United Kingdom Atomic Energy Authority

AWRE, Aldermaston

AWRE REPORT NO. 079/68

A Comparison of the Short Period Seismic Noise at the Four UKAEA Type Arrays and an Estimate of their Detection Capabilities

R.F. Burch

Recommended for issue by

H.I.S. Thirlaway, Superintendent

Approved by

S.D. Abercrombie, Senior Superintendent

C1

550.34
621.391.822

SUMMARY

Samples of short period seismic background noise from arrays at Eskdalemuir (Scotland), Yellowknife (Canada), Gauribidanur (India) and Warramunga (Australia) have been analysed by analogue methods for both frequency content and amplitude. This analysis has been carried out for the outputs of both a single seismometer and for the sum of the outputs of all the seismometers in the array. The power of the arrays to increase the signal to noise ratio has been calculated and detection thresholds have been estimated for the four arrays based on the array processing technique of "delay and sum".

1. INTRODUCTION

Since January 1966 arrays of short period seismometers at Eskdalemuir (Scotland) abbreviated to EKA, Yellowknife (Canada) YKA, Gauribidanur (India) GBA, and Warramunga (Australia) WRA, have been operating continuously and the recorded data have been stored at Blacknest. The location of these arrays was chosen to satisfy two requirements:-

(a) World coverage to give information about the azimuthal variation in the seismic signal.

(b) To have low ambient seismic signal ("noise"), to enable the maximum number of events to be detected.

The object of the work reported here was to measure and to compare the variation of amplitudes and frequency content of the short period noise as recorded by a single seismometer and by the total sum at each array, and thereby to measure the effectiveness of each array in improving the signal to noise ratio with extremes of noise level. The detection threshold of each array could then be estimated for the AWRE standard processing technique of delay, sum and octave width filtering. The noise was analysed using an analogue computer and the filters normally used for event processing.

2. METHOD

The data from the arrays are recorded on twenty four channel FM analogue magnetic tape. The outputs from the single seismometers of the array are recorded on separate tape channels along with a coded time channel. The output of a single seismometer is also recorded on a "helicorder" hot stylus paper record.

The helicorder records for 1966 for one array were examined and from these, four samples of background noise of thirty minutes duration were chosen. Of these, two samples were chosen to represent the noisiest periods during the year and two samples were selected to represent the quietest periods.

The magnetic tape for one sample was then played back, the analogue signals from the individual seismometers were examined and a channel selected which was judged to give an output typical of the whole array. The signal from the selected channel was filtered with bandpass filters having an attenuation rate of twentyfour decibels per octave outside a pre-selected one octave pass-band, and then squared and integrated over the thirty minutes duration of the sample. To calibrate this integral the integration rate was compared with the rate produced by an external sine wave oscillator set to the frequency equal to the geometric mean of the filter pass band. This operation was simultaneously performed for the four pass bands, $\frac{1}{4}$ - $\frac{1}{2}$, $\frac{1}{2}$ - 1, 1 - 2 and 2 - 4 Hz. By means of the array seismometer and amplifier system calibrations, the amplitude of the equivalent frequency component within each band could then be referred to the ground velocities detected by the seismometer. The individual signals from all the seismometers in operation at the time were then summed with no delay and this combined signal for the same thirty minute sample was calibrated and measured as before.

A sample of two minutes duration was selected as an average within the thirty minutes and the signals for the typical single channel and the total sum channel were re-recorded onto a tape loop. For each of these samples an amplitude spectrum was computed using analogue methods. Although the amplitudes of the results of the frequency analysis could not be calibrated to give absolute ground motion, they were calibrated to give results whose relative amplitudes are correct. The process was repeated for the remaining thirty minute samples and for each array.

The sixteen noise samples selected are listed in table 1.

3. RESULTS

All results, including the amplitude spectra and the equivalent half-hour integration velocities, are for the seismic noise as recorded on the magnetic tape, that is, seismic noise modified by the response of the seismometer and recording system. This response is shown as figure 1 and can be used to correct the values to absolute noise velocity levels if required.

The units of many of the following figures are "zero to peak μV". These microvolts are the recorded output from the seismometer and are related to the recorded ground velocity by the operational sensitivity of the seismometer of 3.4 V/cm/s. These μV units have been retained to avoid confusion between ground velocity (= Aw) and the parameter used for magnitude calculation (A/T).

The number of seismometers used in the sums for EKA, WRA and YKA was thirteen to sixteen; sixteen being the greatest number of seismometers fully operating during the periods selected. (Fully operating means that the seismometer was operating and that good system calibrations were available.) For GBA the total number of fully operating seismometers in the array at the time of the analysis was ten.

The amplitude spectra for the noisiest and quietest two minute samples from a single seismometer during the year for the four arrays are illustrated in figures 2 and 3. The corresponding spectra for the sum of the arrays are shown as figures 4 and 5.

The equivalent single frequency ground velocity for each octave is plotted against the geometric mean frequency for the bandwidth for the four half hour samples in figure 6. The corresponding results for the sum of each array have been divided by the number of seismometers used in the sum to give an equivalent single seismometer and are plotted in figure 7.

To compare the spectra (in arbitrary units) and the equivalent single frequency velocities, the spectra were first replotted with a linear ordinate for amplitude and a logarithmic abscissa for frequency. These graphs were divided into the four consecutive bandwidths and for each of these a mean amplitude was obtained. This mean amplitude was plotted against its corresponding single frequency velocity as shown as figure 8. For the sum results, all values were divided by the number of seismometers used to convert them to equivalent single channels.

From the results of the half hour integration we have the noise in a particular octave bandwidth equivalent to a sinusoidal ground motion of zero to peak velocity V for a single seismometer and V_n for the corresponding sum of n seismometers. Suppose we have a seismic event signal b, then on the delay and sum trace this will become a signal nb. The signal to noise ratio was b/V for the single and is now nb/V_n for the sum. The improvement in signal to noise ratio in using the sum is

$$\frac{nb}{V_n} \Big/ \frac{b}{V} = \frac{nV}{V_n} = n^y,$$

ie, the improvement in signal to noise ratio can be expressed as the power of the number of seismometers used in the sum. For random noise the value of y would be expected to be 0.5. The results obtained for all samples are shown as figure 9.

For each array and a particular filter bandwidth, we can calculate a threshold of magnitude above which an event at distance $\Delta°$ will be detected. We are concerned with the recordings from explosions at teleseismic distances (30° - 90°) and the band 1 - 2 Hz. We have made the stipulation that the event size of the Σn trace must be four times that of the background noise. (In this case the ratio is roughly equivalent to a unity signal to noise ratio from a single seismometer assuming $n^{0.5}$ improvement for the array.) The unified magnitude m_b of a surface event is calculated from the signal from a single seismometer by the expression

$$m_b = \log A/T + B(\Delta),$$

where A is the zero to peak ground motion amplitude in millimicrons,
T is the signal period in seconds,
$B(\Delta)$ is Gutenberg's distance normalising factor,
$A/T = \frac{\text{ground velocity}}{2\pi}$.

