COLLINS

report

Collins Radio Company

Volume 3 Theoretical Data Base

Research and Development Contract for Coal Mine Communication System

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Research and Development Contract for Coal Mine Communication System

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Section 1

Theoretical Approach to VLF Through-the-Earth Propagation

A knowledge of the mechanics of wave propagation through the earth is essential if reliable communication systems are to be designed for coal mine environments. To obtain a reliable basis from which accurate propagation predictions could be drawn, a series of theoretical studies have been prepared for the US Bureau of Mines by Mr. Ramsay Decker of Spectra Associates, Inc. through a subcontract with Collins Radio Group. These reports formulate the analytical techniques from which we may derive frequencies and antenna configurations that yield the optimum signal-to-noise ratios over the greatest distances in mine environments.

The reports of sections 2 and 4 deal with analytical techniques for determining the signal-to-noise ratio within a mine environment for loop-to-loop and line source-to-loop antenna configurations. The analytical results of these reports were then implemented into computer programs to obtain predictions concerning through-the-earth signal propagation. These preliminary predictions are based on noise data compiled by Bensema, Maxwell and Stone, and WVU prior to the extensive research conducted by the National Bureau of Standards (NBS). These initial measurements indicated a 20- to 30-dB lower noise level than that measured recently by NBS. The recent NBS data is that used by Collins in the final predictions.

The following outline indicates the order and subject matter treated in the subsequent sections:

Section 2 - Signal-to-Noise Analysis for Loop-to-Loop Mine Communications

Section 3 - The Horizontal Electric Dipole

Section 4 - Signal-to-Noise Analysis for Down-Link Line Source Mine Communications

Section 5 - LF Communication

Section 6 - The Application of Recent NBS Noise Data to Mine Communications

Section 7 - Analysis of Mine Communication Propagation Programs

2.1 ABSTRACT

A method is developed for determining the signal-to-noise power density ratio for a horizontal surface loop (vertical magnetic dipole) to an underground horizontal loop antenna system for use in mine communications. The analysis accounts for the loop weight and diameter, depth, lateral displacement, and external noise fields. The analytic results provide for a computer method of numerical computation which can incorporate available noise data and data which may be derived from noise measurement programs in progress.

2.2 INTRODUCTION

Within the last few years there has been a concentration of theoretical and experimental investigations related to the delineation of telecommunications systems performance in mines. This has been emphasized because of the Mine Safety Act of 1969 and the several recent occurrences of mine disasters. The net result has been to stress the need for the requirements of an optimally integrated mine communications system, one in which both the operational and disaster modes could be accommodated.

As a first step in understanding those modes which may be useful in such systems, we consider through-the-earth propagation paths. Low frequency waves are transmitted through overburdens ranging in thickness from 150 to 1,500 feet. Two common methods of coupling into the mediums are employed; the loop or magnetic dipole and the line source, sometimes referred to as an earth probe (surface) or roof bolt (subsurface) antenna. This report considers loop-to-loop paths, and in particular only horizontal loops, (vertical magnetic dipole). Such loops (parallel vertical magnetic dipoles) exhibit maximum coupling when coplanar, while horizontal magnetic dipoles exhibit nulls and maxima as the antenna rotates, making it an unattractive coupling device for mine communications. Horizontal magnetic dipoles (HMD)* however, may be used as a subsurface source element for location determination since they produce a null in the vertical magnetic field component, and thus a VMD* used for detection would yield a higher S/N ratio since the surface atmospheric noise usually has a strong horizontal component; an additional argument in favor of the VMD.

*Horizontal magnetic dipole, HMD; vertical magnetic dipole, VMD.

2.3 LOOP-TO-LOOP POWER TRANSFER WITHIN A HOMOGENEOUS MEDIUM

Layman* has recently published his doctoral dissertation in which he is concerned exclusively with communications through the earth between VMD's. The expressions are written for the magnetic field of a transmitting VMD (figure 2-1), located within a homogeneous medium of infinite extent (spherical coordinate system):

$$H_r = \frac{IA}{2\pi}\left(\frac{1+i}{\delta r^2} + \frac{1}{r^3}\right)\cos\theta \; e^{-\frac{r}{\delta}} \text{ amperes/meter} \tag{2-1}$$

$$H_\theta = \frac{IA}{4\pi}\left(\frac{2i}{\delta^2 r} + \frac{1+i}{\delta r^2} + \frac{1}{r^3}\right)\sin\theta \; e^{-\frac{r}{\delta}} \text{ amperes/meter} \tag{2-2}$$

in which
I = current in loop - amperes
A = loop area - square meters
δ = the skin depth - meters

where $\delta = \dfrac{1}{\sqrt{\pi f \mu \sigma}}$ - meters

σ = conductivity-mhos/meter
μ = permeability-$4\pi \times 10^{-7}$ henrys/meter
f = frequency in Hz

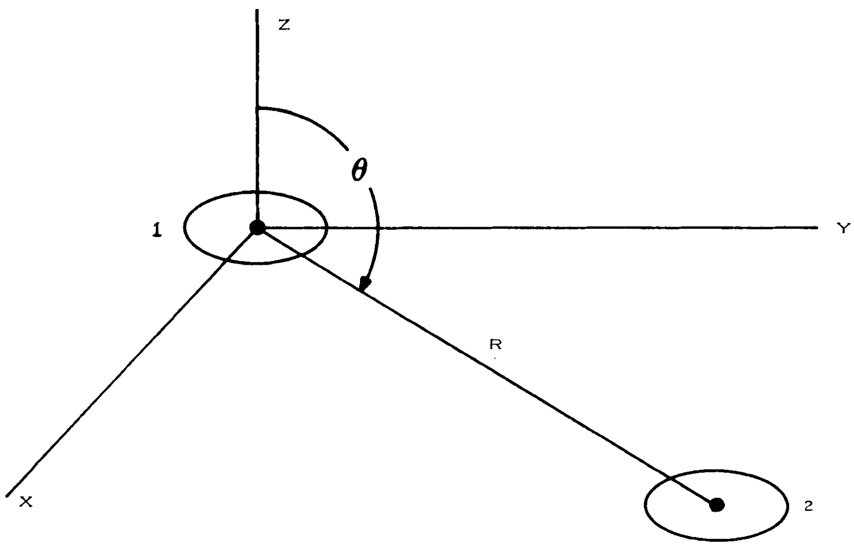

Figure 2-1. Transmitting VMD.

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*Layman, G. E., "Optimization of an EM through the Earth Communication System" WVU PhD Thesis, Morgantown, West Virginia.

The vertical magnetic field at loop 2 is

$$H_{2z} = H_r \cos\theta - H_\theta \sin\theta \qquad (2\text{-}3)$$

and the open circuit voltages at the loop 2 terminals:

$$V_{02} = 4\pi\omega N_2 A_2 H_{2z} \times 10^{-7} \text{ volts} \qquad (2\text{-}4)$$

When the receive loop is matched to the real part of its self-impedance, the available received power is

$$P_r = \frac{V_{02}^{\,2}}{4R_2} \text{ watts} \qquad (2\text{-}5)$$

while the input power to the transmit loop is

$$P_T = I_1^{\,2} R_1 \text{ watts} \qquad (2\text{-}6)$$

so that

$$\frac{P_r}{P_t} = \frac{V_{02}^{\,2}}{4R_1 R_2 I_1^{\,2}} \qquad (2\text{-}7)$$

R_1 and R_2 consist of the ohmic loss resistance plus the radiation resistance of the transmit and receive loops, respectively. The radiation resistance of an electrically small loop in free space is

$$R_r = 20\pi^2 (ka)^4 n^2 \qquad (2\text{-}8)$$

where $k = \frac{2\pi}{\lambda}$

a = loop radius in meters

n = number of turns

λ = wavelength in meters

If the loop were to be completely immersed and surrounded by the lossy medium, a considerable increase in the radiation resistance would occur. This situation is, however, neither operationally desirable nor advantageous from a propagation standpoint. It is far more realistic to consider the loop within an air filled cavity, in which case the effect of the lossy medium may be calculated:

$$R_r = \frac{\sigma(\omega\mu AN)^2}{6\pi b}\left(1 + \frac{b}{\delta}\right) e^{-\frac{2b}{\delta}} \qquad (2\text{-}9)$$

where b is the cavity radius $<< \lambda$.

This equation shows simply that at typical cavity radii that loop wire losses greatly exceed the radiation resistance for frequencies below, say, 100 kHz.

Thus, considering only loop wire losses with coplanar loops, $\theta = \pi/2$ radians

$$H_{2z} = -H_\theta$$

then

$$V_{02} = -4\pi\omega N_2 A_2 H_\theta \times 10^{-7}$$

so that

$$\left.\frac{P_r}{P_t}\right|_{\theta=\frac{\pi}{2}} = \frac{(\omega\mu N_1 A_1 N_2 A_2)^2}{64\pi^2 R_1 R_2 r^2}\left[\frac{4}{\delta^4} + \frac{4}{\delta^3 r} + \frac{2}{\delta^2 r^2} + \frac{2}{\delta r^3} + \frac{1}{r^4}\right] e^{-\frac{2r}{\delta}}. \tag{2-10}$$

Similarly for $\theta = \pi$, coaxial magnetic dipoles

$$\left.\frac{P_r}{P_t}\right|_{\theta=\pi} = \frac{(\omega\mu N_1 A_1 N_2 A_2)^2}{16\pi^2 R_1 R_2 r^4}\left[\frac{2}{\delta^2} + \frac{2}{\delta r} + \frac{1}{r^2}\right] e^{-\frac{2r}{\delta}} \tag{2-11}$$

The low frequency loss resistance of the loop can be estimated from $R_1 = 2\pi N_a R_w$ where R_w is the wire dc resistance Ω/m. The ratio of received to transmit power now becomes:

$$\left.\frac{P_r}{P_t}\right|_{\theta=\frac{\pi}{2}} = \frac{f^2\mu^2\pi^2 a_1^3 a_2^3 N_1 N_2}{64 R_{w1} R_{w2} r^2}\left[\frac{4}{\delta^4} + \frac{4}{\delta^3 r} + \frac{2}{\delta^2 r^2} + \frac{2}{\delta r^3} + \frac{1}{r^4}\right] e^{-\frac{2r}{\delta}} \tag{2-12}$$

$$\left.\frac{P_r}{P_t}\right|_{\theta=\pi} = \frac{f^2\mu^2\pi^2 a_1^3 a_2^3 N_1 N_2}{16 R_{w1} R_{w2} r^4}\left[\frac{2}{\delta^2} + \frac{2}{\delta r} + \frac{1}{r^2}\right] e^{-\frac{2r}{\delta}} \tag{2-13}$$

The terms which have a frequency dependence are collected viz $f^2[\quad]e^{-\frac{2r}{\delta}}$, a differentiation with respect to f is performed, and an f_{opt} determined for the two cases:

$$\left.f_{opt}\right|_{\theta=\frac{\pi}{2}} = \frac{3.78 \times 10^6}{\sigma r^2} \tag{2-14}$$

$$\left.f_{opt}\right|_{\theta=\pi} = \frac{2.03 \times 10^6}{\sigma r^2}, \text{ where r is in meters.} \tag{2-15}$$

These f_{opt}'s in turn yield a skin depth at the optimum frequency. The maximum power transfer conditions are found when these are substituted in equations (2-12) and (2-13).

$$\left.\frac{P_r}{P_t}\right|_{\substack{opt\\ \theta=\frac{\pi}{2}}} = \frac{1.81 a_1^3 a_2^3 N_1 N_2}{\sigma^2 R_{w1} R_{w2} r^{10}} \tag{2-16}$$

and

$$\left.\frac{P_r}{P_t}\right|_{\substack{opt \\ \theta = \pi}} = \frac{.345 a_1^3 a_2^3 N_1 N_2}{\sigma^2 R_{w1} R_{w2} r^{10}} \tag{2-17}$$

showing that under the assumed conditions f_{opt} is a function only of conductivity and loop separation and that at f_{opt} the power loss is proportional to separation to the tenth power.

2.4 LOOP-TO-LOOP POWER TRANSFER ON OR WITHIN A LOSSY HALF-SPACE

While the above analysis has shown some interesting results, the presence of the air-earth interface poses the problem which is considerably more realistic, that is, loop-to-loop communication on or within a lossy half space. Layman proceeds to formulate the classic boundary.value problem (flat earth) with the magnetic Hertz vector, and a solution given in terms of a primary field and a secondary field resulting from the effect of the boundary. The secondary field was presented in terms of some rather cumbersome integral and numerical integrations which were performed. Calculations were made for various depths, loop separations, conductivities, for loops on the surface to subsurface loops and between subsurface loops. The upshot of these calculations showed the dominance of the primary field at the lower frequencies (corresponding to the infinite homogeneous medium) with respect to the secondary field. As a result, Layman was able to show that the maximum power transfer condition derived on the basis of an infinite homogeneous medium was also essentially valid for the lossy half space. The secondary field generally increased the power transfer at higher frequencies and thus is in essential agreement with Wait's* results, although a direct comparison is difficult since Layman failed to show losses between VMD loop on surface to subsurface VMD loop directly beneath.

The important observations from this analysis are as follows:

a. The transmission path between two loops within a mine separated by a distance much greater than the depth is primarily through the upper half space at high frequencies.
b. Placing the transmitting loop at the surface rather than within the mine results in only a small loss in received power if the range (R) is at least four times the depth (h). (See figure 2-2.)

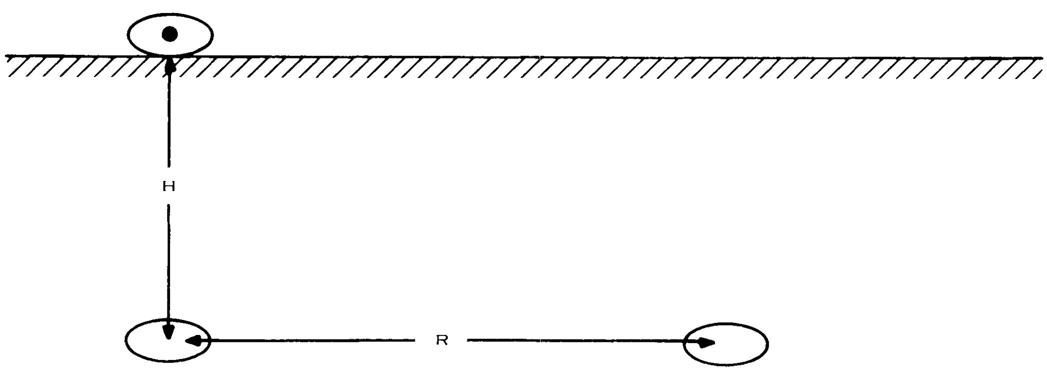

Figure 2-2. Transmitting Loop at Surface.

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*Wait, J. R., "Location of a Buried Source by the EM Induction Technique:, IEEE Transactions of Geoscience Electronics, April 1971.

While the analysis has produced some meaningful results, and particularly in view of the second observation above, we are led to conclude that Wait's*,** recent analyses relative to VMD loops on or within a lossy half space are most applicable to the solution of mine S/N calculations. In an elegant fashion Wait proceeds to show that when the boundary value problem is properly formulated and the solution reduced to integrals that can be handled easily numerically that a lower loss is encountered through the medium than would be calculated by equation (2-1) or (2-2).

Now we consider a buried VMD with a receive loop on the surface. The vertical component of the magnetic field at the surface is

$$H_z = \frac{I_1 A_1 N_1 Q}{2\pi h^3} \tag{2-18}$$

where
h = depth of transmit loop, km
I = current in transmit loop in amperes
N = number of turns in transmit loop

and

$$Q = \int_0^\infty \frac{x^3\, e^{-(x^2 + iH^2)^{1/2}}\, J_0(xD)\,dx}{x + (x^2 + iH^2)^{1/2}}$$

$H = (\sigma\mu\omega)^{1/2} h$
$= .086\, (\sigma_m f)^{1/2} h$ amperes/meter
D = normalized lateral displacement of receive loop, R/h
σ_m = earth conductivity in millimho/meter

Proceeding as before we find for $\frac{P_r}{P_t}$,

$$\frac{P_r}{P_t} = \frac{\left[2\pi f N_1 N_2 A_1 A_2 Q \times 10^{-7}\right]^2}{R_1 R_2 h^6} \tag{2-19}$$

Now, of all the ways in which one can describe the practical limitations on loop size, weight and diameter have the most significance. Therefore, equation (2-19) will be rewritten in these terms. First, we substitute for the ohmic wire losses (dc)

$$R_1 = 2\pi N_1 a_1 R_w \text{ approximately} \tag{2-20}$$

now

$$R_w = \frac{1}{\sigma_w A_w}$$

*Wait, J. R., "Location of a Buried Source by the EM Induction Technique", IEEE Transactions of Geoscience Electronics, April 1971.

**Wait, J. R., "Subsurface EM Fields of a Circular-Loop of Current Located Above Ground", IEEE Transactions on Antennas and Propagation, July 1972.

σ_w = wire conductivity, mhos/meter

A_w = wire area square meters

and $A_w = \frac{w}{2\pi a N \rho}$ square meters

w = weight in kg

ρ = wire density kg/$_m{}^3$

combining the above relations we have

$$\frac{P_r}{P_t} = \frac{\pi^2 f^2 a_1{}^2 a_2{}^2 (\frac{\sigma w}{\rho})^2 W_1 W_2 Q^2 \times 10^{-14}}{4h^6} \qquad (2\text{-}21)$$

now $$\frac{\sigma w}{\rho} = 6.52 \times 10^3 \ m^2/\Omega\text{-kg} \quad \text{(copper)}$$

with a_1, a_2 in meters W in kg, h in km, equation (2-22) becomes

$$\frac{P_r}{P_t} = \frac{1.05 f^2 a_1{}^2 a_2{}^2 W_1 W_2 Q^2 \times 10^{-24}}{h^6} \qquad (2\text{-}22)$$

R_1 and R_2 have been taken simply as the dc resistance of loop. Because of skin effect the effective ac resistance will be somewhat higher. From Terman* for typical multilayer air core loops,

$$\frac{R_{ac}}{R_{dc}} \cong 1 + \frac{1}{4}(5.2m)^2 \left(\frac{d_0}{c}\right)^2 \frac{x^4}{64} \quad \text{for } x \lessgtr 2.5 \qquad (2\text{-}23)$$

where $x = .1078\, d\sqrt{f}$

d = wire diameter in cm

m = number of layers

$\frac{d_0}{c}$ = effective wire spacing factor

where effective wire spacing factor = $\frac{\text{diameter of wire (cm)}}{\text{center-center spacing between turns on same layer}}$

Equation (2-23) will reduce $\frac{P_r}{P_t}$ for both loops, hence $\frac{P_r}{P_t}$ should be divided by $\left(\frac{R_{ac}}{R_{dc}}\right)^2$ for identical loops.

*Terman, F. E., Radio Engineers Handbook, McGraw Hill, 1943, p 81.

2.4.1 System Signal-to-Noise Analysis

The equivalent noise figure of a receiving system is

$$F_s = F_x - 1 + \frac{F_r}{\eta_A} \tag{2-24}$$

where F_x = the external noise figure

F_r = the receive-noise figure

η_A = the efficiency of the receive antenna

multiplying equation (2-24) by kT_0

$$kT_0 F_s = kT_0(F_x - 1) + \frac{kT_0 F_r}{\eta_A}$$

where K = Boltzmann's constant

T_0 = temperature in degree Kelvin

The first term on the right is the available received noise power, hence we write

$$F_s = \frac{P_{nr}}{kT_0} + \frac{F_r}{\eta_A} \tag{2-25}$$

or

$$F_s = \frac{V_{oc}^2}{4R_r kT_0} + \frac{F_r R_L}{R_r}$$

where R_r is the radiation resistance of a lossless antenna and R_L is the loss resistance. Now for systems analysis, it is reasonable to require the external noise contribution to be say 10 times that due to receiver noise and antenna inefficiency, hence we write

$$V_{oc}^2 > 40kT_0 F_r R_L \tag{2-26}$$

substituting

$$V_{oc} = 8\pi^2 f N_2 A_2 10^{-7} H_N$$

where H_N is the external noise field in amperes/m/$\sqrt{Hz}$

since

$$R_L = 2\pi N_2 a_2 R_W$$

and

$$R_W = \frac{2\pi a_2 N_2}{W_2} \frac{\rho}{\sigma}$$

Solving for a_2, the minimal radius of the receive loop is

$$a_2 > \frac{1.26 \times 10^{-6}}{fH_N} \sqrt{\frac{F_R}{W_2}} \text{ meters} \tag{2-27}$$

The Q_l of the transmitter or receive loop can be estimated from the approximate inductance

$$L \cong 2.92aN^2 \log_{10}(96.5a) \times 10^{-6} \text{ Henrys}$$

Using the above relations for weight and wire losses we find

$$Q_l \cong \frac{1.515 \, f \log_{10}(96.5a) W \times 10^{-3}}{a} \tag{2-28}$$

Now on the assumption that equation (2-27) holds, the system noise power/Hz bandwidth is

$$P_{nr} = 4\pi^4 f^2 a_2^2 H_N^2 W_2 \frac{\sigma}{\rho} \times 10^{-14}$$

Combining this with equation (2-22) we have finally for the received S/N power density ratio

$$\frac{P_s}{P_{no}} = \frac{4.13 a_1^2 W_1 Q^2 P_T \times 10^{-17}}{H_N^2 h^6} \tag{2-29}$$

The equivalent background noise fields are shown in figure 2-3 for various noise conditions. These have been derived from Bensema*, WVU**, and Maxwell and Stone***. In the next paragraph, we shall describe a computer method for the S/N analysis which will incorporate the noise data of figure 2-3.

2.5 COMPUTER SIGNAL-TO-NOISE ANALYSIS FOR LOOP-TO-LOOP MINE COMMUNICATIONS

Based on the methods described in the preceding paragraphs, a computer method was written and calculations performed over the parametric ranges of interest.

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*Bensema, W. D., "Coal Mine ELF EM Noise Measurements," NBS Report 10739.

**Mine Communication and Monitoring Second Quarterly and Intermediate Annual Technical Progress Report (5 September 1971 to 4 December 1971) Department of Electrical Engineering, WVU, Morgantown, West Virginia.

***Maxwell and Stone, PGTAP, May 1963, page 339.

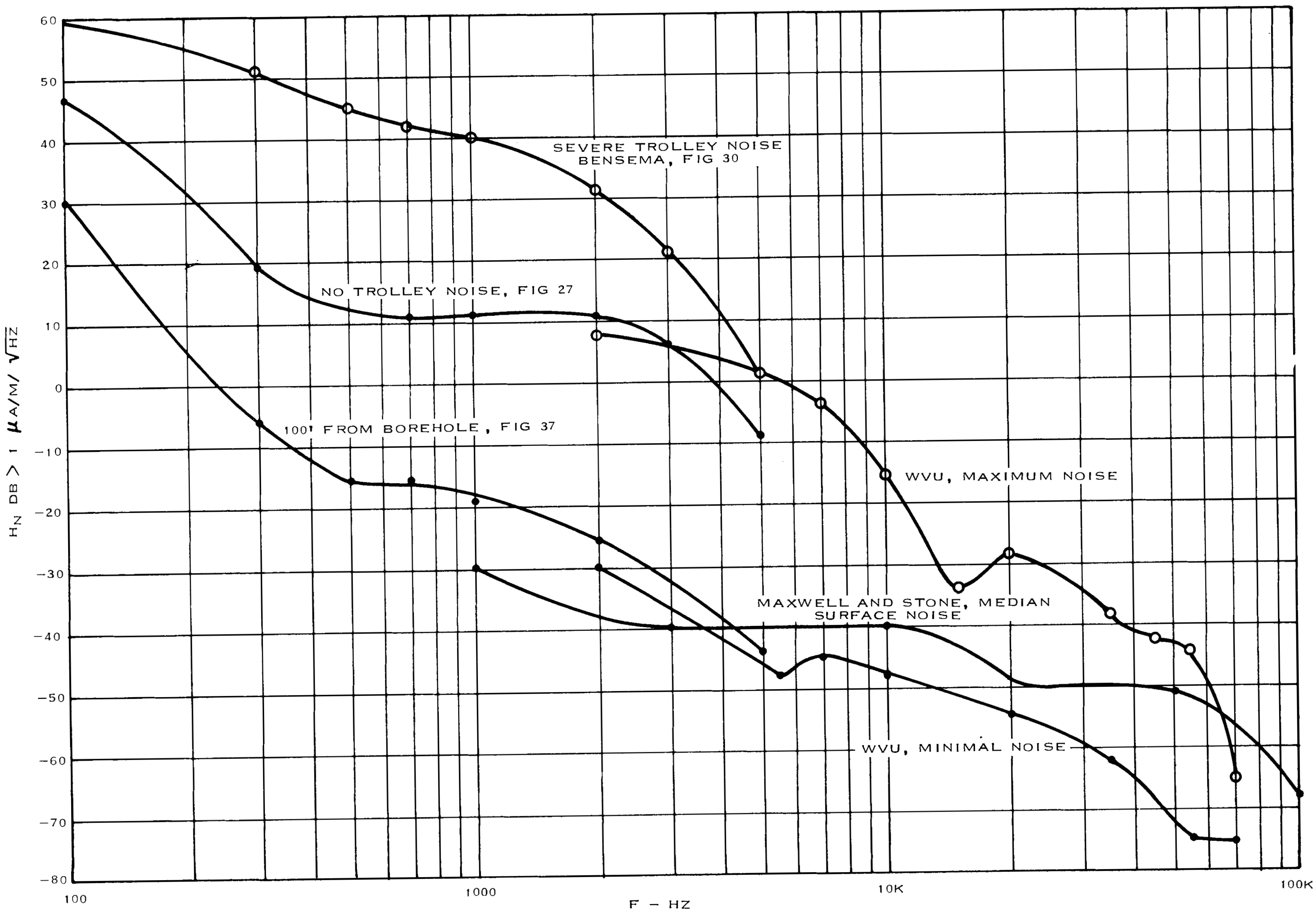

Figure 2-3. Equivalent Background Noise Fields.

