DIGITAL HUM FILTERING

by

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INTRODUCTION

This note describes a simple hum filter that effectively removes high-line hum or other background monofrequency noise when the characteristics of that noise (frequency, amplitude, and phase) are invariant over the time interval of the seismic trace.

Common sources of hum include powerline noise of 60 or 50 Hz; harmonics of the powerline frequency; cathodic protection devices on pipelines usually with full waveform rectification and, therefore, odd higher harmonics of powerline frequencies such as 120 Hz, 240 Hz., etc; and vibrational noise put into the ground by cyclic mechanical devices such as pumps.

Removing power-line noise is easily done by notch filters, but this is undesirable due to distortion and degradation of the data. Not only does a notch filter remove the particular frequency fairly completely and without discrimination between noise and signal, but it also distorts the phase of adjacent frequencies. Unfortunately, power-line frequencies of 60 or 50 Hz are usually right in the middle of the data bandpass, which means that notch filtering is particularly detrimental. Figure 1 shows the difference between recording instrument pulse response with and without the notch filter.

Besides being generally undesirable, notch filters have other limitations. One is that they do not remove harmonics such as 120 Hz, 180 Hz, etc. As higher frequency data are being increasingly obtained, this becomes an increasingly more important limitation. Also, the standard notch filter is useless at removing leakage from full waveform-rectified cathodic protectors which have only the odd harmonics such as 120 Hz, 240 Hz, etc. Notch filters are ineffective with hum due to generators which may not run at a frequency of exactly 60 or 50 Hz. In other words, except for fundamental mode powerline hum, notch filters are useless in application. They operate on only one specific frequency.

Modern seismographs use common mode rejection ratio differential amplifiers which would remove hum noise if it were balanced on input lines. Unfortunately, input lines are not balanced; some lines pick up hum noise more efficiently than others. The differential amplifiers pass the difference through. A common mode attenuator has been described (Smither and Pater, 1982) which corrects cable imbalance of common modes of all frequencies and leads to the common mode rejection of hum noise. The common mode attenuator is a pre-amplifier field device and is presumed for the purposes of this note that it was not used.

Bridges were once used with field equipment to balance the voltage of the hum on a trace-by-trace basis. In effect, the hum is subtracted from the signal. The operator manually adjusts the amplitude and phase of the bridge to minimize hum. Operating a bridge network is a time consuming operation. Each channel must be balanced before each shot because each channel has its own optimum setting, and moving the roll switch changes the channels. Time drift is also a particular problem when there are many channels because once the last channel is adjusted, the first channel may need to be readjusted (Smither and Pater, 1982). Several automatic bridge devices have been described, for instance, McCormick and Tvedt (1973) and Renner (1973). Kostelnicek, et al. (1975) specifically address the problem of drift. The current use of bridges is unknown to me; however, the technique described in this note is a similar principal, only the adjustment is done automatically during processing.

PROCEDURE

In the field, the use of notch filters should be avoided unless the hum level is so extreme that it swamps the data; that is, signal amplitude is very small compared to noise amplitude. Instead, computer processing can effectively be used to remove the hum, and I am recommending a process that removes the hum without affecting the data signal - not a digital notch filter. It must be assumed, usually correctly, that the hum signal is stationary on each trace, i.e., that it is invariant in time interval of the recording, although it may be variant in space (trace-to-trace). Spatial variance depends on the line imbalance. The process uses the pre-event interval of each true amplitude seismic trace to derive the amplitude and phase of each indicated hum frequency. This is done by discrete Fourier transform. The sinusoidal function of the given frequency, amplitude, and phase is subtracted from the trace. The residual is the data signal as it would have been recorded without the hum. That is, signal data are unaffected by the process even at hum frequency.

The pre-event interval is used because it is the quietest interval. The whole trace can be used except that signal may contaminate the fit of the determination. With a large interval or small signal-to-noise ratio, however, such contamination may be slight. Another good interval to use is the very end of the trace where signal amplitudes are very small. In short, the quality of the fit determined depends on the signal-to-noise ratio and the size of the window interval. When signal-to-noise is extremely small, the fit is best; hence, the pre-event interval, which has no signal, is best. When hum noise is much larger than reflection signal, the reflection signal influence becomes negligible, and the end of the trace, using a large window, may be the best interval in this case. As the interval becomes larger, reflection signal again loses its significance.

