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Source Power Spectrum Measurement in Shallow Water

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With a continuous source of unknown power spectrum, one is limited to spatial diversity techniques. These may be divided into two main groups, statistical and deterministic. In shallow water, and with low sound frequencies, the length of a vertical broad side array of sufficient directivity would often exceed the water depth. This is illustrated by a computer simulation of the performance of a 5-element array in a wedge-shaped site. For simplicity, the source spectrum was made flat. The geometry is shown in Fig.1, and the results for a simple broadside array and a focused array are shown in Figs. 2 and 3. Results for a 10-element array were also similar. In the simulations, the broadside and focused array results were compared to that of taking the mean of the power spectrums of the received signals at each hydrophone. It is evident that the power spectrum mean, which is an average quantity, is a better estimate of the free field signal, hence the source spectrum, than the broadside or focused array results. It appears that, with a single vertical string of hydrophones, there is not enough information for deterministic methods to be used efficiently, and therefore, statistical methods are the more robust alternatives.

In a perfect reverberation chamber, Waterhouse [1, 2] and Maling [3] has shown that the p.d.f. of the sound intensity is an exponential function, and it can be shown that, as a consequence, the best estimate of the source level that can be made is the simple average of the sound intensity within the medium. In practice, however, a shallow water site differs significantly from a perfect reverberation chamber. The boundaries absorb sound energy to a certain extent, and this has the effect of giving a finite upper limit to the measured sound intensities. Scattering from rough surfaces produces a lower limit. Therefore, the exponential p.d.f. predicted for an ideal reverberation chamber is not exactly valid in a practical environment, and consequently, the simple average may not be the best estimate. The question is how significant are these differences between the ideal and practical situations, and whether they are of any use.

It is conceivable that a situation exists where the p.d.f. is significantly different from the ideal exponential p.d.f., and in such a way that significant improvements in source level estimation can be made. This approach has produced positive results in cases where the sound spectrum is broad. Although the source power spectrum is unknown, the fact that the acoustic power is spread over a broad band of frequencies allows one to employ, in addition to spatial diversity, certain forms of frequency diversity techniques. The method adopted in this study involves obtaining the power cepstrum of the signal at each receiver. The cepstrum is described in several references, such as Stoffa et al. [4] and Childers et al. [5] . In this instance, it is defined as the inverse Fourier transform of the logarithmic power spectrum.

The power spectrum of the signal at each receiver can be considered as the source spectrum multiplied by the frequency response of the sound channel. The former is a constant while the latter varies from one receiver to the other since it is a function of source and receiver positions. By taking the logarithm, the two components become additive. Since Fourier transformation is a linear process, the cepstrum may also be considered as two additive components, the one arising from the source spectrum and the other from the sound channel. It can be shown that in situations where a small number of ray paths dominate the sound channel, the p.d.f. of the sound channel component resembles a Cauchy distribution. This is confirmed by the computer model of a wedge-shaped site, and by experimental results taken in a tank. In practice, the p.d.f. of the sound channel component cannot be easily measured because the source spectrum is unknown. However, if the signals at each hydrophone are statistically independent, it is possible to estimate the scale of p.d.f. from the p.d.f. of the cepstrum differences, because the Cauchy distribution has the property that the p.d.f. of differences is identical to the p.d.f. of the individual variables.

The Cauchy distribution has infinite standard deviation, and consequently the sample mean is a very inefficient estimator of the population mean. For small samples, the median is a reasonably efficient estimator. For large samples (greater than 10) trimmed means give reasonable results. The optimum result is obtained by the Pitman estimator [6,7] . Computer simulations using the median and the Pitman estimator are shown in Fig. 4 and 5 . These results are also supported by laboratory results.

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References:

