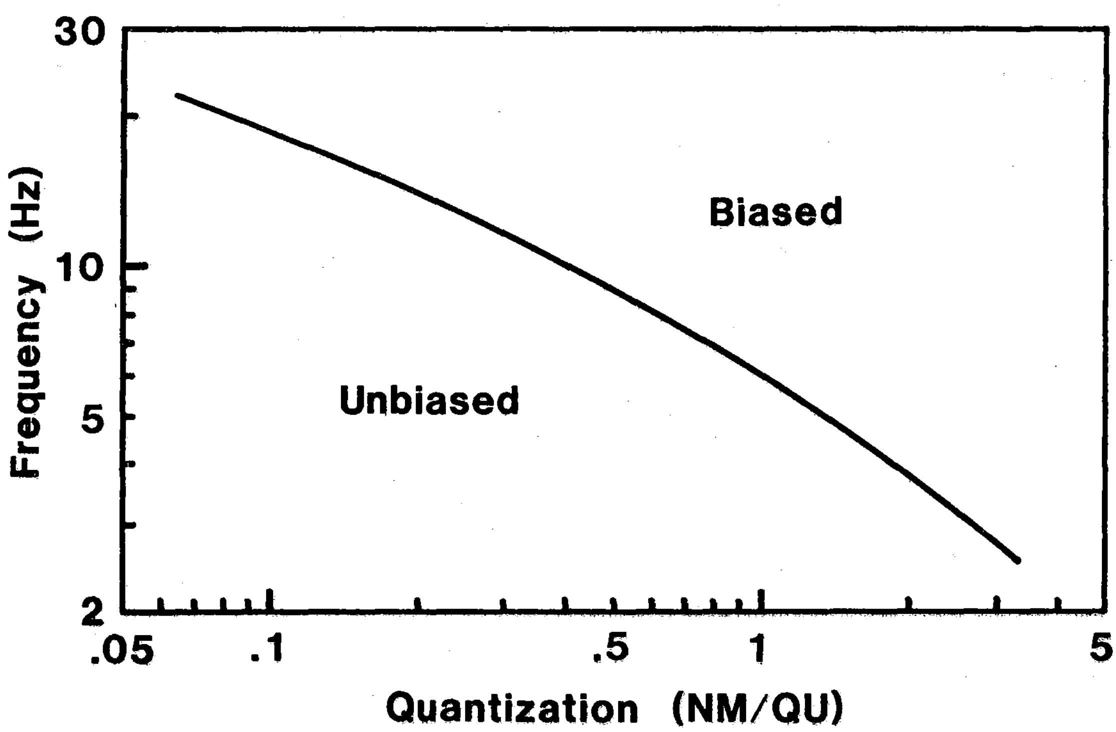

Fig. VI.5.2 Relationship showing the frequency range for which sufficient noise resolution can be obtained (unbiased spectra), given a certain quantization level at 1 Hz. The relationship is valid only for the particular combination of noise power spectrum observed in southeastern Norway (see Section VI.4) and the response functions of the systems used to delineate it (see Section III.4, systems 12, 16 and 17).

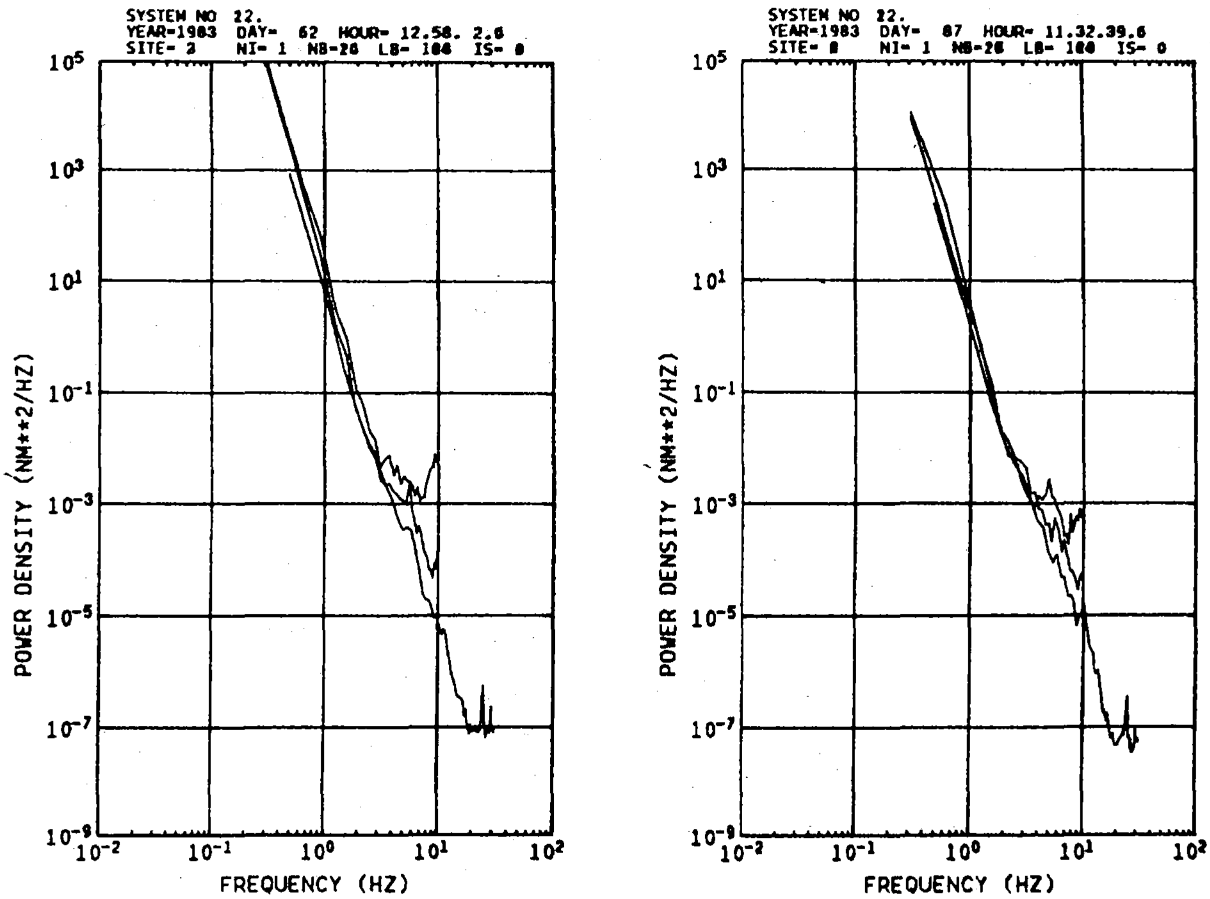

Fig. VI.5.3 Noise power spectra for day 62/1983 (left), and day 87/1983 (right), and with each case covered by: 1) an unbiased PDR-2 recording with sufficient quantization (62.5 Hz sampling rate, 25 Hz filter); 2) NORSAR 20 Hz recording with 8 Hz filter (center trace); and 3) NORSAR 20 Hz recording with 5 Hz filter (top trace, clearly biased).