Limitations of seismic field instrumentation for converted-wave recording

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INTRODUCTION

The recording of converted-wave data, in particular multicomponent data, means that several of the traditional field techniques need to be revised. Over the past few years, the CREWES project together with the Field School run by the Department of Geology and Geophysics has attempted to redefine some of these parameters. One is the use of single geophones which give us point recording, rather than the traditional geophone array; another is the necessity of recording data with no low cut filters applied. Recording data this way leads to several problems, which the geophone arrays and filters were developed to overcome. The main problem is ground roll, which has usually been attenuated by geophone arrays and low cut filters; another is other shot-generated noise which tends to be in the same frequency range as the converted wave signal. A discussion of the noise problems on converted wave data was presented at last years CREWES meeting in Banff (Miller et al., 1990). Analysis of some of the records from a multicomponent data set recorded during the 1990 Geophysics Field School revealed that the real limitation on signal recovery from these data was the dynamic range of the recording instruments. It is surprising how few seismic data processors have a good working knowledge of seismic instrumentation and its operation. Too often assumptions are made regarding dynamic range and signal resolution. A brief description of their operation is necessary to indicate their limitations.

SEISMIC AMPLIFIERS

The modern generation of seismic instruments had its beginning over 20 years ago, with the binary gain systems which stepped the amplifiers in powers of two. The floating point systems appeared later, but because of amplifier recovery speed the gain steps were increased to powers of 4, giving quaternary gain recording. Systems such as the DFS V use this method. Disappointingly, even the latest production systems in common use still use the quaternary gain system, despite advances in electronic components which make a binary gain floating point system feasible. Another area which should have been improved in 20 years is the 14 bit plus sign analog to digital converter all of these systems use.

Limitations

One of the problems apparent with the quaternary gain floating point system is shown in Figure 1. This is a composite count taken over an entire field tape of seismic data recorded by a quaternary gain system, in this case Sercel 338HR instruments. These records are 96 channels, 2 millisecond sample rate and 3 seconds in length. The bars show the percentage use of the analog to digital converter bits. As can be clearly seen the floating point amplifier was effectively running the analog to digital converter at below 50 percent of its full scale input. This is shown by the number of times the converter was only outputting 13 or fewer bits of data. Signal resolution is directly affected by this. Another major consideration in resolution is the gain stepping effect. This is shown in Figure 2. The vertical scale is $\log_2$, and the ladders represent the individual bits of the analog to digital converter. As can be seen from this figure, if the amplifier is running at a gain of 0, the least significant bit of the analog to digital converter is now at twice the level of the 14th bit if the amplifier is running at full gain. The significance of this is realised when the amplitude of the converted-wave with respect to offset is considered along with the amplifier gain settings, which will follow the highest level signal. At small offsets the converted-wave amplitude is reduced, while the shot-generated noise is higher. As the source-receiver offset increases, this situation is reversed, and as is frequently seen, the converted-wave signal is only recognisable on field monitors at the far offset traces.

Window of resolution

Quantisation noise and amplifier linearity make signal reconstruction difficult if only the last couple of bits of the analog to digital converter are actually recording the desired signal, hence it is necessary to make an arbitrary choice of the minimum number of bits a signal should possess in order that the signal be recoverable. If five bits are chosen, the situation becomes:

- the highest bit of the converter in use is the 13th.
- the minimum level for resolvable signal is 5 bits.

From this it is apparent that the signal must be less than 8 bits (or 48dB) below the signal of maximum amplitude (usually ground roll) if there is to be any hope of recovering it. The most important item to remember is that this relationship holds good for all amplifier gains. Figure 3 shows where this window of resolution would fall on a particular record. In this figure, the values labelled RW are measured Rayleigh wave amplitudes, smoothed over 5 adjacent channels, taken from the 1990 Field School data. The model values were calculated using a modelling routine developed by Don Lawton. For offsets greater than 1000 metres the modelled values are matched to values taken from the record, as these far traces were the only part of the record where the converted-wave signal could be identified and measured. The window represents the values 48dB below the RW values. It is clear that for offsets less than 300 metres there is no recoverable converted-wave data. The significance of this increases when desirable offset ranges of P-SV acquisition are considered (Lawton, 1991).

Because of the offset limitations and the necessity to record data using single-point receivers and without filters, the converted-wave data are usually difficult or impossible to detect visually on field monitors, so some assumptions have to be made to process these records. Predictive filters developed over the last few years can extract the signal to some extent, but questions have to be asked regarding the viability of processing all offsets.

