The Woofer, the Squarker and the Tweeter — The 'Varisponse' — An experiment in Geophone Response

B. J. Evans

Curtin University of Technology
Kent Street
Perth, WA 6011
Australia

Summary

The audio range of high fidelity equipment is extremely wide, from 2 Hz to 15 kHz approximately. A single audio speaker cannot maintain efficient operation across the spectrum, so in order to compensate for the losses in efficiency, hi-fi enthusiasts use three speakers with over-lapping spectral operation. Thus, a broad-band signal is produced using a 'woofer' for low frequencies, a 'squarker' for medium range frequencies, and a 'tweeter' for the higher frequencies.

The useful seismic spectrum is limited to a range of 2 Hz to 400 Hz. The range of 2 Hz to 120 Hz is of particular interest to the oil explorer with present technology. In order to image reservoirs successfully, methods of signal enhancement and noise reduction have been designed to improve low signal-to-noise ratios.

In order to reduce the harmful signal-masking effects of surface waves, geophone strings spread over the surface waves' length are used in an attempt to attenuate coherent ground roll. Where waves are dispersive, a higher valued geophone coil resonant frequency may provide assistance in attenuating such waves. Alternatively, in vibrator work, a change of sweep frequency character may assist not only surface wave reduction (by simply not sweeping over the surface wave frequencies) or a concentration of sweeps in the target zone spectrum may enhance reflected signal strength. One innovation — that of Varisweep* — allows a change of sweep frequency with vibrator position, thereby using the source array sweep frequency design to enhance the desired signal, and yet use the source array length to attenuate long wavelength coherent noise.

This paper proposes the combination of the Varisweep approach of source design to receiver design, such that the receiver array improves the spectral response in terms of both signal and noise.

The audio spectrum

The effective range of the human ear is from 2 Hz to approximately 18 kHz dependent upon individual ear drums. To adequately cover this very broad spectral range, large low frequency audio 'woofer' speakers are used to cover the bass frequencies, medium sized 'squarker' speakers cover the centre spectrum and small 'tweeter' speakers cover the higher frequency range. If your ear drums are fairly insensitive to the higher frequency range, a single squarker is perfectly adequate and you do not need to purchase expensive high fidelity sound systems. If however, your hearing covers the complete audio spectrum, you may spend a great deal of funds on the three speaker types, and immediately label yourself a hi-fi enthusiast, even though you don't understand the music. So if the audio spectrum is broadened by the use of different resonant speakers, why can't this logic be applied to the seismic spectrum?

The seismic spectrum

The seismic spectrum realistically received at the surface, is 10 Hz to 90 Hz for deep seismic events, increasing to 250 Hz for shallow reflections. The lowest octave of 10–20 Hz is a mixture of coherent surface wave noise and reflection, whilst the second octave of 20–40 Hz is predominantly reflection. Higher octaves are a mixture of reflected signal and random noise, generally. To a hi-fi enthusiast, the obvious solution to enhance signal is to use three receivers, each with its own specific spectrum.

With this in mind, a post-graduate team of students at Curtin began assembling strings of geophones having different resonant frequencies. Geophone manufacturers' specifications indicate that geophone coils have a flat voltage output over the frequency range above their natural frequency. It is a common belief then that, provided there is adequate recording system gain, we need not worry about recording the higher spectral range, and that the flat spectral response indicates an adequate geophone response. This approach has been called into question by the geophone manufacturers who rightly suggest that a geophones response should not be flat, but have a linear increase with increase in frequency. This enhances higher frequencies at the expense of increased random noise.

Before assembling the geophone strings, it was necessary to test them for their individual response. By pulsing each individual geophone with a spiked input (Asten, 1977; Palmer, 1964), each geophone gave the response observed in Figure 1. Each response was recorded on magnetic tape, and a Fourier analysis gave the typical spectrum of Figure 2. The spectra produced, alerted the students to the fact that a geophone's peak output is at the natural frequency, even though the spike contained all frequencies. Clearly, if we could place three geophones of different natural frequencies in the same string, the output would peak at each individual natural frequency. However, geophones of different natural frequencies have such spectra because they possess different coil impedances, shunt resistances and capacitance values. These properties essentially stymed useful practical experi-

---

* Trade mark of Geosystems Services Corp.

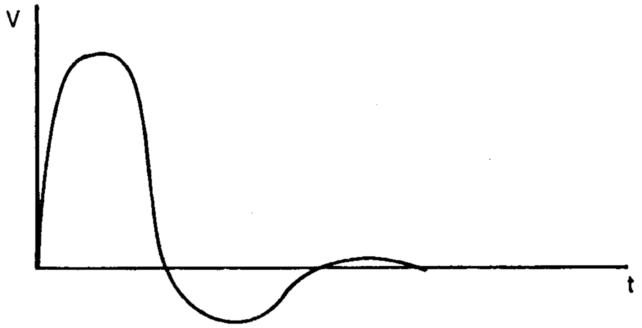

FIGURE 1
The temporal response of a single geophone.