2.5.1 Relation of Loop Design to System Performance

From equations (2-28) and (2-29), we note that the gain-bandwidth product of a loop-to-loop communications system is proportional to

$$\frac{a_1^3}{(1.984 + \log_{10} a_1)}$$

at frequencies generally in the audio range. From this, we see that the diameter of the transmit loop is far more important for information transfer than loop weight. When transmit loop diameter is maintained at a practical maximum and weight held at a minimum, then not only is the gain-bandwidth product improved, but it becomes more feasible to match the receive loop Q to the transmit loop Q so as to approach the minimum required radius of the receive loop. In other words, the minimum radius of the receive loop is not practically realizable for matched loop Q's unless the radius to weight ratio of the transmit loop is quite high, which increases the system gain-bandwidth product in the process. This requires a solution to the following equation:

$$\frac{a_1}{W_1(1.984 + \log_{10} a_1)} = \frac{a_2}{W_2(1.984 + \log_{10} a_2)} \qquad (2\text{-}30)$$

$$a_2 = a_{2min} = \frac{1.26 \times 10^{-6}}{fH_N} \sqrt{\frac{F_R}{W_2}}$$

The number of turns in a loop is

$$N = \frac{3.53 W \times 10^4}{aA_c} \qquad (2\text{-}31)$$

where W = loop copper weight in kg
a = loop radius - meters
A_c = loop wire area in circular-mils

Thus, an optimal transmit loop is one of large diameter with a minimal number of turns.

The minimum number of turns for a fixed receive loop radius is

$$N_{min} = \frac{4.41 F_R \times 10^{-8} \pi}{f^2 H_N^2 A_c \times 4a_2^3} \qquad (2\text{-}32)$$

2.5.2 System Noise Representation

As shown in figure 2-3, equivalent background noise fields were derived from the data of Bensema, WVU and Maxwell and Stone. For the down-link path three noise grades were established as follows:

Noise Grade 1: Bensema figure 30, severe trolley noise. For frequencies above 3 kHz, this was merged into WVU's maximal noise data.

Noise Grade 2: Bensema figure 27, no trolley noise. For frequencies above 3 kHz, this was given a frequency decrement derived from typical WVU data.

Noise Grade 3: Bensema figure 37, 100 feet from borehole. For frequencies above 3 kHz, this was merged into WVU minimal noise.

For the up-link path, two noise grades were established as follows:

Noise Grade 1: Maxwell and Stone "quasi" maximum surface noise. For frequencies below 1 kHz this was merged into Bensema's figure 25.

Noise Grade 2: Maxwell and Stone median surface noise. For frequencies below 1 kHz this was merged into Bensema's figure 39.

2.5.3 Signal and Noise Processing

Low data rate transmission, which can be accommodated in the system bandwidth, offers no difficulty insofar as signal attenuation calculations at a specific carrier frequency is concerned. For broadband, for example, direct up or down-link voice transmission, however, the rms signal power must be calculated over the bandwidth of interest, that is,

$$\frac{P_r}{P_t} = \frac{4\pi^2 N_1^2 N_2^2 A_1^2 A_2^2 \int_{f_1}^{f_2} f^2 Q^2(f)\,df}{R_1 R_2 h^6} \tag{2-33}$$

The rms noise power is handled in exactly the same way.

$$P_N = \frac{64\pi^4 N_2^2 A_2^2 \times 10^{-14}}{4R_2} \int_{f_1}^{f_2} f^2 H_N^2(f)\,df \tag{2-34}$$

If the noise is primarily broadband impulsive, then the integral in equation (2-34) becomes simply a summation of the harmonic noise components. Because the effect of the overburden is to integrate the transmitted signal, it is self-suggestive that for broadband application the signal be differentiated before transmission and signal and/or noise differentiated upon reception. A. D. Little in their working memorandum no. 5 has considered this and has come to the conclusion that there is little to be gained by differentiation except for mine depths of approximately 400 feet or less. For the shallower depths, a 6-dB improvement in received S/N ratio can be realized for the same transmitter output power.

*These noise grades were based on the noise data available at the time the analysis was done. They were ultimately replaced by new data. (See section 6 for more recent data.)

Reference should also be made to A. D. Little working memorandum no. 8 in which a hybrid harmonic commutator type filter is described. The author indicates a practical method of rejecting the impulsive harmonic content of the external noise fields.

2.5.4 Results of Signal-to-Noise Ratio Analysis

The techniques of the preceding sections have been incorporated in a computer method for the calculation of expected received signal-to-noise ratios. For the examples selected σ = .01 mho/m, a value which according to G. Keller is a good value to assume for coal mines less than 1,000 feet in depth. For the up-link we have assumed the following:

W_1 = 10 kg

a_1 = 0.6 m (transmit loop radius)

P_t = 10 watts

Noise grade 2

For the down-link we have the following parameters:

W_1 = 200 kg

a_1 = 10 m

P_t = 10,000 watts

Noise grade 3

The received signal-to-noise ratios were calculated for depths of 100, 300, and 500 meters and lateral displacements of 0, 100, 200, 300, 400, and 500 meters. The results are shown in figures 2-4 through 2-9 of this section. We note at the shallower depths the optimal frequency is extremely broad, for example, where the depth equals the displacement. In fact a secondary maxima occurs at about 20 kHz. This is in essential agreement with Layman. With increasing depths the peak is nore pronounced and occurs essentially at 2 kHz. It appears that for an up-link with a portable transmit loop and a reasonable transmitter power, a 20 dB S/N_0 is practical on the surface for the 90 percentile mine depth of 300 meters. At the 500-meter depth with a maximum S/N_0 of 0 dB, obviously only extremely low data rates could be employed. The down-link curves indicate that at least a 40-dB increase in system gain can be achieved with respect to the up-link case. See page 2-14 for the correction factor for other transmit loop weights and diameters.

2.6 PREDICTIONS FOR THEORETICAL S/N_0

From the foregoing development of theoretical signal-to-noise analysis for the loop-to-loop configuration, we may state the following:

a. VMD (verticle magnetic dipole) arrangement yields a higher S/N_0 ratio than does HMD (horizontal magnetic dipole).

b. The transmission path between two loops within a mine separated by a distance much greater than the depth is primarily through the upper half space at high frequencies.

c. Placing the transmitting loop at the surface rather than within the mine results in only a small loss in received power if the separation is at least four times the depth.

d. Diameter of the transmit loop is far more important for information transfer than loop weight. By maintaining transmit loop diameter at a practical maximum and weight at a minimum, improved gain bandwidth can be obtained and it becomes more feasible to match the receive loop Q to transmit loop Q.

e. Optimal frequency range is extremely broad at shallower depths, but becomes more pronounced with increased depth.

f. Correction factor for loop-to-loop transmission is as follows:

$$10 \log \left(\frac{W}{W_0}\right) + 20 \log\left(\frac{a}{a_0}\right) + 10 \log\left(\frac{P}{P_0}\right)$$

where W = weight of transmitting loop

W_0 = weight of reference loop

a = radius of transmitting loop

a_0 = radius of reference loop

P = power into transmitting loop

P_0 = power into reference loop

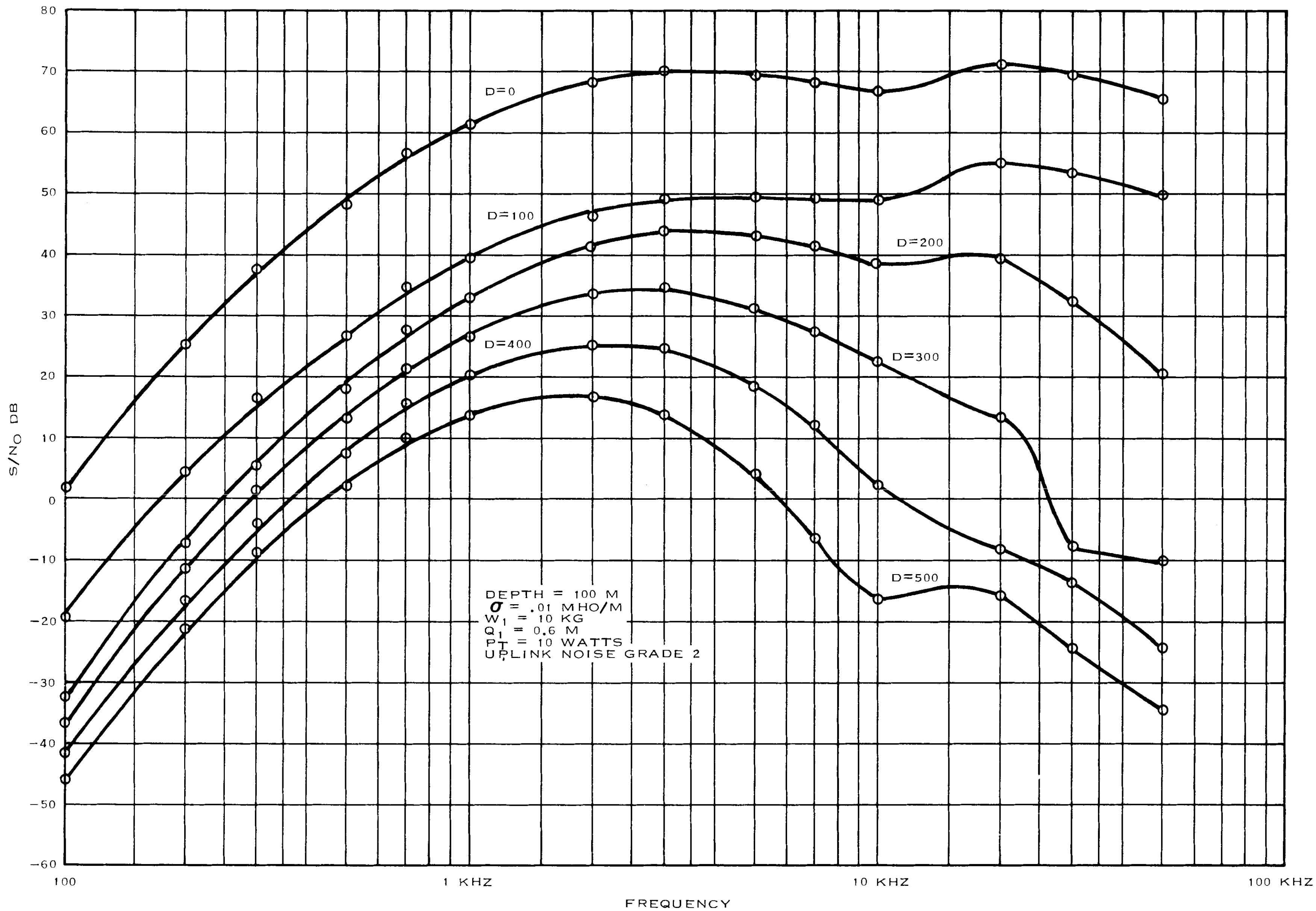

Figure 2-4. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (100 m).

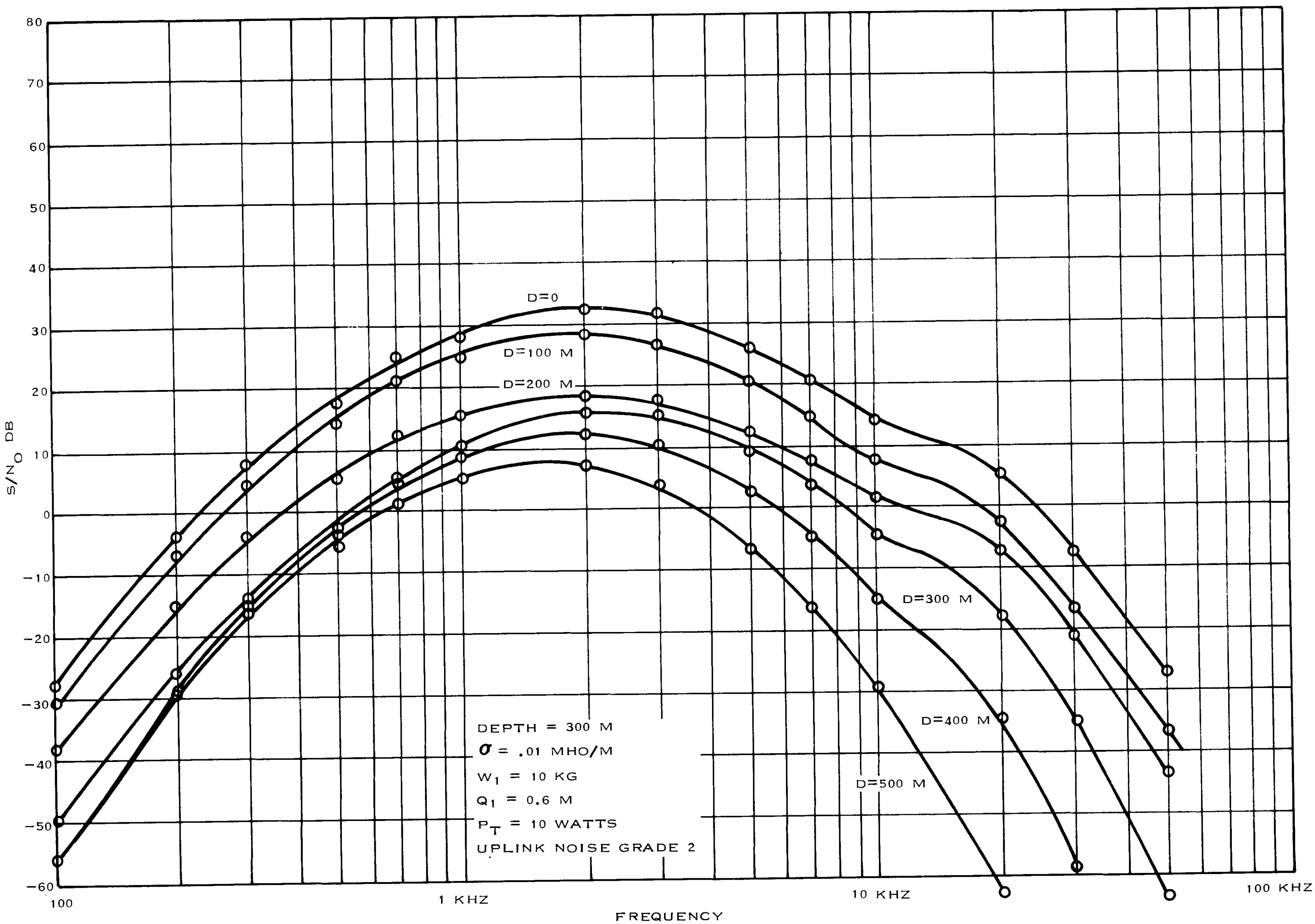

Figure 2-5. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (300 m).

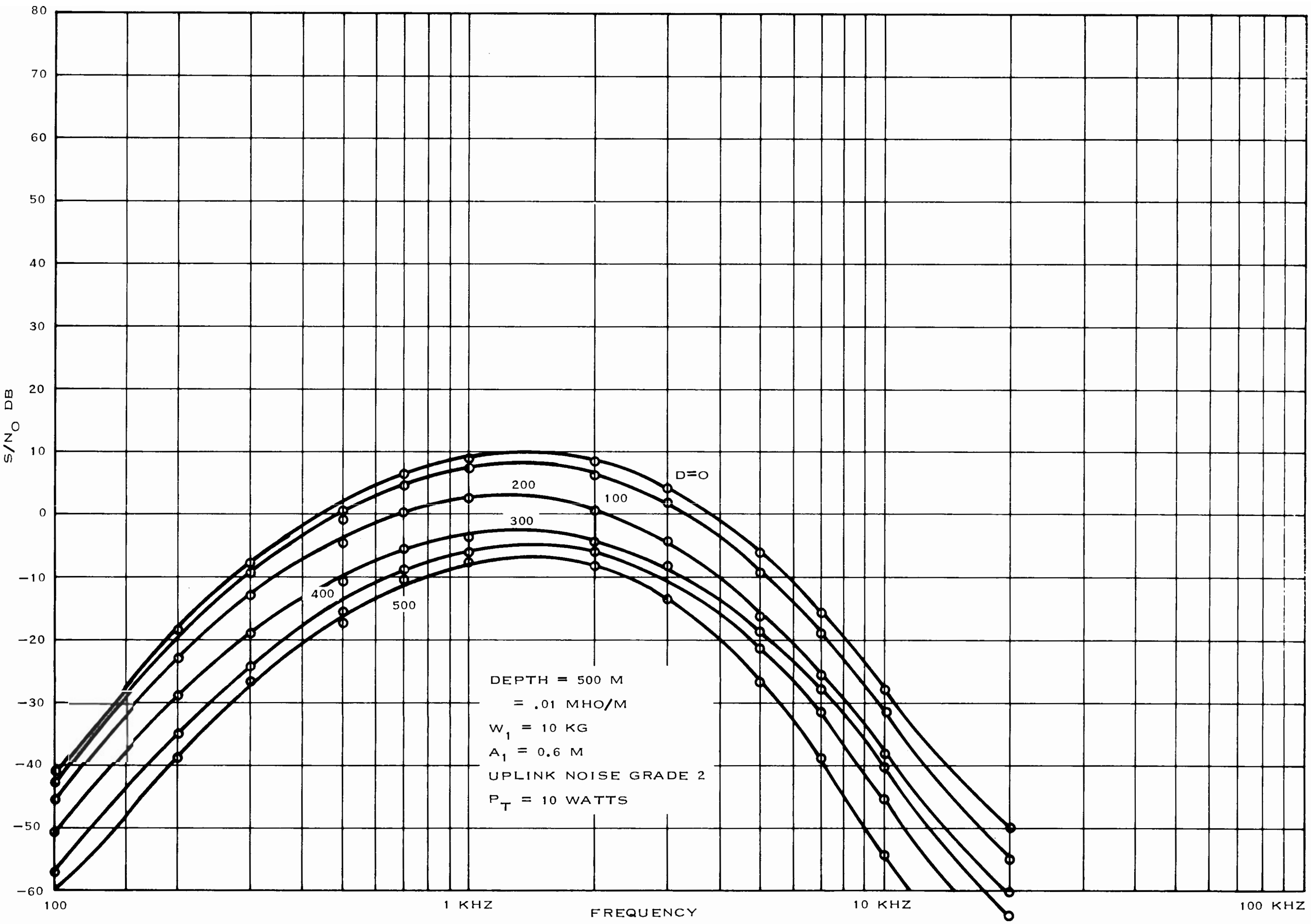

Figure 2-6. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (500 m).

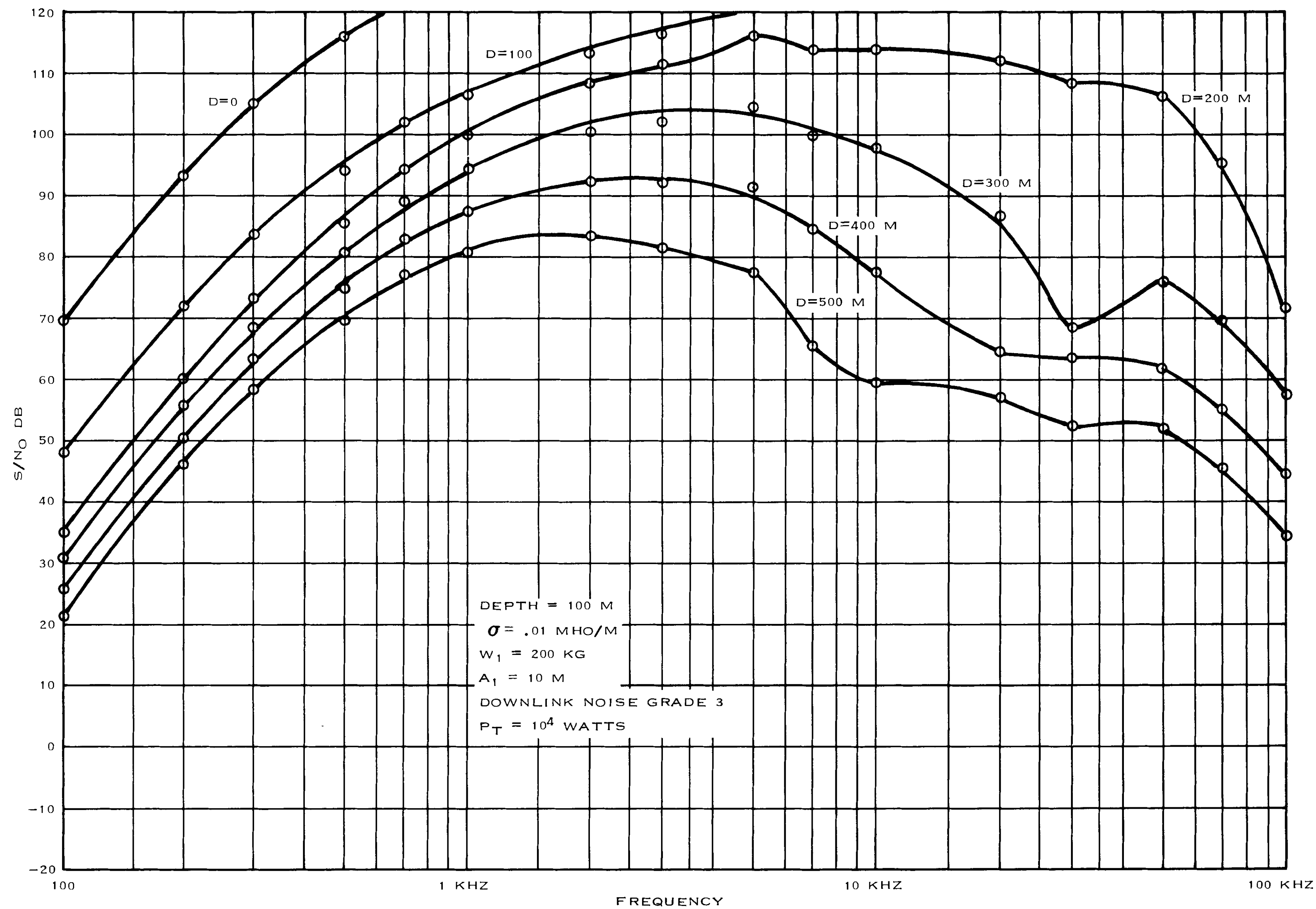

Figure 2-7. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (100 m).