If we reduce the total sum noise to that of a single seismometer by dividing by n, then our threshold event will have a velocity of $4(V_n/n)$. Threshold magnitude = $\log[(A/T)_n/n] + \log 4 + B(\Delta)$. This threshold magnitude for the four arrays is shown as figure 10.

Using the paper helicorder recordings an investigation into the variation of the background noise over a twelve month period at YKA and EKA had already been made by A.H. Fawcett. These data have been used to construct a cumulative distribution curve for each of the two arrays. These are shown as figure 11 with the corresponding values from the half hour integrations superimposed as open circles. From these curves the 50% probability value has been taken and a detection magnitude calculated from it. These 50% probability magnitude curves are shown added to figure 10.

4. DISCUSSION OF RESULTS

4.1 Amplitude spectra

YKA The large noise amplitude peaking at 1 Hz for the noisiest sample is noteworthy (figure 2). This prominent peak is absent on the quiet day samples.

GBA For the noisiest sample large amplitude long period noise is seen, peaking at $\sim$ 0.2 Hz (figure 3). This sample was exceptional as the typically noisy sample (also plotted on figures 3 and 5) gives a spectrum similar to the quietest period.

EKA For the quietest period the single channel gives a very flat spectrum. This is possibly because the low noise amplitude is at the lower end of the dynamic range of the recording system and the seismic noise is near the level of random system noise.

WRA This array gives spectra that are consistent in both shape and amplitude.

4.2 Comparison of spectra with single frequency equivalent velocities

This comparison (figure 8) gives a result of 25 units on the spectra equivalent to one zero to peak microvolt. The standard deviation of the line is approximately 20%. The errors are most probably due to the assumption that the two minute sample is typical of the half hour period for all four bandwidths.

4.3 Improvement in signal to noise ratio

These results (figure 9) should be treated with caution as great reliance is placed on the "typical" single seismometer of the whole array. Also, the amplitude value for the whole array was obtained by summing without delays. Normally the single channels would be delayed before summation to make the event signals coincident in time. The direct summation method is only strictly true if the noise is random or the event is at distance $\Delta = 180°$. However, some general trends are established:-

(1) Greatest improvement is observed at 1 Hz.

(2) Average improvement in frequency bands of interest ($\frac{1}{2}$ - 1 and 1 - 2 Hz) is generally slightly less than $\sqrt{n}$.

(3) At GBA, WRA and YKA there is generally most improvement on noisy days, with the least improvement of all for the quietest site (YKA) at its quietest. The improvement at EKA is independent of the amplitude of the noise and has a trend for best improvement at higher frequencies.

4.4 Threshold magnitudes

The comment in the previous paragraph on the validity of direct summation is also pertinent here. The lower curve (figure 10) represents the quietest operating condition of the array, below which no event will be detected. The upper curve represents the noisiest operating condition above which all events will be detected. The distance between the two curves is the range of event magnitude over which detection is dependent on noise levels at the time. Magnitudes are, of course, those as recorded at the array and cannot take into account azimuthal or regional effects (station corrections) when related to, say, USCGS magnitudes.

Now that twenty seismometers are in operation at GBA, it is expected that the two curves are lowered by $m_b \approx 0.10$ to 0.15 and that they draw closer together. The detection thresholds of GBA will then be very similar to WRA.

At its quietest YKA has significantly the lowest threshold (m_b) of detection but at its worst its noise amplitudes are only exceeded by EKA at its noisiest. EKA at its best is as quiet as GBA and WRA.

Table 2 summaries the detection thresholds of each array for a distance (Δ) of 60°.

TABLE 1

Selected Noise Samples

	YKA	EKA	GBA	WRA
Noisy	16 Oct. 65 0000-0030 14 Oct. 65 0000-0030	11 March 66 1600-1630 12 April 66 0200-0230	9 Dec. 65 0500-0530 10 June 66 0900-0930	27 May 66 1400-1430 10 Sept. 66 0300-0330
Quiet	25 March 66 0000-0030 7 May 66 0000-0030	15 June 66 0800-0830 31 May 66 0800-0830	29 Aug. 66 1000-1030 15 May 66 1100-1130	8 June 66 1100-1130 22 Oct. 66 1330-1400

TABLE 2

Detection Thresholds (m_b) of UKAEA Arrays for Events at Δ = 60°

	EKA	YKA	GBA	WRA
Quietest	4.1	3.7	4.1	4.0
50% Probability	4.4	4.0	-	-
Noisiest	4.7	4.5	4.4	4.2

