NORSAR ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Scientific Report No. 1-81/82

SEMIANNUAL TECHNICAL SUMMARY

1 April 1981—30 September 1981

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Kjeller, December 1981

VI.6 Signal detection using P-wave envelope representation

The beamforming technique conventionally used for detection processing at seismic arrays such as NORSAR is critically dependent upon signal coherency across the array for good performance. Earlier studies, e.g., Ringdal et al (1975) have shown that in numerous instances, particularly for regional events and events with high dominant signal frequency, signal coherency is generally poor across the NORSAR array. A so-called 'incoherent' beamforming detector, which essentially sums the envelopes of the filtered sensor traces, has shown superior performance compared to standard beamforming in such cases, and such a detector has in fact been in operation at NORSAR since 1971.

A study has been undertaken (Nysæter, 1981) to analyze in detail the performance of envelope detectors on NORSAR data, both as a function of envelope representation technique and filter setting. Two representation techniques have been investigated:

(a) Using a sliding short term rectified average (STA), based on a window of 1.5 seconds of the filtered signal of each trace;

(b) Using a squared Hilbert transform of the filtered signal of each trace.

An illustration of these envelope representations is given in Fig. VI.6.1. The Hilbert transform provides a theoretical envelope to the signal, whereas the STA representation is only approximate. On the other hand, the STA envelope is faster to compute.

The actual detection algorithm for each of the two representations has consisted of

(i) Prefiltering of each of 7 sensor traces (one per subarray) with a recursive Butterworth bandpass filter

(ii) Computing the appropriate envelope of each trace

(iii) Summing the envelopes with 64 sets of time delays (as in the NORSAR on-line system)

(iv) Applying a standard linear STA/LTA detector.

The subsequent analysis steps were as follows:

1. Evaluate the false alarm rate as a function of SNR by analyzing selected noise segments using both detectors.
2. Determine comparable thresholds for each detector (i.e., set a threshold such that the number of false alarms were similar).
3. Compare the signal-to-noise ratio of each of a set of 123 events for the two detectors, adjusted for the threshold differences.

The 123 events were based upon reportings from the full 42 element NORSAR SP array. With a false alarm rate comparable to that of the NORSAR on-line envelope detector, 115 and 112 of these events were detected by the Hilbert and STA envelope detectors, respectively. (Note that these detectors were based on 7 SP channels only.) Average SNR (adjusted for threshold differences) were 14.43 and 14.24 dB respectively, thus giving a very marginal improvement for the Hilbert algorithm relative to STA envelopes (see Fig. VI.6.2). This is in some contrast to the results by Wen-Wu-Chen (1974), who reported a significant improvement using Hilbert transforms relative to STA envelopes.

The effect of filter setting was investigated using a subset of 22 events, and applying filters of 2.0-4.0 Hz, 2.4-4.4 Hz and 2.8-4.8 Hz in addition to the standard 1.6-3.6 Hz filter used by the NORSAR on-line envelope beam detector. The results are summarized in Table VI.6.1, which shows that the filter band 2.0-4.0 Hz is the best overall, both with respect to the number of detections and the average SNR. Again, the difference between the two detectors is slight.

In summary, we have thus found:

1. An envelope beam detector based on the Hilbert transform is only slightly better than the computationally simpler envelope detector based on a sliding STA window.

2. A filter setting of 2.0-4.0 Hz appears to be near the optimum choice for overall detection of regional events, although individual variations in signal frequency may cause other bands to be better in some cases.

3. The performance of a 7 element array (one instrument from each subarray) is almost equal to that of the 42 element NORSAR array for regional events. This shows that event gains at the subarray beam level are quite modest for conventional beamforming of regional signals recorded at NORSAR.

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References

Chen, W.W., 1974: Comparison of coherent and incoherent beamforming envelope detectors for NORSAR regional seismic events. Tech. Rep. No. 6, Texas Instruments Report No. ALEX(01)-TR-74-06, AFTAC Contract No. F08606-74-C-0033, Texas Instruments, Dallas, Texas.

Nysæter, A., 1981: Quadratic versus linear envelope beamforming for seismic event detection, NORSAR Tech. Report 3/81, NTNF/NORSAR, Kjeller, Norway.

Ringdal, F., E.S. Husebye & A. Dahle, 1975: P-wave envelope representation in event detection using array data. Proc. NATO ASI Exploitation of Seismograph Networks, Series E, 11, Nordhoff-Leiden, 353-372.

Frequency	1.6-3.6 Hz		2.0-4.0 Hz		2.4-4.4 Hz		2.8-4.8 Hz	
Bands	S-E	STA	S-E	STA	S-E	STA	S-E	STA
No. of detected events	19	19	22	22	19	16	17	16
Average SNR	19.13	18.58	20.90	20.14	20.78	19.69	19.70	18.45
SNR difference	0.55		0.76		1.09		1.25	

Table VI.6.1

Comparison of detection performance of 22 regional events reported by NORSAR for two envelope detectors: Square envelope Hilbert transform (S-E) and sliding STA window envelopes (STA).

