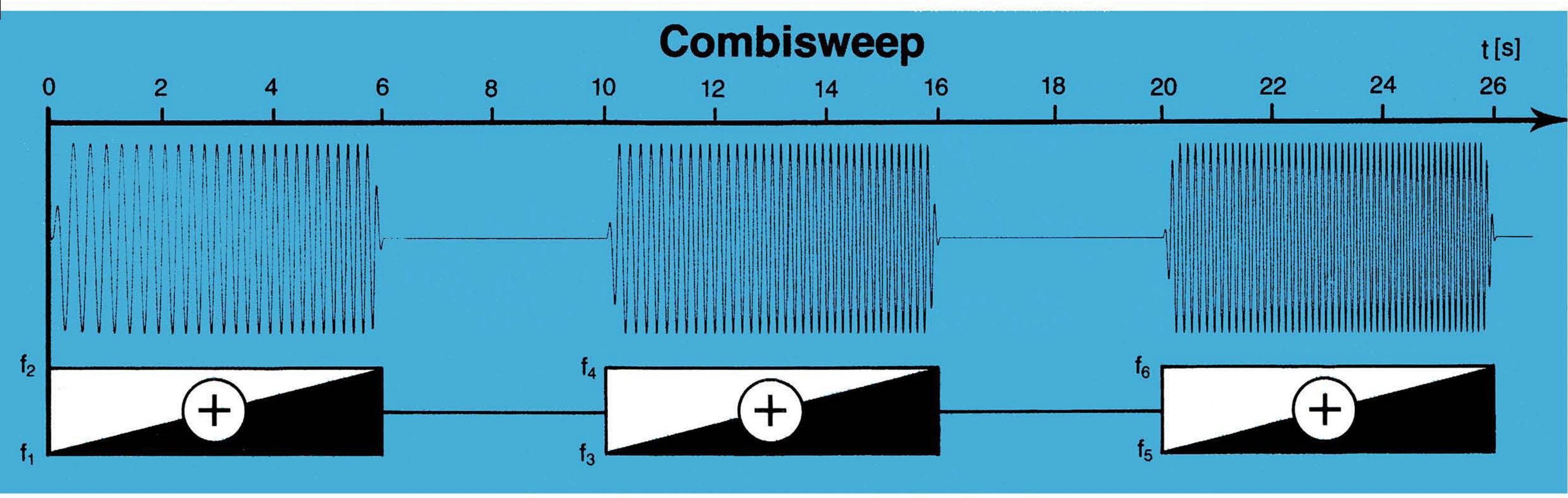
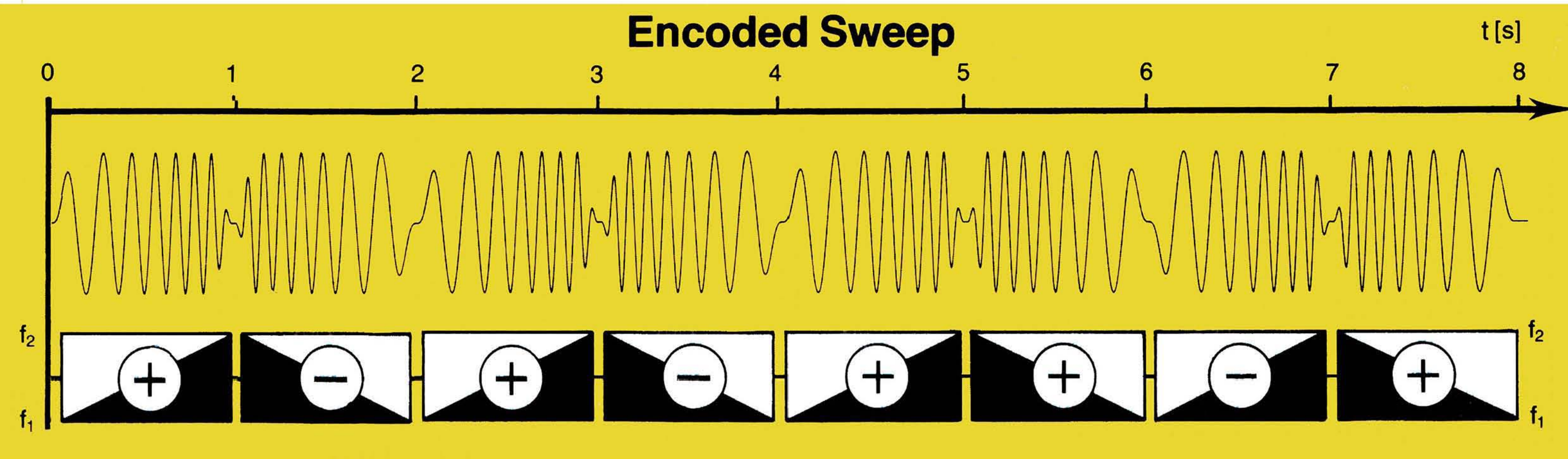
PRAKLA-SEISMOS INFORMATION No.27

Combisweep Techniques®
Encoded Sweep Techniques





Introduction

As well known, the VIBROSEIS* system makes use of frequency-modulated sweep signals, the energy of which being directly proportional to their length and amplitude. As the useable signal amplitude is limited by various factors, the **sweep energy** can only be increased by sweep extension, thus generally improving the signal/noise ratio. In practise sweeps are used mostly with a duration from a few seconds up to 30 seconds. However, in areas with a low level of random noise short sweeps can be advantageous.

Generally, the sweeps are essentially longer than the time delay of subsequent seismic events: for example, the response signal attributed to the refraction arrivals (first breaks) does not decay before the response signal from a deep reflecting horizon arrives, which means that the amplitude of a weak response signal can be impaired by a strong response signal.

Particularly after correlation the unavoidable **correlation noise** of strong events, which is as long as the sweep with decreasing amplitude, can be of about the same level as the correlated main peaks of subsequent weak reflections; undesired destructive interference can then occur.

In principle, **correlation-noise suppression** can be achieved by the following methods in the field:

- increase of sweep band width
- limitation of sweep length.