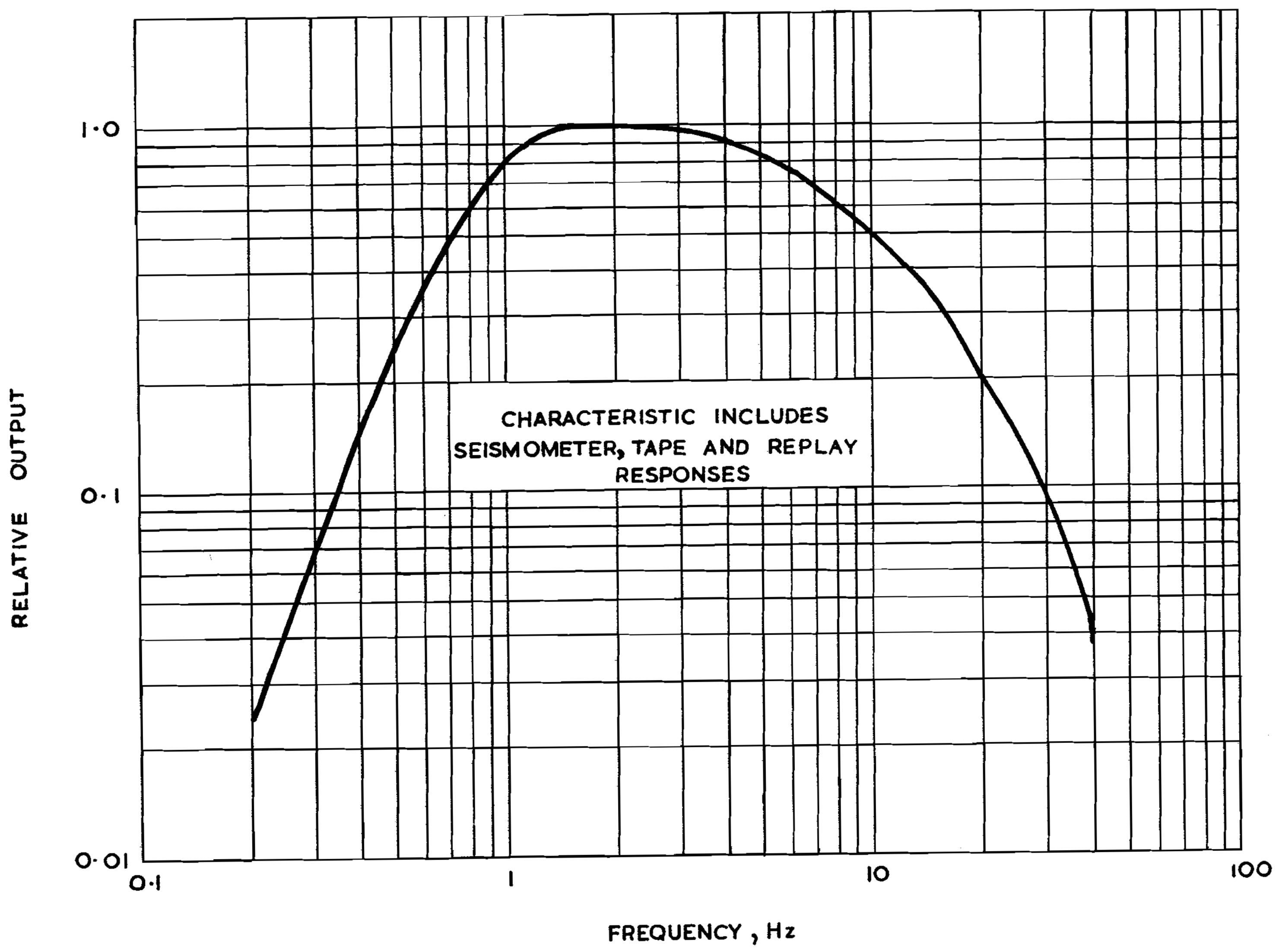

FIGURE 1. OVERALL FREQUENCY RESPONSE FOR CONSTANT VELOCITY INPUT

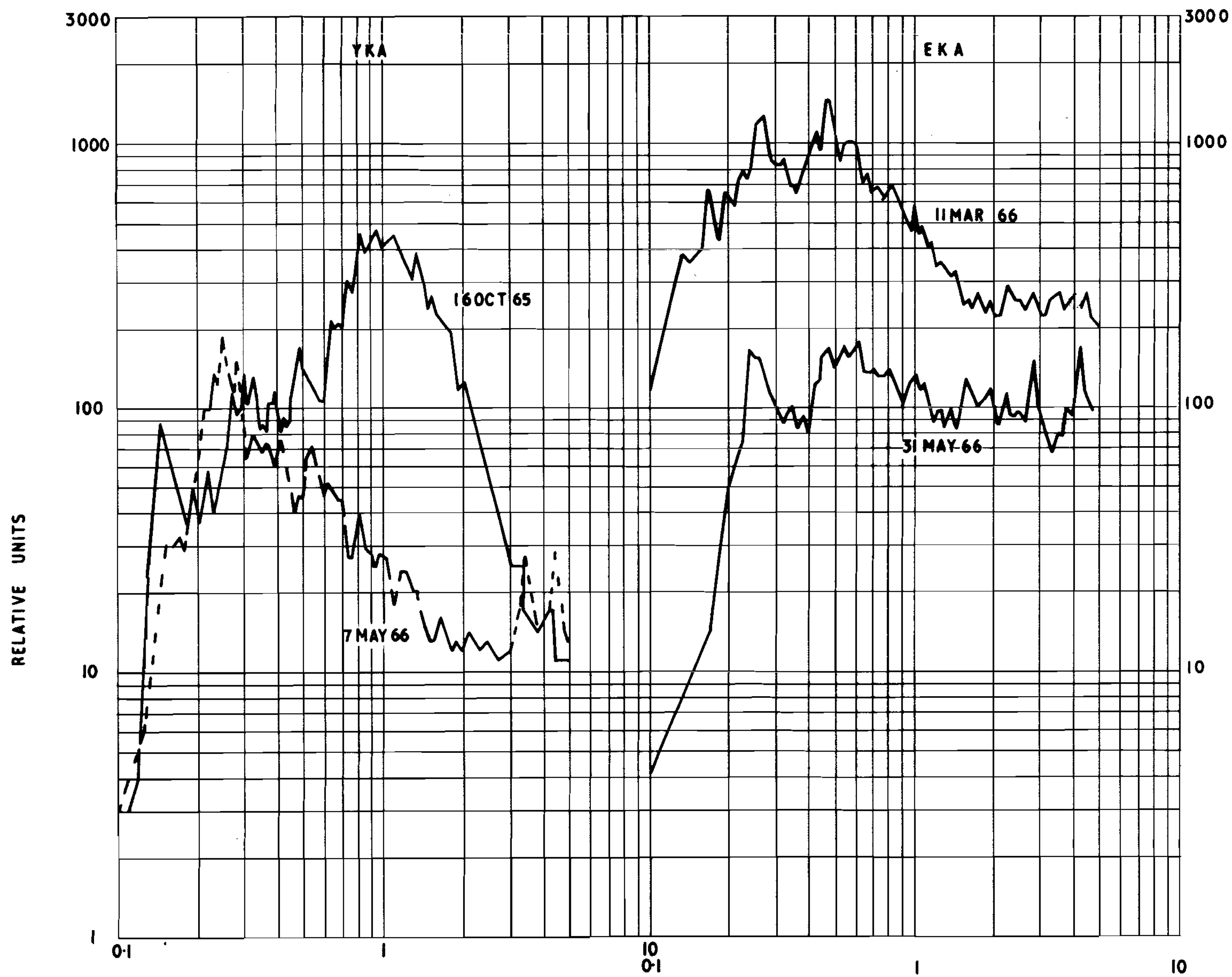

FIGURE 2. SPECTRA OF SINGLE CHANNELS AT YKA AND EKA