If vector processing of multicomponent data is desired, more complications arise. If the geophones are oriented correctly the transverse component should not be affected as greatly by shot-generated noise as the vertical and inline components. As a result vector calculations may have significant errors, due to the different gain selections made by the amplifiers of the three channels.

24-BIT ANALOG TO DIGITAL CONVERTERS

Returning to Figure 2, the ladder on the right side represents the optimum analog to digital converter for seismic recording. This covers the entire range of the existing quaternary gain systems, and retains the low level resolution of these systems running at maximum gain. Unfortunately this requires 28 bits of resolution, and such converters are not as yet available. There is, however, a 24 bit converter which has become available during the last year. Using seismic terminology this can be regarded as 23 bits plus sign. This represents a continuous resolution 30dB below the total range of quaternary gain systems without the necessity of a gain switching amplifier. Since the quaternary gain systems all use a 14 bit converter, at any time the maximum resolution is 84dB, a somewhat misleading figure as this suggests that toggling the least significant bit while recording noise over all 14 bits of the converter will provide a resolvable signal. Using the previously defined instantaneous resolution of 42dB, the comparable resolution of a 24 bit converter is 114dB, while the maximum resolution is 138dB.

The Department of Geology and Geophysics together with the CREWES Project is actively researching this converter, and will be constructing a minimum level recording system designed specifically for testing the recording of converted-wave data. Several other features will be included in this system to make it portable and expandable.

Throughout this discussion the term signal to noise has been avoided, as any information recorded which has been generated by the seismic source should be regarded as signal, and may be useful.

REFERENCES

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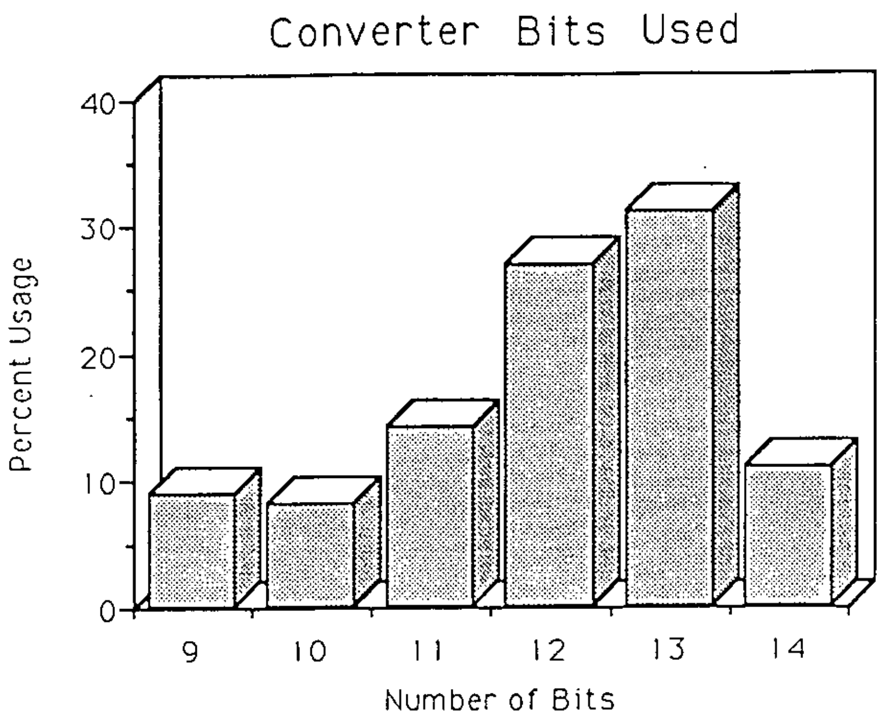

FIG. 1. Number of bits output by the A/D converter measured as a percentage over several records. The '9' column represents 9 or fewer bits.