These principles would entail the application of **sweeps of infinite bandwidth and of zero-convergent duration** respectively. Both principles, separately or combined, theoretically provide a spike-like autocorrelation pulse, practically free of correlation noise, which can be compared with the pulse of an explosive seismic signal.
As to the attainment of an infinite bandwidth, limits are set by instrumental and environmental reasons and by absorption. A similar effect is, however, achieved by the **amplitude spectrum shaping** of a sweep. A very common shaping procedure is the application of sweep tapering or the use of nonlinear sweeps. In particular, the **Combisweep Technique®** provides the possibility of correlation noise suppression by optimizing the amplitude spectrum in the field.

Short sweeps are the basic elements of the recently introduced **Encoded Sweep Technique** by which a reduction of emitted energy can be avoided.

These two techniques may be combined using the Quaternary Encoded Sweep Technique.

Continuous developments of vibrator control systems improve the above mentioned techniques.

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Title page: PRAKLA-SEISMOS VVCA Vibrators on the Adriatic Coast

Combisweep Techniques®

In order to enhance the reflected signal, the correlation noise of neighbouring signals has to be significantly reduced. A well known and proved procedure is the optimization of the amplitude spectrum at sweep emission as well as at sweep correlation.

The **Combisweep Technique** offers the possibility of **amplitude spectrum shaping** in the field seismogram in order to improve conditions for subsequent signal treatment. In general, a Combisweep consists of two or more sequential conventional sweeps (the sweep segments) with time gaps (listening periods) between them (fig. 1 and title page). Symmetrical or asymmetrical frequency weighting can easily be achieved by overlapping the frequency spectra of the different sweep segments, the amount of overlapping being equal or unequal.

Fig. 2 illustrates **symmetrical frequency weighting;** the graphs of the correlation-noise amplitudes show a 10 dB-improvement in attenuation after 1 sec, using the Combisweep.

In order to eliminate particular noise frequencies (60 Hz, 50 Hz, 16 $^{2}/_{3}$ Hz) **frequency gapping** can easily be effected (fig. 3).

Fig. 4 shows two other possibilities using a combination of linear sweeps. Fig. 4a illustrates how an **asymmetrical frequency weighting** can be realized using a Combisweep. In this example the high frequencies are accentuated in order to counteract absorption losses caused by the earth filter. In fig. 4b a **combination of a positive and a negative sweep,** equal in length and frequency content, resulting in one Combisweep, is presented. By such signal combination the strongest harmonics caused by the vibrator baseplate motion can be eliminated quite well, and in consequence correlation ghosts are considerably reduced, so that one can abandon the "inverted-vibrating" method.

- **High flexibility in signal design**
- **Simple signal generation**
- **Full use of the 32-second sweep observation time**

Fig. 1: Definition: Combisweeps are composed of sweep segments separated by gaps (see also title page)