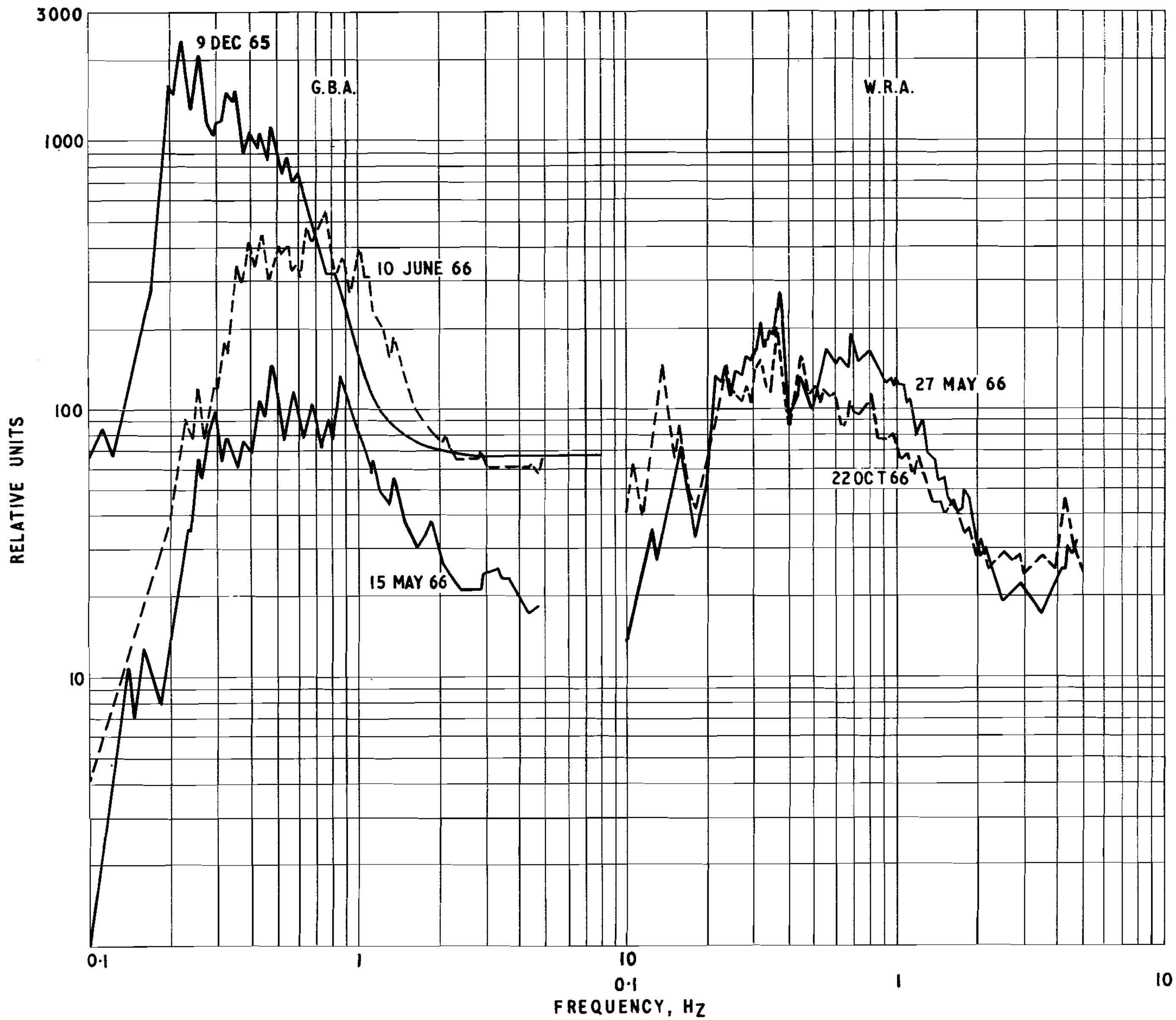

FIGURE 3. SPECTRA OF SINGLE CHANNELS AT GBA AND WRA

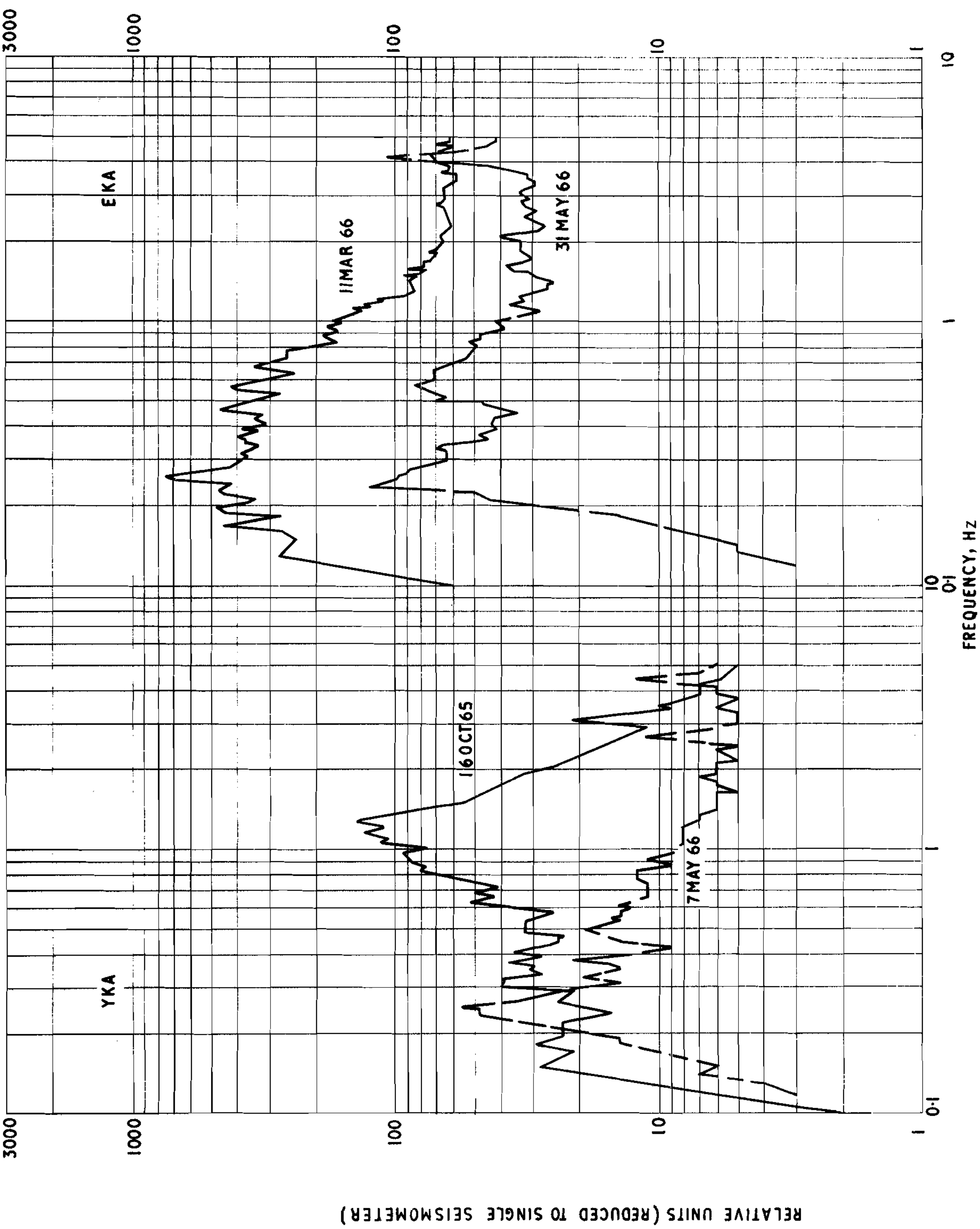

FIGURE 4. SPECTRA OF TOTAL SUMS AT YKA AND EKA

