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ATTENUATION OF THE GROUND WAVE OF A LOW FREQUENCY ELECTROMAGNETIC PULSE

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U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Contents

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The attenuation of the peak of the ground wave EM pulse is presented as a function of distance. These attenuation functions are compared to combinations of single frequency attenuation functions and simple attenuation functions based on inverse distance raised to integral and non-integral exponents, $(1/d)^n$.

1. Introduction

A method of describing the propagation of an electromagnetic pulse as a ground wave has been developed to define the effective propagation time of a pulse. The theory which describes propagation of the ground wave of a pulse of low radio frequency energy around a finitely conducting spherical earth has been treated in detail by Johler and Walters [1959], Johler and Lilley [1961], and has been presented for both ground and ionospheric wave by Johler [1962, 1963 a, b]. The validity of the theory of the ground wave, in particular, has been carefully checked experimentally by Johler and Lilley [1961]. The theory describes the effects of physical constants and boundaries of the various media on the propagation of the pulse. These effects manifest themselves in the apparent velocity of propagation and the distortion of the waveform of the pulse as it is propagated. Since the effective values ascribed to the physical constants in the theory are frequency dependent and the pulse contains essentially a continuous frequency spectrum, it is extremely difficult to evaluate these effects on the basis of tabulated data such as NBS Circular 573 [Johler, Kellar, and Walter, 1956] or NBS Technical Note 60 [Johler, Walters, and Lilley, 1960]. Therefore, the pulse propagation theory has been translated into a computer program to enable further study of the effects of these physical constants.

2. Theory

Johler and Morgenstern [1963] have utilized the theory and computer methods to predict the effective propagation time of an electromagnetic pulse propagating in the ground wave mode. These mathematical methods simulated theoretically the propagation of a pulse generated by a nuclear detonation as detected by a wide band receiver, 44 km from ground zero, to distances up to 2414 km (1500 statute miles) for various values of conductivity.

An effective conductivity can be ascribed to the ground between a source and an observer for use in the theory of propagation (see Johler and Lilley [1961]). The effective conductivity is not necessarily the actual conductivity along the geodetic connecting source and observer, but represents the integrated effect of a large volume of ground on each side of the geodetic. Indeed, the rigorous calculations of the ground wave used by Johler and Morgenstern [1963] is an integration throughout all space.

The outputs of the computer program, which simulated the propagation of the pulse, included the waveform which would be expected at various distances and effective conductivities. Attenuation rates of the ground wave can therefore be obtained from these computer data.

3. Attenuation of a Peak of the Pulse

A sensing system generally acts on signals which either exceed a lower limit or which fall between two amplitude limits. Since it is desirable, particularly in a system designed to detect an electromagnetic pulse, to observe the entire wavefore in the time domain, it is important that one is able to predict the amplitude of an early peak of the waveform. The computer data shown in figures 1 through 11 provide information regarding the attenuation rate of the first peak of an observed waveform, the complex spectrum of which is illustrated in figure 15. This waveform has been propagated theoretically as a ground wave pulse. From these data, curves are drawn (figures 1 through 7) showing the attenuation rates vs. distance of the first peak of the propagated pulse in terms of decibels (dB) below the amplitude of the pulse as detected at 44 km. These curves show that effective conductivity has a small effect on the attenuation rate for the usual conductivities found in practice, i.e., $\sigma = .001$ to $\sigma = 5$.

4. Illustration of Dispersive Effects

The waveforms given by Johler and Morgenstern [1963] show the dispersive properties of the medium, that is, they show that different frequency components of the pulse are affected differently by the propagation medium. The phenomenon is further illustrated in figures 8 and 9.

NBS Technical Note 60 [Johler, Walters, and Lilley, 1960] gives values for attenuation of the ground wave for specific conductivities. Using these data, composite attenuation curves for $\sigma = .005$ and $\sigma = .0005$ have been constructed. The frequency component used in the construction of a particular portion of the composite curve was chosen to give the best fit to the corresponding pulse attenuation curve. The composite attenuation curves are given as overlays to both the corresponding pulse attenuation curves in figures 8 and 9. For $\sigma = .0005$, it is seen that the higher frequency components are attenuated more rapidly.

5. An Approximation to the Attenuation Rate

It would be convenient if a simple approximation could be developed to describe the attenuation of the first peak of the propagated ground wave pulse. An attempt has been made to evolve such an approximation. Figure 10 shows a composite curve superimposed on the attenuation curve for $\sigma = .005$. This composite curve is based on attenuation rates proportional to $1/d^n$ where d is the distance from the pulse source. A deviation of the fitted curve from the actual curve less than 1 decibel has been obtained by letting $n = 5/4$ to 600 km, $n = 3/2$ to 1000 km, and $n = 5/2$ from 1000 km out. A better fit is obtained by increasing the number of divisions of the curve. In figure 11, five divisions with corresponding $1/d^n$ fits illustrate a closer approximation to the curve.

6. Sky-Wave Contamination

In practice, the detected pulse is made up of the ground wave component plus a number of ionospheric wave components. The arrival time of each ionospheric wave depends on the number of hops, altitude of ionosphere at the reflection point, distance to the source, and several other secondary factors.

The next propagation component to arrive after the ground wave, at the distances under consideration, is the first ionospheric wave hop. To utilize the attenuation curves given in section 3 for the first peak of the ground wave, it is necessary to demonstrate that the first ionospheric wave hop does not contaminate the first peak of the ground wave. The arrival time of the first ionospheric wave hop, parametric in ionospheric height, was given by J. R. Johler [1962] and is shown in figures 12, 13, and 14.

The time of the peak of the ground wave must be compared to the arrival time of the first ionospheric wave hop to determine the presence of first ionospheric wave hop contamination at any distance for any given ionospheric height. The time of the peak of the ground wave is plotted on the ionospheric wave delay curves for $\sigma = 5$, $\sigma = .005$, and $\sigma = .0001$ (figures 12 through 14). These figures show that ground wave attenuation rates presented earlier are valid to at least the following values of distance for any ionospheric height.

σ	d(km)
5	1300
.005	1300
.0001	800

7. Experimental Verification

The data presented in this paper has been compared with measurements of both man-made sferics and nuclear detonation waveforms obtained at three distances. The two sets of data were found to be within the estimated experimental error [Johler and Morgenstern, 1964].

8. Acknowledgments

The authors are indebted to Miss Mary McDonnell of MITRE for her work with the computer data, Mr. Richard Millman of MITRE for his review of the paper and work with the experimental data and Miss Carlene Lilley of NBS for her computer work.

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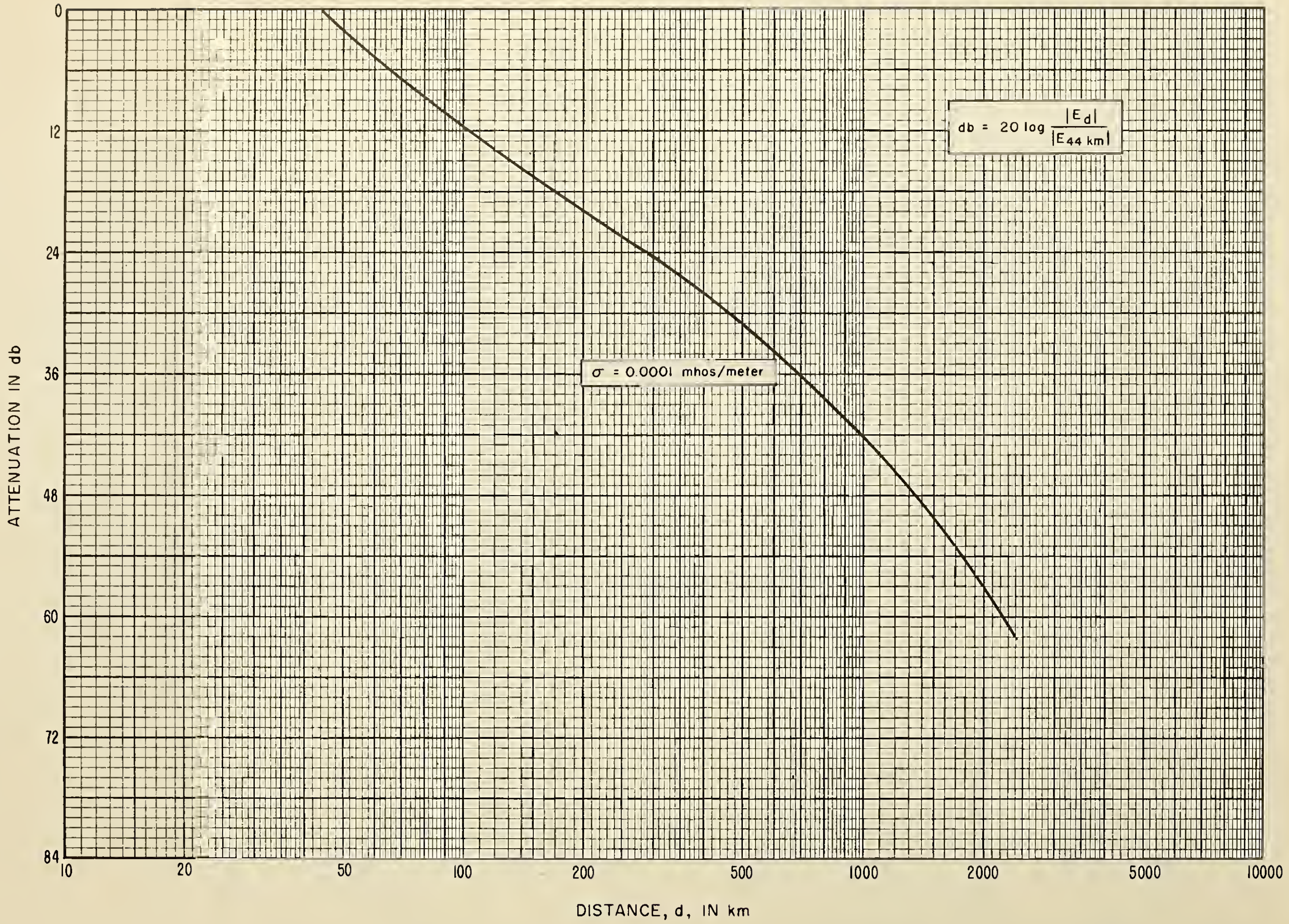


Figure 1. Attenuation with distance of the initial crest of the ground wave pulse. $\sigma = 0.0001$ mhos/meter.