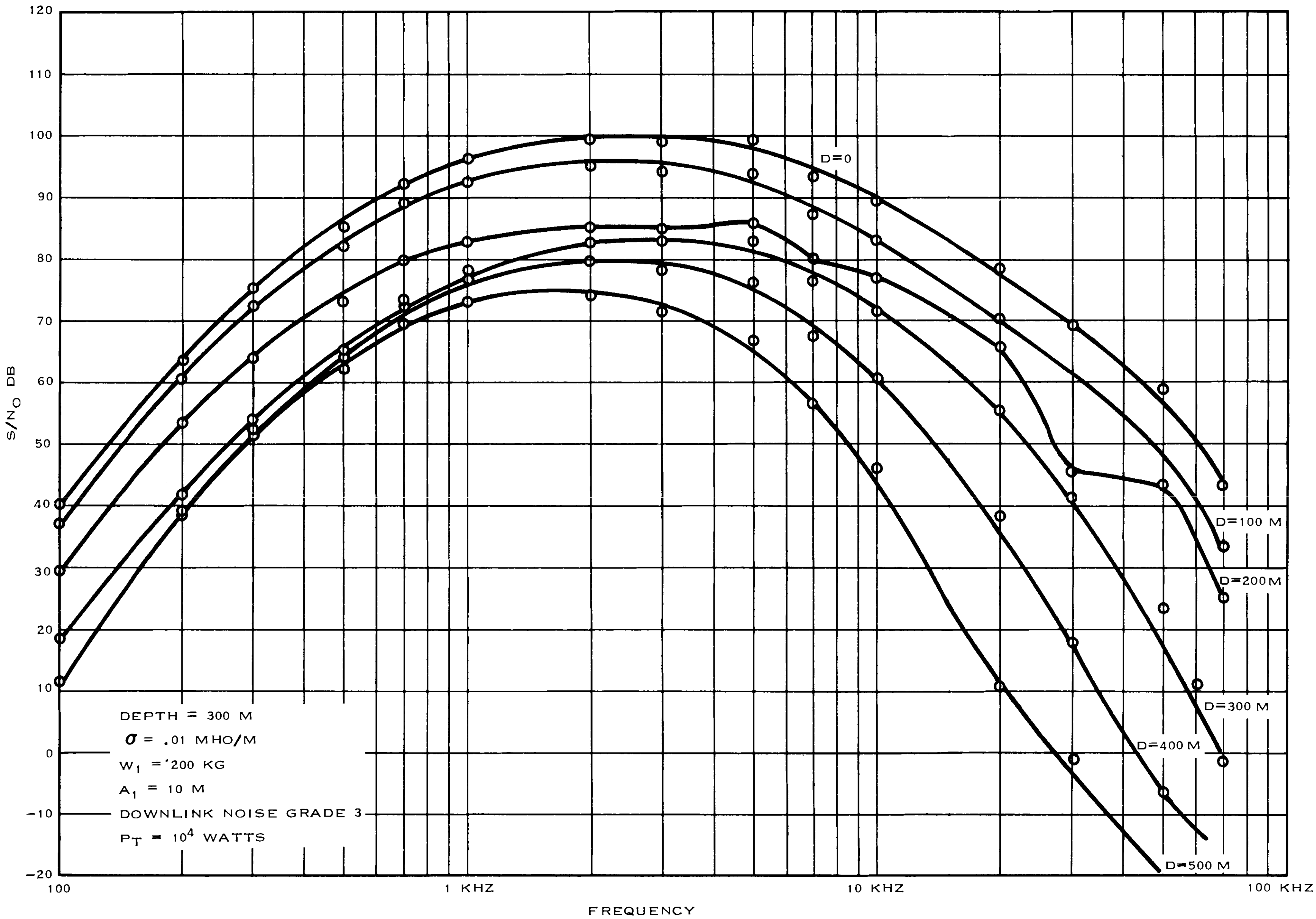

Figure 2-8. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (300 m).

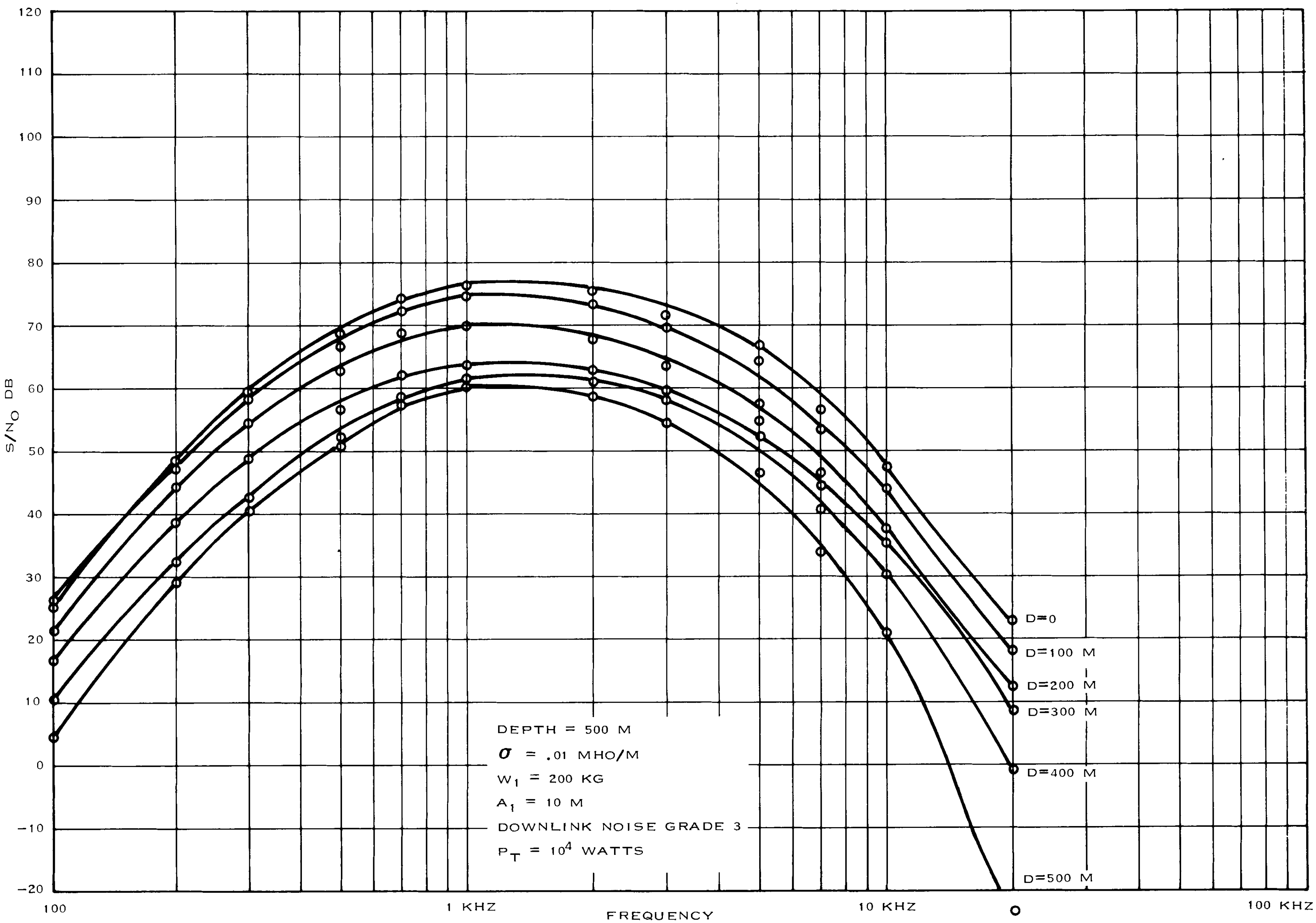

Figure 2-9. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (500 m).

We shall now develop the signal-to-noise power density ratio for a horizontal electric dipole as we did for the loop source in section 2. A method described by Sommerfeld in 1909 forms the basis for determining the field components due to an elementary vertical or horizontal dipole located near the interface of a conducting half space. The hertz vector in this problem is comprised of the primary potential of the source plus the secondary potential due to the interface.

3.1 THE FIELD EQUATIONS FOR A SUBMERGED HORIZONTAL ELECTRIC DIPOLE

Assume a plane interface between air and earth, with the horizontal hertz dipole source located on the z-axis in the conducting half space at a depth of +h and aligned with the x-axis (figure 3-1). A cylindrical coordinate system is employed, with the z-axis vertical with ρ measured radially along the surface, and with the angle ϕ measured from the x-axis. A time factor e^{iwt} is assumed.

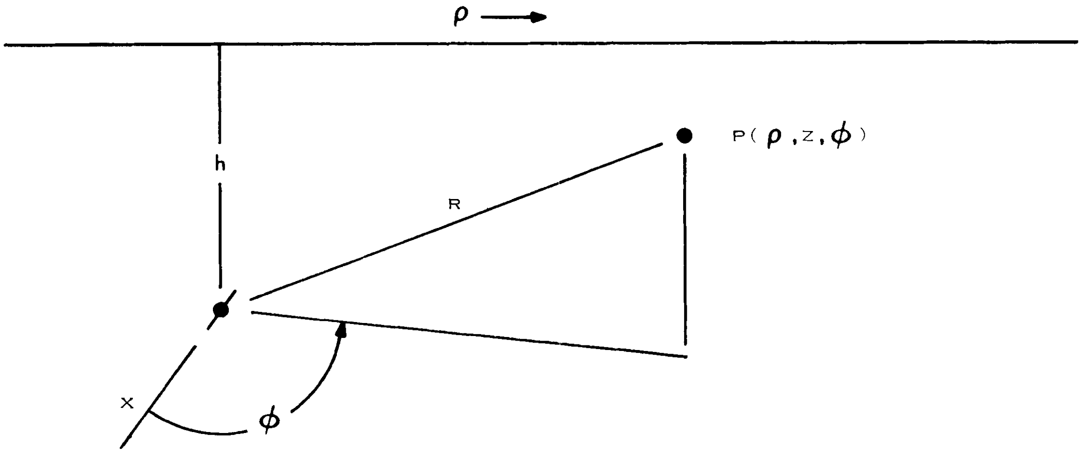

Figure 3-1. Submerged Horizontal Electric Dipole.

The hertz potential underground for this case has two components that follow directly from Sommerfeld:

$$\Pi_x = \frac{Idl}{4\pi(\sigma + i\epsilon_1\omega)} \int_0^\infty J_0(\lambda\rho) \left[e^{-u_1(z-h)} + \frac{u_1 - u_0}{u_1 + u_0} e^{-u_1(z+h)} \right] \frac{\lambda d\lambda}{u_1} \tag{3-1}$$

$$\Pi_z = \frac{Idl \cos\phi}{2\pi(\sigma + i\epsilon_1\omega)\gamma_0^2} \int_0^\infty J_1(\lambda\rho) \frac{u_1 - u_0}{N_1^2 u_0 + u_1} e^{-u_1(z+h)} \lambda^2 d\lambda \tag{3-2}$$

where $\gamma_1^2 = j\mu_0\omega(\sigma_1 + j\epsilon_1\omega)$

$\gamma_0^2 = j\mu_0\omega(j\epsilon_0\omega)$

$u_0 = (\lambda^2 + \gamma_0^2)^{1/2}$

$u_1 = (\lambda^2 + \gamma_1^2)^{1/2}$

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$\omega = 2\pi f$

$\epsilon_0 = \frac{1}{36\pi} \times 10^{-9}$ F/m

$N_1^2 = \frac{\gamma_1^2}{\gamma_0^2} = \frac{(\sigma_1 + j\epsilon_1\omega)}{j\epsilon_0\omega}$

Equations (3-1) and (3-2) represent a solution of the wave equation that satisfies the boundary conditions requiring the tangential components of E and H to be continuous across the boundary, between media.

The electric and magnetic fields may be obtained from

$$\tilde{E} = \text{grad div II} - \gamma_1^2 \text{II} \tag{3-3}$$

and

$$\tilde{H} = \frac{\gamma_1^2}{j\omega\mu_0} \text{curl II} \tag{3-4}$$

from equations (3-3) and (3-4), we obtain the tangential and vertical components of $\tilde{E}$ and $\tilde{H}$:

$$E\rho = -\gamma_1^2 \cos\phi \text{II}_x + \cos\phi \frac{\delta^2 \text{II}_x}{\delta\rho^2} + \frac{\delta^2 \text{II}_z}{\delta_z \delta_\rho} \tag{3-5}$$

$$E\phi = \gamma_1^2 \sin\phi \text{II}_x - \frac{\sin\phi}{\rho} \frac{\delta \text{II}_x}{\delta\rho} + \frac{1}{\rho} \frac{\delta^2 \text{II}_z}{\delta_z \delta\phi} \tag{3-6}$$

$$E_z = -\gamma_1^2 \text{II}_z + \cos\phi \frac{\delta^2 \text{II}_x}{\delta\rho \delta z} + \frac{\delta^2 \text{II}_z}{\delta_z^2} \tag{3-7}$$

$$H\rho = \frac{\gamma_1^2}{j\mu_0\omega} (\sin\phi \frac{\delta \text{II}_x}{\delta z} + \frac{1}{\rho} \frac{\delta \text{II}_z}{\delta\phi}) \tag{3-8}$$

$$H\phi = \frac{\gamma_1^2}{j\mu_0\omega} (\cos\phi \frac{\delta \text{II}_x}{\delta_z} - \frac{\delta \text{II}_z}{\delta\rho}) \tag{3-9}$$

$$H_z = \frac{-\sin\phi \gamma_1^2}{j\mu_0\omega} \frac{\delta \text{II}_x}{\delta\rho} \tag{3-10}$$

Thus we see that for E_ρ

$$E_\rho = \cos\phi\left[-\gamma_1^2 + \frac{\delta^2}{\delta\rho^2}\right]\left[\Pi_x^{(p)} + \Pi_x^{(s)}\right] + \frac{\delta^2\Pi_z}{\delta z\delta\rho} \tag{3-11}$$

where

$$\Pi_x^{(p)} = \frac{Idl}{4\pi(\sigma + i\epsilon\omega)}\int_0^\infty J_0(\lambda\rho)e^{-u_1(z-h)}\frac{\lambda d\lambda}{\mu_1} = \frac{Idl}{4\pi(\sigma + i\epsilon\omega)}\frac{\exp(-\gamma_1 r)}{r} \tag{3-12}$$

(primary field)

where
$$r = \left[\rho^2 + (z-h)^2\right]^{1/2}$$

$$\Pi_x^{(s)} = \frac{Idl}{4\pi(\sigma + i\epsilon\omega)}\int_0^\infty J_0(\lambda\rho)\frac{(u_1-u_0)}{(u_0+u_1)}e^{-u_1(z+h)}\frac{\lambda d\lambda}{u_1} \tag{3-13}$$

(secondary potential due to interface)

The primary field $E_\rho^{(p)}$ follows easily from equation (3-12).

$$E_\rho^{(p)} = \frac{-Idl\cos\phi e^{-\gamma r}}{4\pi(\sigma + i\epsilon\omega)\rho^3}\left(\frac{\rho}{r}\right)^3\left[1 + \gamma r + \gamma^2 r^2 - \left(\frac{\rho}{r}\right)^2\left[3 + 3\gamma r + \gamma^2 r^2\right]\right] \tag{3-14}$$

where $\rho = r$ (point P at same depth as HED)

$$E_\rho^{(p)} = \frac{+Idl\cos\phi e^{-\gamma\rho}\left[\gamma\rho + 1\right]}{2\pi(\sigma + i\epsilon\omega)\rho^3} \tag{3-15}$$

Utilizing the recurrence relations for the derivatives of the Bessel functions:

$$\frac{dJ_0(\lambda\rho)}{d\rho} = -\lambda J_1(\lambda\rho)$$

and
$$\frac{dJ_1(\lambda\rho)}{d\rho} = \lambda\left[-\frac{J_1(\lambda\rho)}{\rho\lambda} + J_0(\lambda\rho)\right]$$

The secondary field (including that due to Π_z) is therefore:

$$E_\rho^{(s)} = \frac{Idl\cos\phi}{4\pi(\sigma + i\epsilon\omega)}\int_0^\infty \frac{\left[J_0(\lambda\rho)u_1^2\lambda\rho - J_1(\lambda\rho)\lambda^2\right]}{\rho u_1}\frac{u_0-u_1}{u_1+u_0}e^{-u_1(z+h)}d\lambda$$

$$+ \frac{Idl\cos\phi}{2\pi(\sigma + i\epsilon\omega)\gamma_0^2}\int_0^\infty \frac{1\lambda^2}{\rho}\left[J_0(\lambda\rho)\lambda\rho - J_1(\lambda\rho)\right]\frac{u_0-u_1}{N_1^2u_0+u_1}e^{-u_1(z+h)}d\lambda \tag{3-16}$$

Similarly for E_ϕ:

$$E_\phi = \sin\phi\left[\gamma_1^2 - \frac{1}{\rho}\frac{d}{d\rho}\right]\left[\Pi_x^{(p)} + \Pi_x^{(s)}\right] + \frac{1}{\rho}\frac{\delta \Pi_z}{\delta z \delta\phi} \tag{3-17}$$

$$E_\phi^{(p)} = \frac{Idl \sin\phi\, e^{-\gamma r}}{4\pi(\sigma + i\epsilon\omega)\rho^3}\left(\frac{\rho}{r}\right)^3\left[\gamma^2 r^2 + \gamma r + 1\right] \tag{3-18}$$

$$E_\phi^{(s)} = \frac{Idl \sin\phi\, \gamma_1^2}{4\pi(\sigma + i\epsilon\omega)}\int_0^\infty J_0(\lambda\rho)\frac{u_1 - u_0}{u_0 + u_1} e^{-u_1(z+h)}\frac{\lambda d\lambda}{u_1} \tag{3-19}$$

$$+ \frac{Idl \sin\phi}{4\pi(\sigma + i\epsilon\omega)}\int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\frac{u_1 - u_0}{u_0 + u_1} e^{-u_1(z+h)}\frac{\lambda^2 d\lambda}{u_1}$$

$$+ \frac{Idl \sin\phi}{2\pi(\sigma + i\epsilon\omega)\gamma_0^2}\int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\frac{u_1 - u_0}{N_1^2 u_0 + u_1} e^{-u_1(z+h)} u_1\lambda^2 d\lambda$$

We are interested primarily in

$$E_\rho\Big|_{\phi = 0},\ \text{and } E_\phi\Big|_{\phi = \frac{\pi}{2}},\ \text{and } H_\phi\Big|_{\phi = 0},\ \text{and}$$

$$H_z\Big|_{\phi = \frac{\pi}{2}},\ \text{and } H_\phi\Big|_{\phi = \frac{\pi}{2}}$$

$$H_\phi = \frac{\gamma_1^2}{j\mu_0\omega}\cos\phi\frac{\delta}{\delta z}\left[\Pi_x^{(p)} + \Pi_x^{(s)}\right] - \frac{\gamma_1^2}{j\mu_0\omega}\frac{\delta \Pi_z}{\delta\rho} \tag{3-20}$$

$$H_\phi^{(p)} = \frac{-Idl \cos\phi}{4\pi}\frac{e^{-r}}{\rho^2}\left(\frac{\rho}{r}\right)^2\left[\gamma r + 1\right]\left[1 - \frac{\rho^2}{r^2}\right]^{1/2} \tag{3-21}$$

$$H_\phi^{(s)} = \frac{-Idl \cos\phi}{4\pi}\int_0^\infty J_0(\lambda\rho)\frac{u_1 - u_0}{u_0 + u_1} e^{-u_1(z+h)}\lambda d\lambda \tag{3-22}$$

$$+ \frac{Idl \cos\phi}{2\pi\gamma_0^2}\int_0^\infty\left[\frac{J_1(\lambda\rho)}{\rho} - \lambda J_0(\lambda\rho)\right]\frac{u_1 - u_0}{N_1^2 u_0 + u_1} e^{-u_1(z+h)}\lambda^2 d\lambda$$

$$H_\rho = \frac{\gamma_1^2}{j\mu_0\omega}\sin\phi\frac{\delta}{\delta z}\left[\Pi_x^{(p)} + \Pi_x^{(s)}\right] + \frac{\gamma_1^2}{j\mu_0\omega}\frac{1}{\rho}\frac{\delta \Pi_z}{\delta\phi} \tag{3-23}$$

$$H_\rho^{(p)} = \frac{-Idl \sin\phi}{4\pi}\frac{e^{-\gamma r}}{\rho 2}\left(\frac{\rho}{r}\right)^2\left[\gamma r + 1\right]\left[1 - \frac{\rho^2}{r^2}\right]^{1/2} \tag{3-24}$$

$$H_\rho^{(s)} = \frac{-Idl\ \sin\phi}{4\pi}\int_0^\infty J_0(\lambda\rho)\frac{u_1-u_0}{u_0+u_1}\ e^{-u_1(z+h)}\lambda d\lambda \qquad (3\text{-}25)$$

$$\frac{-Idl\ \sin\phi}{2\pi\gamma_0^2}\int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\ \frac{u_1-u_0}{N_1^2 u_0+u_1}\ e^{-u_1(z+h)}\lambda^2 d\lambda$$

$$H_z = \frac{-\sin\phi\gamma_1^2}{j\mu_0\omega}\ \frac{\delta}{\delta\rho}\left[II_x^{(p)} + II_x^{(s)}\right] \qquad (3\text{-}26)$$

$$H_z^{(p)} = \frac{Idl\ \sin\phi}{4\pi\rho^2}\left(\frac{\rho}{r}\right)^3 e^{-\gamma r}\left[\gamma r + 1\right] \qquad (3\text{-}27)$$

$$H_z^{(s)} = \frac{Idl\ \sin\phi}{4\pi}\int_0^\infty J_1(\lambda\rho)\frac{u_1-u_0}{u_1+u_0}\ e^{-u_1(z+h)}\ \frac{\lambda^2 d\lambda}{u_1} \qquad (3\text{-}28)$$

Thus we see that broadside to the dipole ($\phi = \pi/2$), we have H_ρ and H_z field components, whereas at $\phi = 0$, H_ϕ is the only magnetic field component. The primary field contributions to H_ρ and H_ϕ vanish however at $\rho = r$ (receiving point at same depth as the dipole).