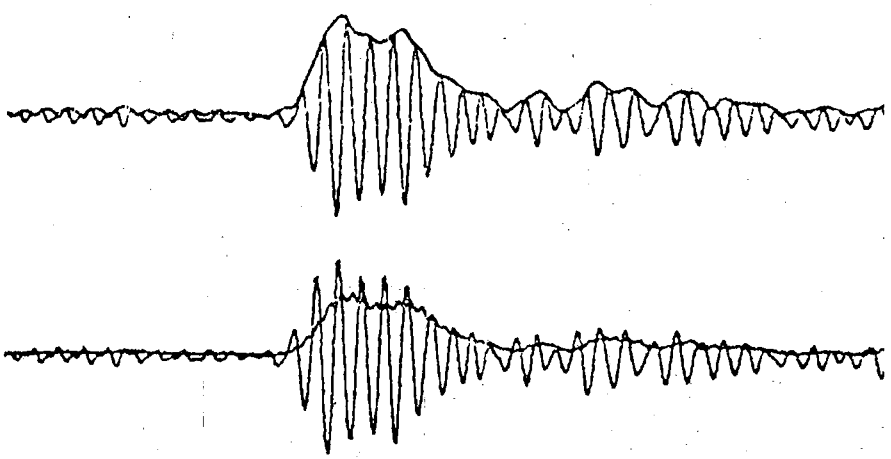

Fig. VI.6.1 Hilbert type envelope (top) and STA type envelope (bottom) of a seismic signal.

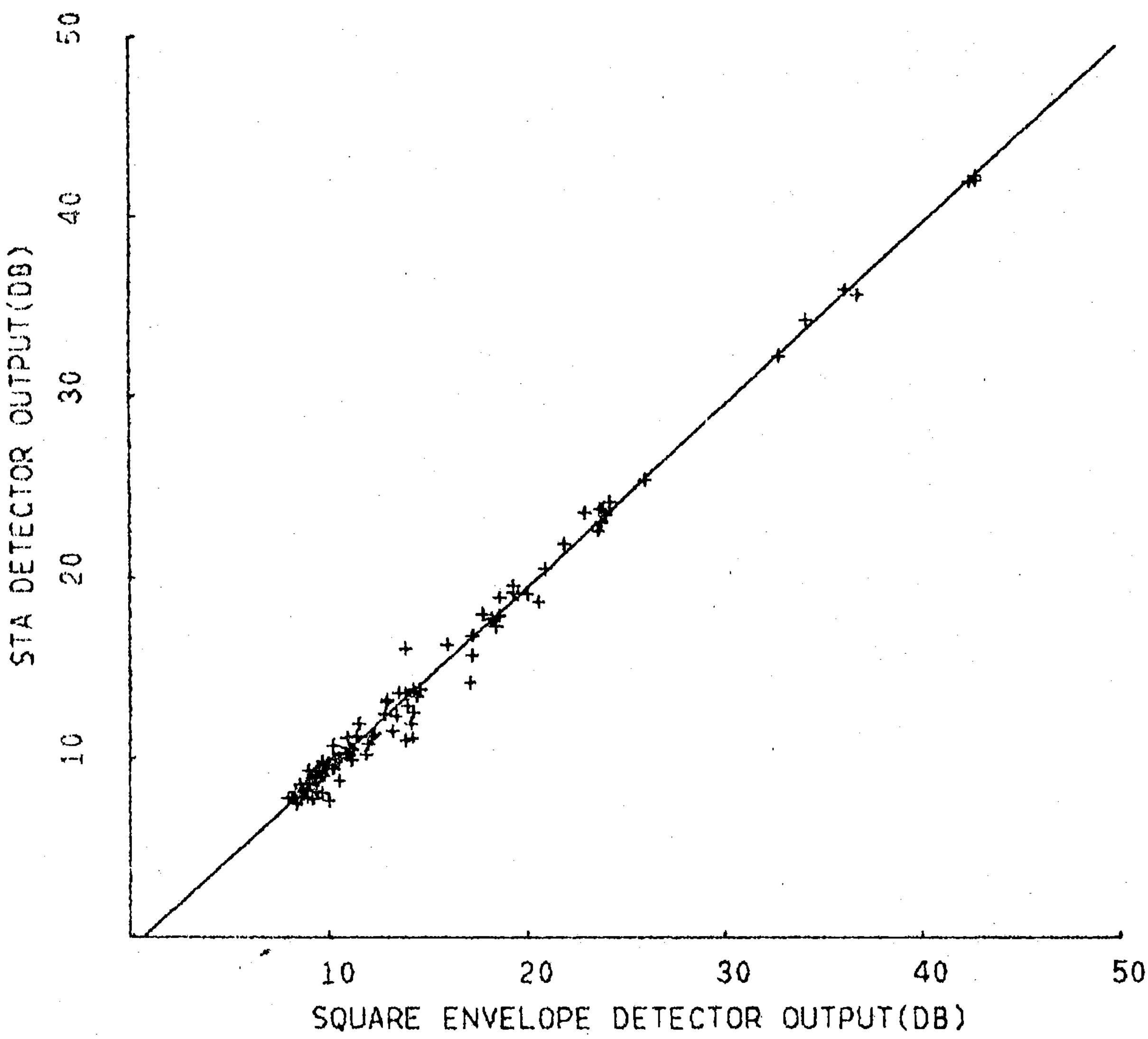

Fig. VI.6.2 Max. SNR from the square envelope detector versus max. SNR from the STA-detector for signals detected by both. The equation for the straight line is $y = -0.6 + x$, which corresponds to equal false alarm rate from the two detectors.