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FIG 1 GEOMETRY

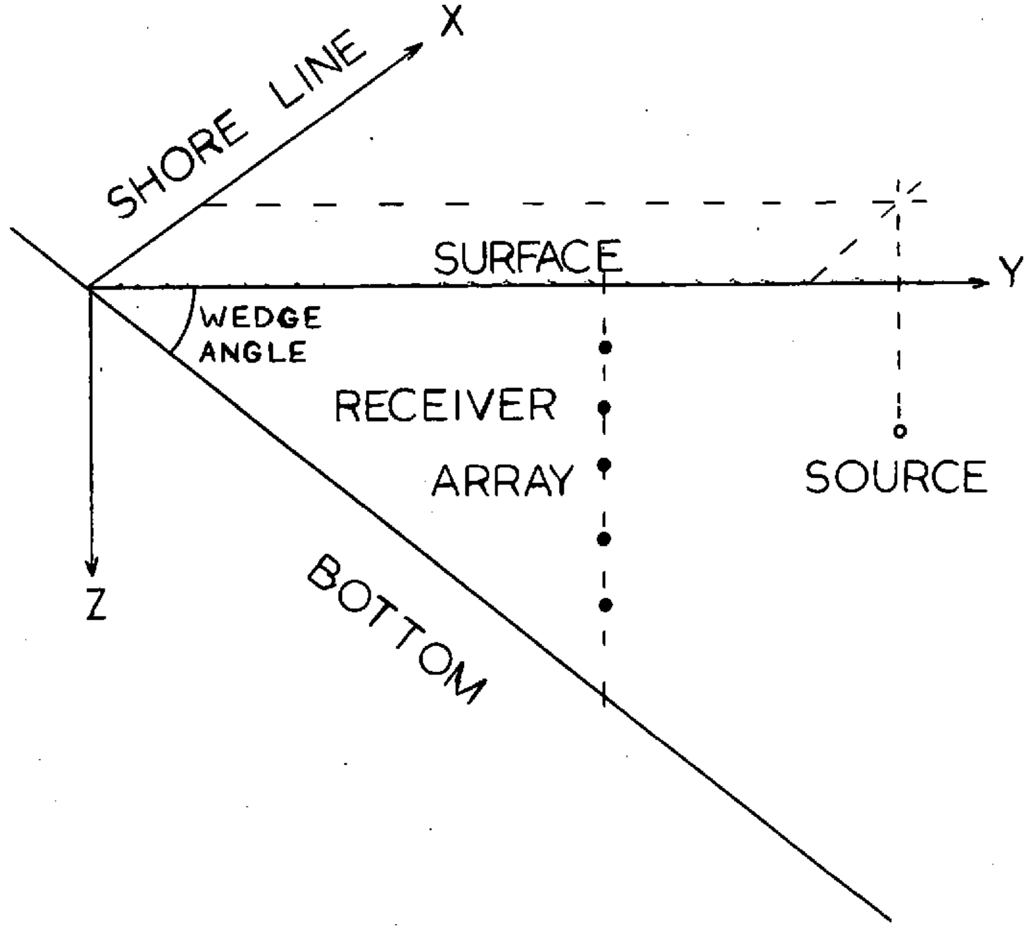

FIG. 2 PROGRAMS - BGCEP79, BMPA53, CEP79 , S 0
SPECTRUM ESTIMATION BY LINE ARRAY AND PWR SPECTRUM AVERAGING
FREQ INTVL 0.4 HZ, 19 RAYS COMPLETE, BOTTOM REFLEC COEF = (0.600, 0.000)
SOURCE POSITION (X, 700.0, 80.0) M RECEIVER POSITIONS (0, 600.0, 30.0/ 160.0/ 100.0/ 65.0/ 130.0) M
WEDGE ANGLE = ARCTAN (0.350) X = 100.0 M , SNR = 47.110 DB
SDEVS = 4.751, 1.848 , 2.570