3.2 THE SUBMERGED VERTICAL MAGNETIC DIPOLE

For completeness in intramine communications we shall indicate the expressions for the submerged VMD. The VMD on the surface has been treated exhaustively by Wait 1, 2; however, computational procedures are needed for the submerged VMD which will adequately account for the interfaces. The hertz potential is

$$II_z^* = \frac{IdA}{4\pi}\int_0^\infty J_0(\lambda\rho)\left(e^{-u_1(z-h)} + \frac{u_1-u_0}{u_1+u_0}\right)e^{-u_1(z+h)}\frac{\lambda d\lambda}{u_1}$$

and

$$H_z = \left(-\gamma_1^2 + \frac{\delta}{\delta_z^2}\right)\left(II_z^{*(p)} + II_z^{*(s)}\right)$$

by some simple algebra we find

$$H_z^{(p)} = \frac{IdA}{4\pi\rho^3}\ e^{-\gamma r}\left(\frac{\rho}{r}\right)^3\left\{-1-\gamma r(1+\gamma r) + \left[1-\left(\frac{\rho}{r}\right)^2\right] \times \left[3(1+\gamma r) + \gamma^2 r^2\right]\right\}$$

1. Characteristics of Antennas Over Lossy Earth, J. R. Wait. Chapter 23 of "Antenna Theory," Edited by Collin and Zucker.
2. On Radio Propagation Through the Earth, J. R. Wait. IEEE Transactions on Antennas and Propagation, volume AP-19, no. 6, November 1971, pp 796-798.

and

$$H_z^{(s)} = \frac{-IdA\,\gamma_1^2}{4\pi}\int_0^\infty J_0(\lambda\rho)\frac{u_1-u_0}{u_1+u_0}e^{-u_1(z+h)}\frac{\lambda d\lambda}{u_1}$$

$$+\frac{IdA}{4\pi}\int_0^\infty J_0(\lambda\rho)\frac{u_1-u_0}{u_1+u_0}e^{-u_1(z+h)}u_1\lambda d\lambda$$

$$=\frac{IdA}{4\pi}\int_0^\infty J_0(\lambda\rho)\frac{u_1-u_0}{u_1+u_0}e^{-u_1(z+h)}\frac{\lambda^3}{u_1}d\lambda$$

$$E_\rho \equiv 0\ ; \quad E_\phi^{(p)} = \frac{-j\mu_0\omega I_0 dA e^{-\gamma r}\left[\gamma_1 r + 1\right]}{4\pi}\frac{\rho}{r^3}$$

$$E_\phi^{(s)} = \frac{jI_0 dA\mu_0\omega}{4\pi}\int_0^\infty J_1(\lambda\rho)\frac{u_0-u_1}{u_0+u_1}e^{-u_1(z+h)}\frac{\lambda^2 d\lambda}{u_1} = \frac{jI_0 dA\mu_0\omega I_2}{4\pi}$$

3.3 THE SUBMERGED HED AND VMD*

From the foregoing development we may write the expressions for the primary fields at a point P (ρ,ϕ,z) for a submerged HED.

$$E_\rho^{(p)} = -A\cos\phi\frac{e^{-\gamma r}}{\rho 3}\left(\frac{\rho}{r}\right)^3\left[1+\gamma r+\gamma^2 r^2 - \left(\frac{\rho}{r}\right)^2\left[3+3\gamma r+\gamma^2 r^2\right]\right] \quad (3\text{-}29)$$

$$E_\phi^{(p)} = A\sin\phi\frac{e^{-\gamma r}}{\rho^3}\left(\frac{\rho}{r}\right)^3\left[\gamma^2 r^2+\gamma r+1\right] \quad (3\text{-}30)$$

$$H_\phi^{(p)} = -B\cos\phi\frac{e^{-\gamma r}}{\rho 2}\left(\frac{\rho}{r}\right)^2\left[\gamma r+1\right]\left[1-\frac{\rho^2}{r^2}\right]^{1/2} \quad (3\text{-}31)$$

$$H_\rho^{(p)} = -B\sin\phi\frac{e^{-\gamma r}}{\rho 2}\left(\frac{\rho}{r}\right)^2\left[\gamma r+1\right]\left[1-\frac{\rho^2}{r^2}\right]^{1/2} \quad (3\text{-}32)$$

$$H_z^{(p)} = B\sin\phi\frac{e^{-\gamma r}}{\rho^2}\left(\frac{\rho}{r}\right)^3\left[\gamma r+1\right] \quad (3\text{-}33)$$

For the VMD our prime concern is H_z

$$H_z^{(p)} = \frac{C}{\rho 3}e^{-\gamma r}\left(\frac{\rho}{r}\right)^3\left[-1-\gamma r(1+\gamma r)+\left[1-\frac{\rho^2}{r^2}\right]\times\left[3(1+\gamma r)+\gamma^2 r^2\right]\right] \quad (3\text{-}34)$$

where

$$A = \frac{I(dl)}{4\pi(\sigma+i\epsilon\omega)} \qquad B = \frac{I(dl)}{4\pi} \qquad C = \frac{IAN}{4\pi}$$

---

*(a) The Field Equations for a Submerged Horizontal Electric Dipole, 4 January 1973, R. P. Decker, Spectra Associates, Inc.
(b) The Submerged HED and VMD-II, 8 January 1973, R. P. Decker, Spectra Associates, Inc.

For the computation of the secondary fields we define the following integrals:

$$I_1 = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{u_1+u_0} e^{-u_1(z+h)} u_1\lambda d\lambda \tag{3-35}$$

$$I_2 = \int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\frac{u_0-u_1}{u_1+u_0} e^{-u_1(z+h)} \frac{\lambda^2}{u_1} d\lambda \tag{3-36}$$

$$I_3 = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{N_1^2 u_0+u_1} e^{-u_1(z+h)} u_1\lambda^3 d\lambda \tag{3-37}$$

$$I_4 = \int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\frac{u_0-u_1}{N_1^2 u_0+u_1} e^{-u_1(z+h)} u_1\lambda^2 d\lambda \tag{3-38}$$

$$I_5 = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{u_0+u_1} e^{-u_1(z+h)} \frac{\lambda d\lambda}{u_1} \tag{3-39}$$

$$I_6 = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{u_0+u_1} e^{-u_1(z+h)} \lambda d\lambda \tag{3-40}$$

$$I_7 = \int_0^\infty \frac{J_1(\lambda\rho)}{\rho}\frac{u_0-u_1}{N_1^2 u_0+u_1} e^{-u_1(z+h)} \lambda^2 d\lambda \tag{3-41}$$

$$I_8 = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{N_1^2 u_0+u_1} e^{-u_1(z+h)} \lambda^3 d\lambda \tag{3-42}$$

$$I_9 = \int_0^\infty J_1(\lambda\rho)\frac{u_0-u_1}{u_1+u_0} e^{-u_1(z+h)} \frac{\lambda^2 d\lambda}{u_1} \tag{3-43}$$

$$I_{10} = \int_0^\infty J_0(\lambda\rho)\frac{u_0-u_1}{u_1+u_0} e^{-u_1(z+h)} \frac{\lambda^3 d\lambda}{u_1} \tag{3-44}$$

The field equations therefore become

$$E_\rho = E_\rho^{(p)} + A\cos\phi(I_1-I_2) + \frac{2A\cos\phi}{\gamma_0^2}(I_3-I_4) \tag{3-45}$$

$$E_\phi = E_\phi^{(p)} - \gamma_1^2 A\sin\phi I_5 + A\sin\phi I_2 + 2A\sin\phi I_4 \tag{3-46}$$

$$H_\phi = H_\phi^{(p)} + B\cos\phi I_6 - \frac{2B\cos\phi}{\gamma_0^2} I_7 + \frac{2B\cos\phi}{\gamma_0^2} I_8 \tag{3-47}$$

$$H_\rho = H_\rho^{(p)} + B\sin\phi I_6 + \frac{2B\sin\phi}{\gamma_0^2} I_7 \tag{3-48}$$

$$H_z = H_z^{(p)} - B\sin\phi I_9$$

$$H_z(VMD) = H_z^{(p)}(VMD) - CI_{10}$$

Now we introduce the transformations used by Wait

$$x = \lambda\rho$$

$$D = (z+h)/\rho$$

$$\Gamma = \gamma\rho$$

$$U = (x^2 + \Gamma^2)^{1/2}$$

$$U_0 = (x^2 - (\frac{\omega\rho}{c})^2)^{1/2}$$

$$K = N_1^2$$

$$R(x) = \frac{U_0 - U_1}{U_1 + KU_0}$$

$$T(x) = \frac{U_0 - U_1}{U_0 + U_1}$$

The transformed integrals become

$$I_1 = \frac{1}{\rho^3}\int_0^\infty J_0(x)T(x)\exp(-UD)Uxdx \tag{3-49}$$

$$I_2 = \frac{1}{\rho^3}\int_0^\infty J_1(x)T(x)\exp\frac{(-UD)}{U}x^2dx \tag{3-50}$$

$$I_3 = \frac{1}{\rho^5}\int_0^\infty J_0(x)R(x)\exp(-UD)Ux^3dx \tag{3-51}$$

$$I_4 = \frac{1}{\rho^5}\int_0^\infty J_1(x)R(x)\exp(-UD)Ux^2dx \tag{3-52}$$

$$I_5 = \frac{1}{\rho}\int_0^\infty J_0(x)T(x)\exp\frac{(-UD)}{U}xdx \tag{3-53}$$

$$I_6 = \frac{1}{\rho^2}\int_0^\infty J_0(x)T(x)\exp(-UD)xdx \tag{3-54}$$

$$I_7 = \frac{1}{\rho 4}\int_0^{\infty} J_1(x)R(x)\exp(-UD)x^2dx \qquad (3\text{-}55)$$

$$I_8 = \frac{1}{\rho 4}\int_0^{\infty} J_0(x)R(x)\exp(-UD)x^3dx \qquad (3\text{-}56)$$

$$I_9 = \frac{1}{\rho 2}\int_0^{\infty} J_1(x)T(x)\exp\frac{(-UD)}{U}\,x^2dx \qquad (3\text{-}57)$$

$$I_{10} = \frac{1}{\rho 3}\int_0^{\infty} J_0(x)T(x)\exp(-UD)x^3dx \qquad (3\text{-}58)$$

As pointed out by Wait, these integrals must be integrated cautiously because of the various branch points and poles. Following the same approach we define the limits of each subinterval used for integration.

$$x_1 = 0,\ x_2 = Z_0-\Delta_0,\ x_3 = Z_0-\Delta_K,\ x_4 = Z_0+\Delta_K,\ x_5 = Z_0+\Delta_0$$

$$x_6 = \left[R_e\Gamma^2\right]^{1/2},\ x_7 = 2x_6,\ x_8 = 3x_6,\ x_9 = 4x_6,\ x_{10} = 6x_6$$

$$Z_0 = \frac{\omega\rho}{c} \qquad \Delta = Z_0\left|1-\left(\frac{K}{K+1}\right)^{1/2}\right|$$

The results of this analysis will be described in paragraph 3.4. For the line source, we shall use a contact resistance of 100 ohms. For the VMD, the current moment will be computed from

$$IAN = 0.5a\sqrt{(W)(P_t)(6.52)(10^{+3})} \qquad (3\text{-}59)$$

where W = weight of loop in kg
P_t = transmitted power in watts
a = loop radius in meters

3.4 THE FIELD COMPONENTS OF A SUBMERGED INFINITE LINE SOURCE

In this note we assume a wire of infinite length located in the xz-plane at a depth, h, and carrying a current of uniform amplitude and phase, $Ie^{i\omega t}$. Such an antenna radiates a cylindrical wave, in contrast to the spherical wave radiated from a hertz dipole (figure 3-2). We are concerned first with an expression for the primary hertz potential, that is, that under ground.

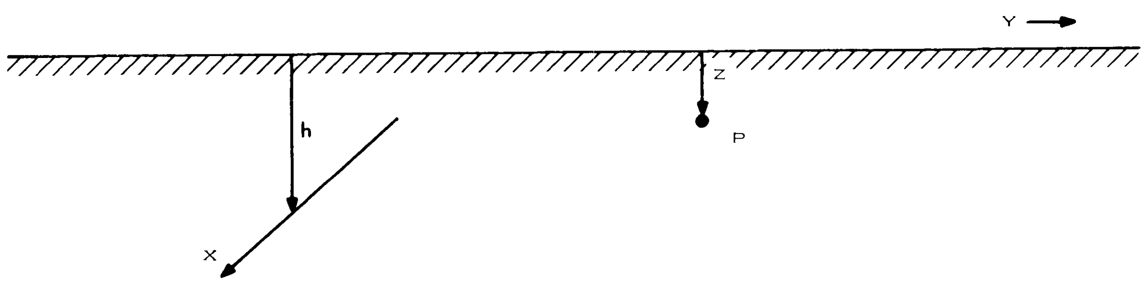

Figure 3-2. Submerged Infinite Line Source.

The hertz potential due to the elementary current moment I(dx) is

$$d\Pi = \frac{I(\delta x)e^{-\gamma_1 R}}{4\pi(\sigma + i\epsilon\omega)R} \quad (3\text{-}60)$$

where $R = \sqrt{r^2 + x^2}$ and $r = \sqrt{y^2 + (z-h)^2}$

and R is the distance between the current element and point P (in y-z plane), and $r = \sqrt{y^2 + (y-h)^2}$ is the radial distance of P from the wire.

This potential has only an x-component. The total potential at P is

$$\Pi = \frac{I}{4\pi(\sigma + i\epsilon\omega)} \int_{-\infty}^{\infty} \frac{e^{-\gamma_1 R}}{R}\,dx = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{0}^{\infty} \frac{e^{-\gamma_1 R}}{R}\,dx \quad (3\text{-}61)$$

since $dR = \frac{xdx}{R}$ or $dx = \frac{RdR}{\sqrt{R^2 - r^2}}$

we have

$$\Pi = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{r}^{\infty} \frac{e^{-\gamma_1 R}}{\sqrt{R^2 - r^2}}\,dR \quad (3\text{-}62)$$

Let $\dot{R} = r\mu$, where μ is a new variable of integration and r is a fixed radial distance. Then

$$\Pi = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{1}^{\infty} \frac{e^{-\gamma_1 r\mu}\,d\mu}{\sqrt{\mu^2 - 1}} \quad (3\text{-}63)$$

since

$$\int_{1}^{\infty} \frac{e^{-ixt}\,dt}{\sqrt{t^2 - 1}} = -i\frac{\pi}{2} H_0^{(2)}(x)$$

equation (3-63) becomes

$$\Pi = \frac{-I}{4(\sigma + i\epsilon\omega)} H_0^{(2)}(-j\gamma_1 r) \quad (3\text{-}64)$$

Here, $H_0^{(2)}$ is the second kind of Hankel function of zero order. Its asymptotic form at large distances is

$$H_0^{(2)}(-j\gamma_1 r) \cong \left(\frac{2}{-j\pi\gamma_1 r}\right)^{1/2} e^{i\,\pi/4}\, e^{-\gamma_1 r} \quad (3\text{-}65)$$

This is clearly an outgoing cylindrical wave.

By the use of the Sommerfeld integral representation for the Hankel function

$$H_0^{(2)}(-j\gamma_1 r) = \frac{1}{\pi}\int_{-(\pi/2 + i\infty)}^{(\pi/2 + i\infty)} e^{-\gamma_1 r\cos\gamma}\, d\gamma \tag{3-66}$$

The Weyl transformation

$$H_0^{(2)}(-j\gamma_1 r) = \frac{1}{\pi}\int e^{-\gamma_1 r\cos\alpha}\, d\alpha \tag{3-67}$$

and the boundary conditions

$$\gamma_0^2 \Pi_0 = \gamma_1^2 \Pi_1 \tag{3-68}$$

$$\gamma_0^2 \frac{\delta \Pi_0}{\delta z} = \gamma_1^2 \frac{\delta \Pi_1}{\delta z}$$

We finally arrive at the hertz potential below ground

$$\Pi = \frac{I}{4\pi(\sigma + i\epsilon\omega)}\int_{-\infty}^{\infty} e^{-i\lambda y}\left[e^{\pm u_1(z-h)} + \frac{u_1 - u_0}{u_1 + u_0}e^{-u_1(z+h)}\right]\frac{d\lambda}{u_1} \tag{3-69}$$

where u_1 and u_0 are defined on page 3-2.

Note that the upper sign applies when $z > h$ and the lower sign when $0 \leq z \leq h$.

Now since

$$Ex = -\gamma_1^2 \Pi$$

$$Hy = \frac{\gamma_1^2}{j\omega\mu_0}\frac{\delta \Pi}{\delta z} = (\sigma + i\epsilon\omega)\frac{\delta \Pi}{\delta z} \tag{3-70}$$

$$H_z = -(\sigma + i\epsilon\omega)\frac{\delta \Pi}{\delta y}$$

We have finally

$$Ex = \frac{-j\mu_0\omega I}{4\pi}\int_{-\infty}^{\infty} e^{-i\lambda y}\left[e^{\pm u_1(z-h)} + \frac{u_1 - u_0}{u_1 + u_0}e^{-u_1(z+h)}\right]\frac{d\lambda}{u_1} \tag{3-71}$$

$$Hy = \frac{-I}{4\pi}\int_{-\infty}^{\infty} e^{-i\lambda y}\left[\pm e^{\pm u_1(z-h)} + \frac{u_1 - u_0}{u_1 + u_0}e^{-u_1(z+h)}\right]d\lambda \tag{3-72}$$

$$H_z = \frac{iI}{4\pi}\int_{-\infty}^{\infty} e^{-i\lambda y}\left[e^{\pm u_1(z-h)} + \frac{u_1 - u_0}{u_1 + u_0}e^{-u_1(z+h)}\right]\frac{\lambda\, d\lambda}{u_1} \tag{3-73}$$

3.4.1 Results of the Submerged Infinite Line Source Analysis

From paragraph 3.4, the field components can be restated as:

$$Ex = \frac{-j\mu_0 \omega I}{2\pi} \int_0^\infty \cos(\lambda y) \left[e^{-u_1(z-h)} + \frac{u_1-u_0}{u_1+u_0} e^{-u_1(z+h)} \right] \frac{d\lambda}{u_1}$$

$$Hy = \frac{-I}{2\pi} \int_0^\infty \cos(\lambda y) \left[\pm e^{-u_1(z-h)} + \frac{u_1-u_0}{u_1+u_0} e^{-u_1(z+h)} \right] d\lambda$$

$$Hz = \frac{I}{2\pi} \int_0^\infty \sin(\lambda y) \left[e^{-u_1(z-h)} + \frac{u_1-u_0}{u_1+u_0} e^{-u_1(z+h)} \right] \frac{\lambda d\lambda}{u_1}$$

These can be suitably transformed by

$$x = \lambda h \qquad D = y/h \qquad Z = z/h$$

so that $u_0 = \left[x^2 - \left(\frac{\omega h}{c}\right)^2 \right]^{1/2} \Big/ h$

$$u_1 = (x^2 + \Gamma^2)^{1/2} \qquad \Gamma = \gamma_1 h$$

When $z \neq h$ these integrals offer no particular difficulty in integration. With $z = h$, there are:

$$Ex = \frac{-j\mu_0 \omega I}{2\pi} \left[\int_0^\infty \frac{\cos(\lambda y) d\lambda}{u_1} + \int_0^\infty \cos(\lambda y) \frac{u_1-u_0}{u_1+u_0} e^{-2u_1 h} \frac{d\lambda}{u_1} \right]$$

$$Hy = \frac{-I}{2\pi} \int_0^\infty \cos(\lambda y) \frac{u_1-u_0}{u_1+u_0} e^{-2u_1 h} d\lambda$$

$$Hz = \frac{I}{2\pi} \left[\int_0^\infty \frac{\sin(\lambda y) \lambda d\lambda}{u_1} + \int_0^\infty \sin(\lambda y) \frac{u_1-u_0}{u_1+u_0} e^{-2u_1 h} \frac{\lambda d\lambda}{u_1} \right]$$

The first integrals in Ex and Hz cannot be evaluated as they stand. However, they are related to the modified Bessel functions:

$$K_0(\gamma_1 y) = \int_0^\infty \frac{\cos(\lambda y) d\lambda}{\mu_1}; \quad \gamma_1 K_1(\gamma_1 y) = \int_0^\infty \frac{\sin(\lambda y) \lambda d\lambda}{\mu_1}$$

Considerable effort has been made to evaluate K_0 and K_1, without resorting to special numerical techniques. Further work must be done, however, for adequate accuracy. The field components that are valid have been computed, viz those on the surface and Hy at z = h.

The results have been prepared in terms of S/N_0 as a function of frequency for a transmitter depth of 300 meters, σ = 0.01 mhos/m and Pt = 100 W*. Figure 3-3 depicts S/N_0 at the surface, whereas figure 3-4 shows S/N_0 at 300 meters and a displacement of 200 meters taken from elementary dipole computations.

These generally show an optimum up-link frequency of about 10 kHz, and an optimum intramine frequency for a displacement of 200 meters of 25 to 50 kHz.

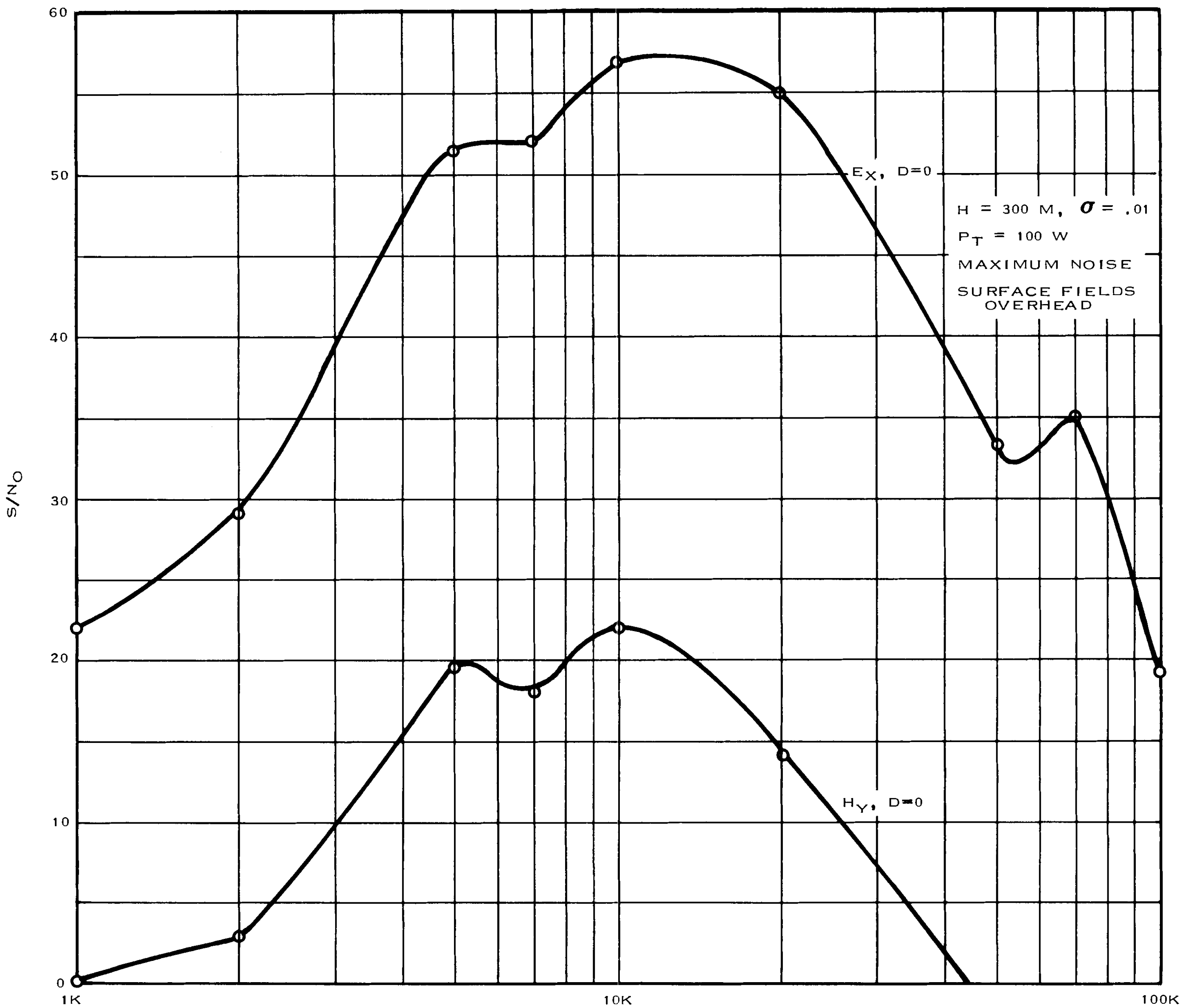

Figure 3-3. Submerged Infinite Line Source.

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*With preliminary noise grades.