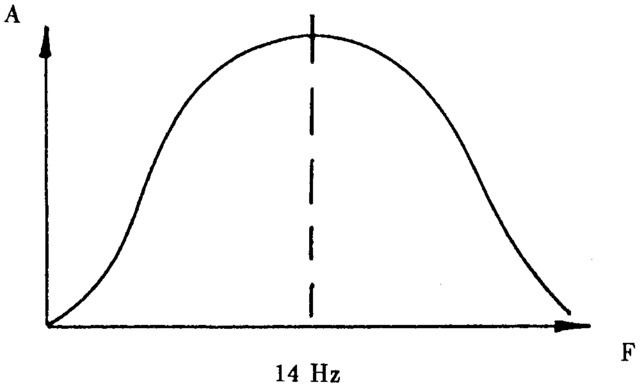

FIGURE 2
Amplitude spectrum of a single 14 Hz geophone.

mentation, because after some considerable attempt at trying to match transient impedance values, it was found that in real time, as one coil gave a positive output, the next coil was going partially negative in their different cyclical response. Indeed, the perfect transient mismatch allowed, on an upward motion of all geophones in the string, one coil to drive the next, and so on giving a negligible total array response output. Various mixed geophone strings were pulsed and tapped and their amplitude and phase spectra was random.

Consequently, the impedance mismatch problem in assembling a geophone string of multiple natural frequency geophones proved insurmountable in the short time-frame a graduate student has for experimental field practice. It is hoped that this paper may prompt geophone manufacturers to take up that challenge. In the interim, the proposed application of the mixed geophone array may be considered.

The Varisweep concept

Vibroseis sweep types consist essentially of three forms — a linear or monosweep across the spectrum of interest, a logarithmic sweep which spends a majority of time sweeping in the frequency of interest, and the Varisweep which changes sweep frequency with vibrator location. An adaption of Varisweep is 'Modelled Varisweep'. With low frequency sweeps at the outer ends of the source array and higher frequency sweeps at the array's centre, Modelled Varisweep offers the opportunity of both time and spatial filtering at once (Tobin, 1987), a simple example being shown in Figure 3, with an example of Modelled Varisweep spectra in Figure 4. Additionally, Modelled Varisweep offers potential for spectral transmission equalization and side lobe attenuation. It is the spectral equalization which is of interest here, since it is possible to perform the same feat using geophones.

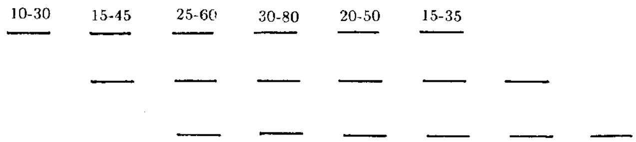

FIGURE 3
Modelled Varisweep source array configuration.

The 'Varisponse' geophone array

The simplest geophone array has two geophones, and attenuates surface waves when they are spaced a half the surface wavelength apart. Their natural frequency may either be below the predominant surface wave frequency (if useful reflectors are of the same order as the surface waves), or may be above the surface wave frequency — in which case the array is considered a time and spatial filter, and ground roll is attenuated by wavelength and frequency. Consider reflectors of interest have dominant frequencies of 30 Hz and 55 Hz. If two geophones with a natural frequency of 30 Hz are now placed within the initial two geophone array, surface waves are again attenuated but the 30 Hz reflector enhanced markedly. Perform a similar placement with two 55 Hz geophones, and once more, surface waves are attenuated with enhancement of the major event of interest. The result is spectral equalization in a manner similar to Varisweep, Figure 5.

In order to determine which geophone frequencies are needed, a knowledge of surface wave and reflector frequencies is required. This can be determined from previously recorded data or walkaway noise analysis wave tests. If such data is not available then field experiments must be performed. In new operational areas, it is customary to perform extensive Varisweep tests. In like manner, if geophones had the ability for their natural frequency to be changed in the field by a simple switch, the Varisponse array may be gainfully employed. Furthermore, spectral weighting may be performed on individual geophones in the array by the application of signal amplifier circuitry in each geophone. This is not inconceivable with the current state of electronics. It just needs someone to manufacture it.

Conclusions

Initial work on the Varisponse geophone array indicates that there is potential for receiver array spectral equalization. Such an array would have the same outward appearance and application as the conventional geophone array but would respond quite differently. The Varisponse array would be tuned to individual exploration objectives, and offers hope for signal-to-noise enhancement, irrespective of the type of energy source used. It is just waiting to be manufactured.