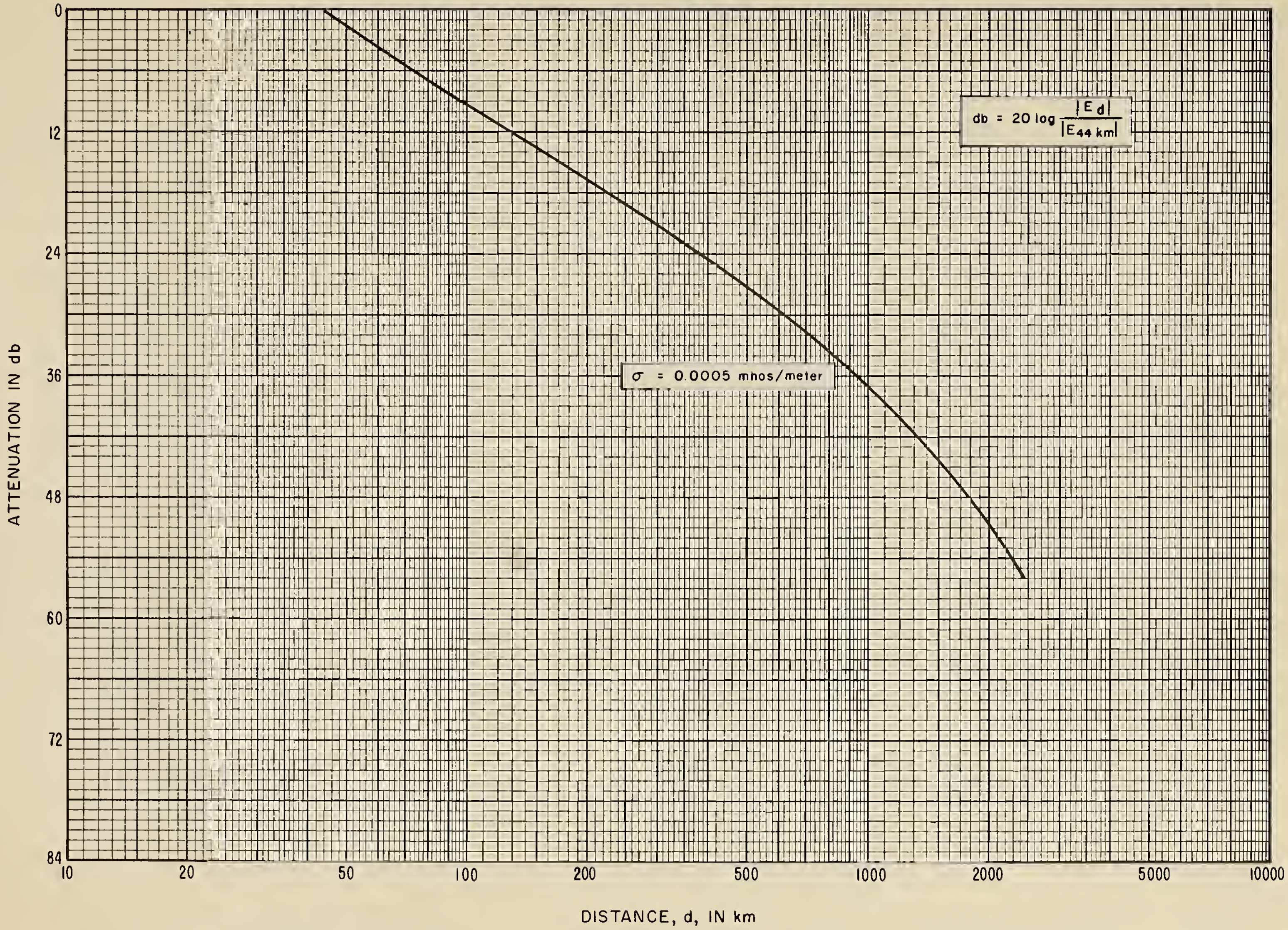


Figure 2. Attenuation with distance of the initial crest of the ground wave pulse. $\sigma = 0.0005$ mhos/meter.

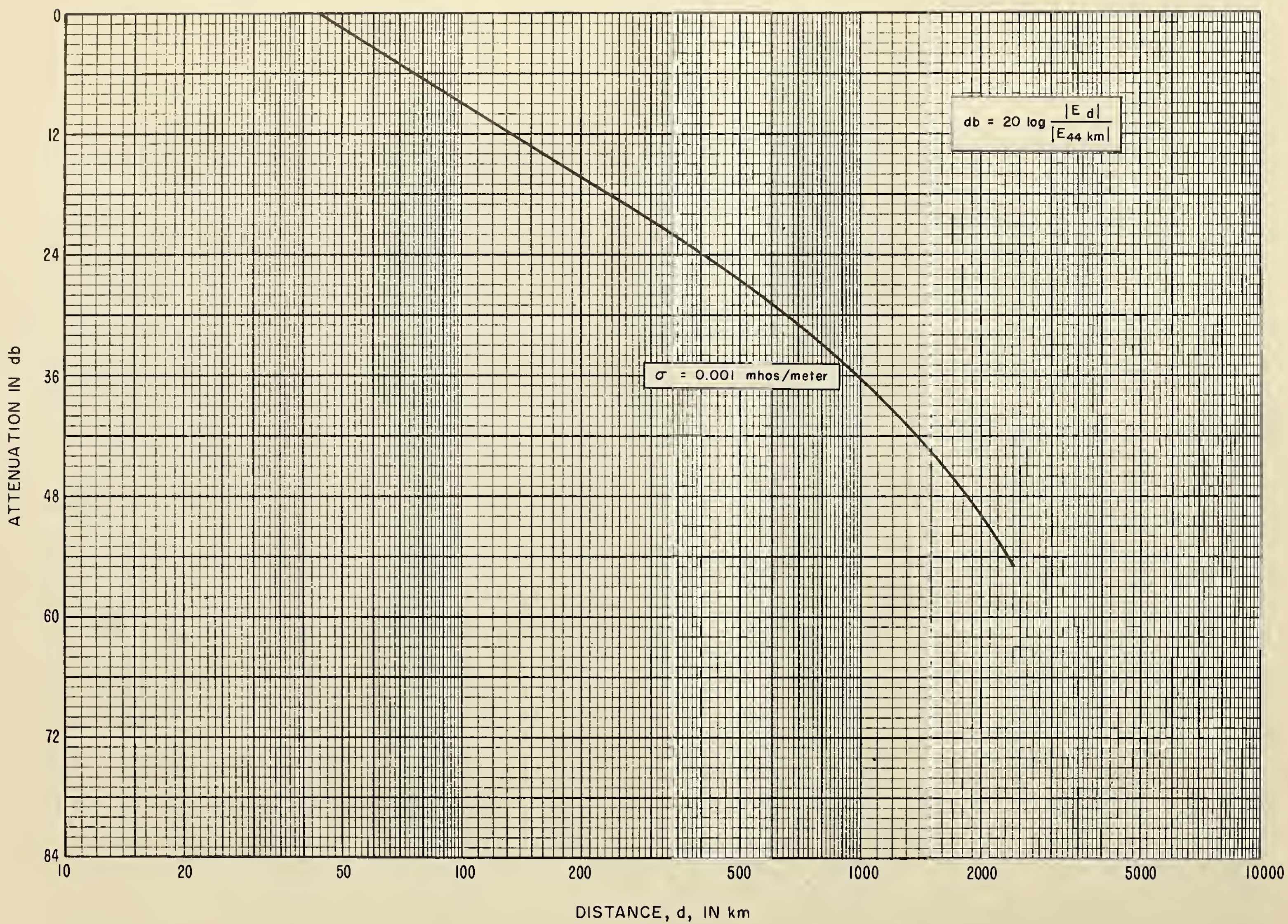


Figure 3. Attenuation with distance of the initial crest of the ground wave pulse. σ = 0.001 mhos/meter.

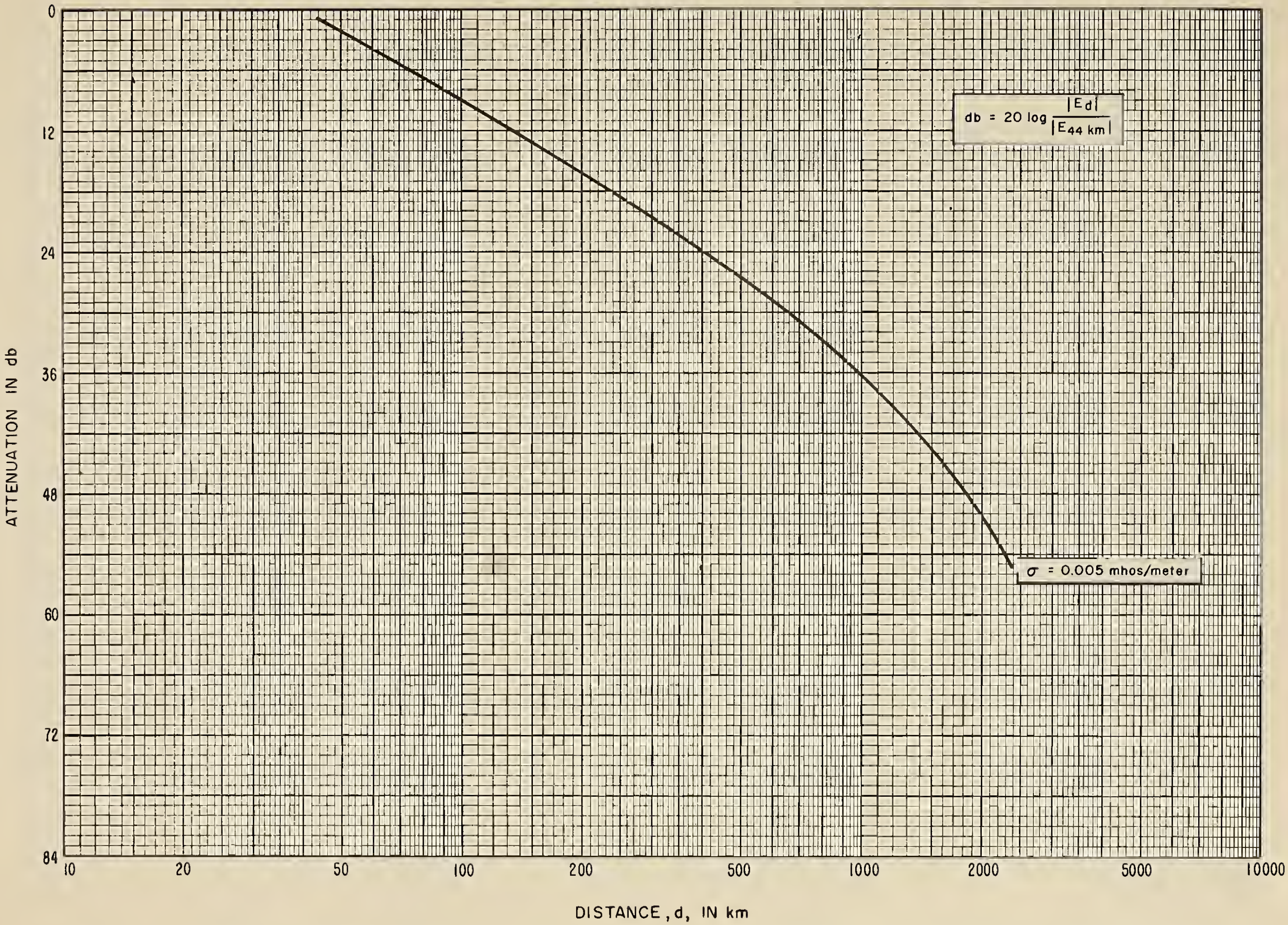


Figure 4. Attenuation with distance of the initial crest of the ground wave pulse. $\sigma = 0.005$ mhos/meter.