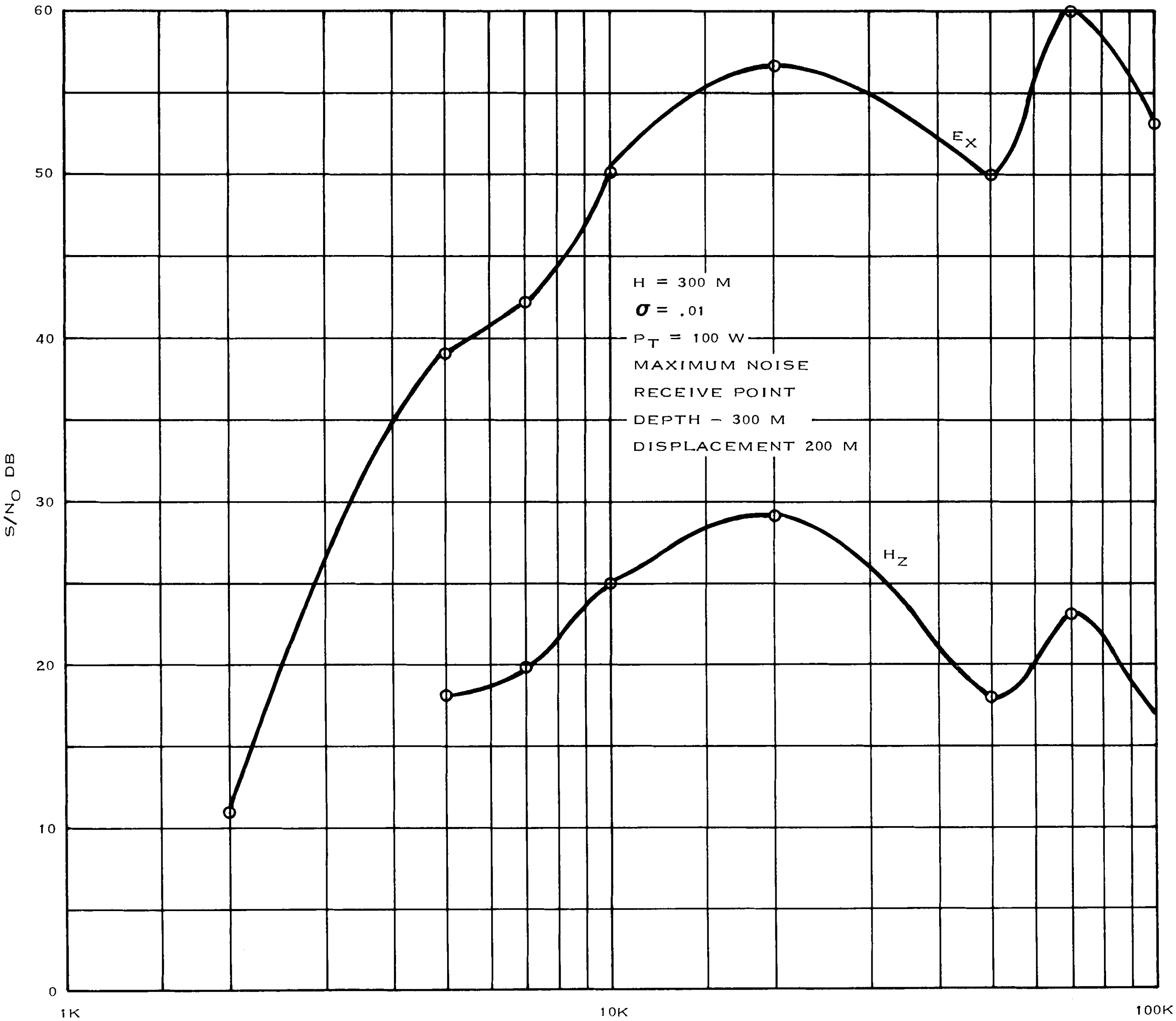

Figure 3-4. Submerged Line Source.

Signal-to-Noise Analysis for Down-Link Line Source Mine Communications

This section is part of a continuing series of notes regarding analytical techniques for calculating signal-to-noise ratios in a mining environment. These propagation modes consist of low-frequency waves transmitted through the earth or within the mine itself.

Some of the antenna configurations that may be used for coupling energy into the medium and detection are loop-to-loop, line source-to-loop, line source-to-line source, etc. Except for intramine loop communication, the loop-to-loop case was handled previously. This note considers a line current source on the surface for down-link communications.

4.1 THE SUBSURFACE H-FIELDS FOR A LINE CURRENT SOURCE

Consider a line current source (figure 4-1) in which there are no variations in the z direction.

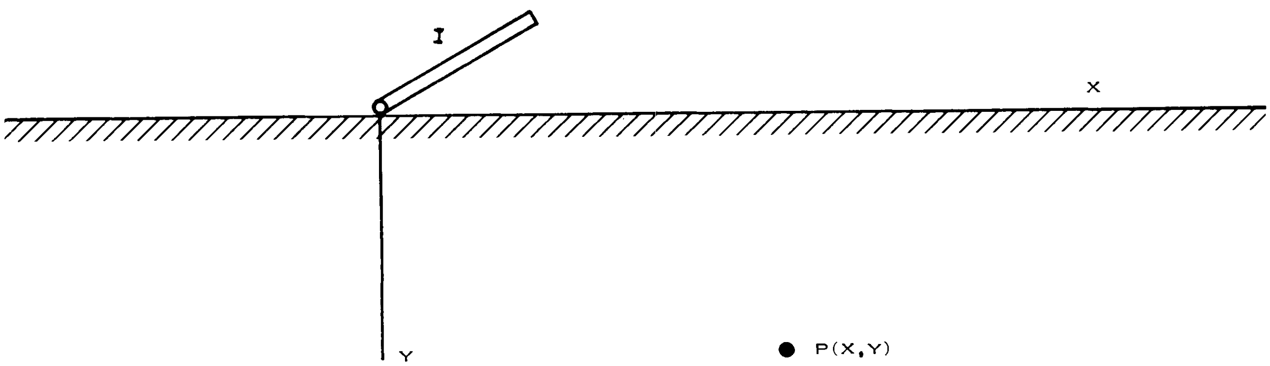

Figure 4-1. Line Current Source.

Then from Wait* the H-field components below the surface at (x,y) are

$$H_y = \frac{I}{2\pi h} B(H, X) \tag{4-1}$$

$$H_x = \frac{-I}{2\pi h} A(H, X) \tag{4-2}$$

*J. R. Wait and K. P. Spies, "Subsurface EM Fields of a Line Source On A Conducting Half Space," Radio Science 6, 8-9, 1971 page 781.

where

$$B(H, X) = 2 \int_0^{\infty} \frac{s\, e^{-(s^2 + iH^2)^{1/2}}}{s + (s^2 + iH^2)^{1/2}} \sin(sx)ds \tag{4-3}$$

$$A(H, X) = 2 \int_0^{\infty} \frac{(s^2 + iH^2)^{1/2}\, e^{-(s^2 + iH^2)^{1/2}}}{s + (s^2 + iH^2)^{1/2}} \cos(sx)ds \tag{4-4}$$

and

$$X = x/h, \; H = (\sigma\mu_0\omega)^{1/2}h$$

The electric field is

$$E = \frac{-i\mu\omega I\, F(H, X)}{2\pi} \tag{4-5}$$

where

$$F(H, X) = \int_0^{\infty} \frac{e^{-(s^2 + iH^2)^{1/2}}}{s + (s^2 + iH^2)^{1/2}} \cos(sx)ds$$

4.1.1 Signal-to-Noise Ratios

Now in the case of surface line sources, the current produced by a given input power is dependent to a large extent on the contact resistance that can be obtained near the earth probes. According to Dr. Geyer "porous pots" may be used to reduce this resistance to as low as 10 ohms. Typical values for the input resistance to a line source will then range from 10Ω to 200Ω.

As before, the ratio of received to transmit power is

$$\frac{P_r}{P_t} = \frac{V_{02}^2}{4R_1R_2I_1^2} \tag{4-6}$$

for a loop receive antenna

$$V_{02} = 4\pi\omega N_2A_2H \times 10^{-7}$$

so that

$$\frac{P_r}{P_t} = \frac{4\omega^2N_2^2A_2^2B^2(H, X) \times 10^{-14}}{R_1R_2h^2} \tag{4-7}$$

the noise power received per Hz bandwidth is

$$P_{nr} = \frac{64\pi^2f^2N_2^2A_2^2H_N^2 \times 10^{-14}}{4R_2}$$

therefore

$$S/N_0 = \frac{P_T B^2(H, X)}{h^2 H_n^2 R_1} \text{ (h in meters)} \quad (4\text{-}8)$$

Line source on surface to VMD subsurface

and

$$S/N_0 = \frac{P_T A^2(H, X)}{h^2 H_n^2 R_1}, \quad (4\text{-}9)$$

line source on surface to HMD subsurface.

Likewise for the E field at a submerged line source

$$\frac{P_r}{P_t} = \frac{\omega^2 F^2(H, X) L_2^2 \times 10^{-14}}{R_1 R_2} \quad (4\text{-}10)$$

where L_2 is the length of the receive line source.

Since

$$P_{nr} = \frac{E_n^2 L_2^2}{4R_2}$$

$$S/N_0 = \frac{16\pi^2 f^2 F^2(H, X) P_T \times 10^{-14}}{R_1 E_n^2} \quad (4\text{-}11)$$

where E_n is the electric noise field in V/m/Hz.

The above relations for S/N_0 all assume the loop or line source is adequately dimensioned so that the external noise pickup exceeds receiver noise.

4.2 COMPUTATIONAL RESULTS

Equations (4-8) and (4-9) were employed in a computer method for the calculation of S/N_0 for depths of 300 m and 500 m as a function of frequency for various displacements (figure 4-2). Since Wait's A, B, and F functions are similar to his P and Q functions, the modification to the computer program was straightforward. All of these various S/N_0 calculations can now be made with the basic computer program by selection of the desired option.

The results are shown in figures 4-3 through 4-7 (with preliminary noise grades). A contact resistance of 100Ω has been assumed for the line source. The VMD, of course, will produce a null directly below the line source, thus there would be a preference for the HMD. At the 500-meter displacement, however, there is little difference between the two.

For comparison purposes, figures 4-6 and 4-7 show a 100-meter radius loop, 200-kg weight driven by the same power as the line source. The subsurface S/N_0 is comparable to the line source case considering the size of the transmit loop.

The E-field signal-to-noise ratios were not presented because of the inadequacy of E-field subsurface noise data. A few sample calculations made with Dr. Geyer's* line source surface noise data indicate that with the same subsurface noise fields, the signal-to-noise at 2 kHz would be comparable to the H-field cases.

Future plans call for the injection of new noise data in the computer program as it becomes available and the consideration of intramine paths.

4.3 THEORETICAL PREDICTIONS FOR S/N_0

As a result of the theoretical analysis of this section, several predictions can be made. For a line source, typical values of input resistance will range from 10 to 200 ohms. For a loop receiving antenna, the HMD orientation is preferable to the VMD orientation at shallower depths due to the null created by the VMD in the horizontal plane. However, at depths around 500 meters, the two arrangements are relatively equal. For the line source transmitter configuration, the frequencies in the 1- to 2-kHz range appear to yield the optimum signal-to-noise ratios.

*R. Geyer, G. Keller, M. Major. "Research on the Transmission of Acoustic and EM Signals Between Mine Workings and the Surface." Quarterly technical report. Colorado School of Mines, December 30, 1971.

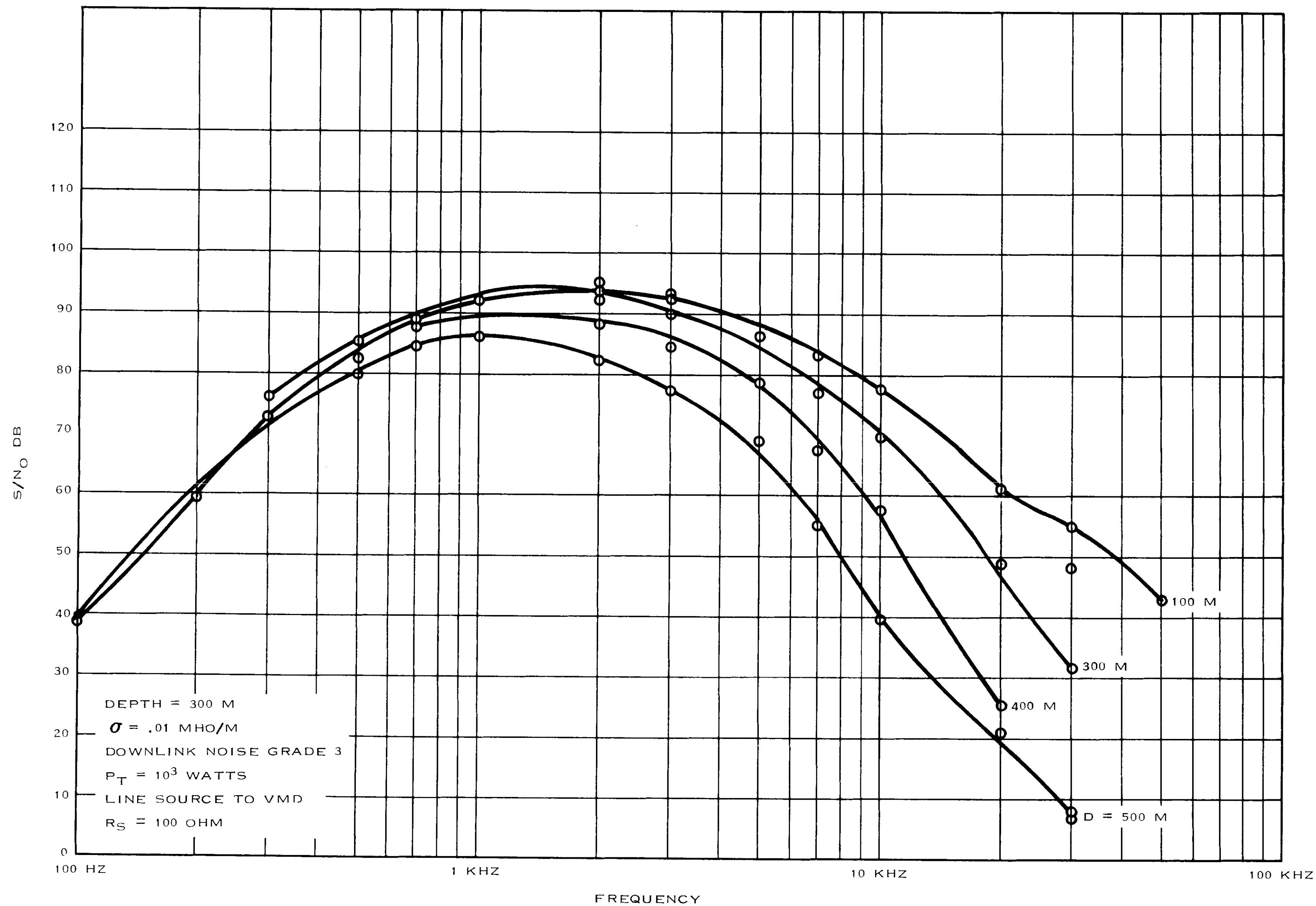

Figure 4-2. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency (300 m).