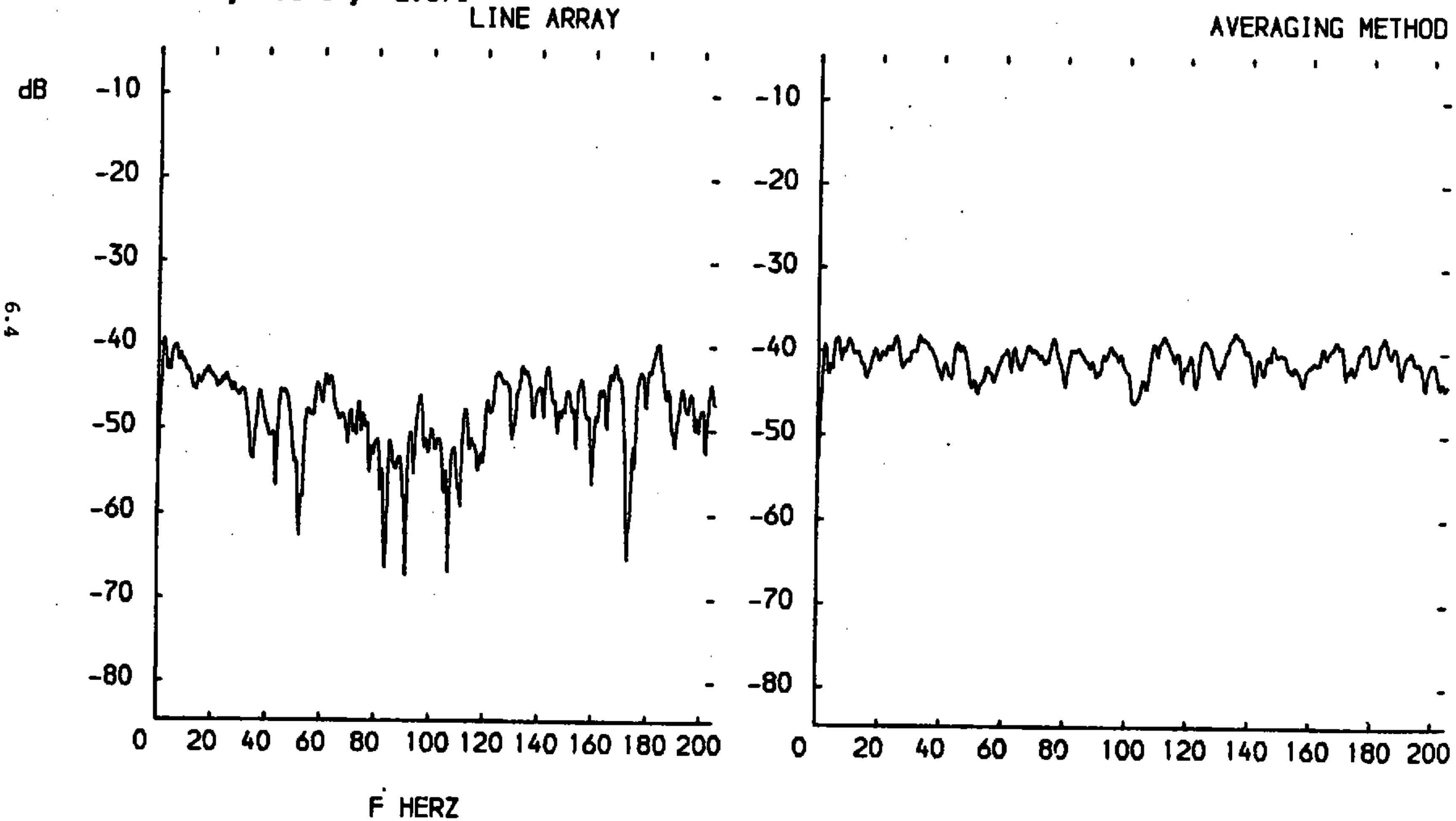

FIG. 3 PROGRAMS - BGCEP78, BMPA53, CEP78 , S 0
SPECTRUM ESTIMATION BY FOCUSED LINE ARRAY AND PWR SPECTRUM AVERAGING
FREQ INTVL 0.4 HZ, 19 RAYS COMPLETE, BOTTOM REFLEC COEF = (0.600, 0.000)
SOURCE POSITION (X, 700.0, 80.0) M RECEIVER POSITIONS (0, 600.0, 30.0/ 160.0/ 100.0/ 65.0/ 130.0) M
WEDGE ANGLE = ARCTAN (0.350) X = 100.0 M , SNR = 47.110 DB
SDEVS = 2.723, 1.848 , 1.473