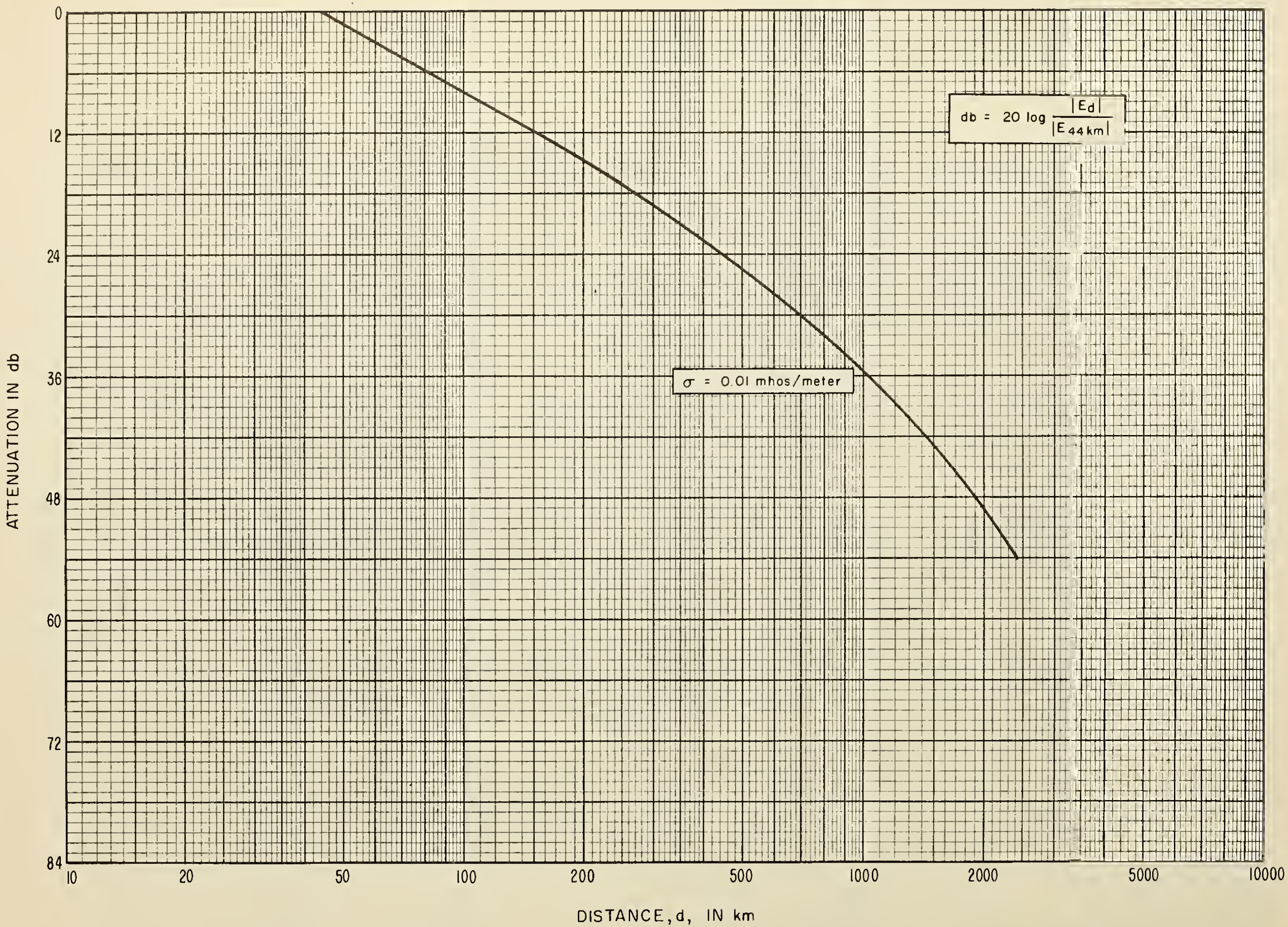


Figure 5. Attenuation with distance of the initial crest of the ground wave pulse. $\sigma = 0.01$ mhos/meter.

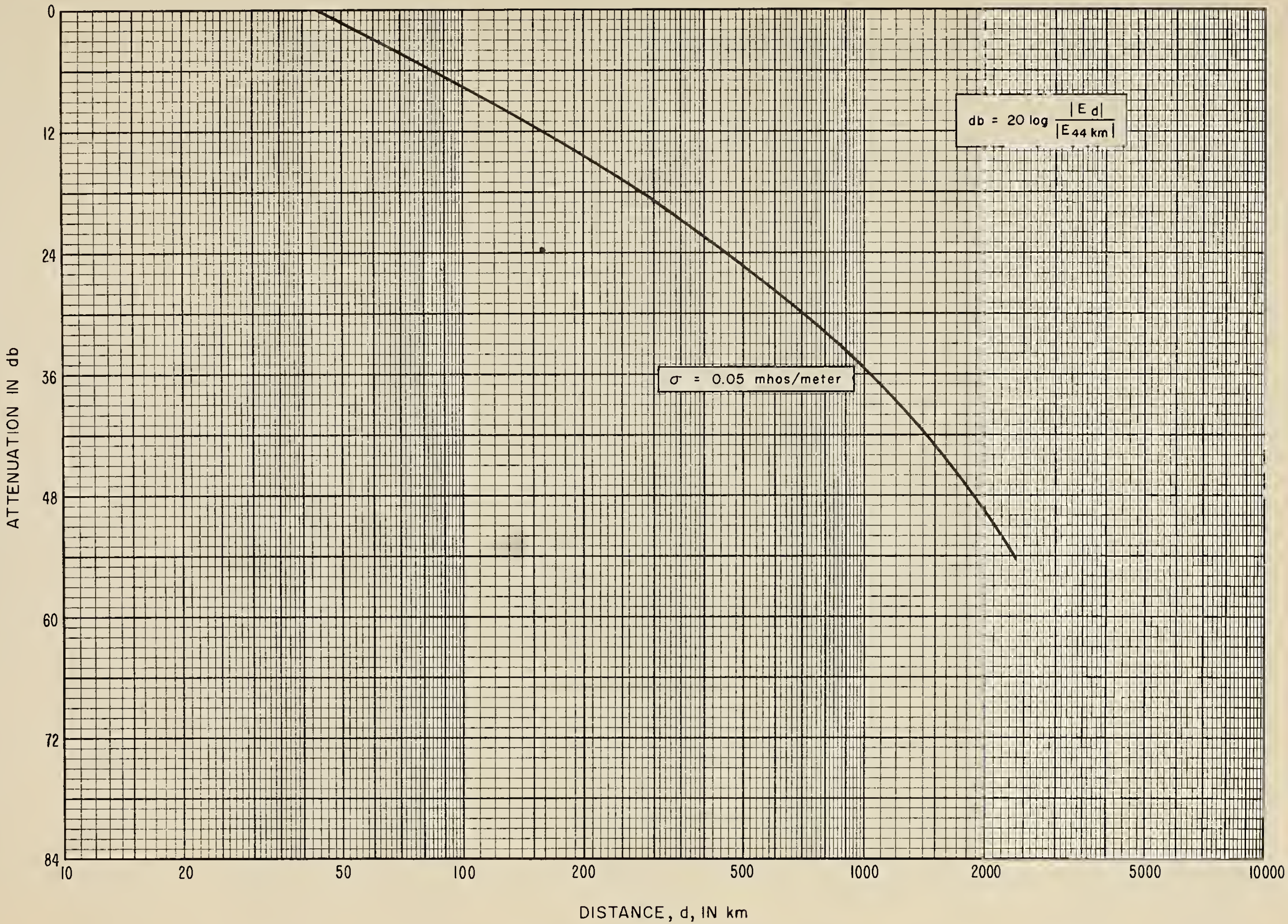


Figure 6. Attenuation with distance of the initial crest of the ground wave pulse. $\sigma = 0.05$ mhos/meter.

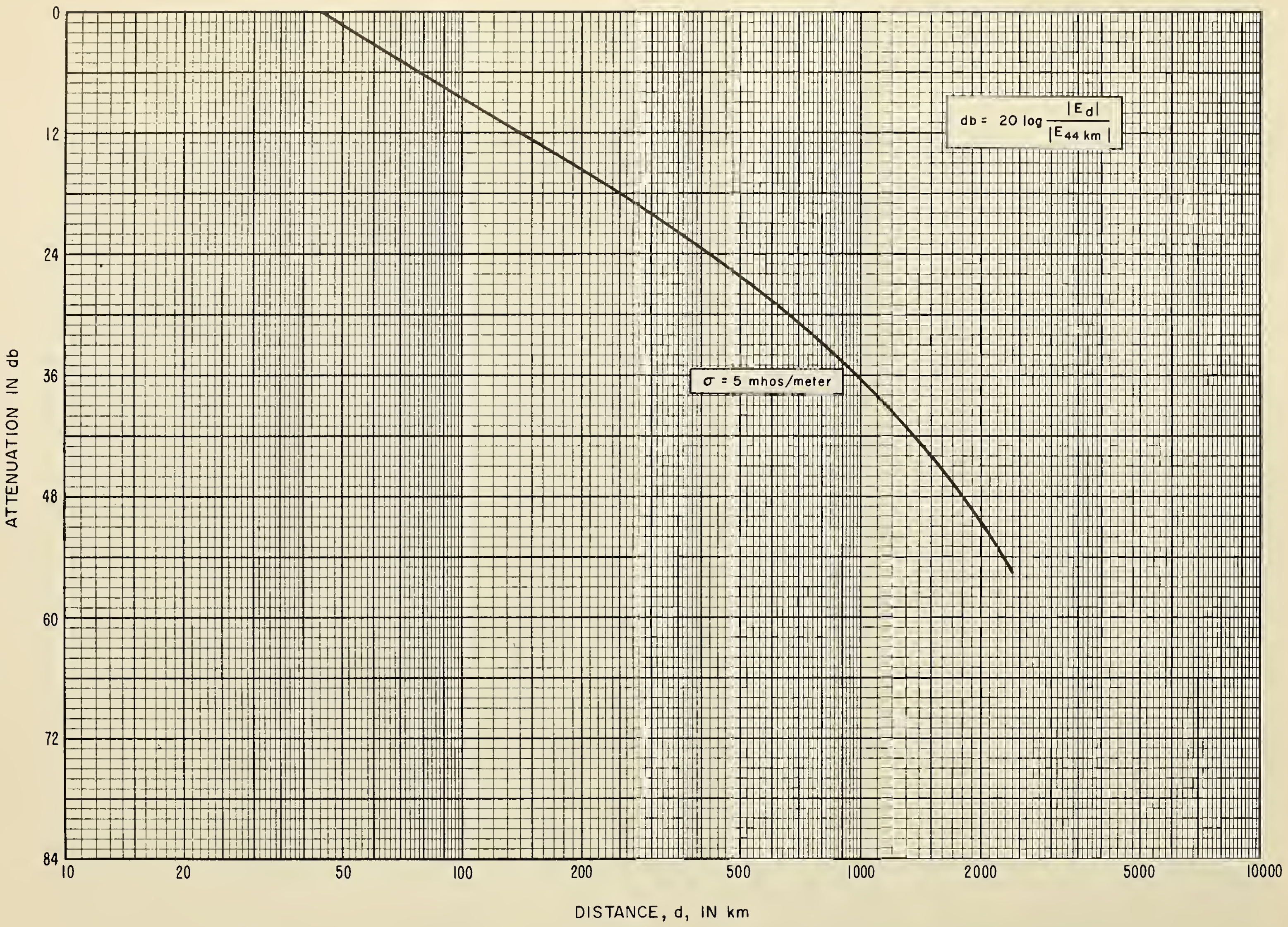
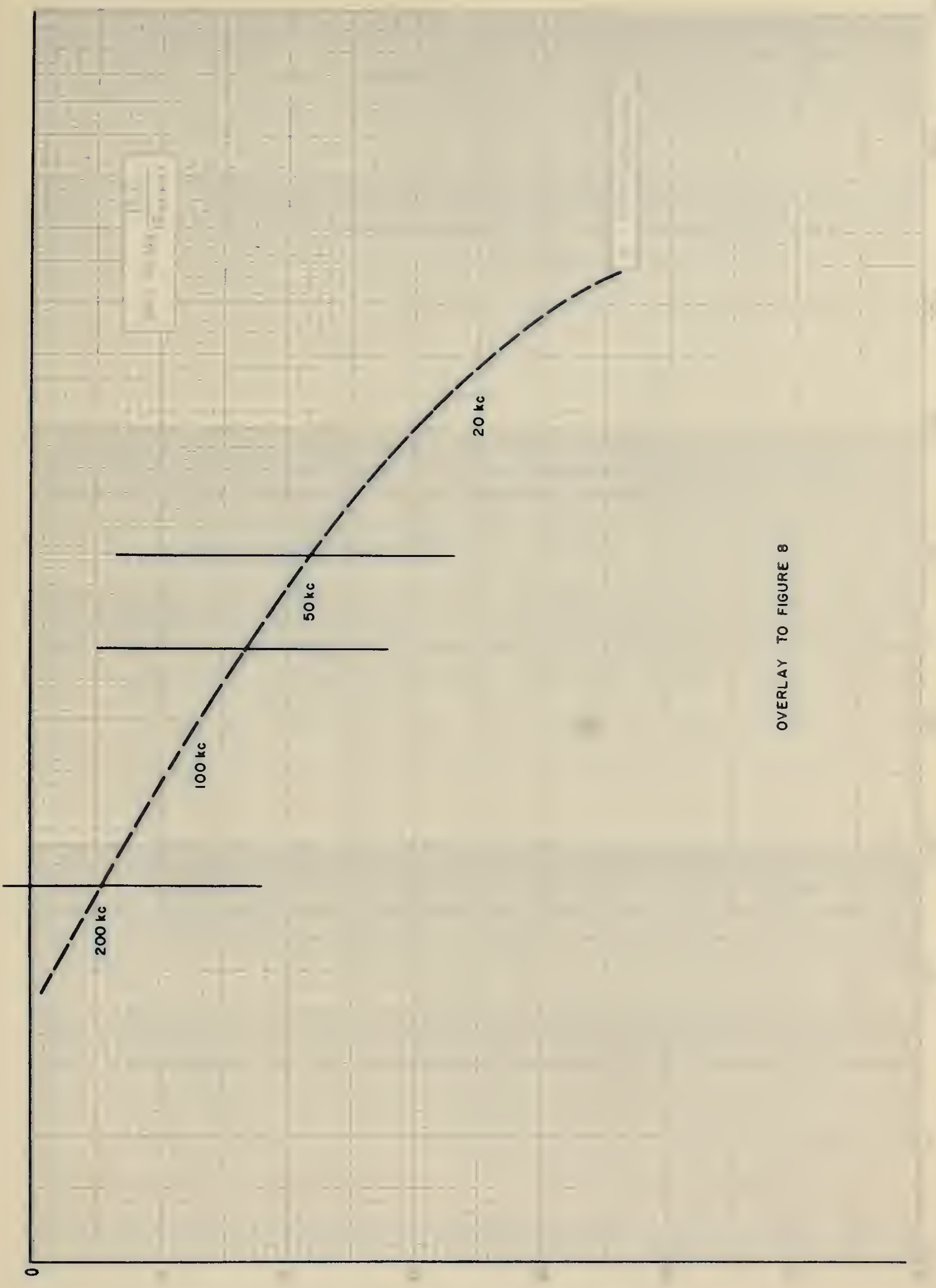
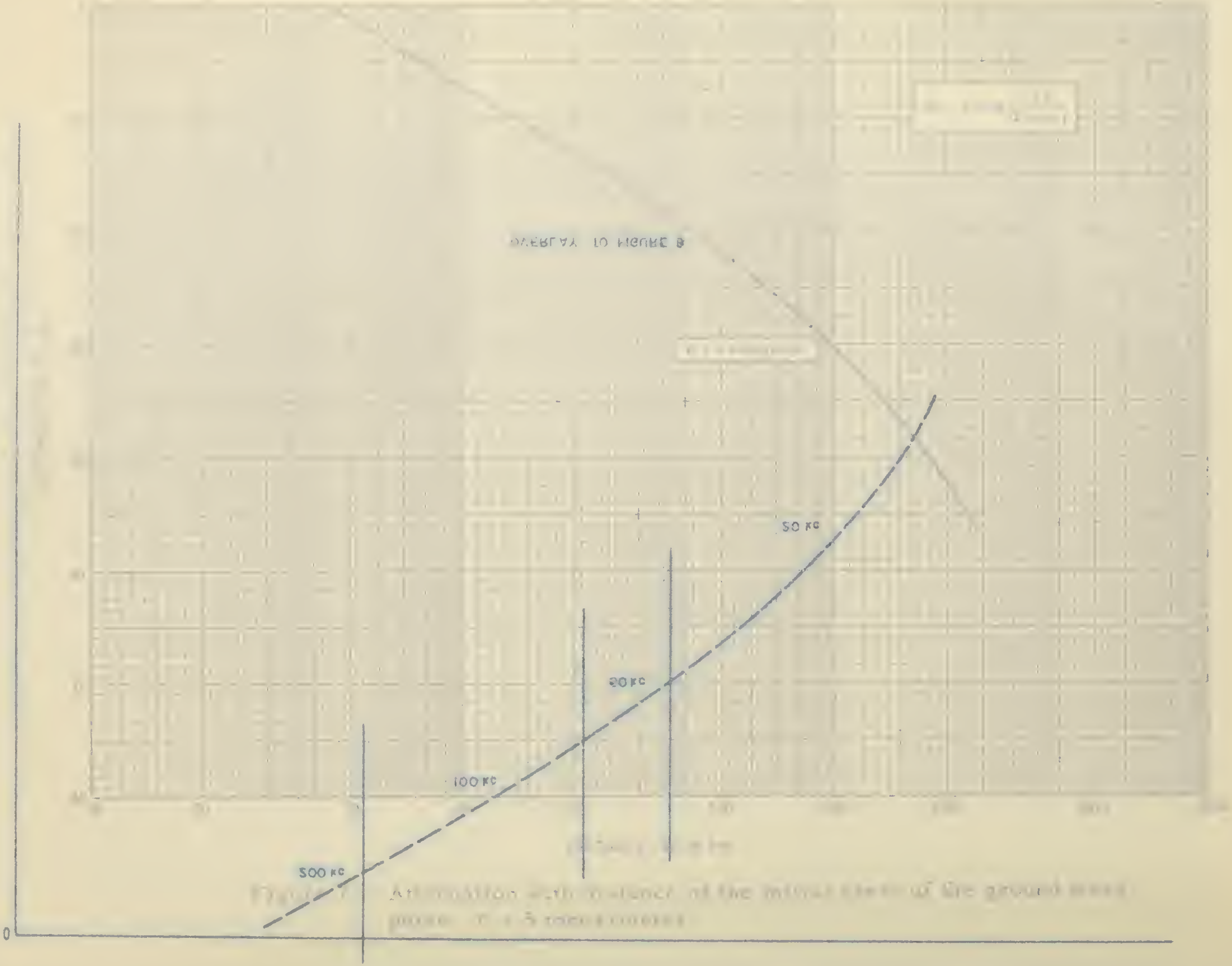