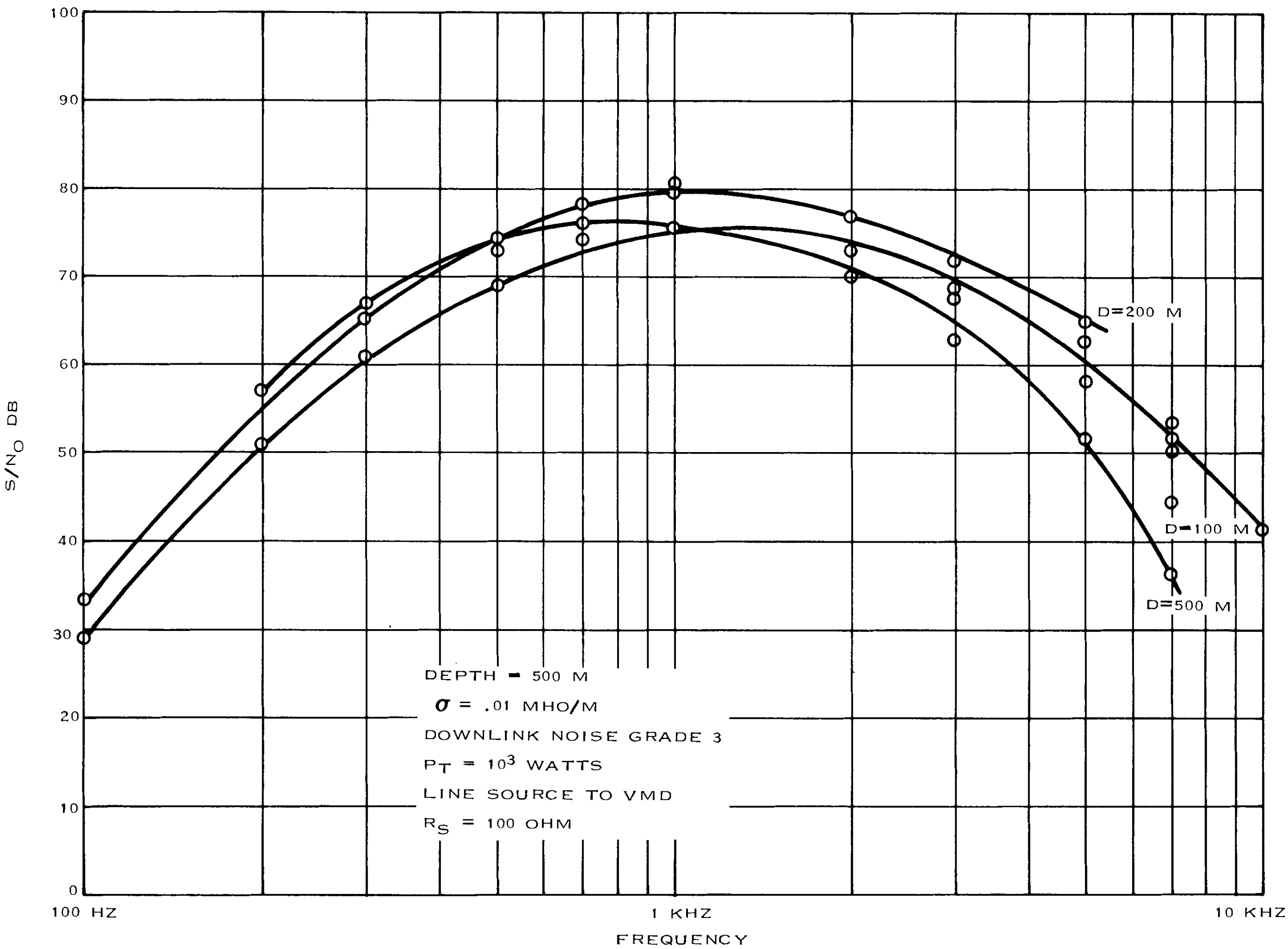

Figure 4-3. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

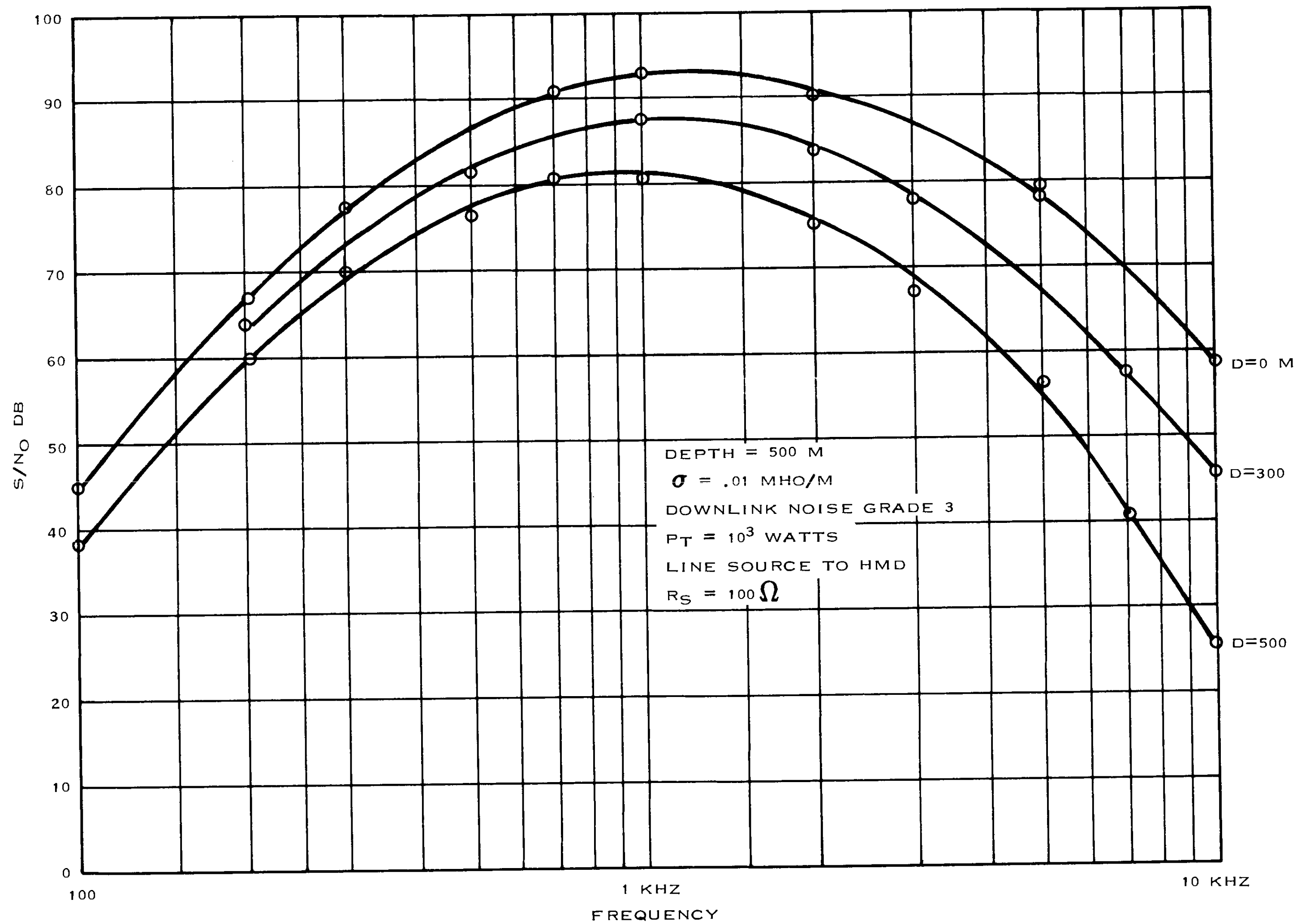

Figure 4-4. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

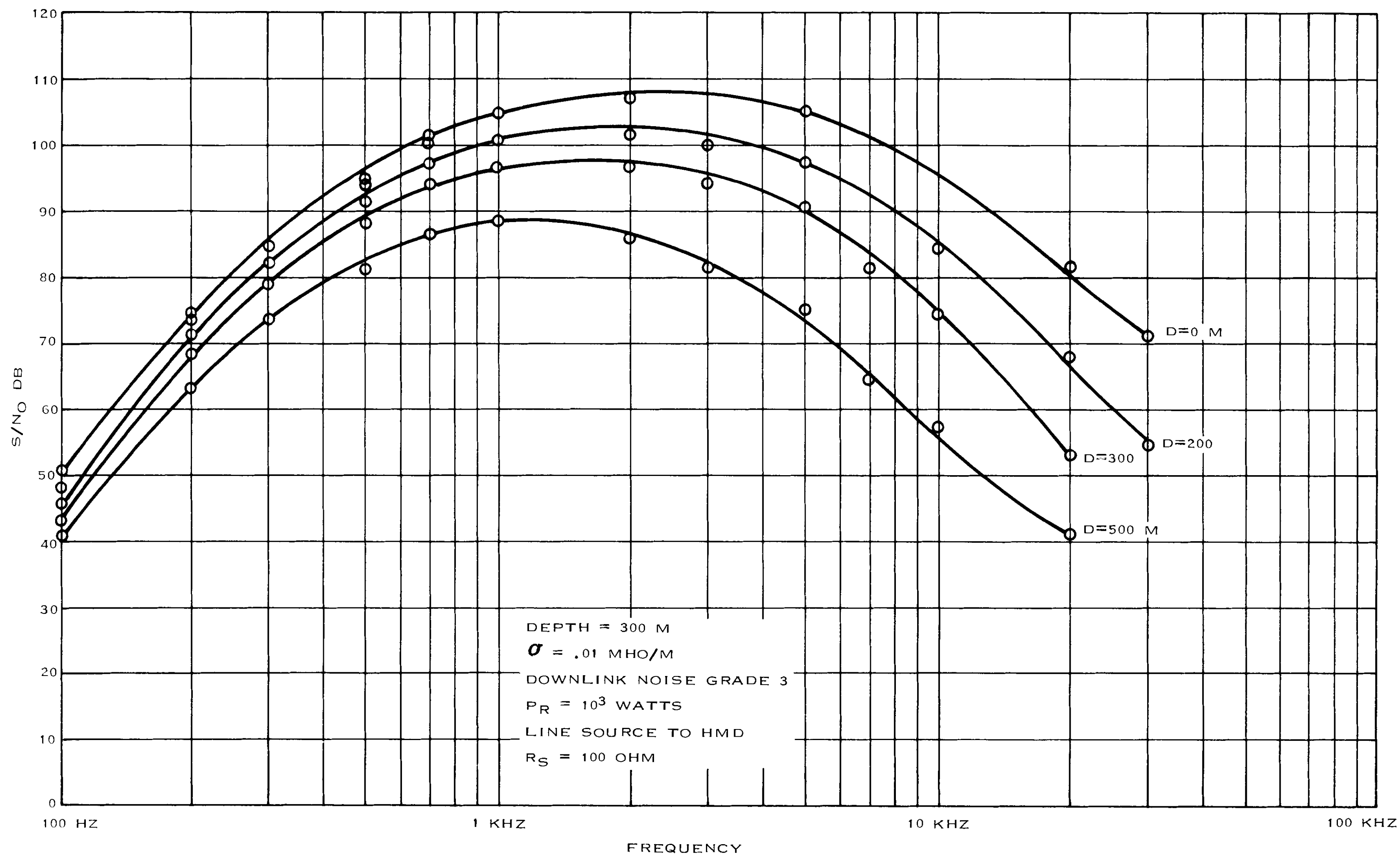

Figure 4-5. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

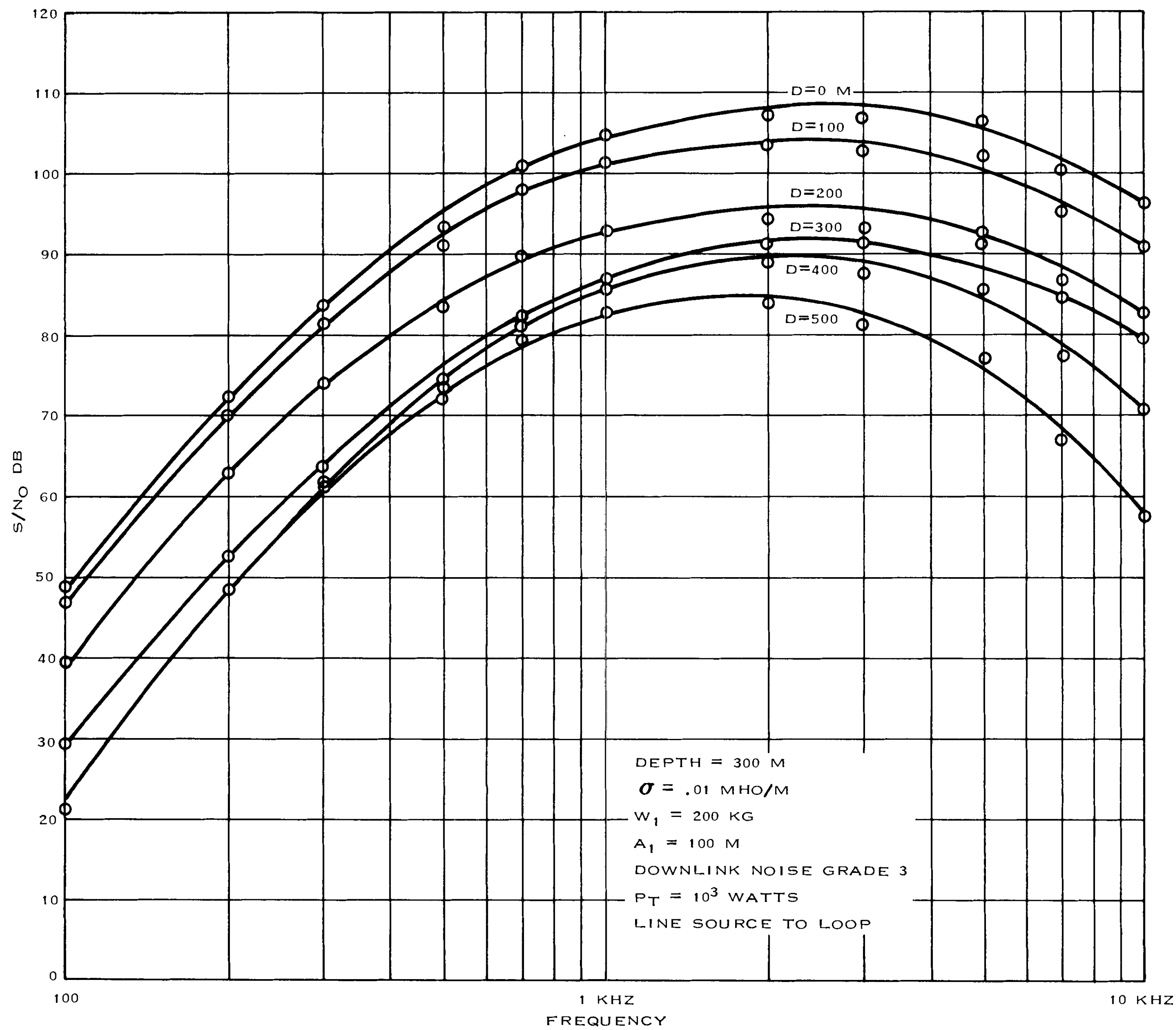

Figure 4-6. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

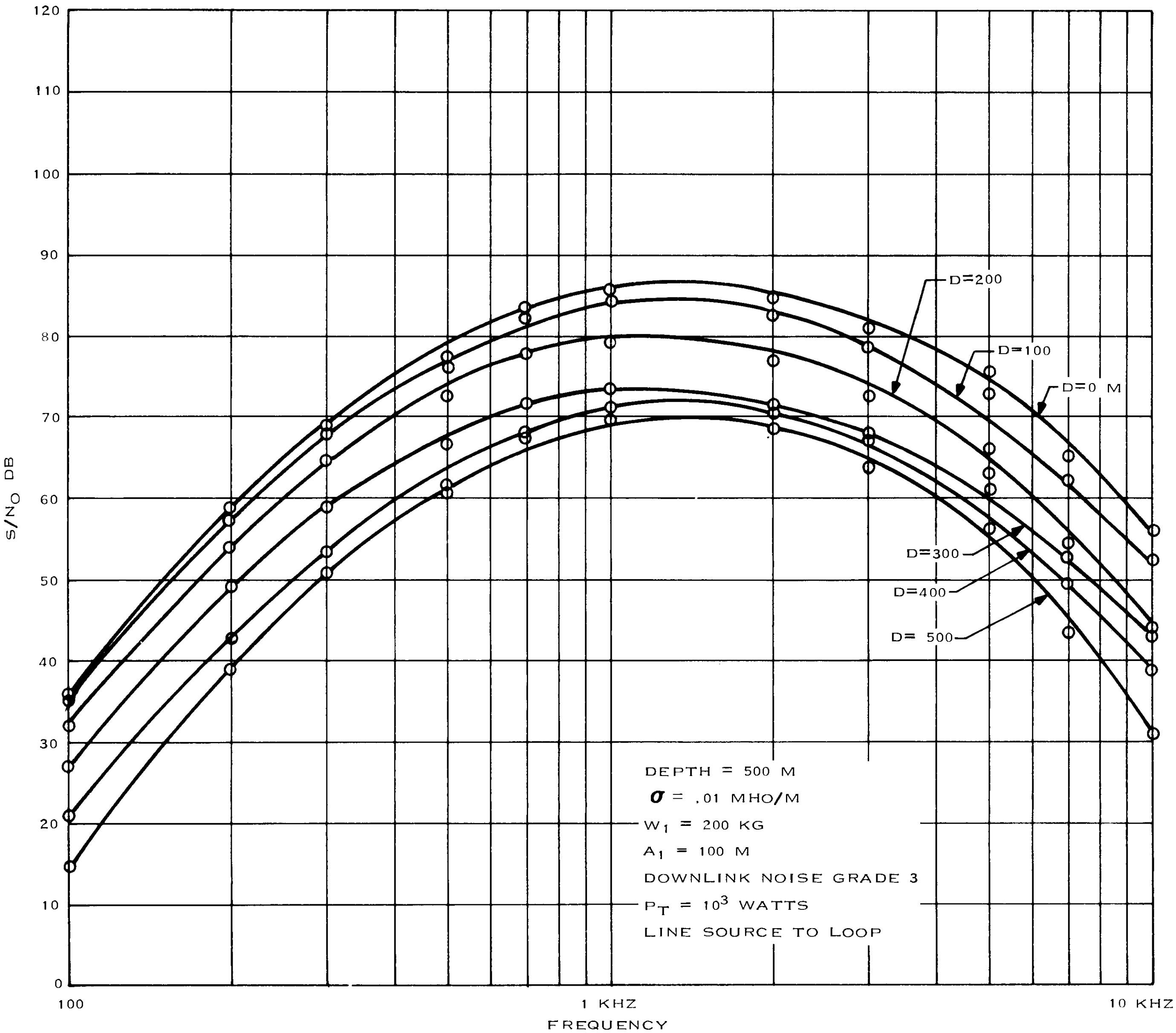

Figure 4-7. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

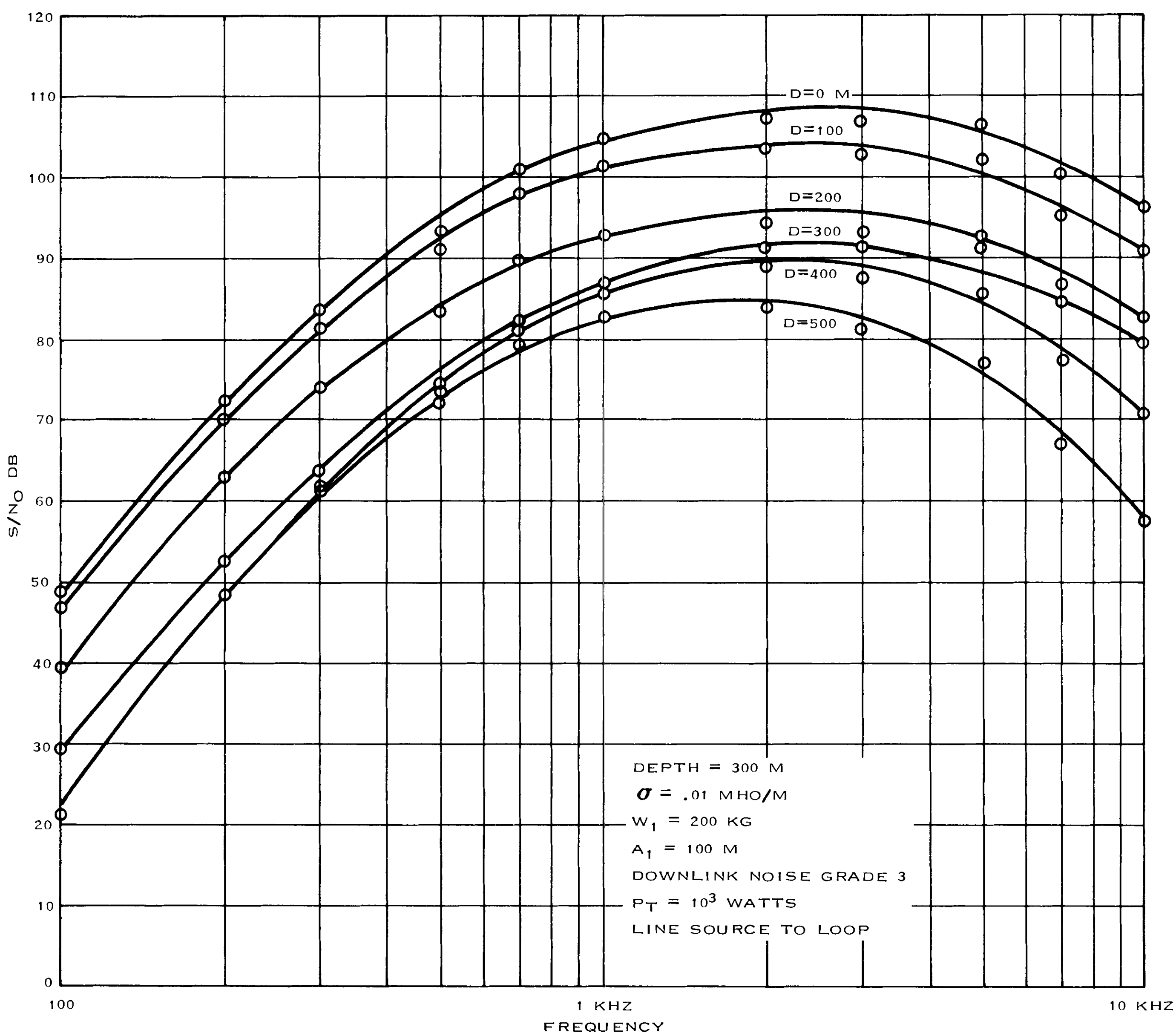

Figure 4-6. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

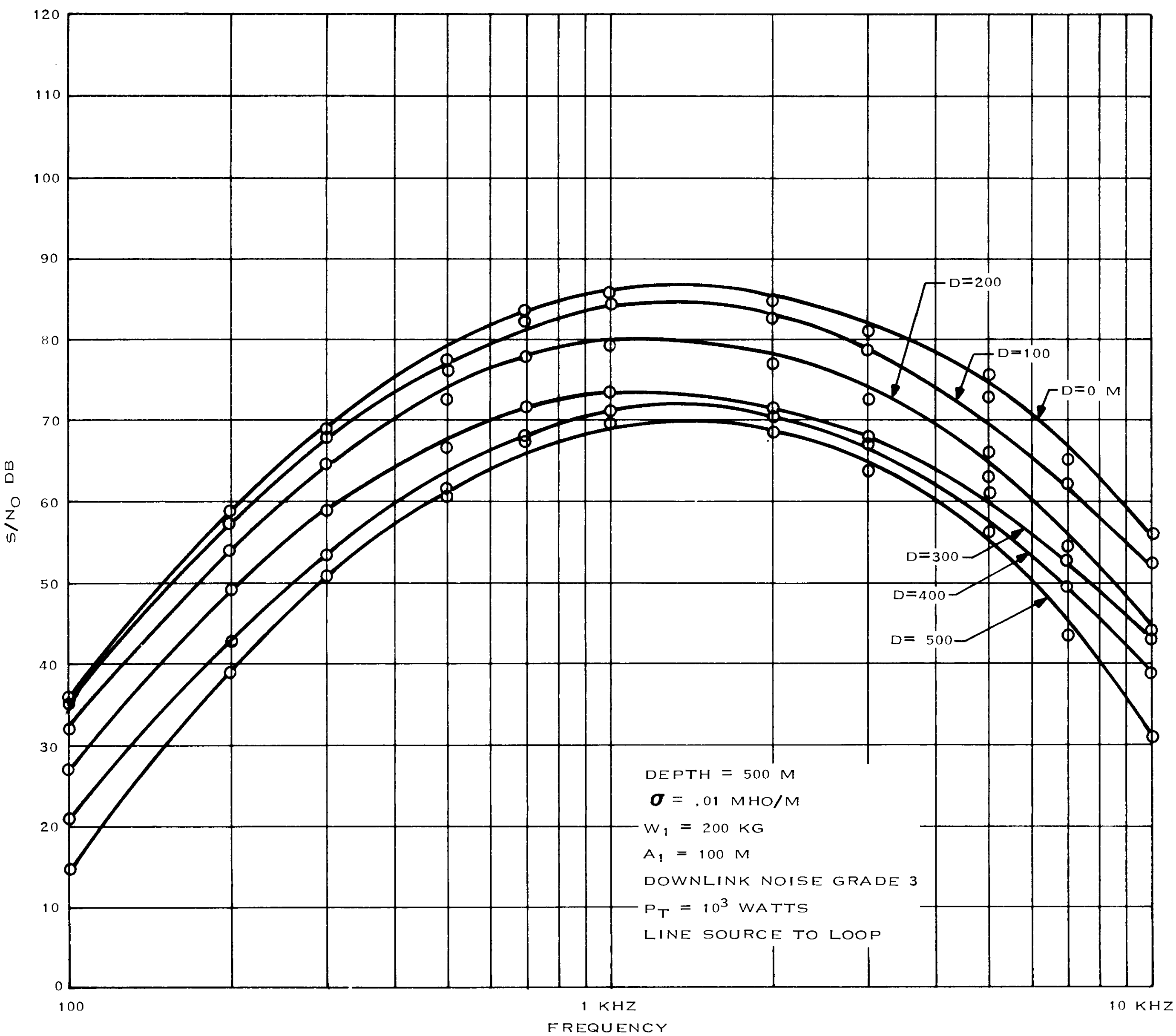

Figure 4-7. Receive Signal-to-Noise Ratios as a Function of Lateral Displacement and Frequency.

Paragraph 5.1 provides an overview of the mechanics of wave propagation within a coal mine and a preliminary look at optimum intramine frequencies. The report employs the techniques developed in the prior reports to analyze overall propagation for loop-to-loop and line source-to-loop transmission for both HED and VMD orientations. There are 10 basic input parameters for computer programs. These are as follows:

a. Transmitted output power
b. Weight of VMD in kg
c. Radius of VMD in meters
d. Frequency in Hz
e. Relative dielectric constant of overburden
f. Conductivity of overburden in mhos/m
g. Earth probe contact resistance of HED
h. Depth of HED or VMD in meters
i. *Noise grade
j. Length of HED in meters

Seven field components, five for submerged HED and two for VMD, are calculated for each receiving point. Comparison of theoretical and Collins measured values of transmission losses between line sources and the magnetic field components produced by these line sources are also included. While the agreement is fairly good, there are certain discrepancies. These can be explained at least partially by the following:

a. Elementary dipoles employed in theory instead of extended sources
b. The array of roof bolts between transmitter and receiver can and undoubtedly do distort the E and H fields

5.1 ON INTRAMINE WIRELESS LF COMMUNICATIONS

Collins has recently completed a series of brief but significant mine communications experiments.** In this section we wish to comment on their relevance to intramine communications and compare their results with theory in the frequency range 1 kHz to 100 kHz.

The theory presented in the previous sections has been incorporated into a basic computer program which evaluates five field components for the submerged HED:

$$E_\rho\Big|_{\phi=0}, \text{ and } E_\phi\Big|_{\phi=\pi/2}, \text{ and } H_\rho\Big|_{\phi=\pi}\Big|2, \text{ and}$$

$$H_\phi\Big|_{\phi=0}, \text{ and } H_z\Big|_{\phi=\pi/2}$$

For the VMD we compute Hz and E

*Preliminary noise grades.
**Coal Mine Communications Field Test Report, Collins Radio Company, December 29, 1972.

The basic input parameters for the computer program are as follows:

a. Transmitted output power
b. Weight of VMD in kg
c. Radius of VMD in meters
d. Length of HED in meters
e. Frequency in Hz
f. Relative dielectric constant of overburden
g. Conductivity of overburden in mhos/m
h. Earth probe contact resistance of HED
i. Depth of HED or VMD in meters
j. Noise grade

For each set of the above parameters, the seven field components are computed for receiving point depths of 0 to 350 meters in 50-meter steps and for receiving point displacements of 100 to 1000 meters in 100-meter steps. The seven field components required the integration of 10 Sommerfeld type integrals, which were effectively performed simultaneously. As indicated previously, due caution was employed in the determination of the various subinterval limits and experimentation performed near the branch points and poles until confidence was obtained for adequate engineering accuracy.*

5.1.1 Comparison of Experiment With Theory

In figures 5-1 through 5-5 of this section, we have shown a comparison of Collins measured values of transmission losses between line sources and the magnetic field components produced by these line sources with their corresponding theoretical values. Collins measured field components, which, for an elementary dipole do not exist viz $E\phi$ at $\phi = 0$, $E\rho$ at $\phi = \pi$, $H\phi$ at $\phi = \pi$, $H\rho$ at $\phi = 0$, and Hz at $\phi = 0$. For an extended line source, particularly for the first three components, these fields actually do exist, of course, since the fields should be integrated over the length of the conductor.

Referring now to figure 5-1, we have shown $E\phi$ at $\phi = \pi$ (line sources broadside). For this and those through figure 5-5 we have selected $E_r = 10$, and $\sigma = 0.005$ mhos/m. This value appeared to offer the best fit in the loss decrement characteristic with frequency and distance and therefore is probably reasonably close to the average overburden value. We note insofar as this field component is concerned, theory actually indicates a lower loss than experiment below 50 kHz, but a higher value above 50 kHz. In figure 5-2, $E\rho$ at $\phi = 0$ (line sources end fire) we find the same effect, however, somewhat more emphasized. Figure 5-3 shows $H\phi$ at $\phi = 0$ now plotted in magnetic field strength dB $> 1\mu A/m$. We find now that theory predicts a lower loss (about 10 dB) than experiment indicates. For $H\rho$ at $\phi = 90°$ (figure 5-4) and Hz at $\phi = 90°$ (figure 5-5) a good agreement with an rms error of 2 to 3 dB is observed.

While the agreement is fairly good, the discrepancies can be explained partially at least by the following:

a. Elementary dipoles employed in theory instead of extended sources.
b. The array of roof bolts between transmitter and receiver can and do undoubtedly distort the E and H fields.

*R. P. Decker, "Signal-to-Noise Analysis for Loop-to-Loop Mine Communications," Subject Data C-684420, 25 September 1972.

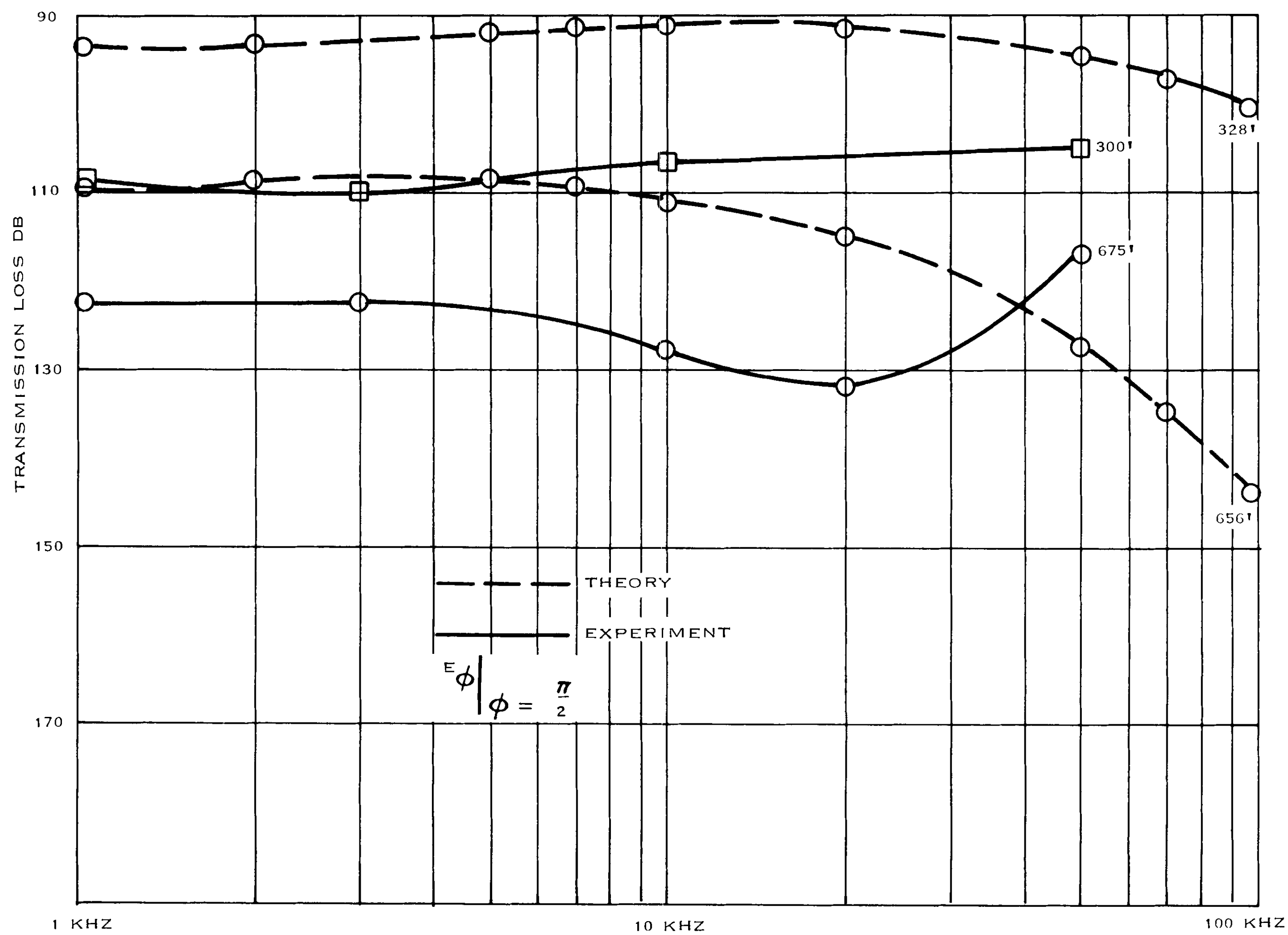

Figure 5-1. Comparison of Theoretical and Measured Transmission Losses Between Line Sources - $E_\phi \Big|_{\phi = \pi/2}$.