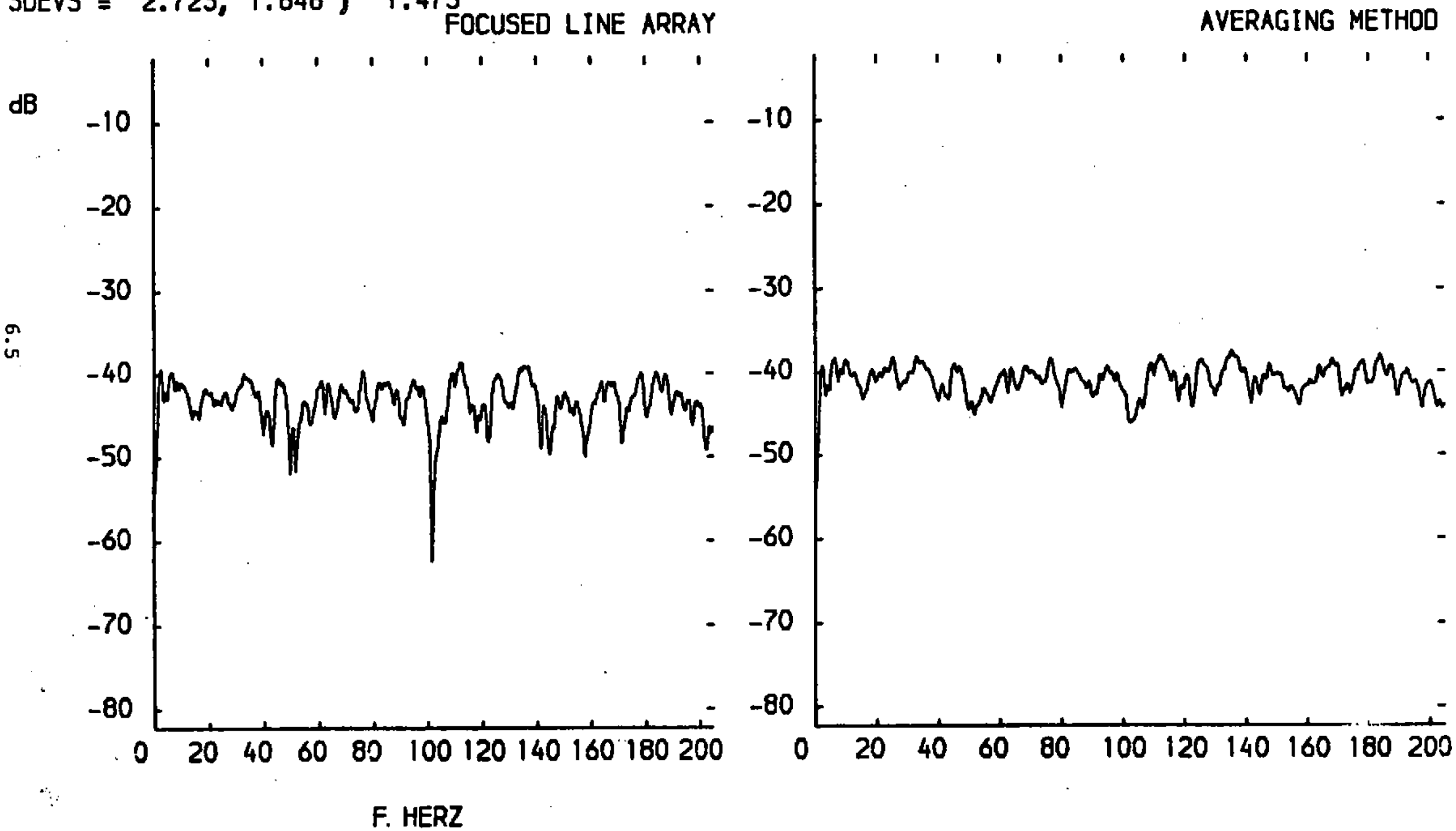

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FIG. 4 PROGRAMS - BGCEP72, BMPA51, CML5 , S 0
SPECTRUM ESTIMATION BY CEPSTRAL METHOD (REAL) AND PWR SPECTRUM AVERAGING
FREQ INTVL 0.4 HZ, 19 RAYS COMPLETE, BOTTOM REFLEC COEF = (0.600, 0.000)
SOURCE POSITION (X, 700.0, 80.0) M RECEIVER POSITIONS (0, 600.0, 30.0/ 160.0/ 100.0/ 65.0/ 130.0) M
WEDGE ANGLE = ARCTAN (0.350) X = 100.0 M, TAPER = 1.000 PER 0.0024 SEC
SDEVS = 1.431, 1.848 , SDEV RATIO = 0.774, SNR = 47.110 DB