It is important that the interval over which the determination is made be at least a couple of cyles wide. If signal data are included in the interval window, large width becomes more important so that the effect of reflectors is minimized. It is important that a window of exactly an integer number of cycles be used for accuracy of the fit, and it is important that a true amplitude or fixed-gain trace be used so that the hum is time invariant.

Results are shown in Figures 2 and 3. Hum which is evident in Figure 2 is effectively removed leaving only signal data in Figure 3. Table 1 is a brief outline of the computer program for the process.

DISCUSSION AND CONCLUSIONS

Given the undesirable properties of a notch filter, its use is to be discouraged in the field. Except in extremely noisy situations where signal-to-noise becomes so large that the recovery of signal is jeopardized, field-applied analog notch filters are to be avoided. To remove time invariant predictable hum through processing, the standard usage of a digital notch filter is likewise inappropriate. The hum filter described by this note, when properly designed, is effective against noise and is innocuous to the signal data. Basically, it uses the stationary and predictability properties of the hum to isolate and destroy it. One could suggest doing a complete Fourier transform of the pre-event interval and thereby apply this process to all frequencies, but it would not be appropriate because not all frequencies are necessarily stationary and predictable for the duration of the seismic trace. In fact, such practice would add random noise to the signal portion of the trace, although the pre-event portion would be quieter.

REFERENCES

Kostelnicek, R.J., Herbert, C.B., and Crawford, T.H., 1975, System for eliminating monochromatic signals from data records: U.S. Patent 3 889 229.

McCormick, K. and Tvedt, T.J., 1973, Signal cancellation: U.S. Patent 3 757 235.

Renner, D.S., 1973, Automatic noise nulling circuit: U.S. Patent 3 723 883.

Smither, M.A., and Pater, A., 1982, Common mode interference reduction in seismic recording: Geophysics 47, 1672-1680.

TABLE 1. Hum Filter Program Code

```
   LENGTH = FLOAT (N)/FREQ/DELTAT   !  calculate integer length interval
   A = 0; B = 0                                      !  preset components
   DO 1  I = IFIRST, IFIRST+LENGTH-1
   T = DELTAT * FLOAT(I)
   A = A + TRACE(I) * SIN (2*PI*FREQ*T)                 ! even component
1  B = B + TRACE(I) * COS (2*PI*FREQ*T)                  ! odd component
   A = A/FLOAT(2*LENGTH)                                     ! normalize
   B = B/FLOAT(2*LENGTH)
   DO 2  I = 1, NSAMP                                         ! subtract
   T = DELTAT*FLOAT(I)
   TRACE(I) = TRACE(I) - A*SIN(2*PI*FREQ*T)
2  TRACE(I) = TRACE(I) - B*COS(2*PI*FREQ*T)
```

LENGTH = interval length in points
FIRST = first point of interval
N = length of interval in cycles
DELTAT = sample interval in seconds
FREQ = frequency in Hertz
A = sine (odd) component
B = cosine (even) component
TRACE = seismic trace data points
NSAMP = length of trace in points

FIGURE CAPTIONS

FIGURE 1. Instrument response to seismic data. (a) without notch filter (b) with notch filter.

FIGURE 2. Field data recorded with 60 Hz powerline noise.

FIGURE 3. Field data after application of 60 Hz hum filter.