Figure 7. Attenuation with distance of the initial crest of the ground wave pulse. σ = 5 mhos/meter.


0
200 kc
100 kc
50 kc
20 kc
OVERLAY TO FIGURE 8



500 kc
100 kc
50 kc
20 kc
0

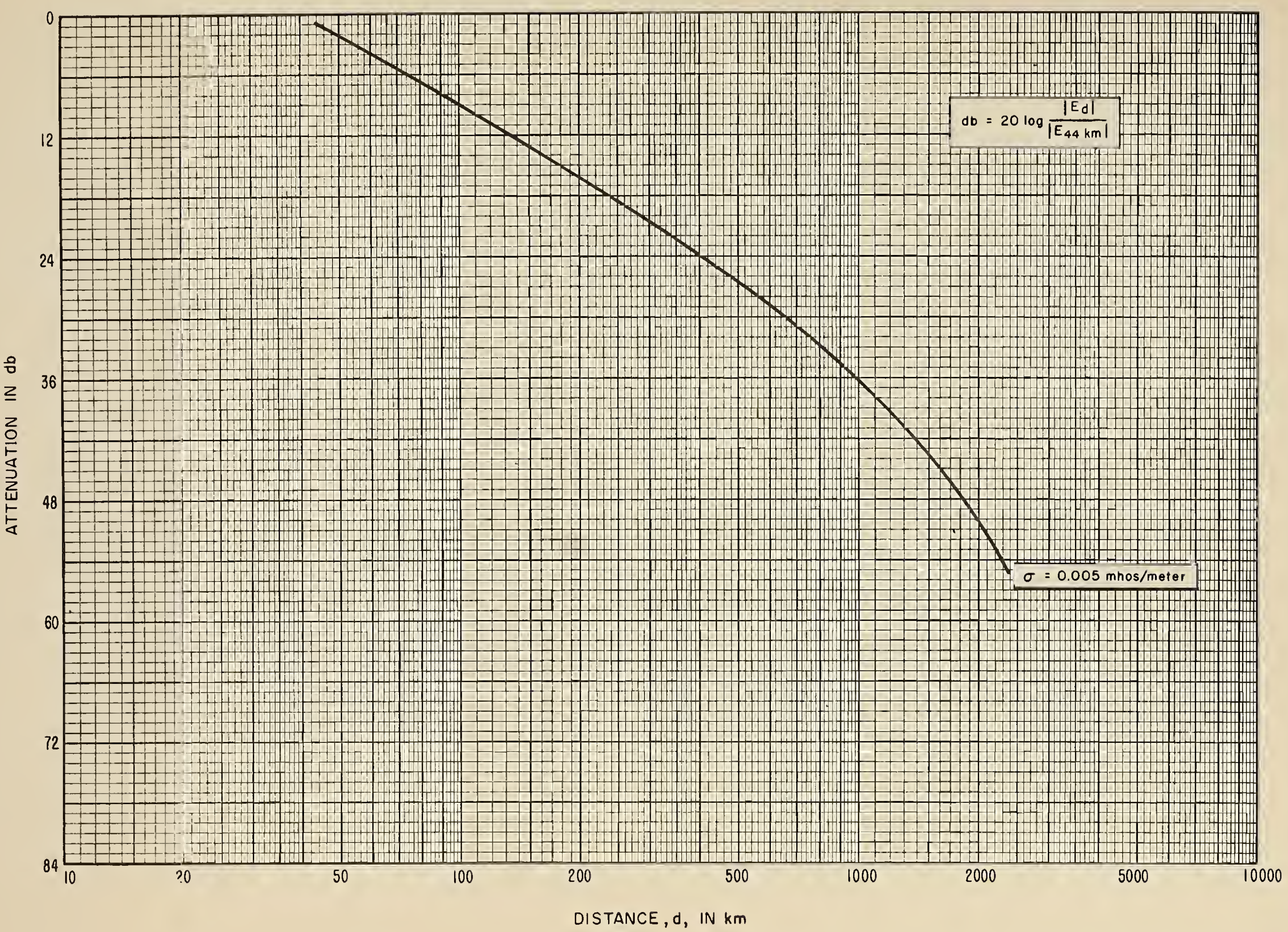
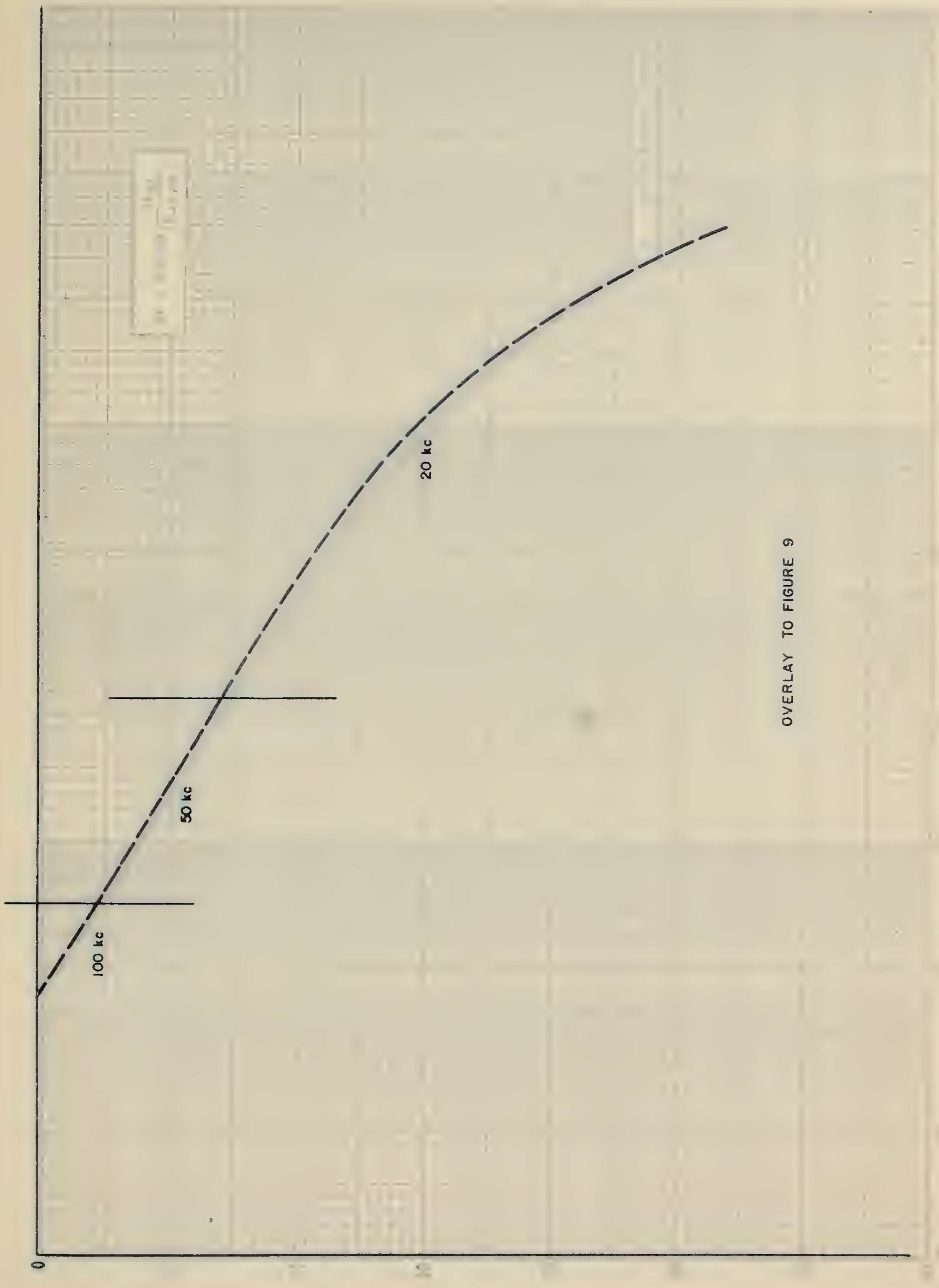
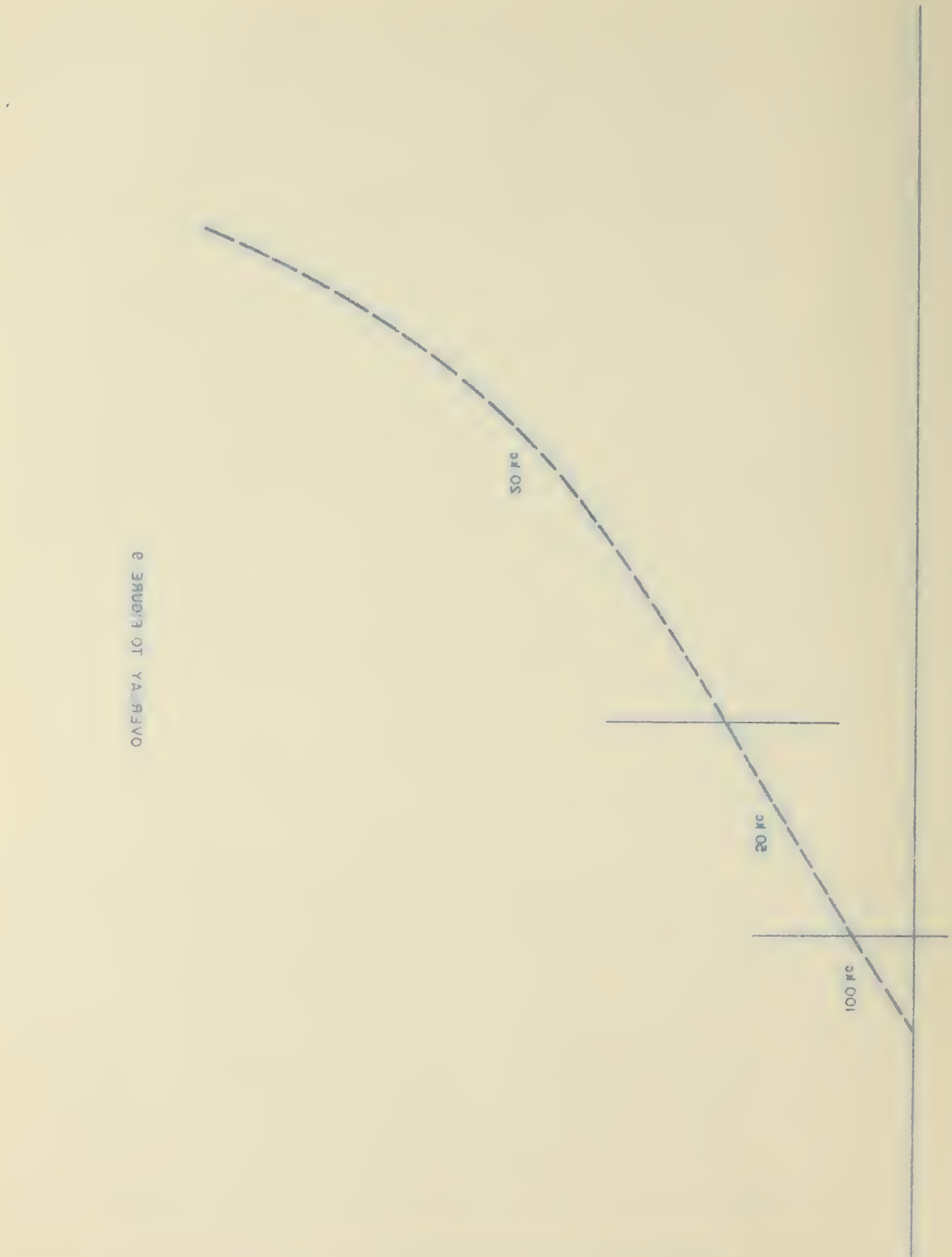