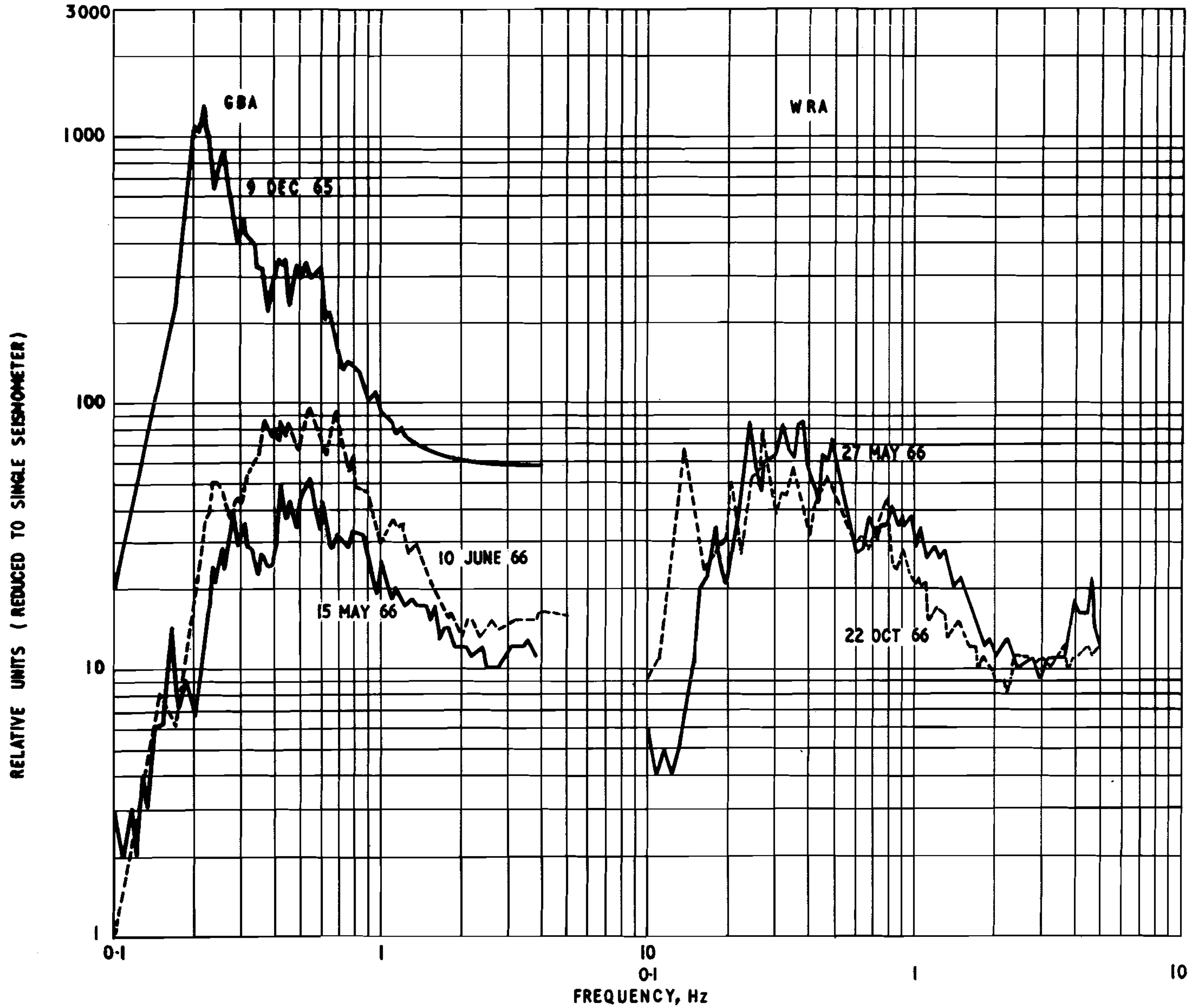

FIGURE 5. SPECTRA OF TOTAL SUMS AT GBA AND WRA

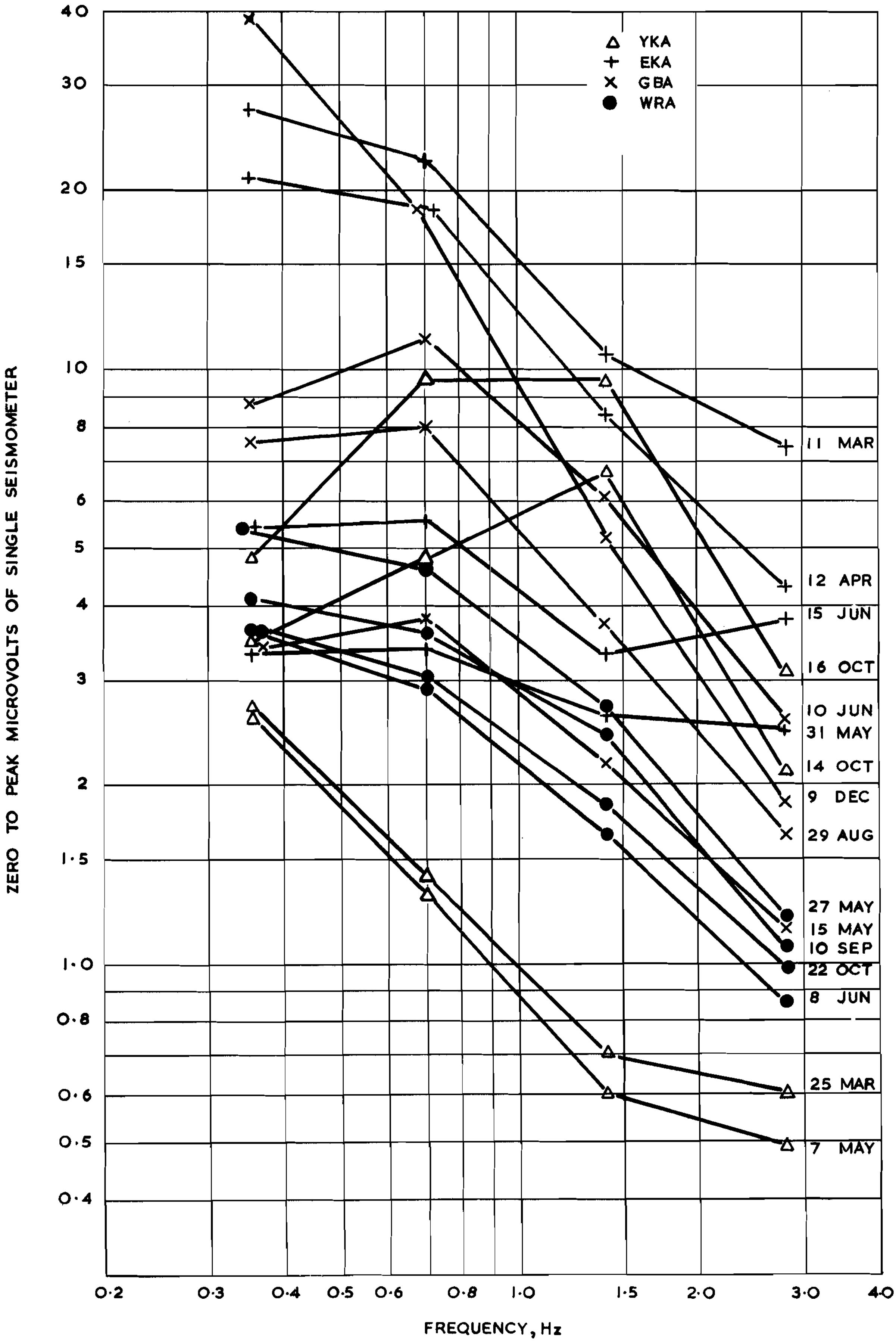

FIGURE 6. SINGLE FREQUENCY SIGNALS FOR EACH OCTAVE FOR SINGLE SEISMOMETERS