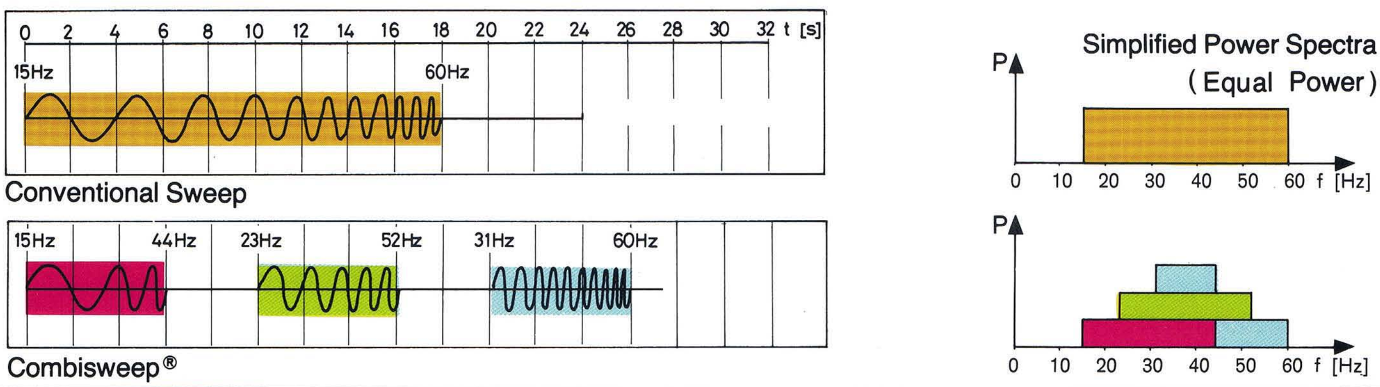


Fig. 2: Symmetrical Frequency Weighting to minimize correlation noise

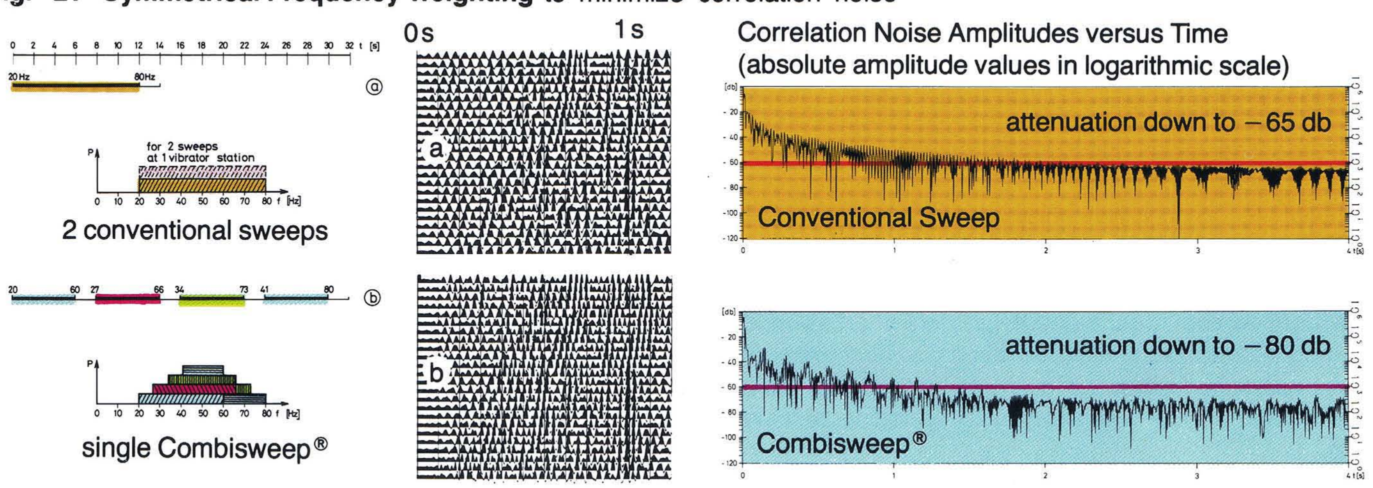


Fig. 3: Frequency Gapping of Discrete Frequencies to avoid correlation with "high-line pick up"

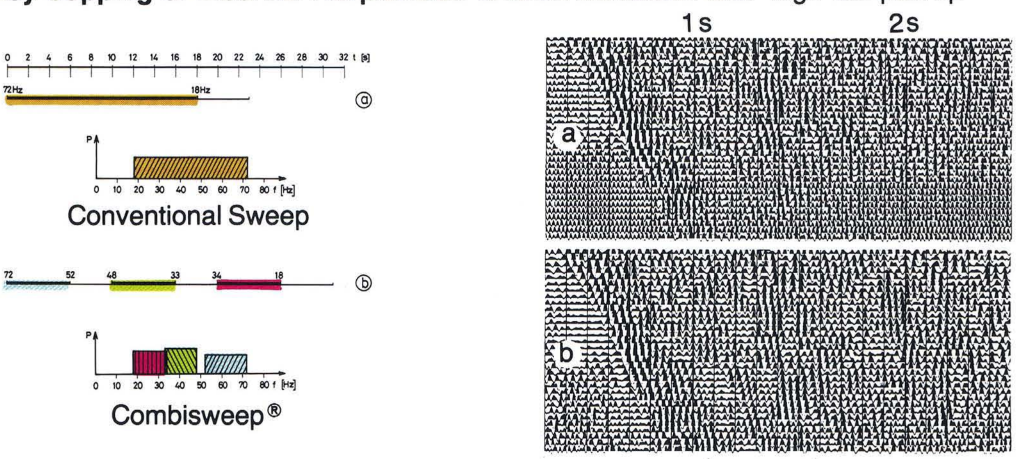
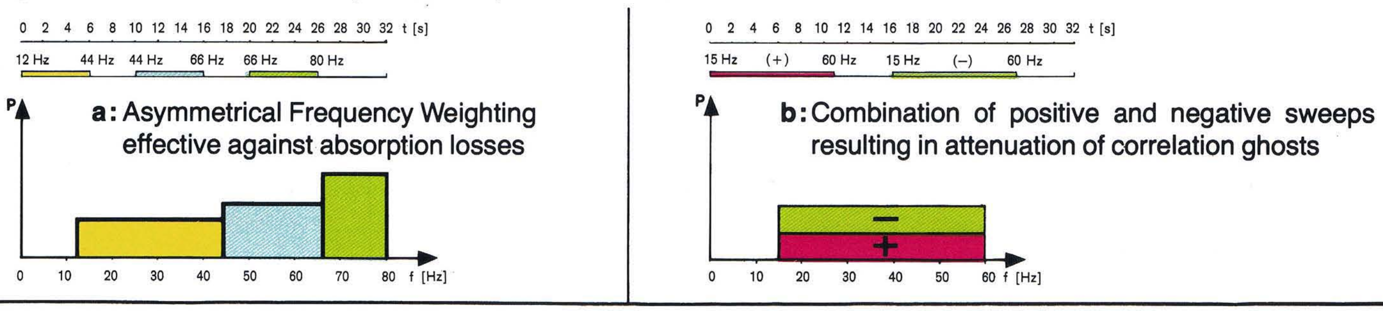


Fig. 4: Possibilities offered by other sweep combinations



Encoded Sweep Techniques

In order to completely separate correlation noise originating from two neighbouring seismic events, the sweep length has to be shorter than the travel-time difference between the interfering signals. This would entail the application of sweeps of zero-convergent duration. As short sweeps contain only little energy, they offer only little possibility for the suppression of statistical noise.

However, **short sweeps** of about 1 second duration are very effective, if for instance weak reflection signals with travel-times of several seconds follow strong refraction events. In such a case, the correlation noise can often be completely separated from the reflection events. The resulting seismograms offer better conditions for further treatment, particularly for data processing using single correlograms (e.g. calculation of automatic static corrections). Judging each case individually, it has to be decided to what extent the lower energy of a short sweep is compensated by the advantage of correlation-noise suppression.

It should be mentioned that short sweeps normally have the disadvantage that the correlation of the vibrator-generated harmonics (asymmetric ghosts) come close to the correlation of the basic event. Therefore, short sweeps should be chosen with a bandwidth of less than one octave, thus making the correlation of harmonics disappear.

In order to make use of the advantages of short sweeps and to overcome the above mentioned disadvantages of low energy and of bandwidth to be limited it is, according to the Combisweep-method, possible to **transmit a specific number of matched octave sweeps.**

As a far better method PRAKLA-SEISMOS introduced the **Encoded Sweep Technique,** derived from radar technology. Here short sweeps (the code members) are combined to code sequences without gaps. Best experiences have been made by combining 8 code members of 1 sec to a sequence, two of which (the code and the complementary code with a listening period in between) forming the encoded sweep.

Fig. 5 illustrates the principle.

Fig. 5a shows a conventional two-octave sweep of 16 seconds with the graph of correlation-noise amplitudes below. At 1 sec the correlation noise has reached −40 dB.