Figure 8. Single frequency fits to pulse attenuation curve. σ = 0.005.



OVERLAY TO FIGURE 9

OVERLAY TO FIGURE 6



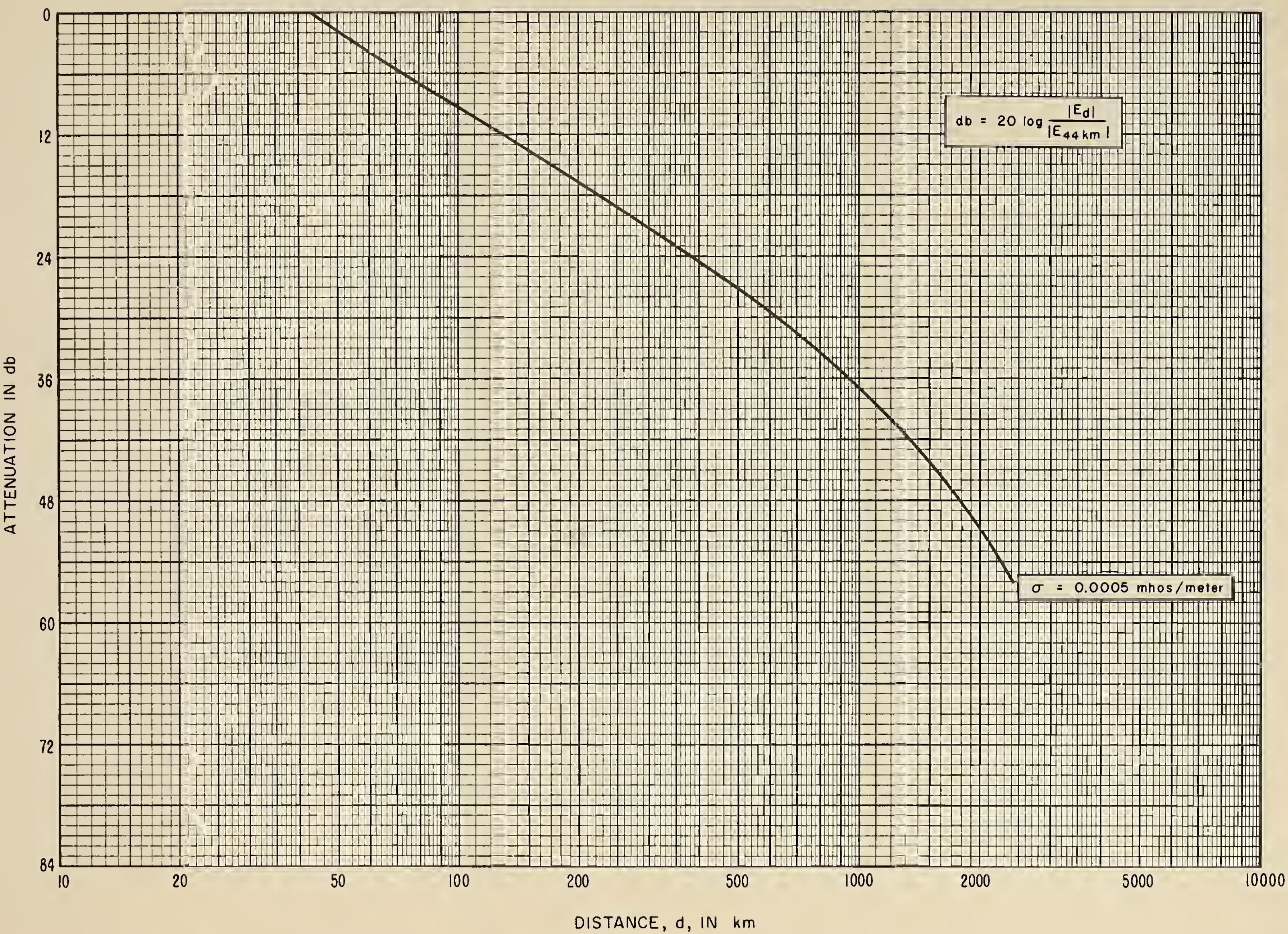
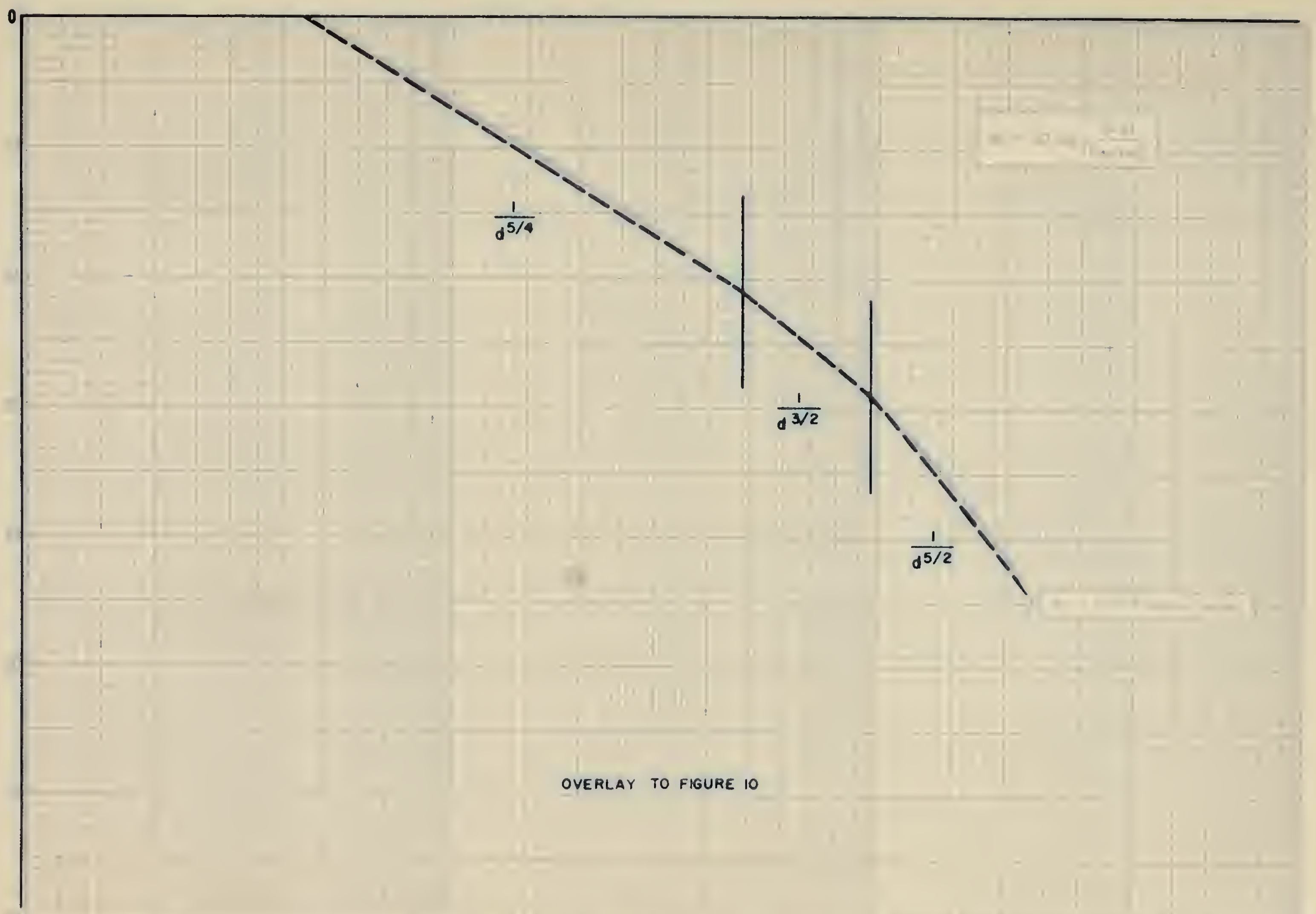
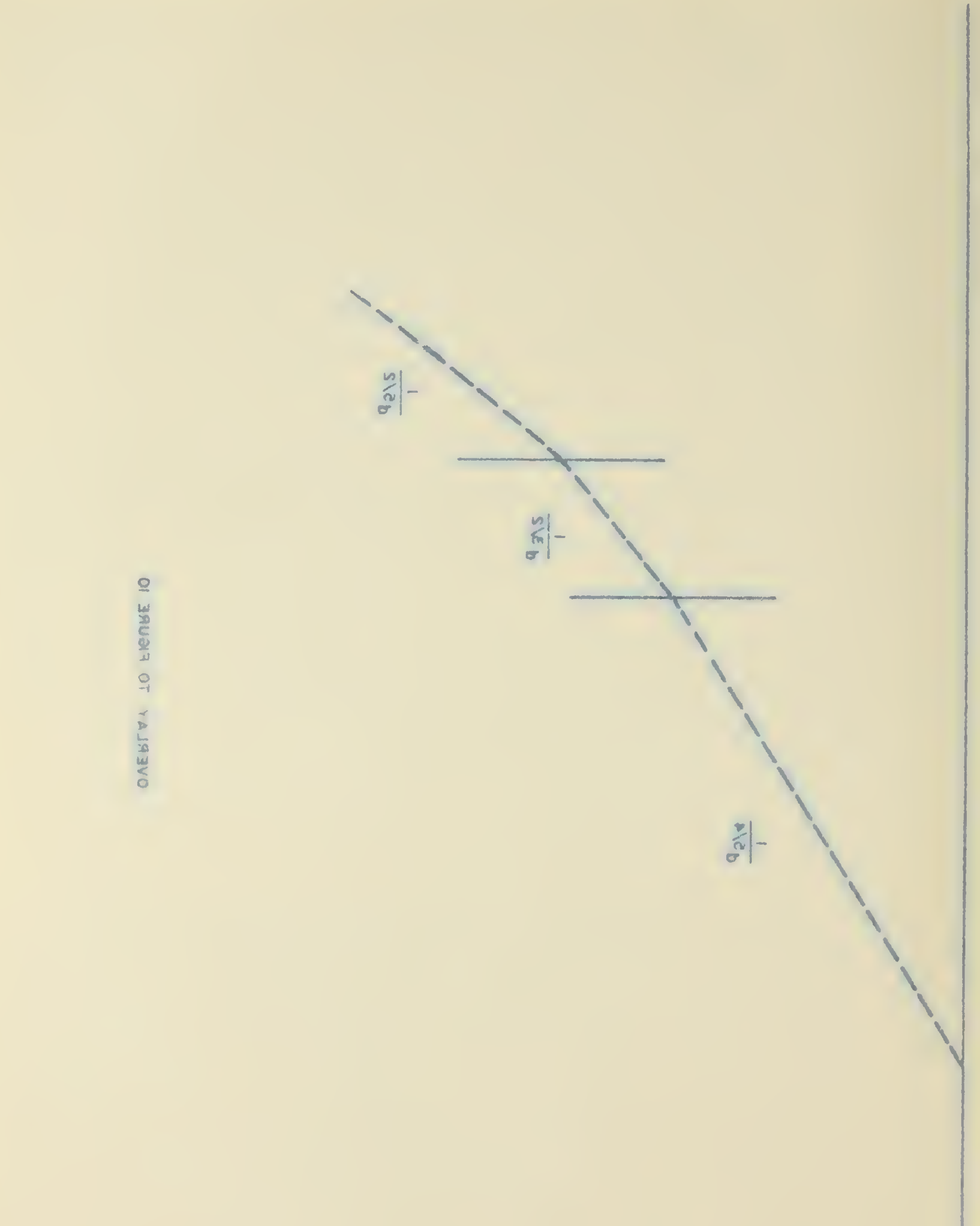