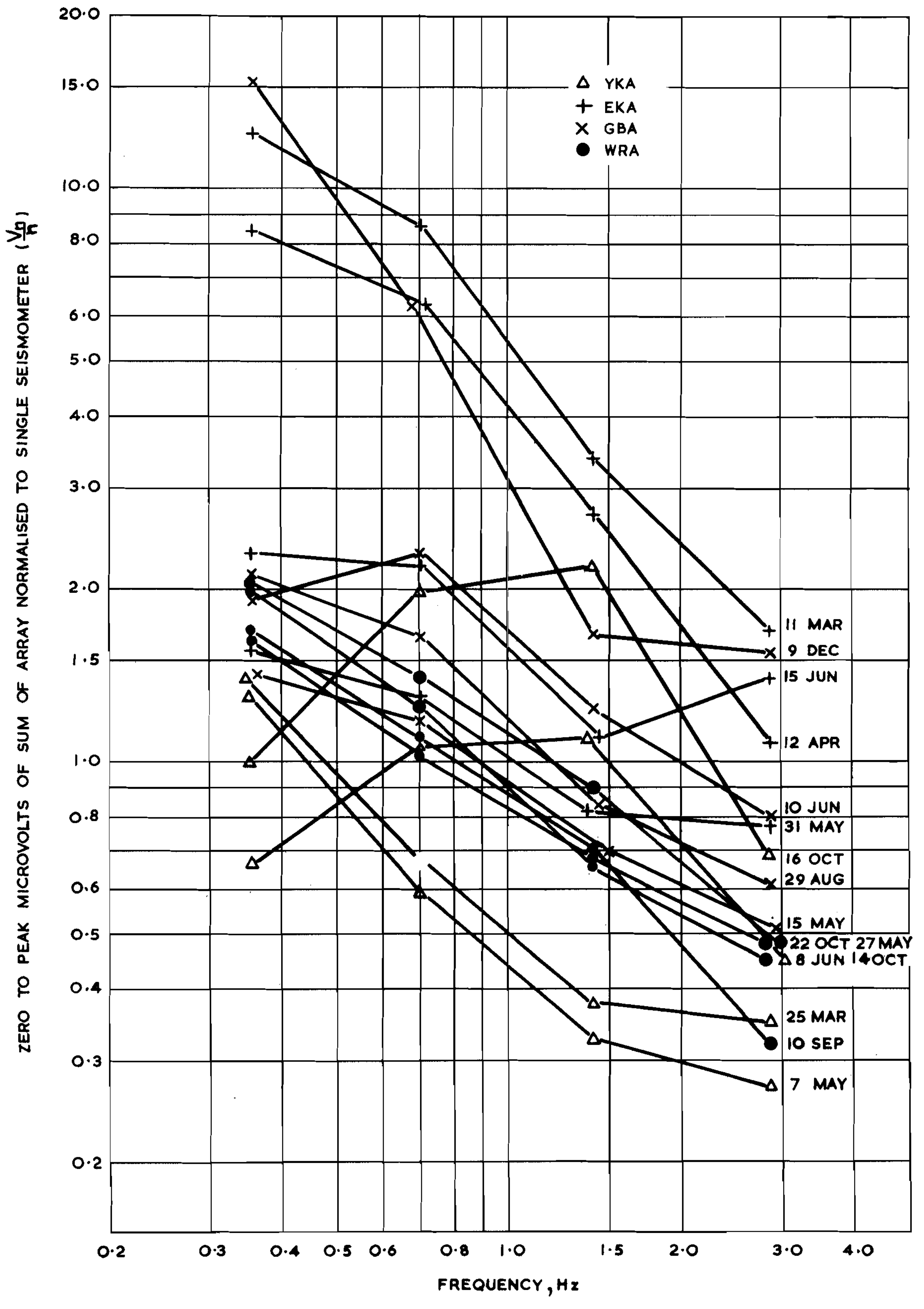

FIGURE 7. EQUIVALENT SINGLE FREQUENCY SIGNAL FOR EACH OCTAVE FOR SUM OF EACH ARRAY

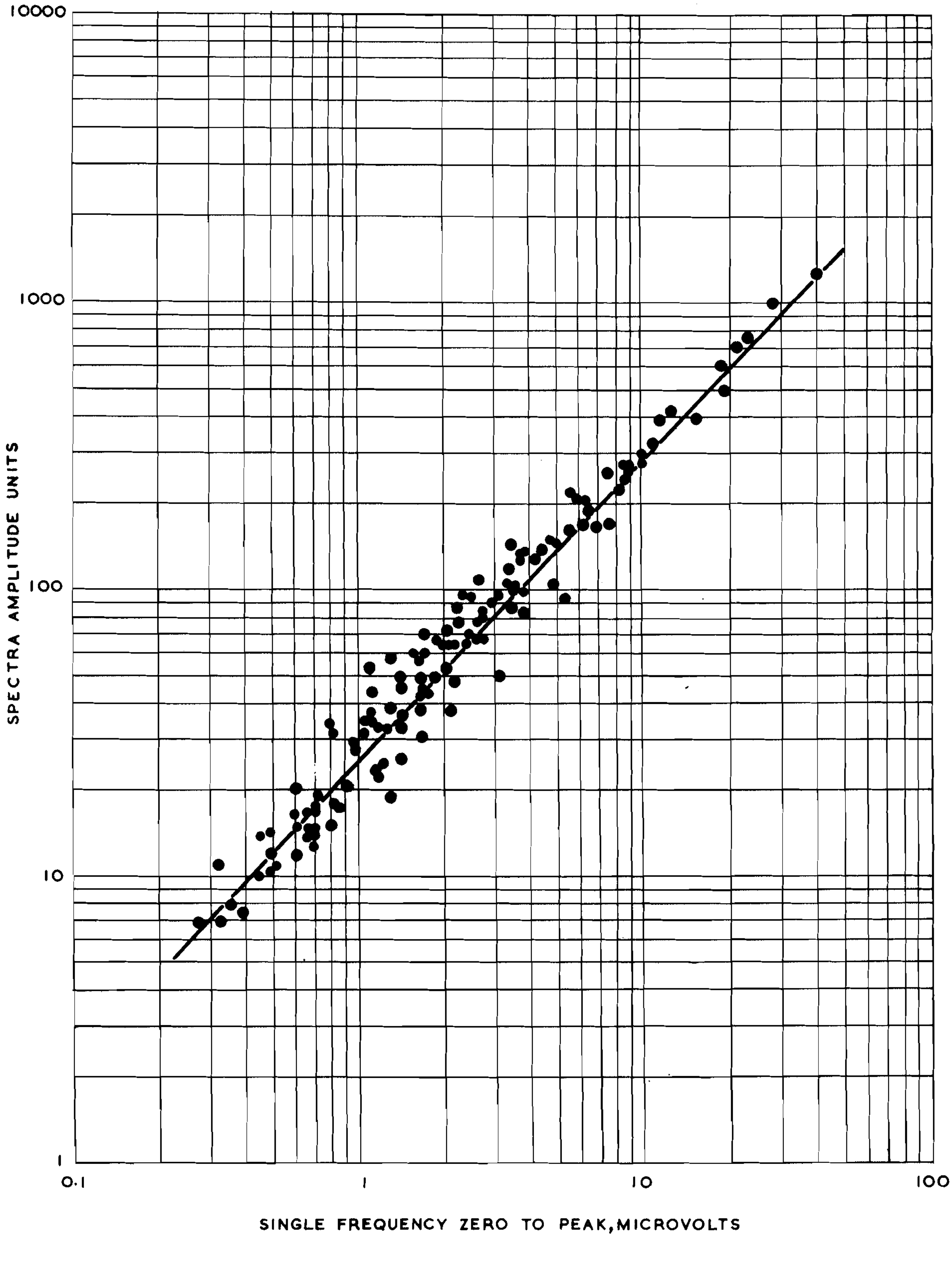