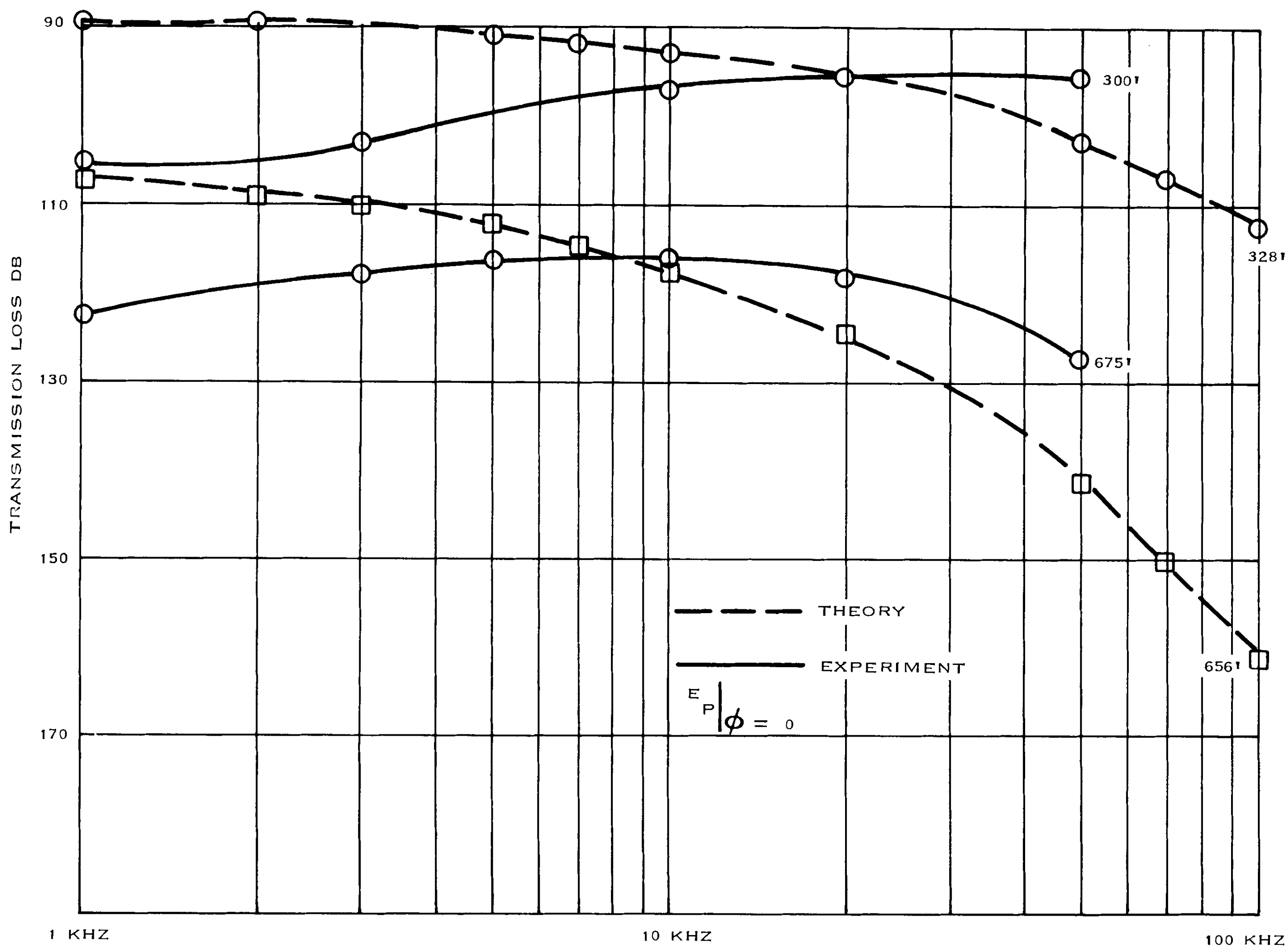

Figure 5-2. Comparison of Theoretical and Measured Transmission Losses Between Line Sources - $E_\rho\big|_{\phi = 0}$.

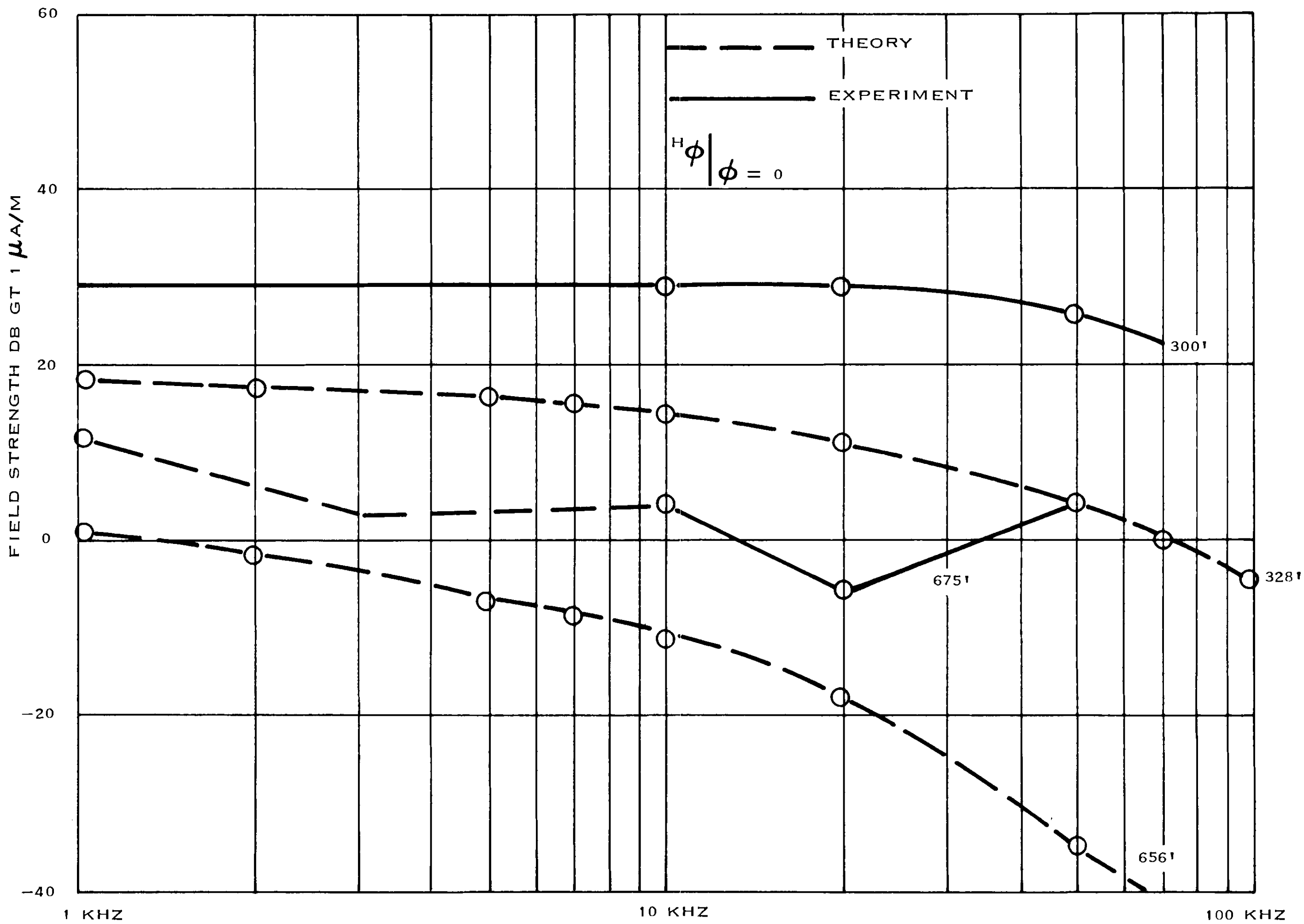

Figure 5-3. Comparison of Theoretical and Measured Transmission Losses Between Line Sources - $H_\phi, \phi = 0$.

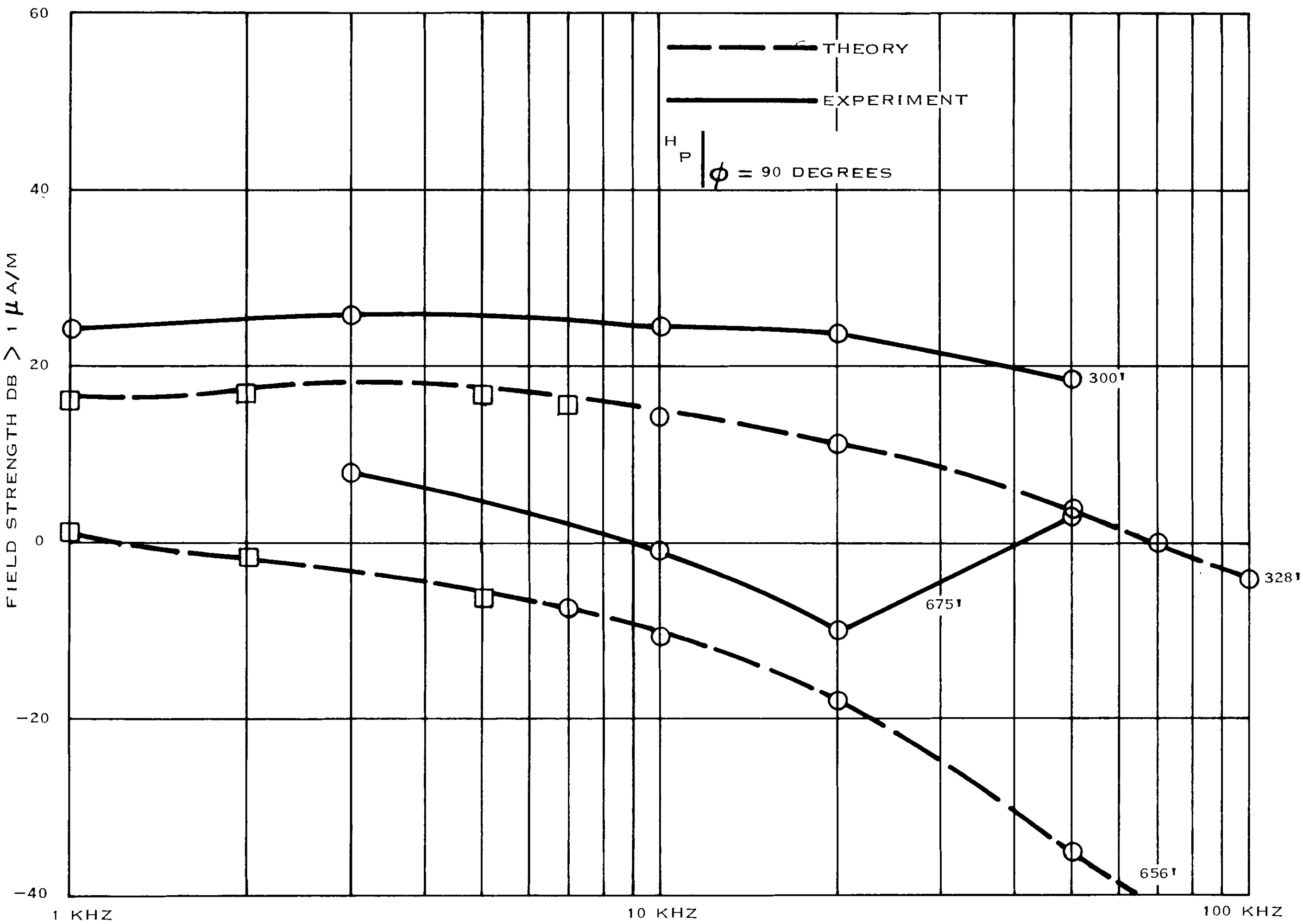

Figure 5-4. Comparison of Theoretical and Measured Transmission Losses Between Line Sources - $H_\rho \big|_{\phi = 90°}$

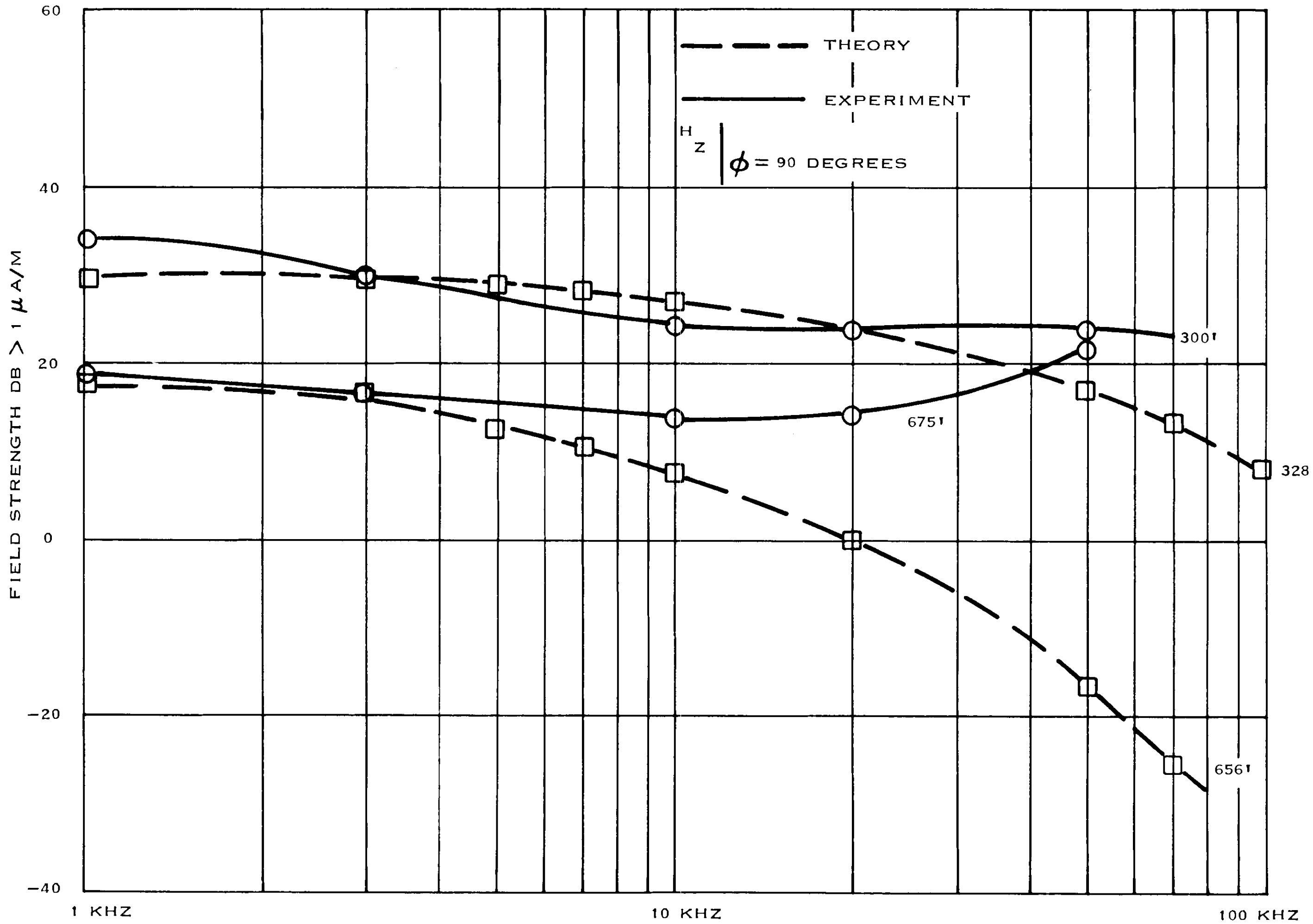

Figure 5-5. Comparison of Theoretical and Measured Transmission Losses Between Line Sources - $H_Z \Big|_{\phi = 90°}$

The extended line sources can be handled fairly easily as far as their primary fields are concerned; however, the "bed of nails" in the overburden may be an intractable theoretical problem.

As time permits we will calculate the effect of an extended source on the received field strength and open circuit voltage of a receiving line source and the vertical magnetic field component, with the receiver at the same depth as the transmitter.

For $E\rho$, $\phi = 0$

$$E\rho^{(p)} = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{\rho_0-\ell/2}^{\rho_0+\ell/2} \frac{e^{-\gamma R}(\gamma R+1)dR}{R^3} \tag{5-1}$$

The open circuit voltage on an identical receive line source is:

$$V\rho_0^{(p)} = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{\rho_0-\ell/2}^{\rho_0+\ell/2} \int_{\rho-\ell/2}^{\rho+\ell/2} \frac{e^{-\gamma R}(\gamma R+1)dR\,d\rho}{R^3} \tag{5-2}$$

For $E\phi^{(p)}$, $\phi_0 = \pi/2$

$$E\phi^{(p)} = \frac{I}{2\pi(\sigma + i\epsilon\omega)} \int_{\rho_0}^{\sqrt{\rho_0^2+(\ell/2)^2}} \frac{\rho}{R} \frac{e^{-\gamma R}}{R^3}\left[\gamma^2R^2 + \gamma R + 1\right]\frac{R\,dR}{\sqrt{R^2-\rho_0^2}} \tag{5-3}$$

$$V\phi^{(p)} = \frac{I}{2\pi(\sigma + i\epsilon\omega)\rho_0} \int_{\rho_0}^{\sqrt{\rho_0^2+(\ell/2)^2}} \int_{\rho_0}^{\sqrt{\rho_0^2+(\ell/2)^2}} \frac{\rho e^{-\gamma R}}{R^3}\left[\gamma^2R^2 + \gamma R + 1\right]\frac{dR\,d\rho}{\sqrt{R^2-\rho_0^2}} \tag{5-4}$$

For $H_z^{(p)}$, $\phi = \pi/2$

$$H_z^{(p)} = \frac{I\rho_0}{2\pi} \int_{\rho_0}^{\sqrt{\rho_0^2+(l/2)^2}} \frac{e^{-\gamma R}}{R^2} \frac{[\gamma R + 1]dR}{\sqrt{R^2 - \rho_0^2}} \tag{5-5}$$

A significant aspect of this data is that above 50 kHz, say 50 to 100 kHz, theory is consistently pessimistic for both the E and H field components. Also, field components exist where none would under the half-space model and elementary dipole conditions. From the Collins measurements apparently these components are seldom less than 15 dB below the main component.

5.1.2 System Design of Basic Intramine Paths

With the basic computational tools in hand, we now proceed to examine some basic intramine path configurations. Consider first a personal portable transmitting loop with a receiving line source within a mine working section. For this we have taken $\sigma = 0.01$ mhos/m, depth 222 meters, a displacement of 100 meters (half the length of a working section) a power of 1 watt into a 6-inch-diameter loop with a weight of 0.25 kg. We need, of course, E-field noise data which is essentially nonexistent. However, by establishing the quiet mine E-field noise at 20 kHz deduced from Collins measurements and the use of R. Geyer's limited surface noise data, we have been able to assemble a first or zero order approximation to the max and min values of this noise from 1 to 100 kHz.

The results are plotted in figure 5-6 in terms of S/N_0. They show a possibility for quite acceptable voice quality in the frequency range of 70 to 100 kHz. This would also include a "loop orientation variability" margin of at least 15 dB.

In figure 5-7 we have taken the same transmit loop, but now reception is on another VMD. Adequate noise data is available for this case and the S/N_0 is shown versus frequency for the extreme cases.* Here we find essentially the same optimum frequency range; however, the maximum S/N_0 is approximately 28 dB lower than in the case of the line source receiver.

The next type of intramine path which is self-suggestive is a line source to line source link between working sections (figure 5-8). We have taken a power of 100 watts and a line source length of 16 meters and a displacement of 200 meters. Using the maximum noise characteristic, the optimum frequency range of 25 to 50 kHz produces an output S/N_0 of about 55 dB. This should also be an acceptable value for a voice link. (Note that larger paths exhibit a lower optimum frequency range.)

The next logical case is VMD to VMD between working sections (figure 5-9). Here we have used a 4-meter diameter 10-kg transmit loop with a power of 100 watts. We find the same optimum frequency range as the previous one, but the (max) S/N_0 is 10 dB lower. This could be made up by a 12-meter diameter transmitting loop, but would be considerably more expensive and less convenient than line source to line source.

Figure 5-10 depicts the expected S/N_0 for a line source transmitter to a VMD receiver within a working section, Pt = 100 watts and a line source length of 16 meters. Figure 5-11 is identical except for a displacement of 200 meters.

This clearly demonstrates that a line source with a reasonable power input at maximum noise conditions has a maximum voice range of about 140 meters (460 feet).*

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*With preliminary noise grades.

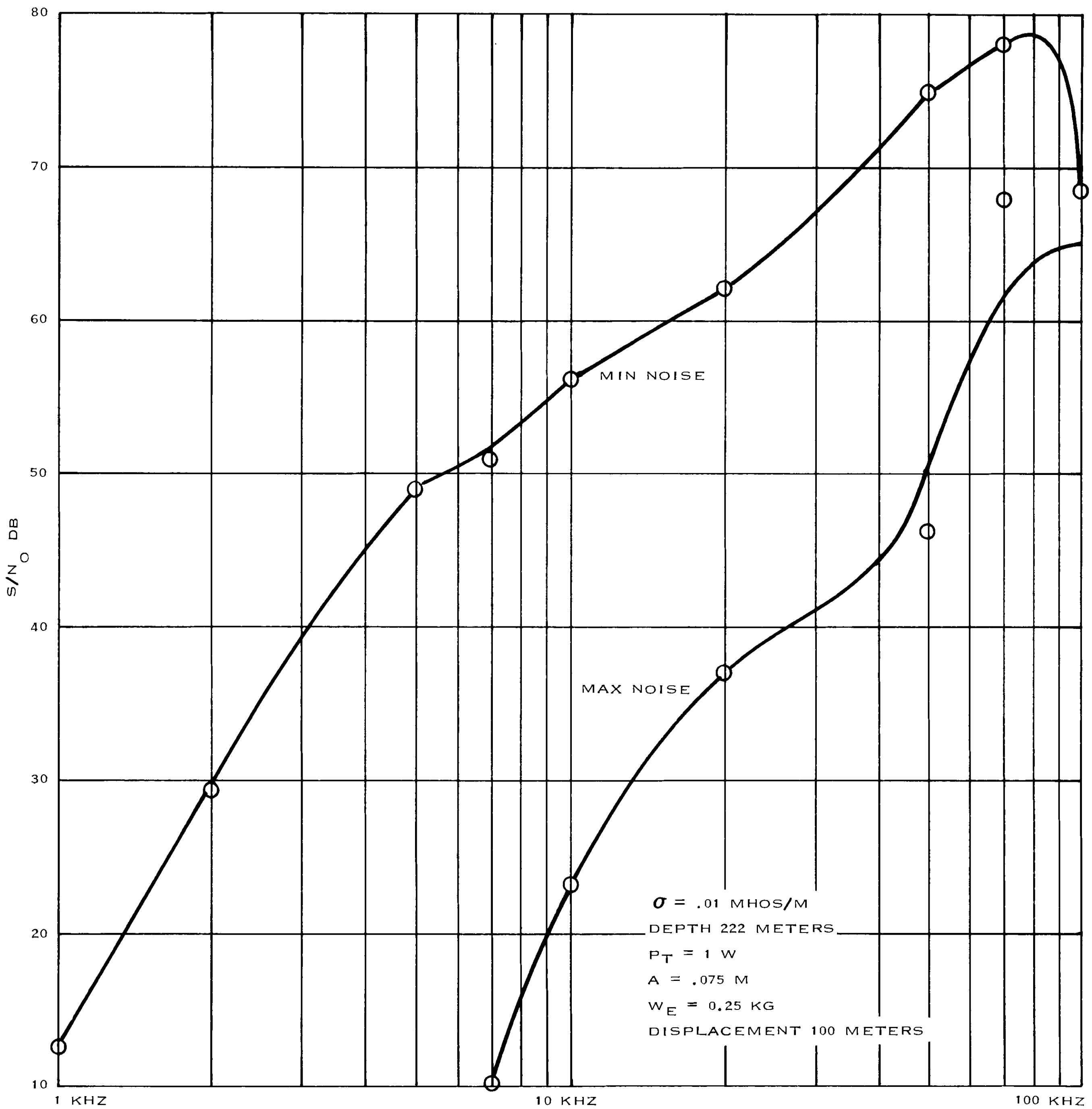

Figure 5-6. Portable VMD to Line Source.