Figure 9. Single frequency fits to pulse attenuation curve. σ - 0.0005.



OVERLAY TO FIGURE 10



OVERLAY TO FIGURE 10

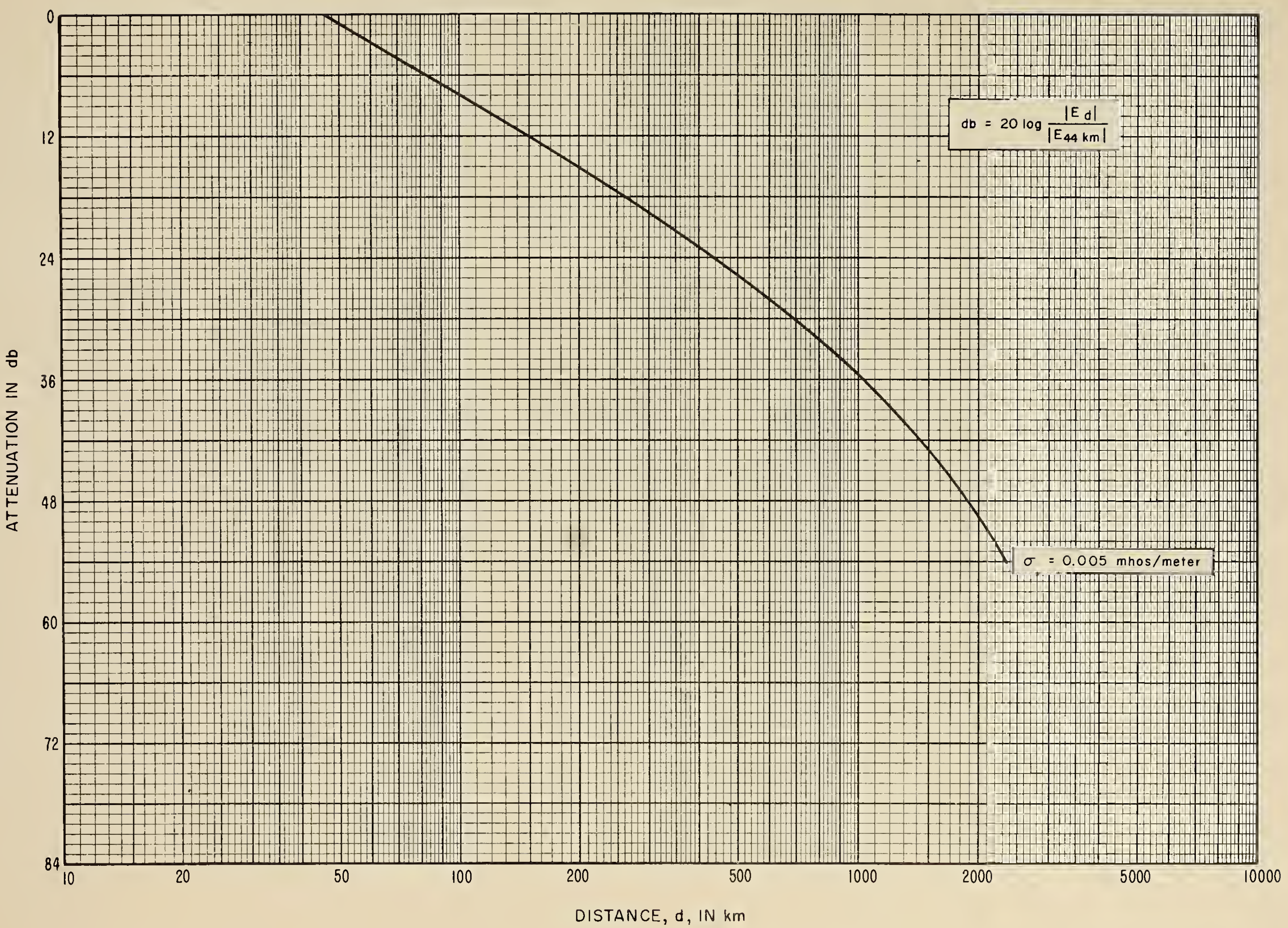
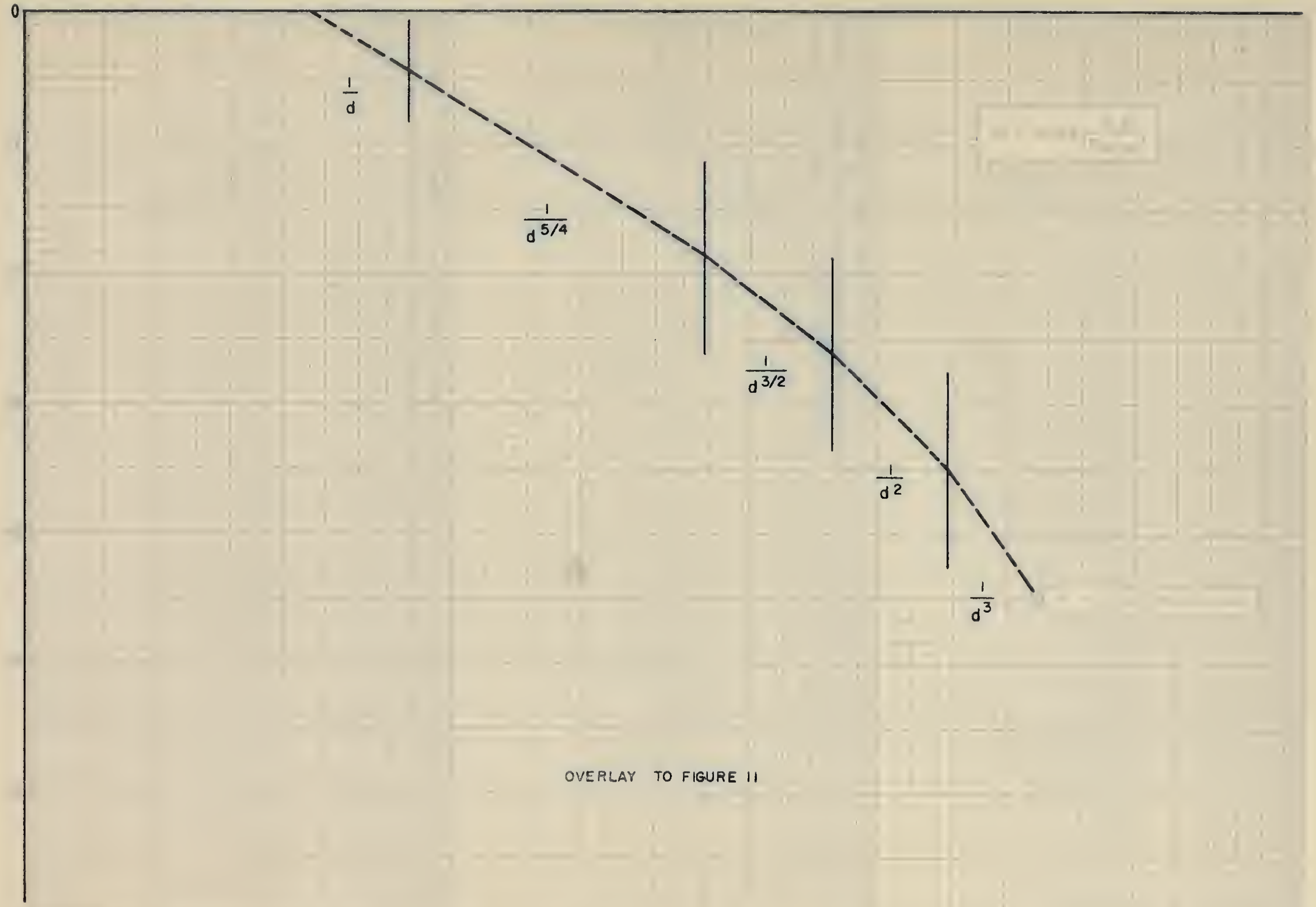
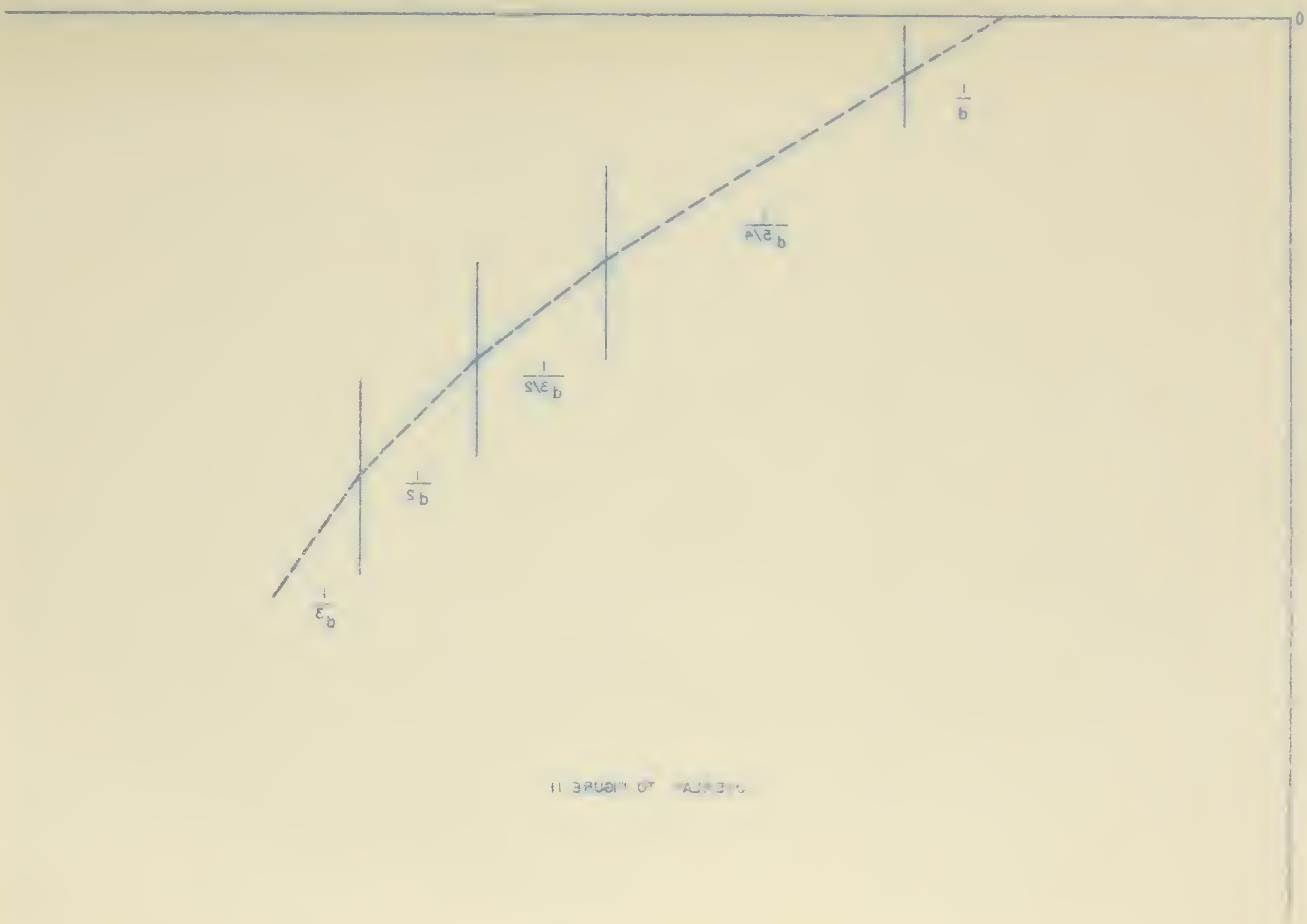