FIGURE 8. COMPARISON OF SPECTRA AMPLITUDES WITH SINGLE FREQUENCY SIGNALS

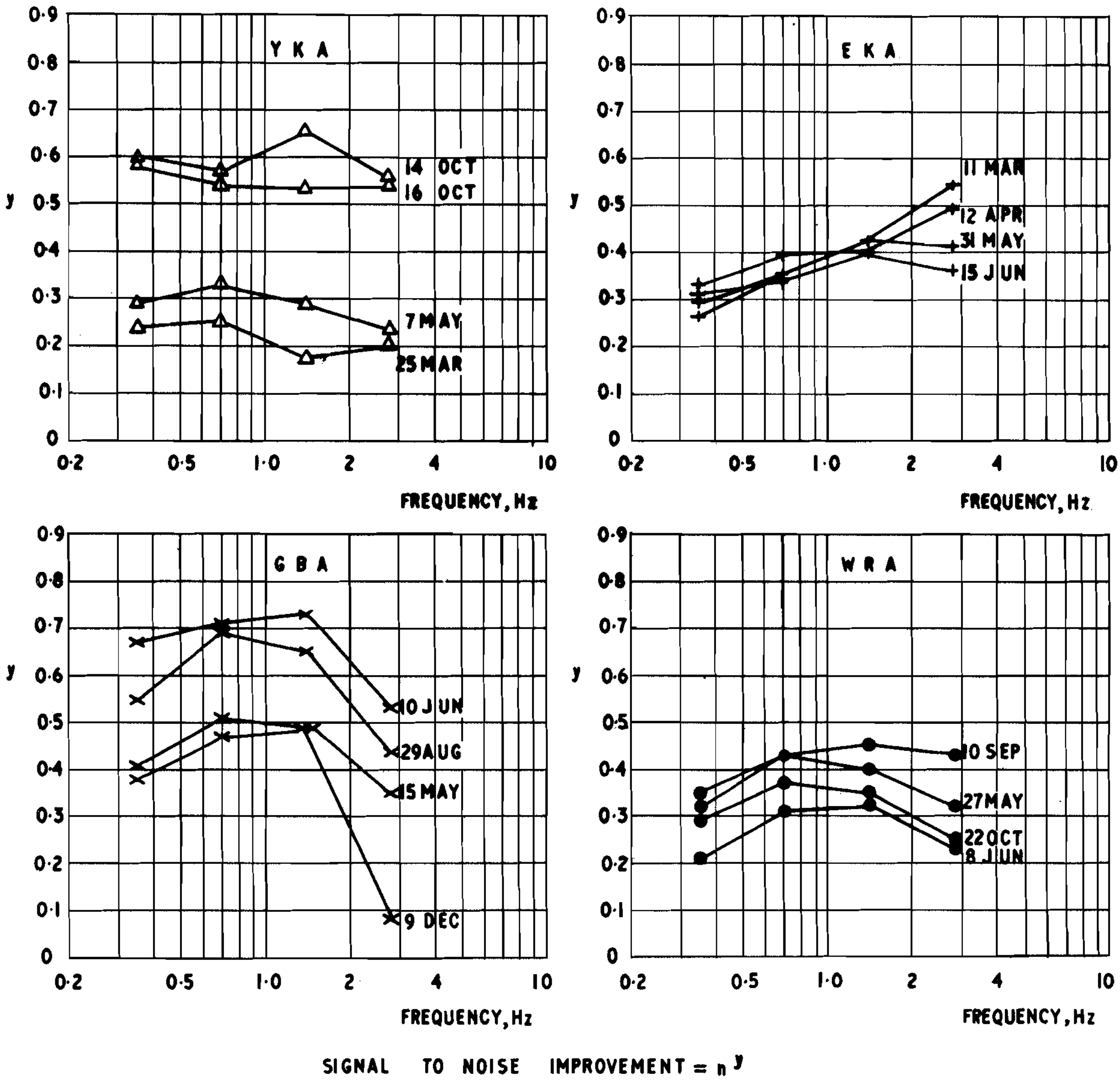

FIGURE 9. SIGNAL TO NOISE IMPROVEMENT AT THE FOUR ARRAYS

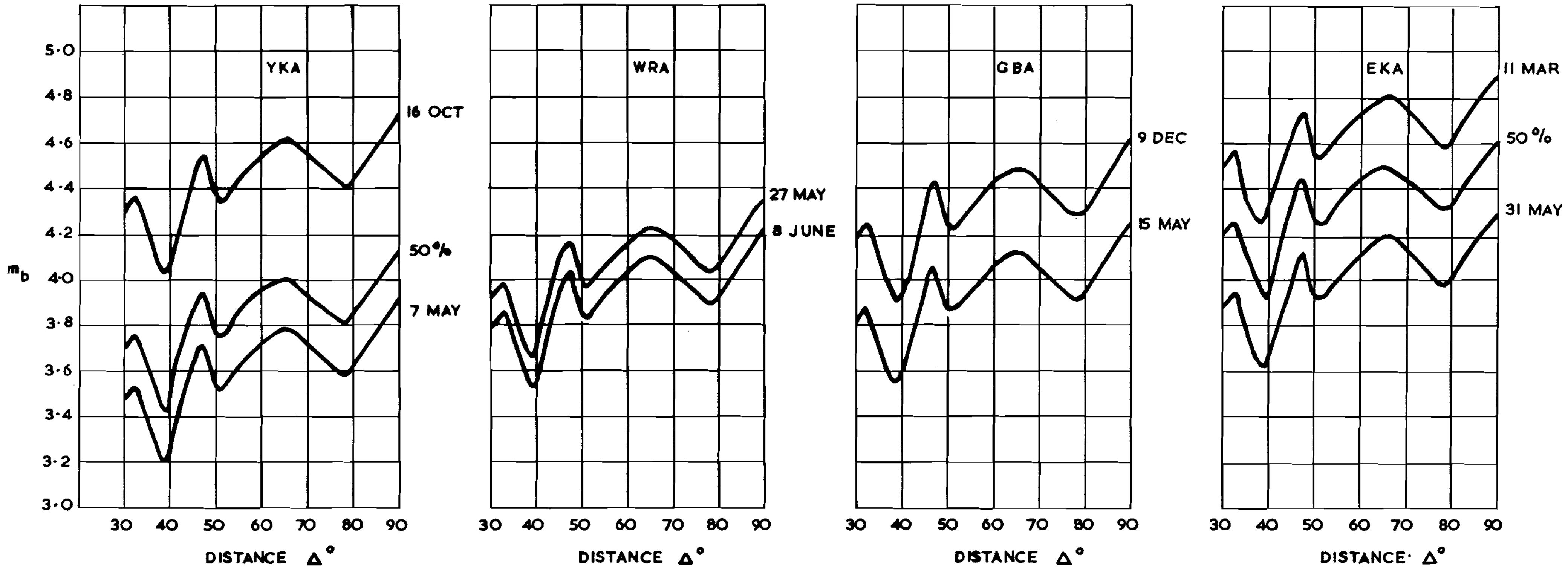