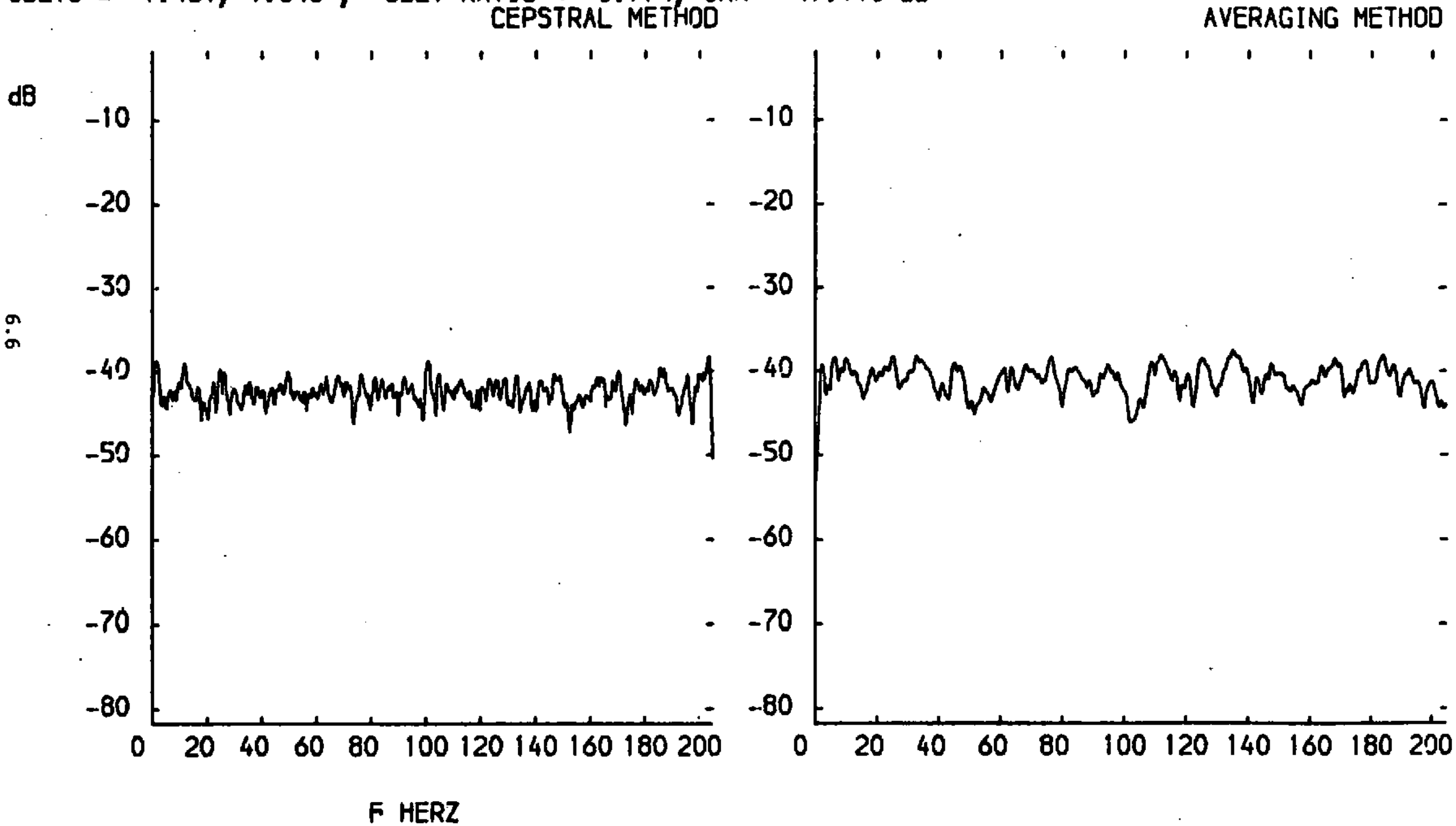

FIG. 5 PROGRAMS - BGCEP72, BMPA51, CML7 , 5 0
SPECTRUM ESTIMATION BY CEPSTRAL METHOD (REAL) AND PWR SPECTRUM AVERAGING
FREQ INTVL 0.4 HZ, 19 RAYS COMPLETE, BOTTOM REFLEC COEF = (0.600, 0.000)
SOURCE POSITION (X, 700.0, 80.0) M RECEIVER POSITIONS (0, 600.0, 30.0/ 160.0/ 100.0/ 65.0/ 130.0) M
WEDGE ANGLE = ARCTAN (0.350) X = 100.0 M, TAPER = 1.000 PER 0.0024 SEC
SDEVS = 1.398, 1.848 , SDEV RATIO = 0.756, SNR = 47.110 DB