Figure 10. Attenuation $\frac{1}{d^n}$ approximation for three values of n.



OVERLAY TO FIGURE 11



OVERLAY TO FIGURE 11

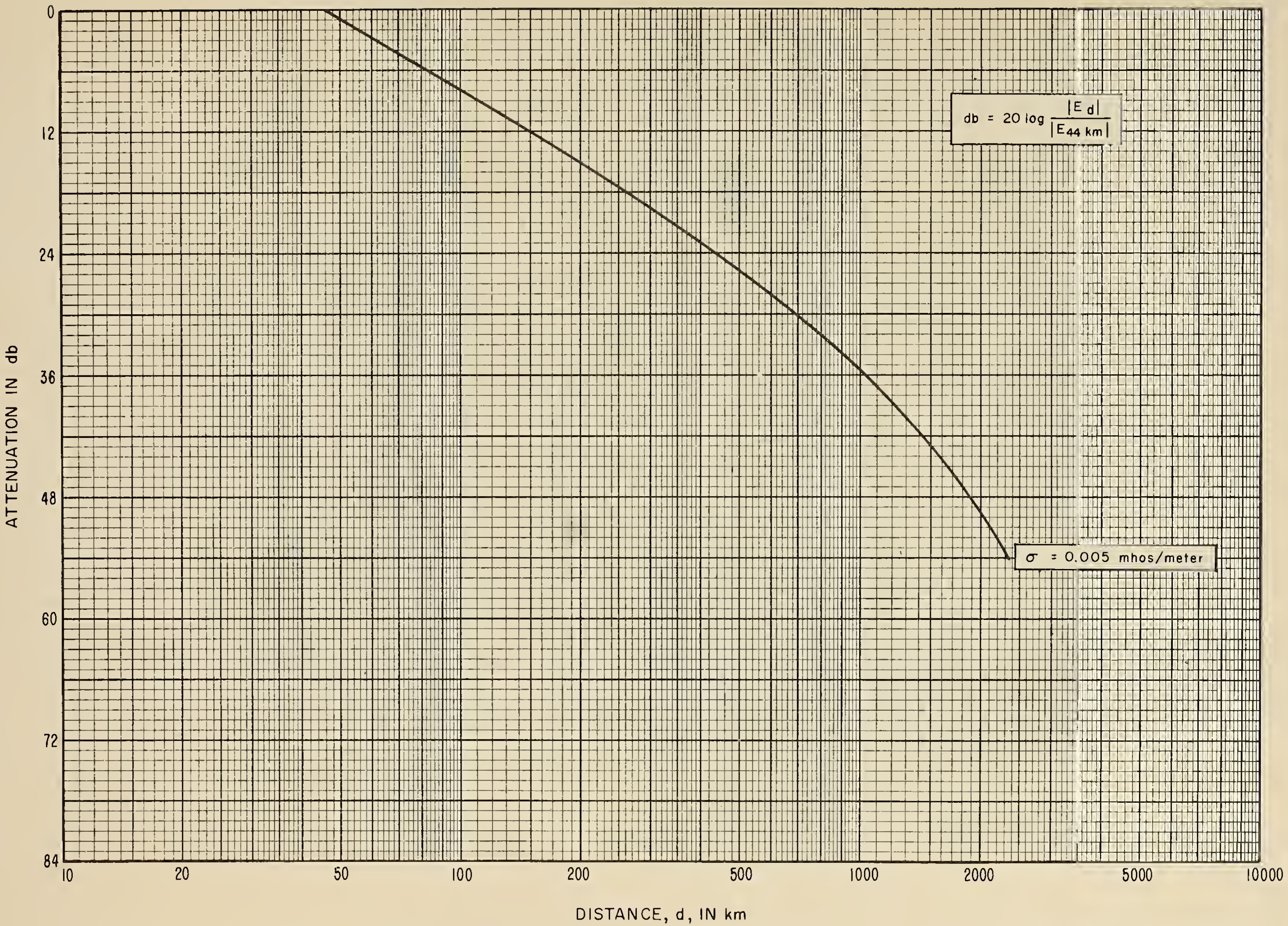


Figure 11. Attenuation $\frac{1}{d^n}$ for five values of n.

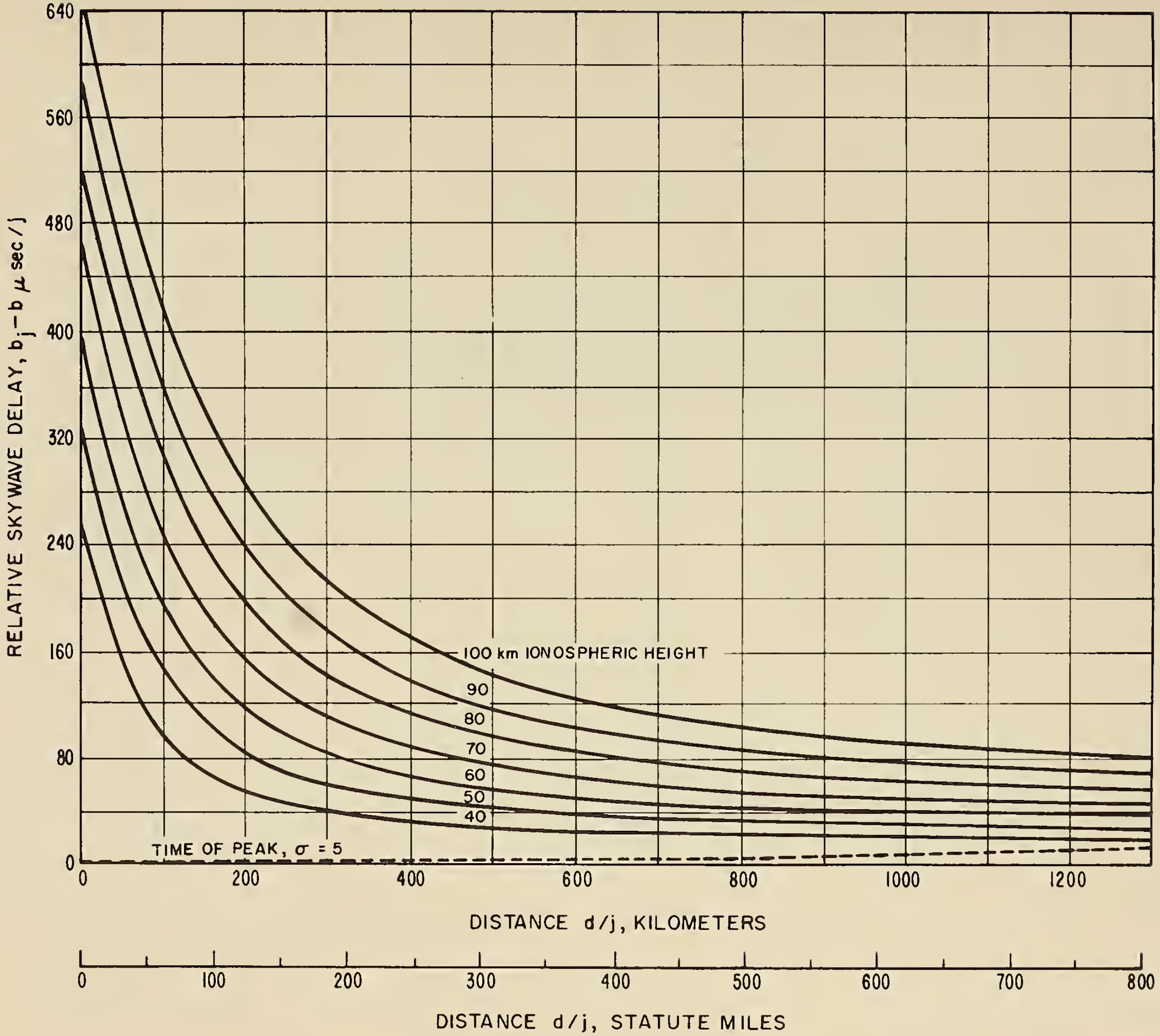


Figure 12. Time of the crest of pulse as a function of relative delay of first ionospheric wave hop, $\sigma = 5$.