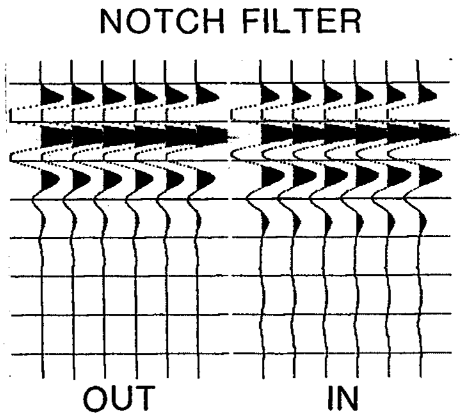

FIG 1

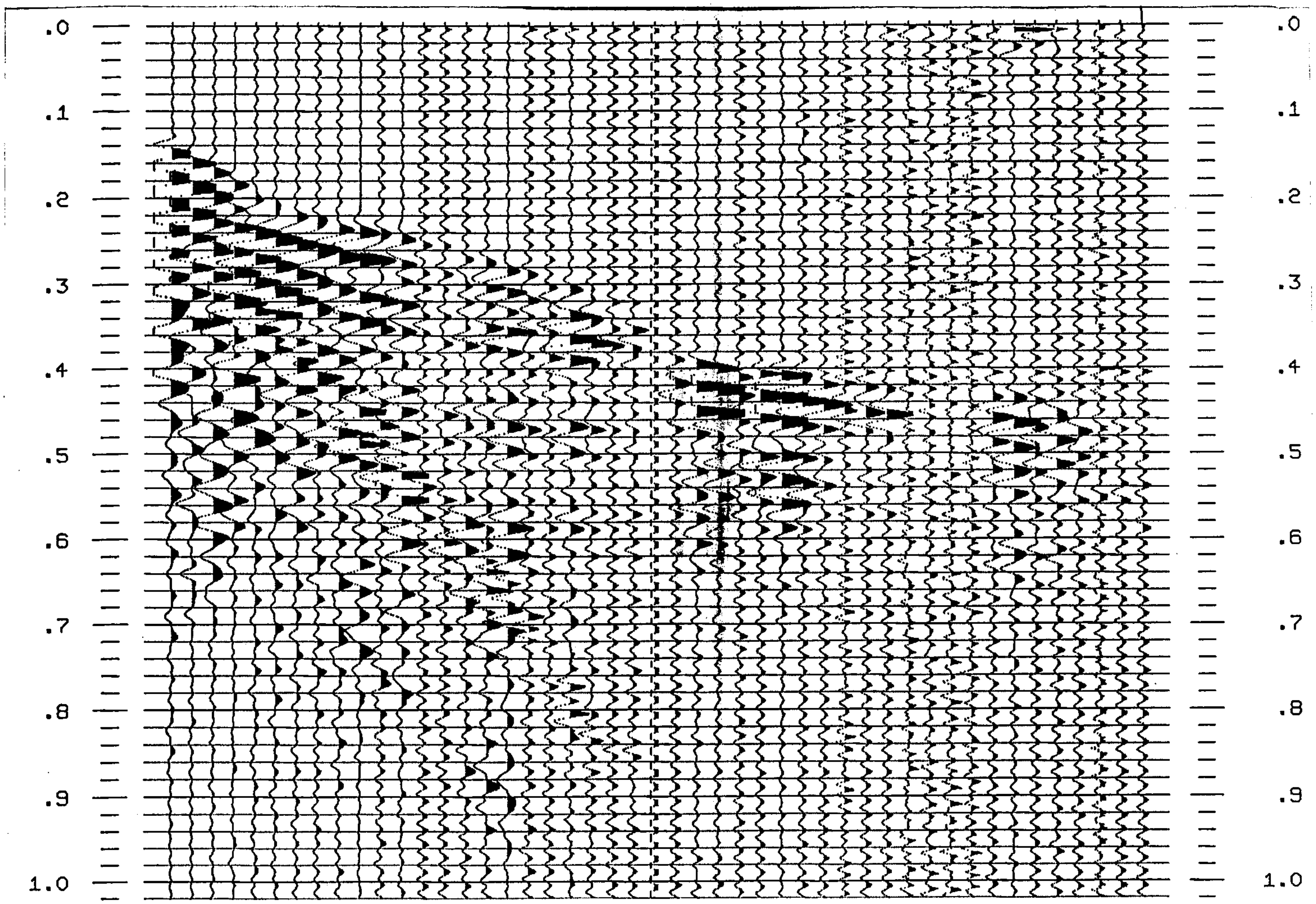