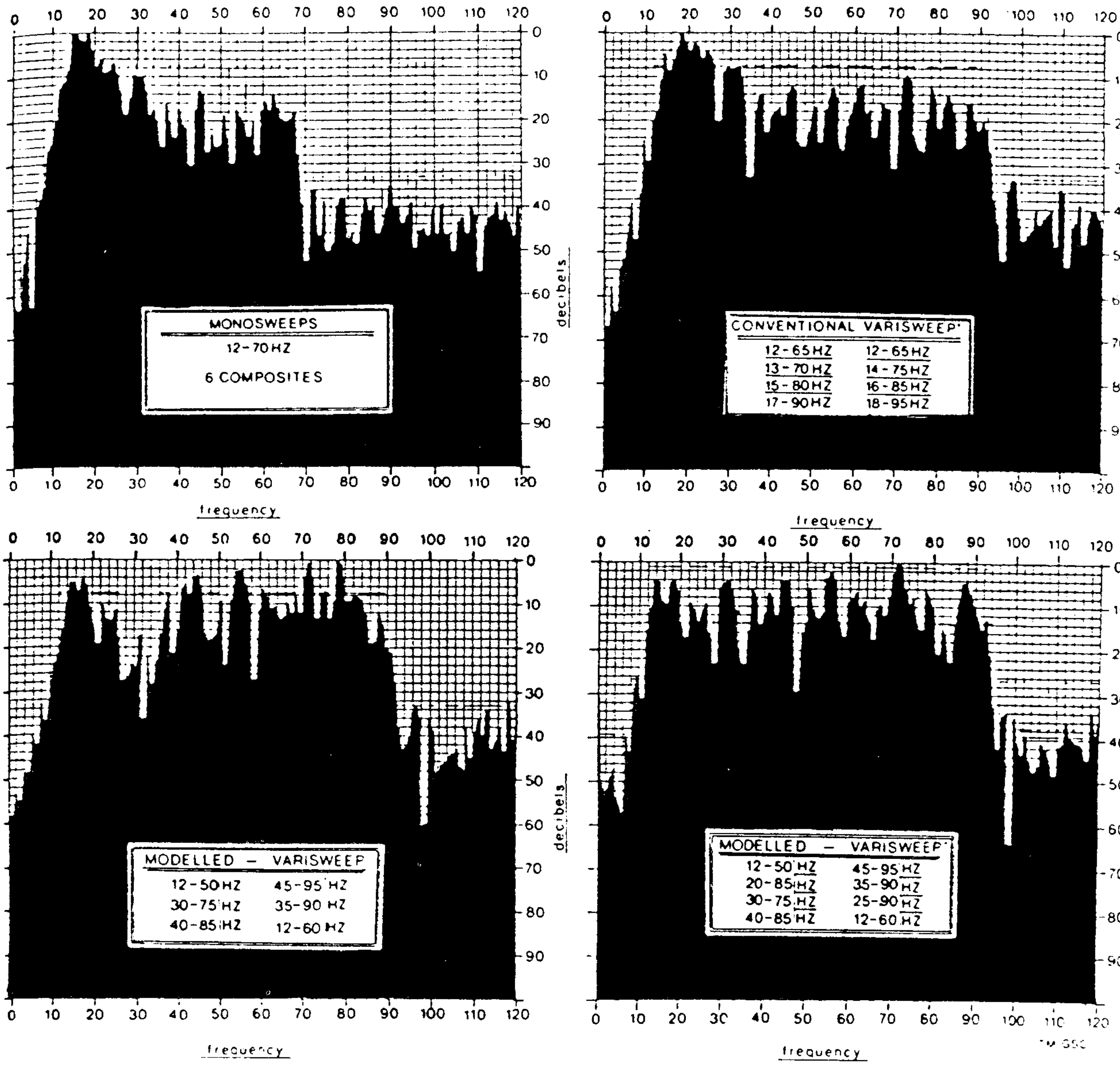

FIGURE 4
Modelled Varisweep amplitude spectra (after Tobin, 1987).

Acknowledgements

The author wishes to acknowledge the contributions and frustrations experienced by graduate students Nigel Smith and Angela Sawiak (but it was good 'experience'); the facilities available to perform seismic experiments at Curtin Field Research Laboratory and Seismic Processing Laboratory; the loan of various natural frequency geophones by Western Geophysical; and finally the idea which was given by Barry Long and without which this concept may not have surfaced.

References

Asten, M. W. (1977)—'Theory and practise of geophone calibration in situ using a modified step method', *IEEE Transactions*, Vol. GE 15, No. 4, pp. 208–214.

Palmer, B. A. (1964)—'A new technique for the measurement of geophone parameters under field conditions', *Geophysical Prospecting*, Vol. 12, No. 4, pp. 422–433.

Tobin, S. P. C. (1987)—'A study of amplitude recovery techniques of sign bit acquired seismic data including applications and recent developments of the sign bit acquisition concept', Masters thesis, Curtin University of Technology, Perth.

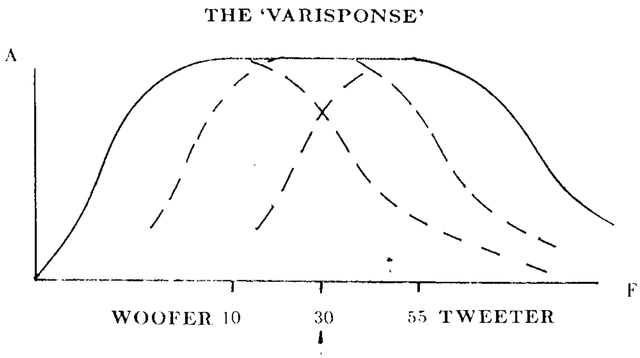

FIGURE 5
Amplitude spectrum of Varisponse.