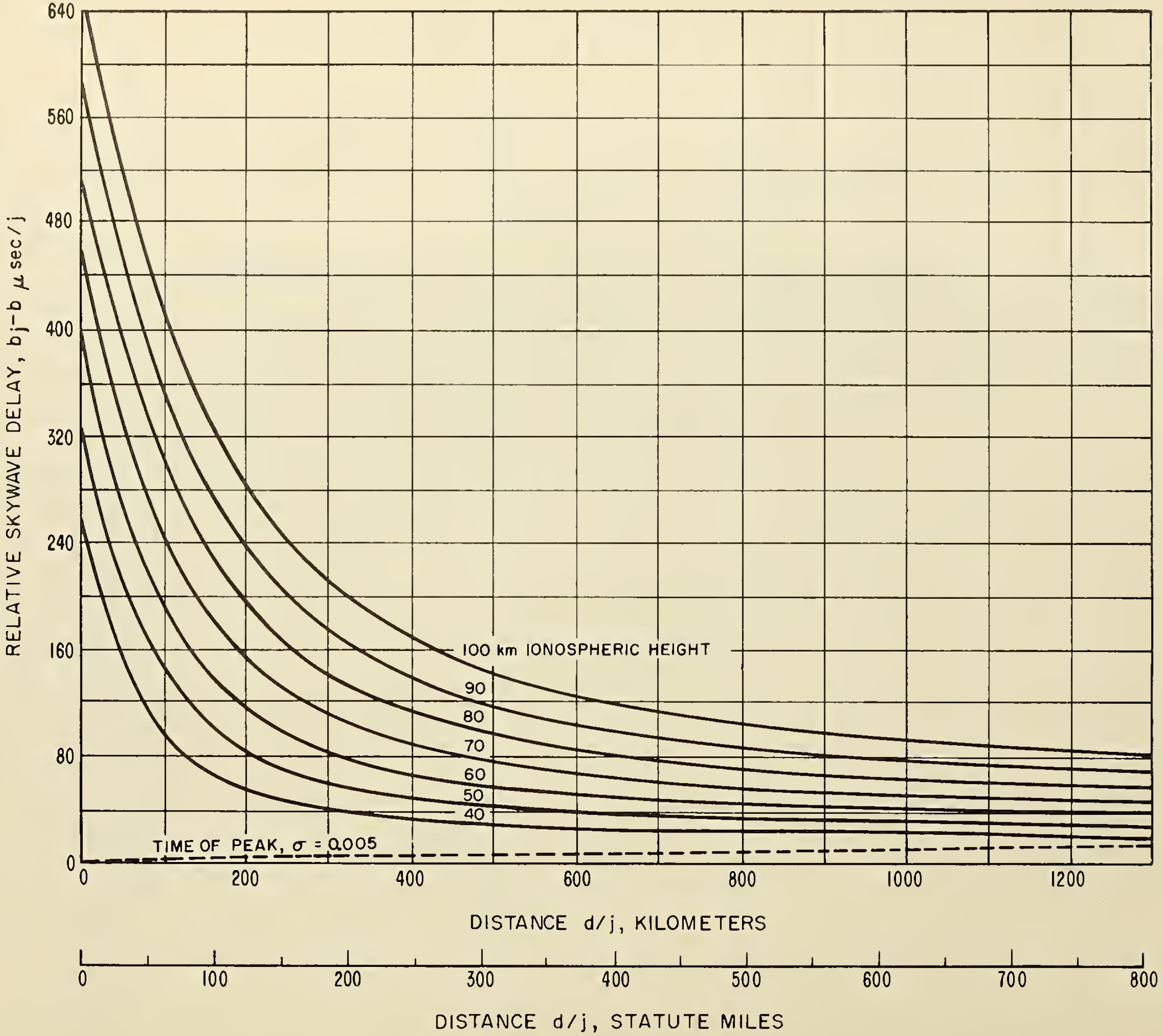


Figure 13. Time of the crest of pulse as a function of relative delay of first ionospheric wave hop, $\sigma = 0.005$

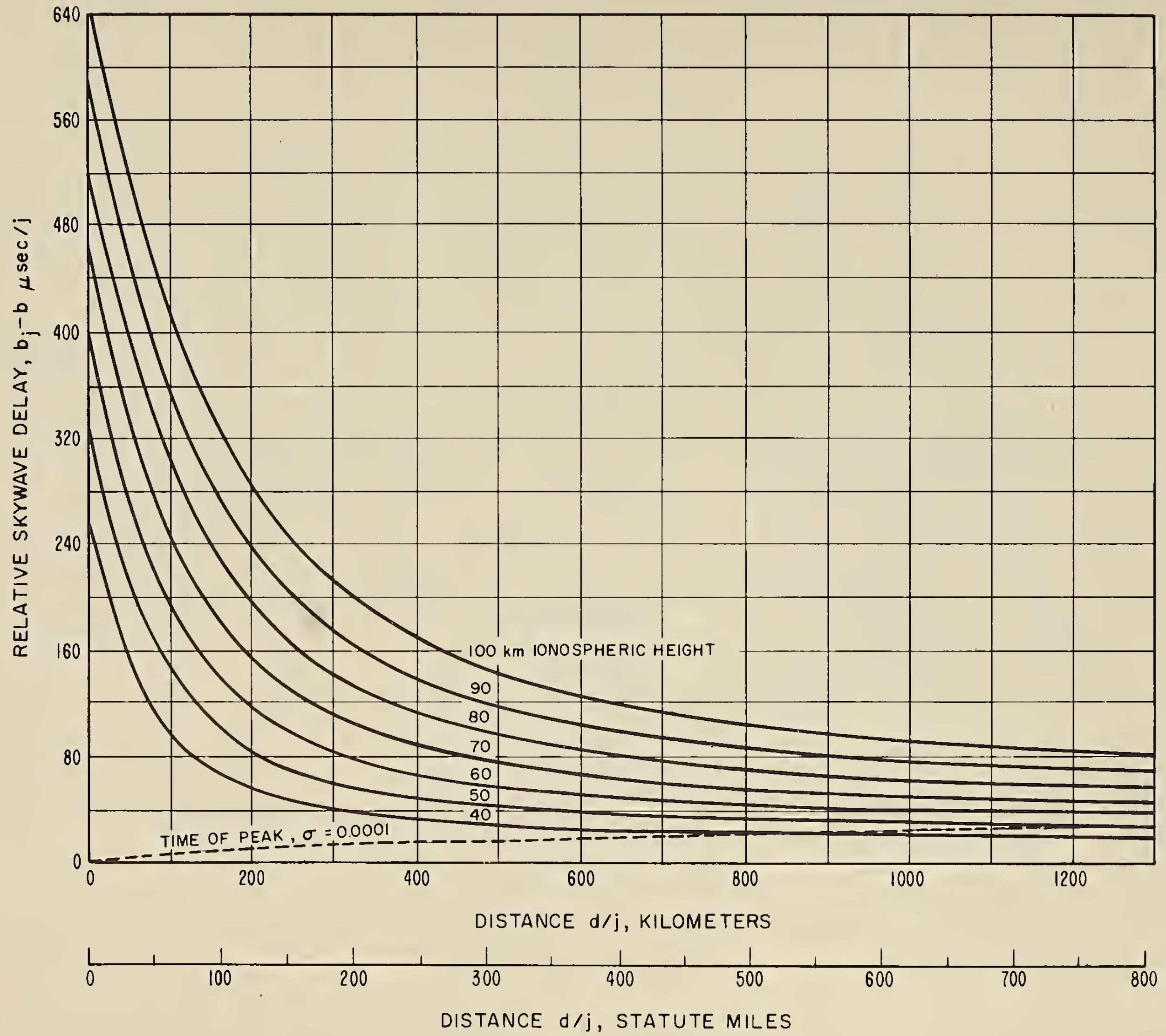


Figure 14. Time of the crest of pulse as a function of relative delay of first ionospheric wave hop, $\sigma = 0.0001$.

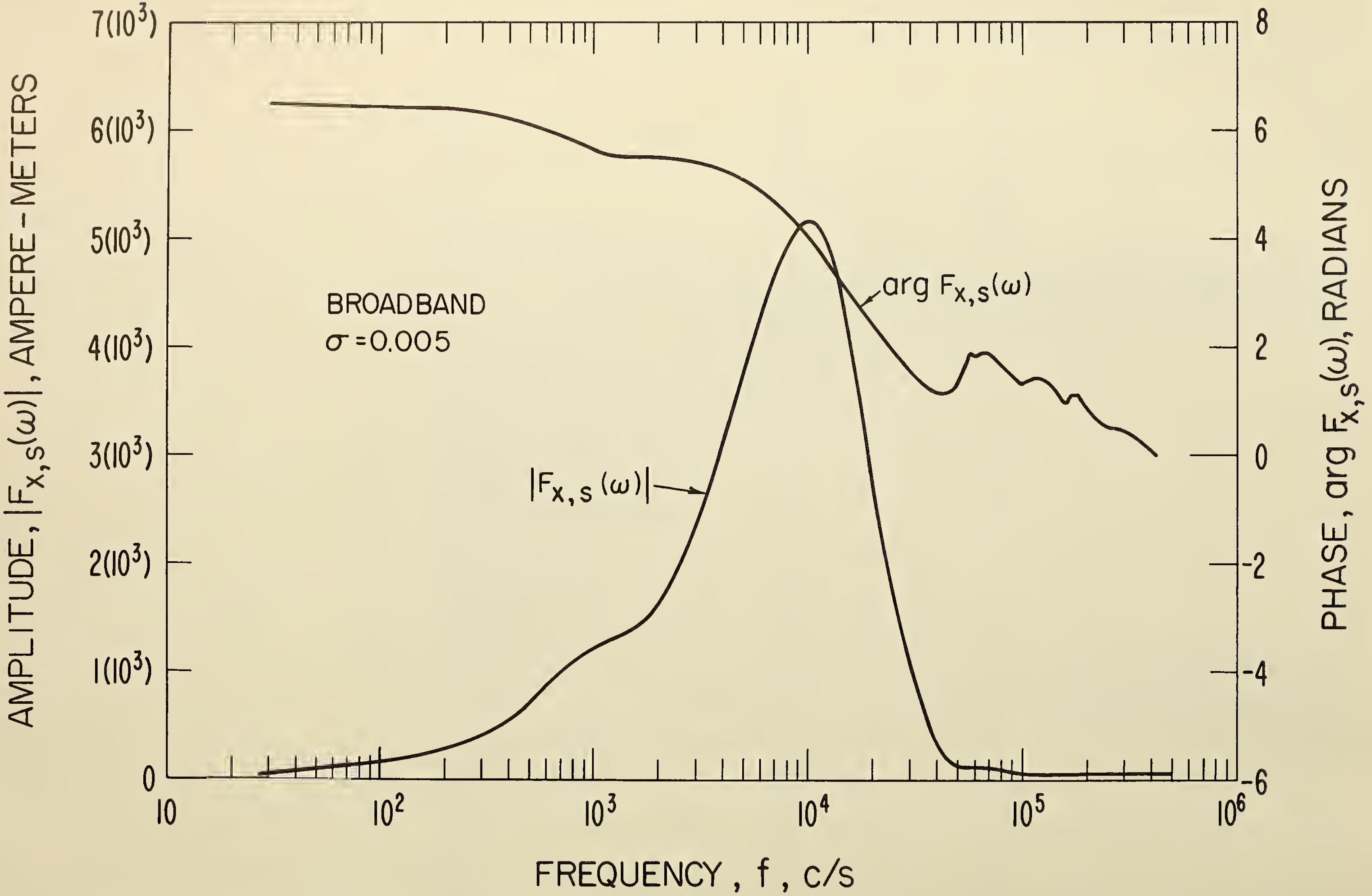


Figure 15. Complex spectrum of observed pulse in terms of source dipole current moment. Both the amplitude $|F_{x,s}(\omega)|$ and the phase arg $F_{x,s}(\omega)$ are illustrated as a function of frequency.

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