FIGURE 2

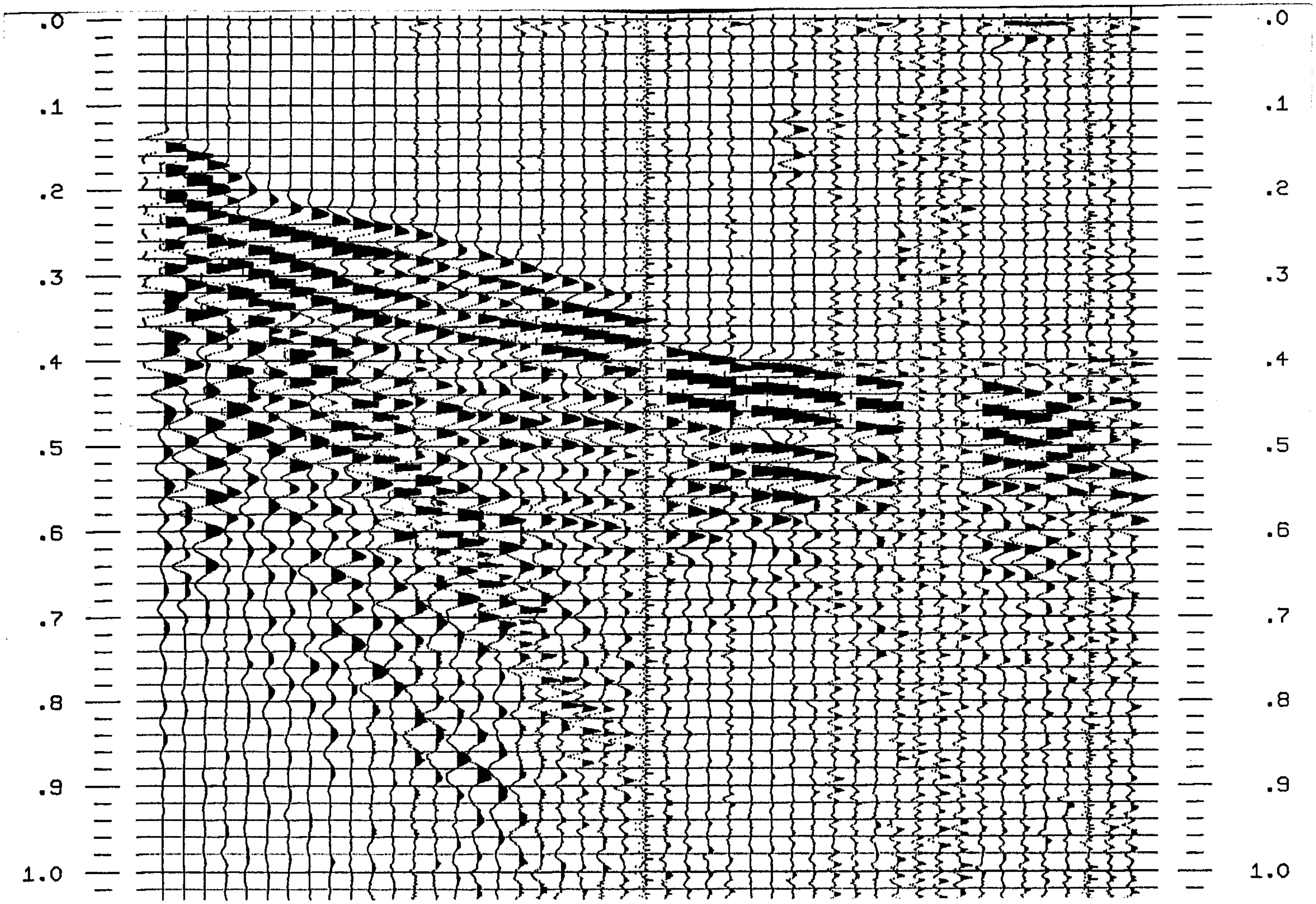

FIGURE 3