Fig. 5b shows a very short conventional two-octave sweep of 1 sec only. As expected, the correlation noise practically disappears after 1 sec. In fig. 5c 16 of those short conventional sweeps of equal bandwidth are combined to an encoded sweep consisting of code and complementary code. This results in a total sweep length of 16 seconds, as with the conventional sweep of fig. 5a. The basic parameters for sweep encoding are the signs plus and minus **(varying polarity of the code-members)** by means of which correlation repetitions (ghosts), caused by overlapping correlation, are avoided. The graph of the correlation-noise amplitudes shows a similar improvement in attenuation after 1 second as in figure 5b.

Fig. 6 and 7 explain binary and quaternary encoded sweeps.

In the binary encoded sweep only the basic parameters for sweep encoding are used: varying polarity of the code-members according to a predetermined encoding procedure (fig. 6).

In the quaternary encoded sweep, besides the basic polarity encoding, additional parameters are introduced: **alternating up- and down-sweeps** (fig. 7a and title page) or application of matched octave sweeps **(signal decomposition)** in order to avoid correlation ghosts originating from harmonics (fig. 7b).

Field examples are shown in fig. 8 and 9.

- **Essential reduction of correlation noise using sequences of short sweeps**
- **Elimination of asymmetric ghosts by using sequences of octave sweeps**

Fig. 5: Conventional, Short and Encode

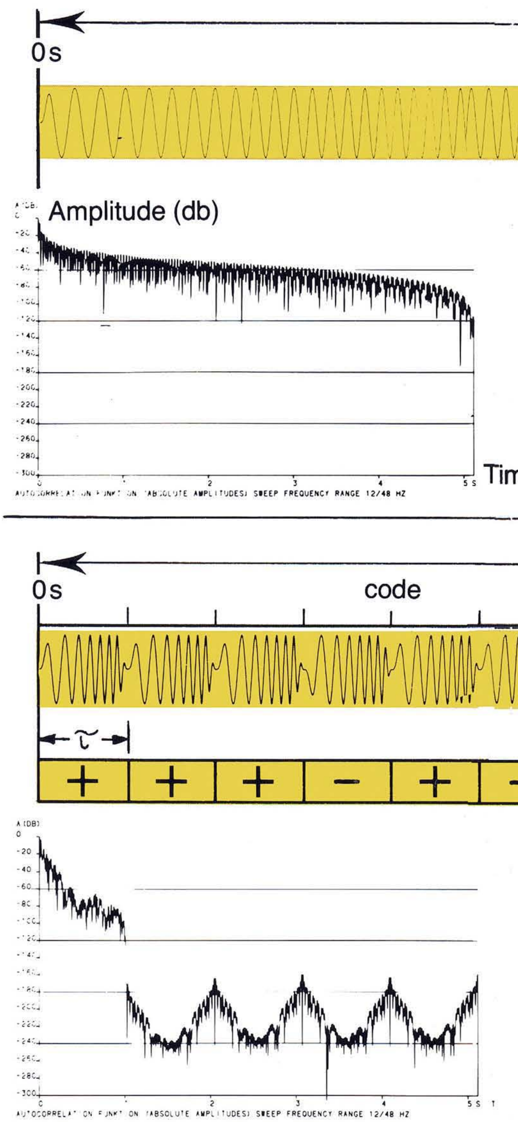


Fig. 6: Binary Encoded Sweep (polarity e

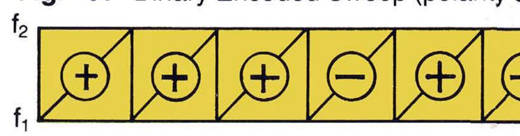
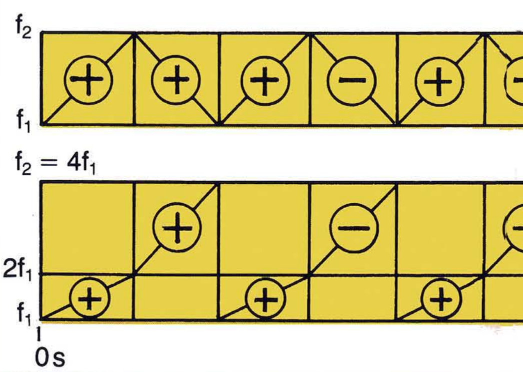


Fig. 7: Quaternary Encoded Sweeps



For presentation purposes all sweeps are ed .Sweeps with Correlation- Noise Amplitudes (absolute amplitude values in logarithmic scale)

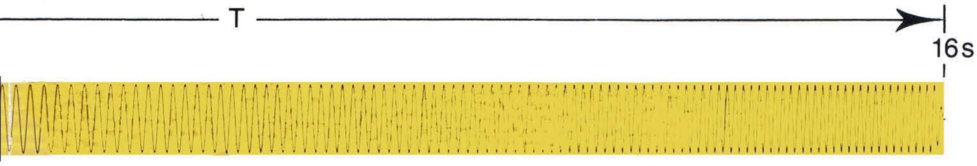


Fig. 5a: Conventional Sweep

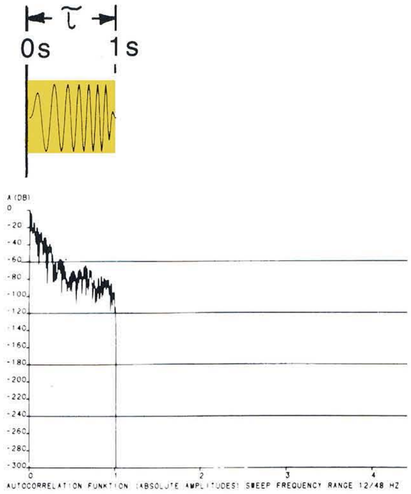


Fig. 5b: Short Sweep

me (sec)