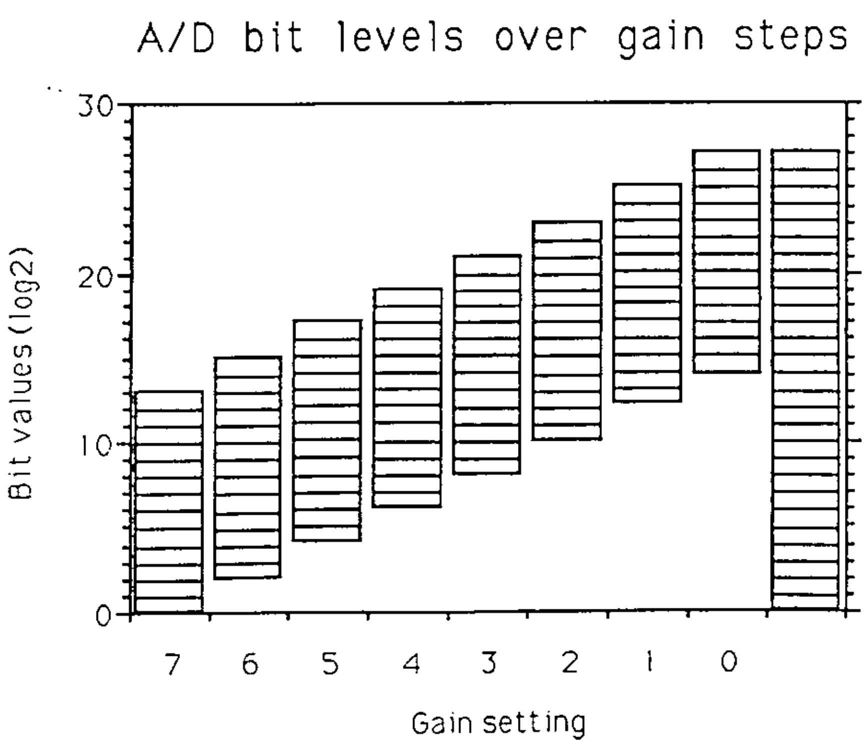

FIG. 2. Representation of A/D converter bit levels across all amplifier gains.

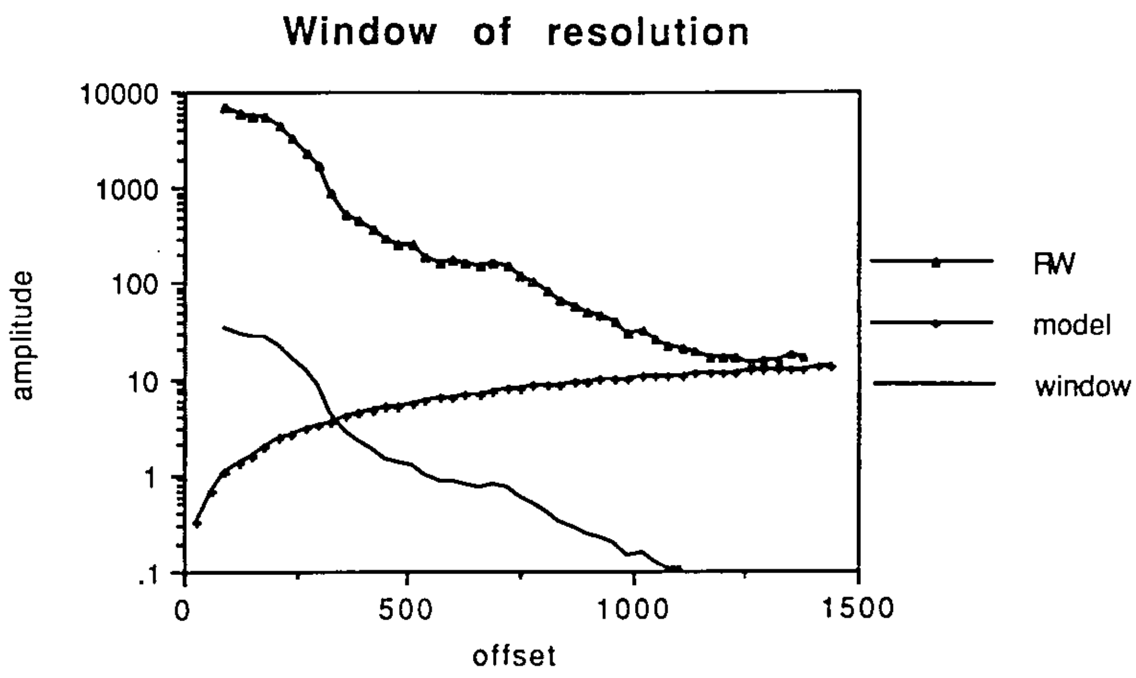

FIG. 3. Window of resolution plotted against modelled P-SV amplitudes.