FIGURE 10. DETECTION THRESHOLD FOR ARRAYS AFTER 1 TO 2 Hz FILTERING — SIGNAL TO NOISE RATIO ON SUM TO BE FOUR

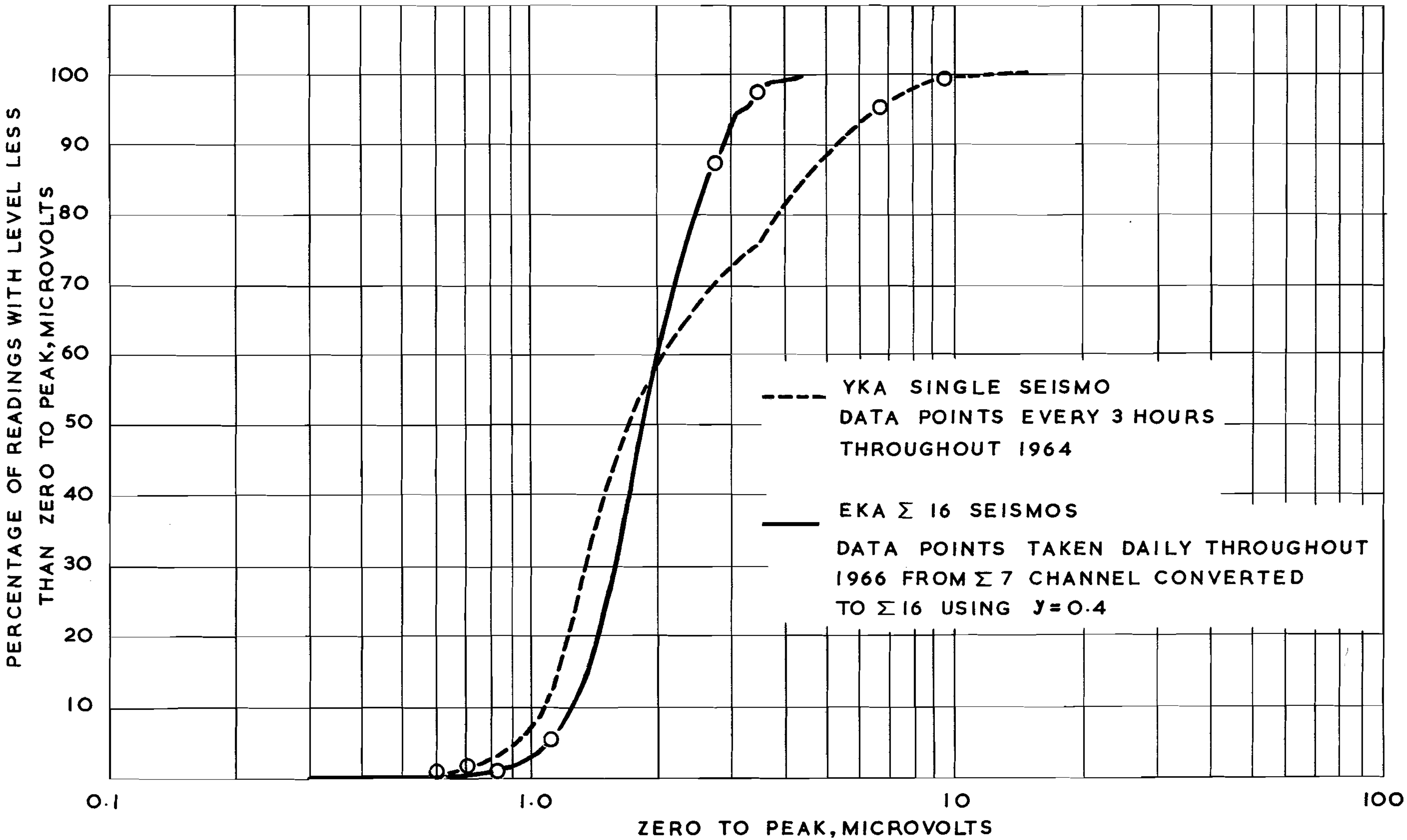

FIGURE 11. CUMULATIVE DISTRIBUTION CURVES FOR YKA AND EKA