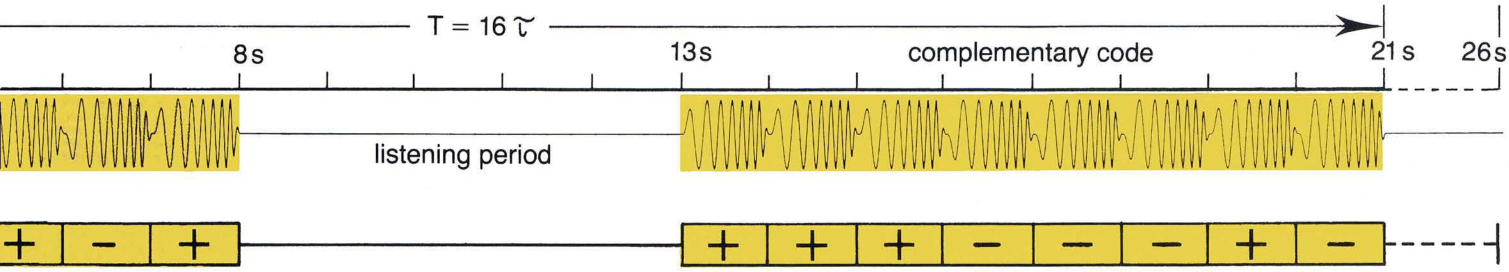


Fig. 5c: Encoded Sweep

encoding only)

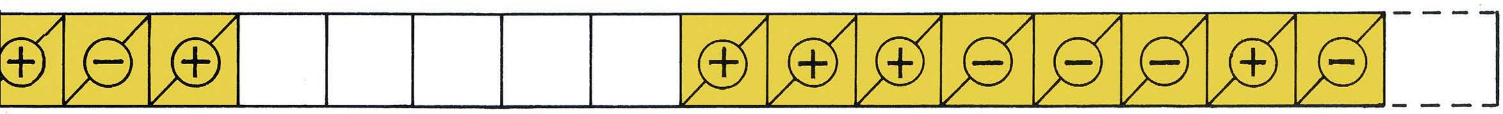


Fig. 7a: Polarity encoding and alternating up- and down-sweeps (see also title page)

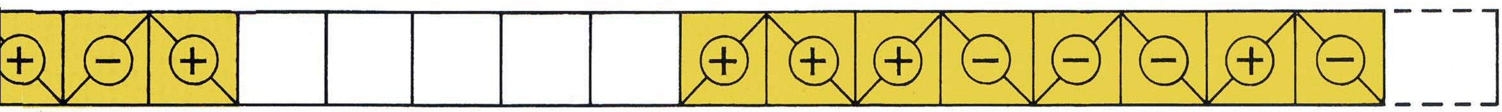
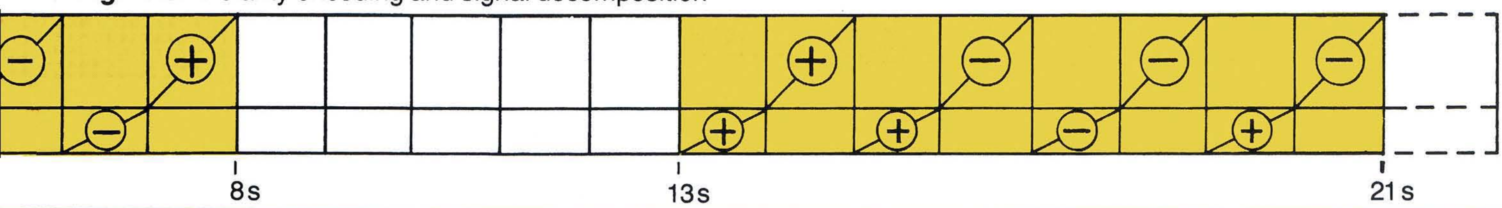


Fig. 7b: Polarity encoding and signal decomposition



e displayed with a quarter of their frequencies (e.g. 3–12 Hz instead of 12 – 48 Hz)

Fig. 8: Comparison: Encoded Sweep/Conventional Sweep (single records)

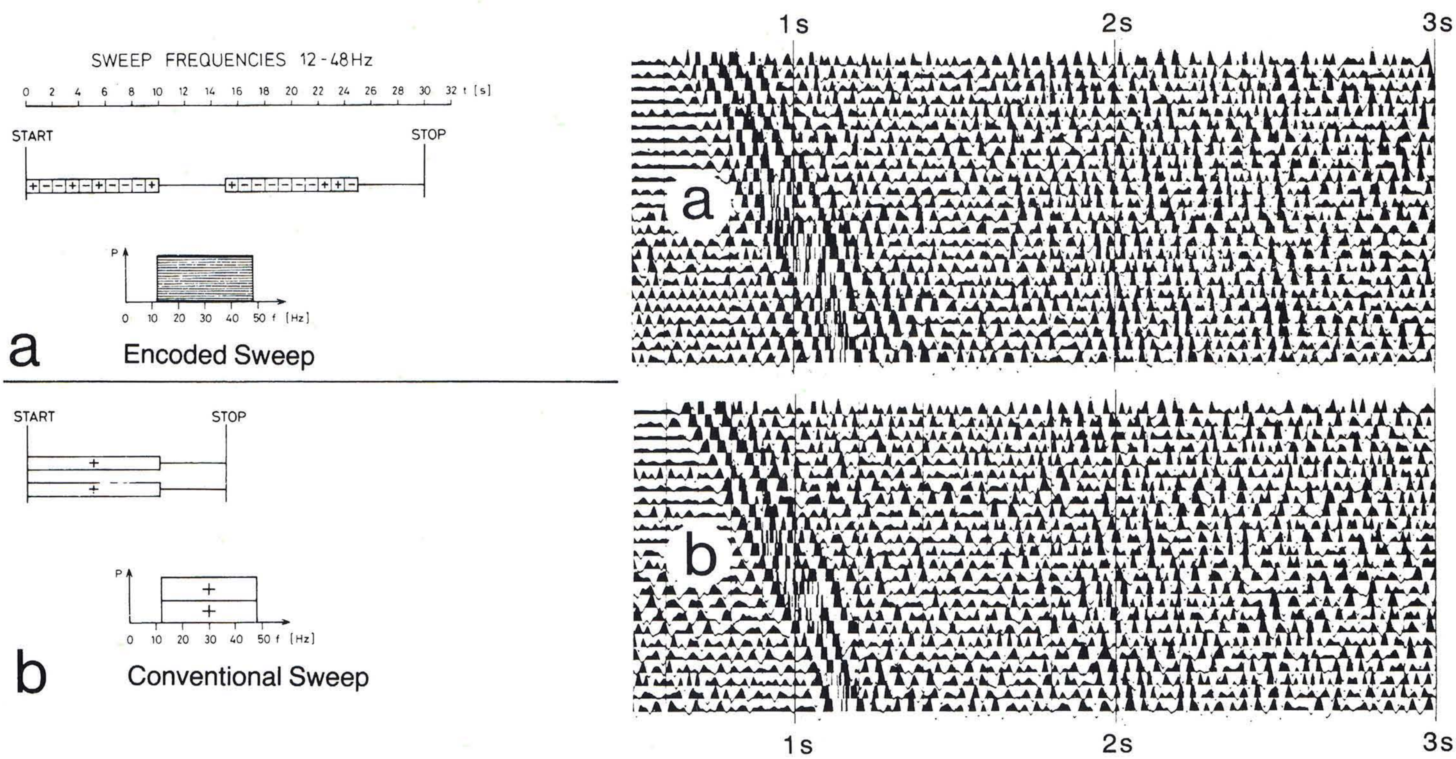
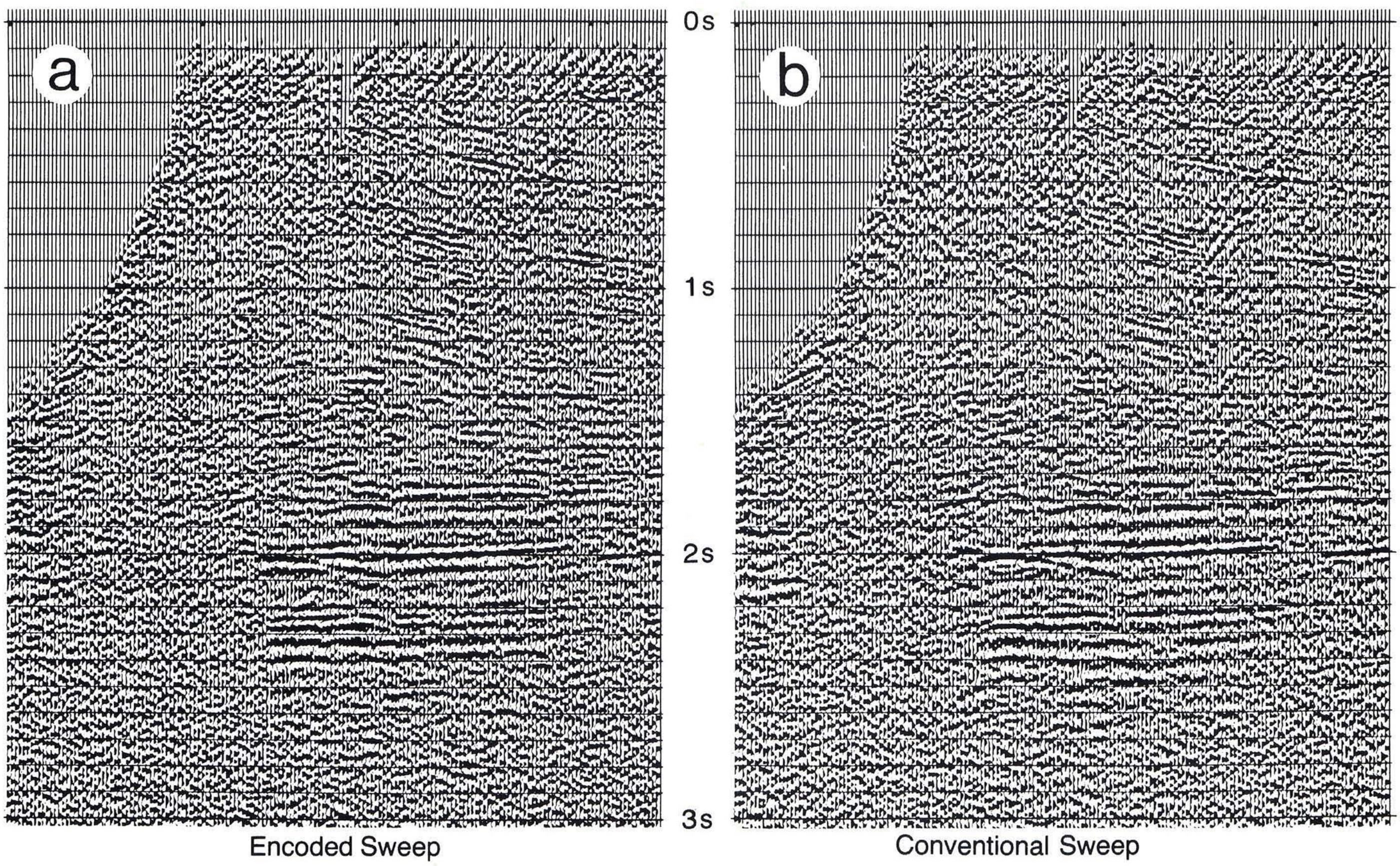


Fig. 9: Comparison: Encoded Sweep/Conventional Sweep (stacked sections)



Sweep techniques, in a broader sense, include such methods which make better use of the computerized recording instrument Extended CFS I. Generally the relatively long recording time is applied in connection with certain switching techniques.
Firstly, by means of combined sweeps, **signal selection as a function of spread geometry** (mainly in-line offset) can be achieved. Secondly, the **number of available recording channels can be used more economically.**

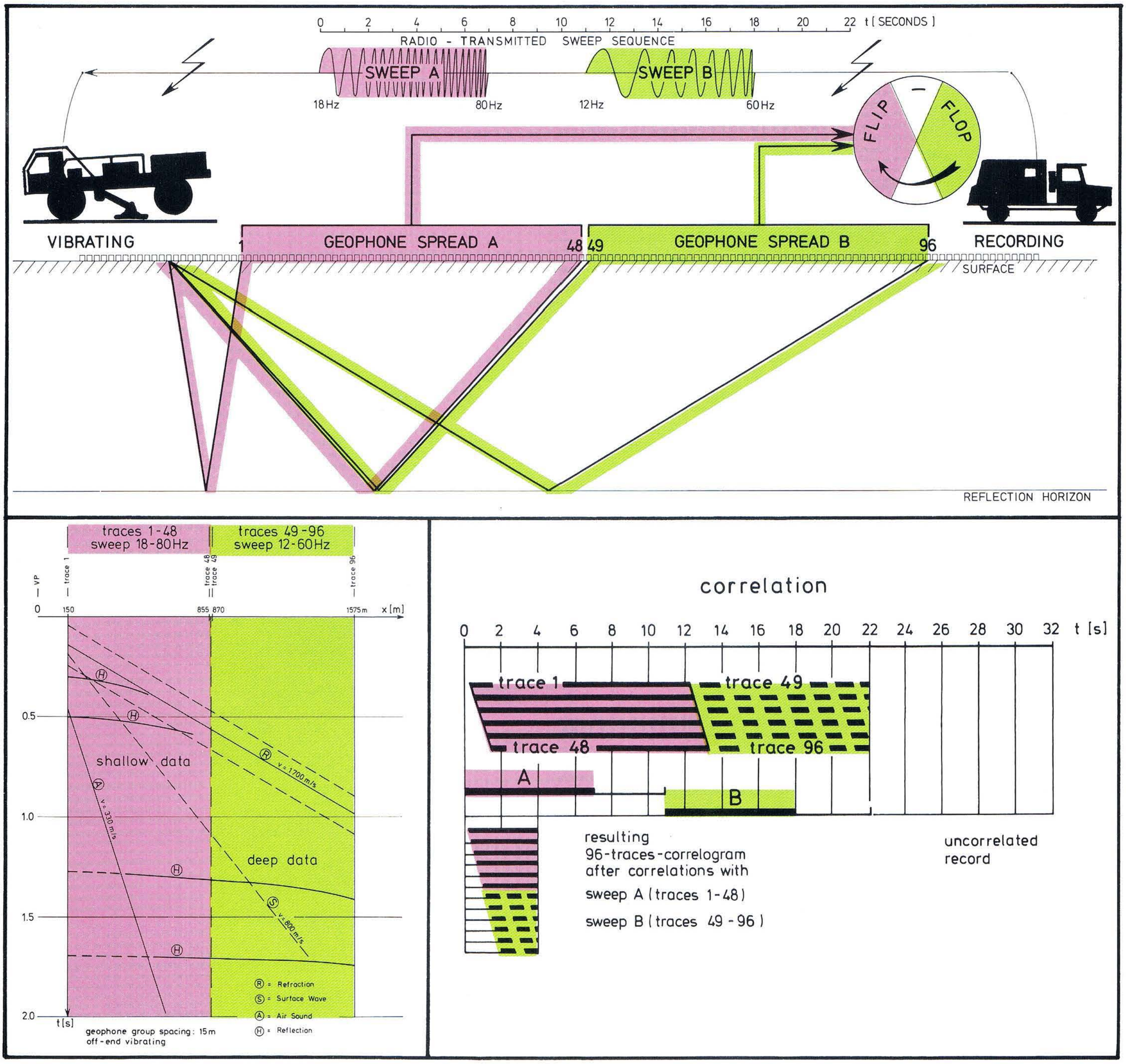
In practical field work the trace switching device for multiple coverage is controlled by a program switch (Flip-Flop).

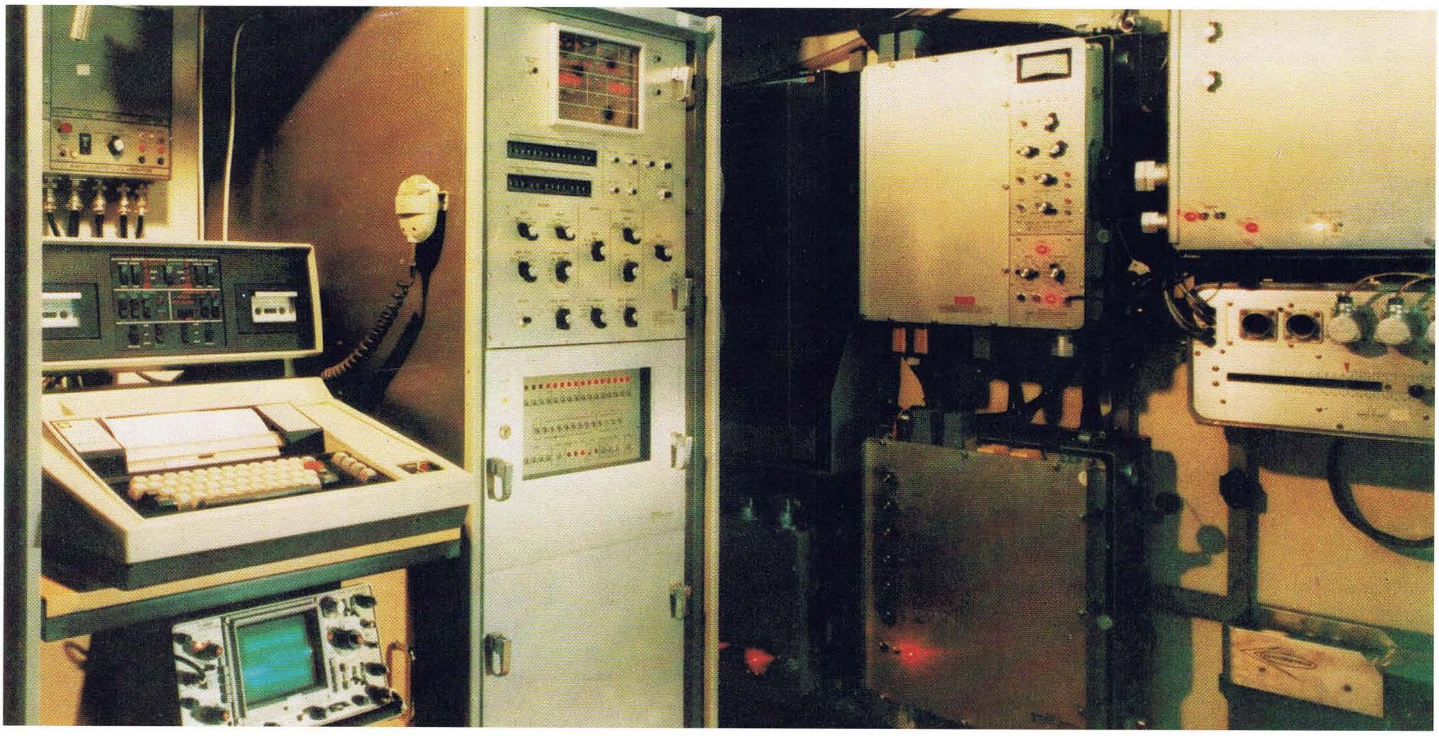
During the recording time from 0s to 11s, in which sweep-segment A is emitted by the vibrators, geophone spread A is connected to the 48 recording channels. After 11 seconds geophone spread B is connected to the 48 recording channels by the program switch. During the recording time from 11 s to 22 s sweep-segment B is emitted by the vibrators. From this the following logic combination becomes evident:

High frequency sweep → short in-line offset → shallow data recording

Low frequency sweep → long in-line offset → deep data recording.

- **96 trace recording on 48 channel instrument during a single recording cycle**
- **Signal selection as a function of spread geometry**

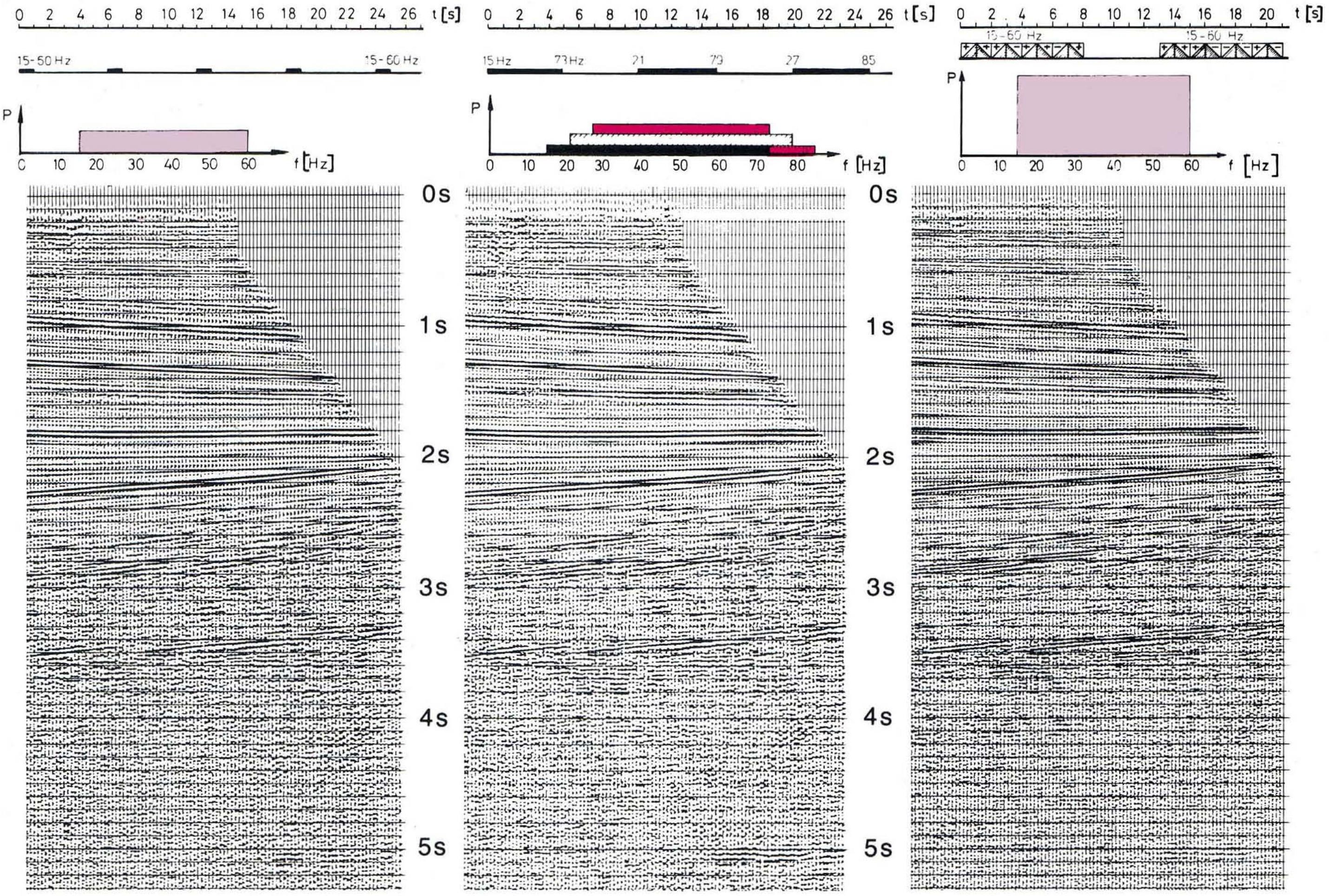




A remarkable application of the computerized recording instrument Extended CFS I (Texas Instruments) is the application of sophisticated sweep techniques

Different Sweep Techniques

Short Sweeps (5 x 1 sec) 15 – 60 Hz ● Combisweep® (3 x 5 sec) 15 – 85 Hz ● Encoded Sweep (16 x 1 sec) 15 – 60 Hz



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