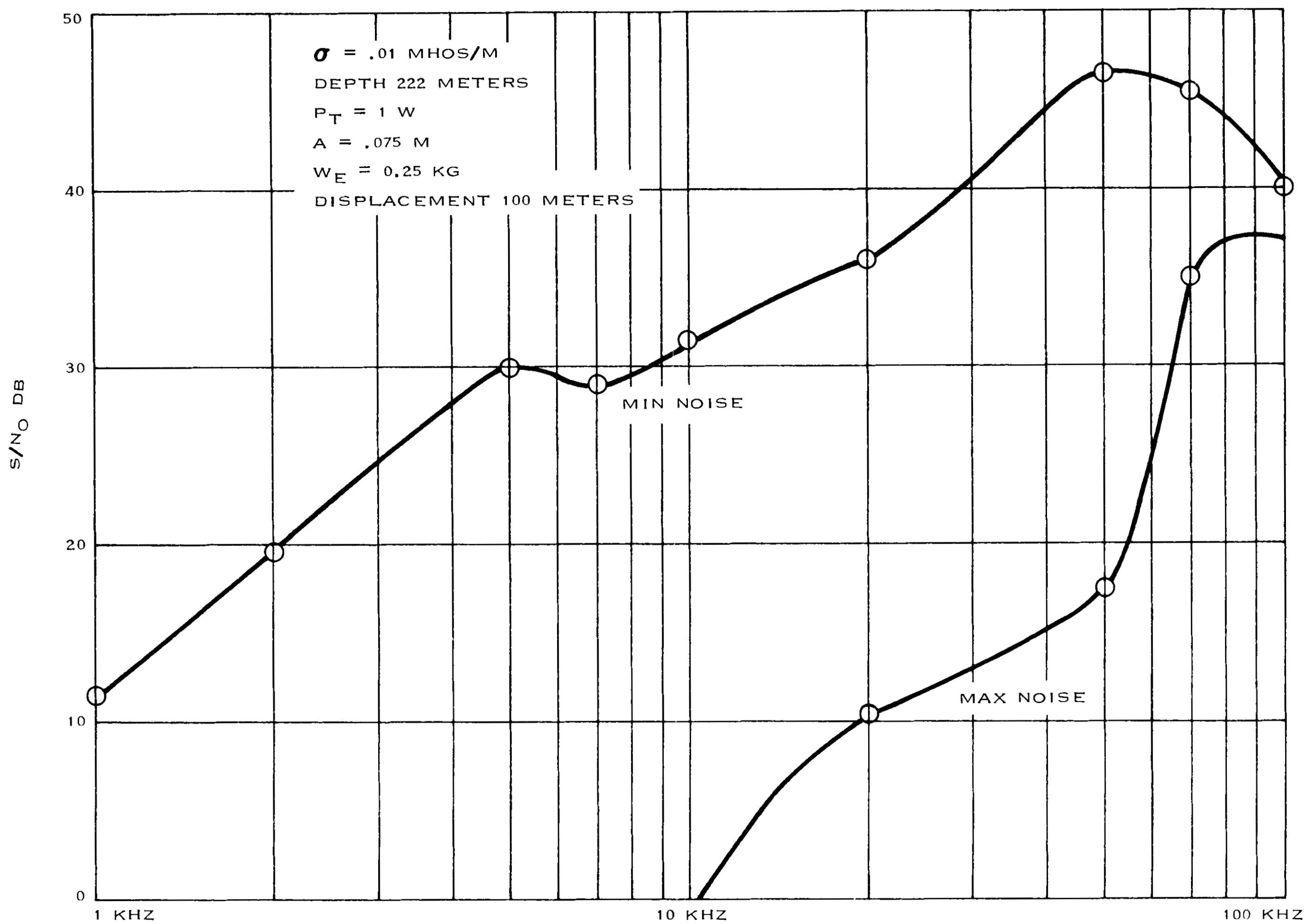

Figure 5-7. Portable VMD to VMD.

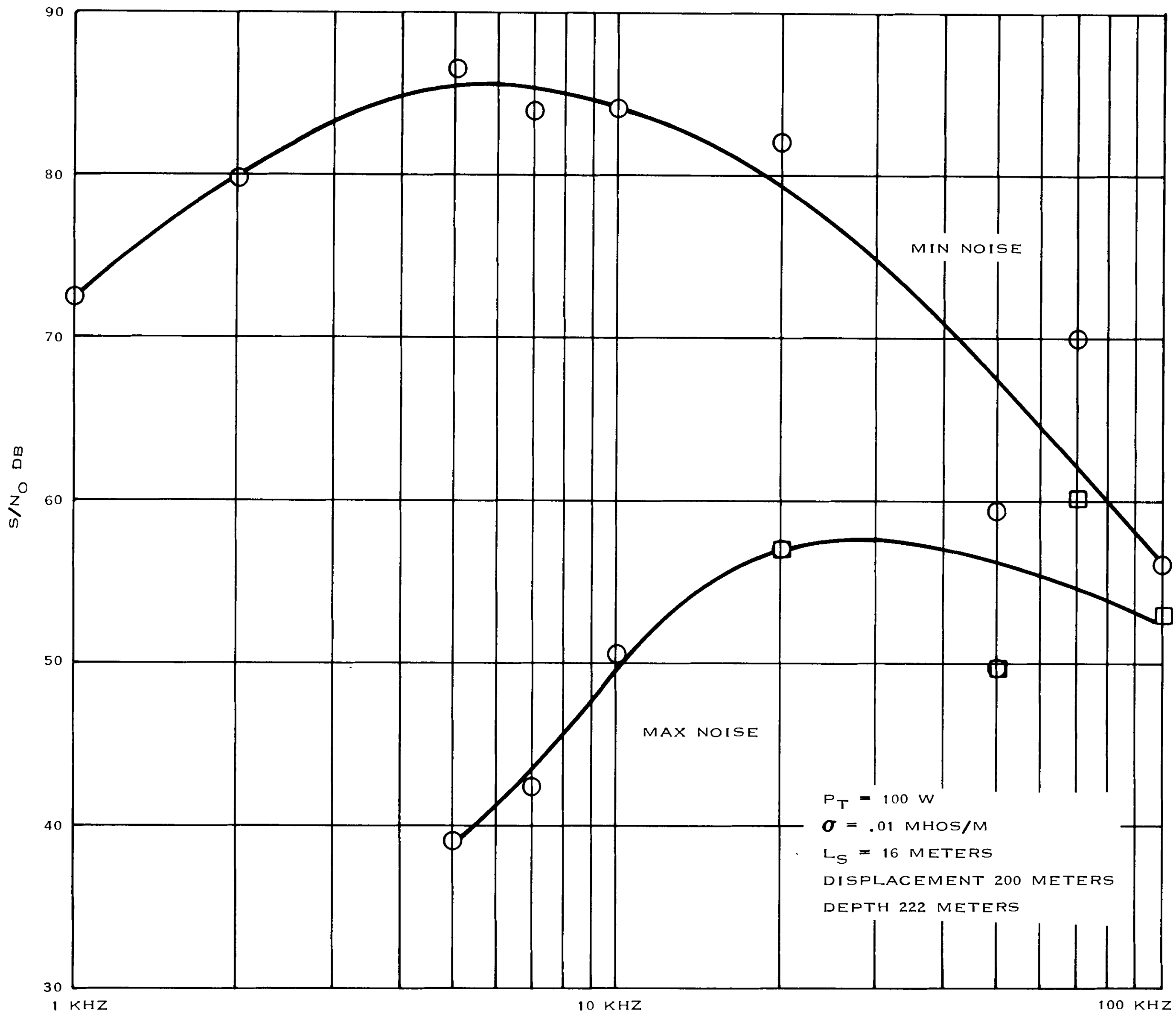

Figure 5-8. Line Source to Line Source (Broadside).

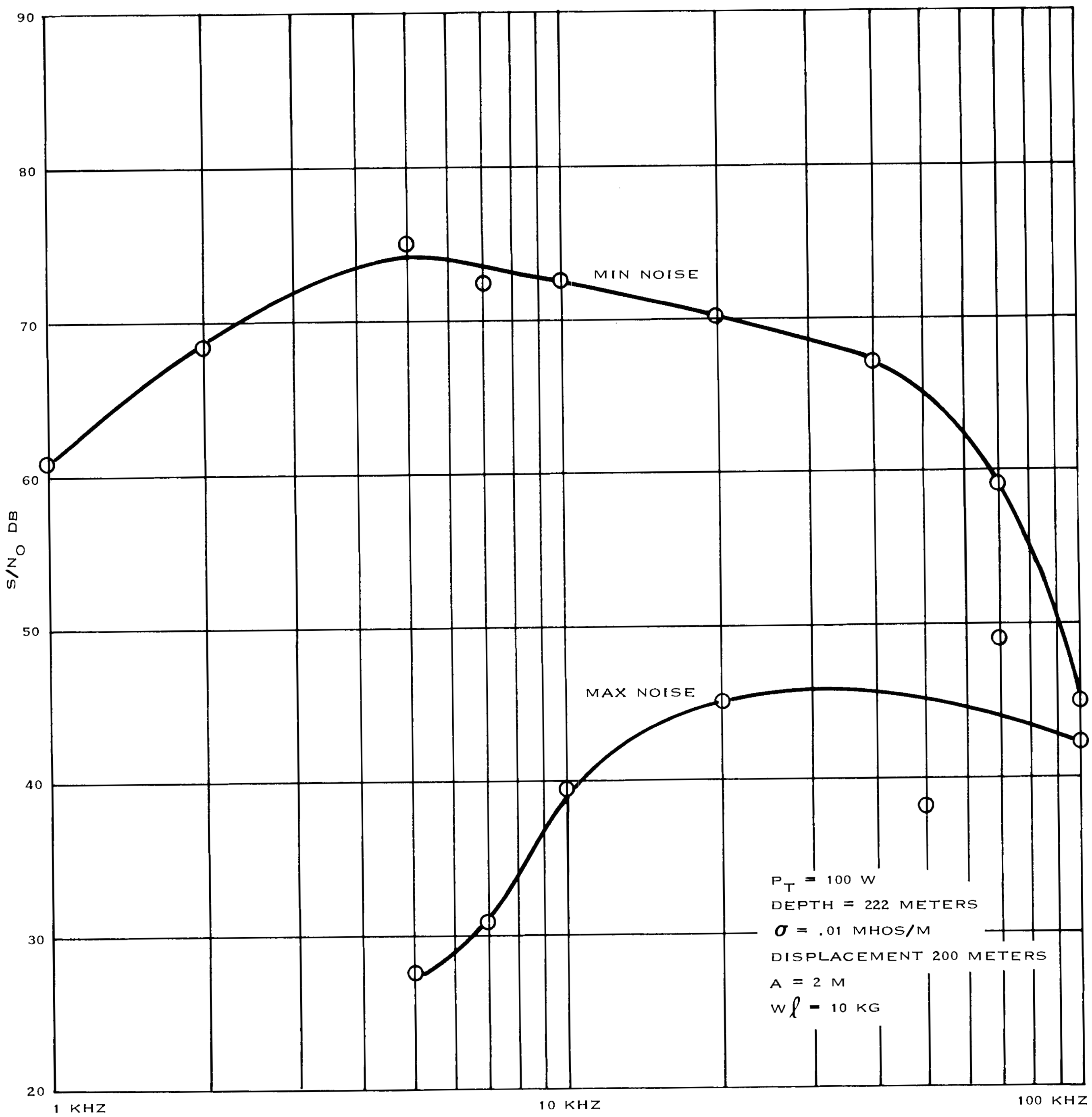

Figure 5-9. VMD to VMD.

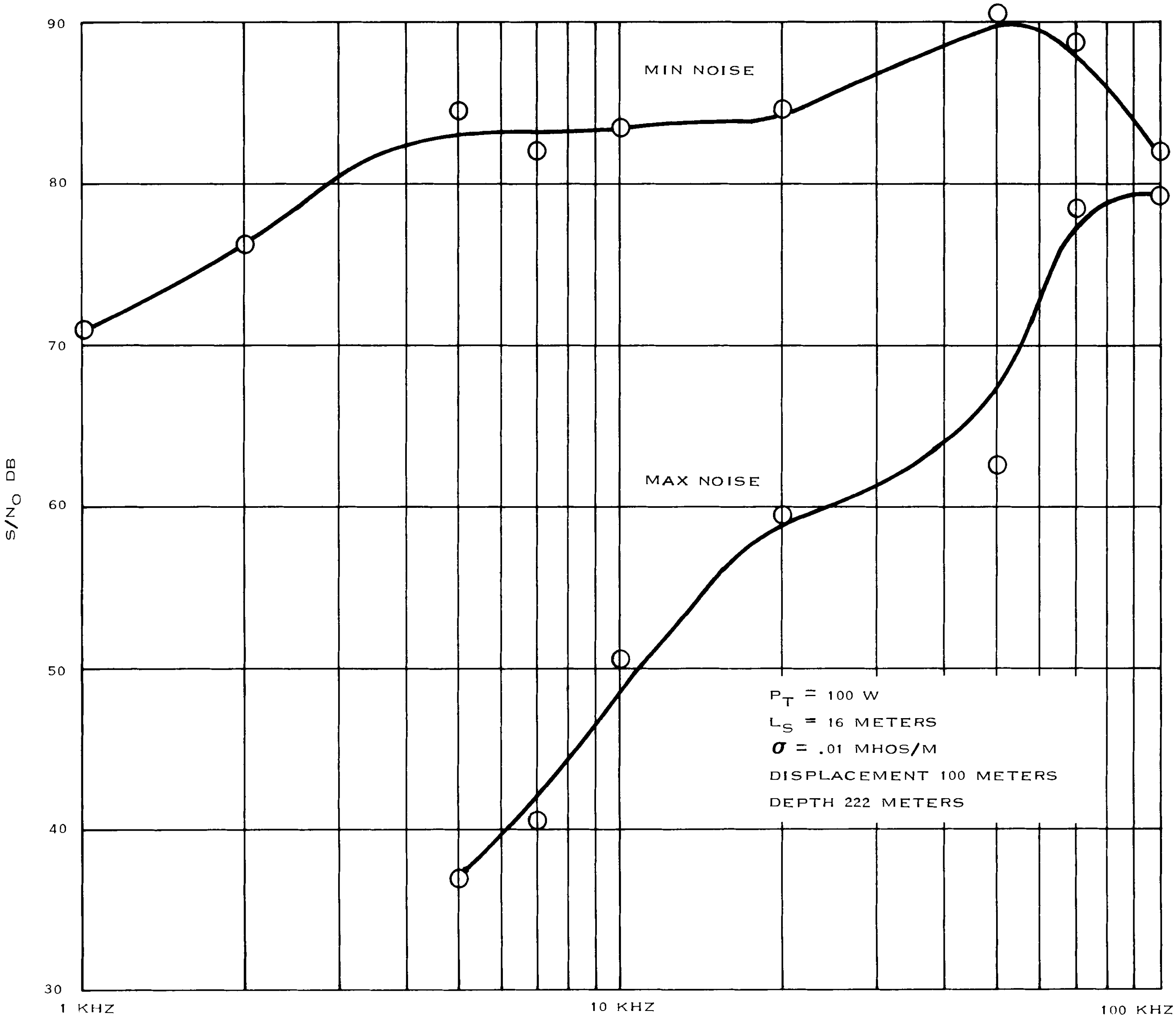

Figure 5-10. Line Source to VMD/Displacement - 100 Meters.

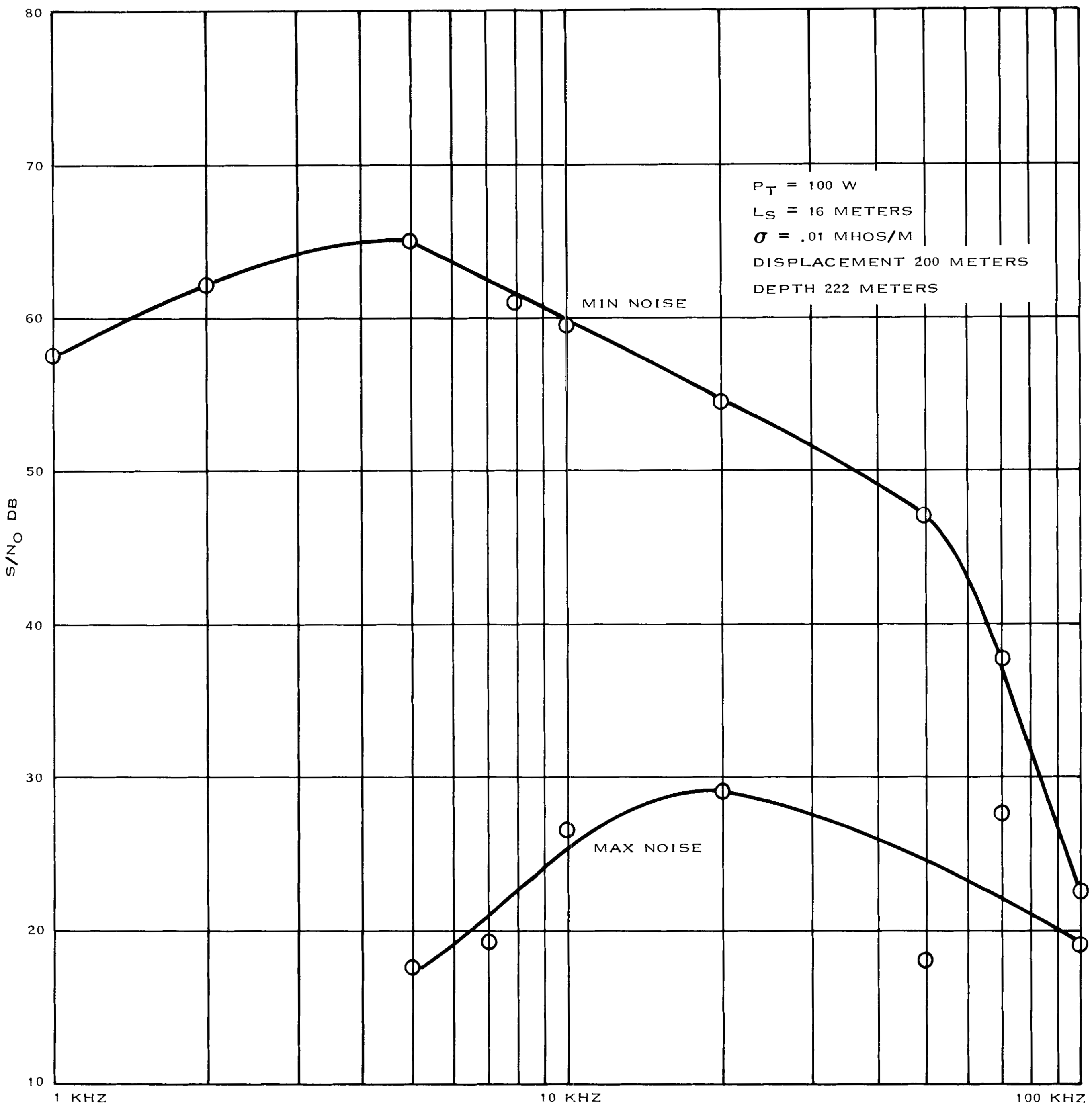

Figure 5-11. Line Source to VMD/Displacement - 200 Meters.

5.1.3 Conclusions and Recommendations

From the above analysis we can formulate some basic conclusions for intramine communications:

a. For personal portable lf wireless communications within a working section a loop-line source 2-way link is indicated as optimum in the frequency range of 70 to 100 kHz. The portable loop input power should be approximately 0.5 to 1.0 watt.
b. For relayed transmission between working sections a line source to line source (broadside) 2-way link is indicated as optimum in the frequency range of 25 to 50 kHz. Line source lengths should be 16 meters (or more) with an input power of about 100 watts.

While these conclusions are quite significant, the VMD to line source link needs experimental verification and a series of measurements should be outlined to confirm the efficacy of the link under maximum noise conditions encountered in a working section. Also, we must again stress the urgent need for subsurface E-field noise data.

The Application of Recent NBS Noise Data to Mine Communications

Recently, NBS has generated a considerable amount of surface and subsurface mine noise data, principally that of the horizontal and vertical magnetic field components at a representative sampling of locations, all under power-on conditions. The spectrum date of W. Bensema generally covers the range of 1 to 100 kHz, while Kandu's APD data was taken at 6 or 8 frequencies beginning at 10 kHz and extending into the hf range. While the location sampling was representative, there appeared to be considerable attention given to finding the maximum noise possible (for example, trolley noise with car pull). Also, the spectrum data was again, in several instances, system noise limited, which is an inherent problem with wide bandwidth analysis in setting the system gain unless a low-pass filter is employed below, say, 10 kHz. An additional comment is that frequencies of interest were generally considered to be below 20 kHz, whereas, frequencies for certain intramine paths exhibited optimal S/N performance at frequencies in the range of 30 to 90 kHz, based on previously available noise data. All things considered, the data is of excellent quality, covers several types of mines, and lends itself well to mine communication system analysis.

The following discussions consider data from the following mines:

MINE	TYPE
Robena	600 V dc, rail haulage
McElroy	Ac/dc, underground rectification, belt and rail haulage
Itman	Same as McElroy
Geneva	Ac/dc, rail haulage

6.1 METHOD OF ANALYSIS

Each curve of W. Bensema's spectrum data was subjected to a regression analysis to determine the equivalent running average of the minimum noise between spectral peaks. About 100 sampling points were used for each curve. This was done principally to improve the accuracy of noise representation and facilitate the injection of this data into the general intramine path propagation program. The functional dependence was determined entirely in terms of dB $>/\mu A/\text{meter}/\sqrt{Hz}$.

6.2 ROBENA MINE

The Robena mine is a 600 V dc mine, (dc conversion on surface) with rail haulage. The summary of the equivalent background (between peaks) noise fields are shown in figures 6-1 through 6-5. Both horizontal and vertical magnetic field noise components were measured and a few roof-bolt measurements were included. Figure 6-1 shows trolley and face area noise levels. The trolley noise indicated in the upper curve represents some of the highest noise fields ever measured in a mine. The face area levels are many dB less, but the vertical component at the face area is roughly 25 dB higher than either horizontal component.

Figure 6-2 represents noise components in crosscuts 7 and 9 in which the spectrum display was system noise limited. The only conclusion that can be obtained from these curves is that the true noise levels are no greater than those shown in this figure. The APD data in figure 6-3, shows generally the same levels of noise that were determined from spectrum data aside from trolley noise. We note here a high degree of variance of horizontal component with frequency. Figure 6-4 illustrates the extremes and means of the subsurface horizontal component and figure 6-5 the same for the vertical component.

The mean of the vertical component is about the same as the mean of the horizontal component. The vertical component of the surface noise field is also shown in figure 6-5. The roof-bolt noise data was examined, but the conversion factor to absolute values was lacking. As soon as this conversion is available, W. Bensema will inform the writer.

The conclusions that were reached from the Robena data are as follows:

a. There is no preference between the horizontal and vertical magnetic noise fields from the standpoint of their mean values as a function of frequency.
b. Less system gain protection factor is needed for the vertical component to allow for noise level variations with location.
c. Noise pickup on roof bolts does not increase with separation.
d. The surface noise fields were less than the minimum power-on subsurface fields, for the data presented.
e. The extreme noise fields represented, for example, by trolley noise may preclude the application of LF quasi-static propagation paths intramine with receive antennas near this noise source.

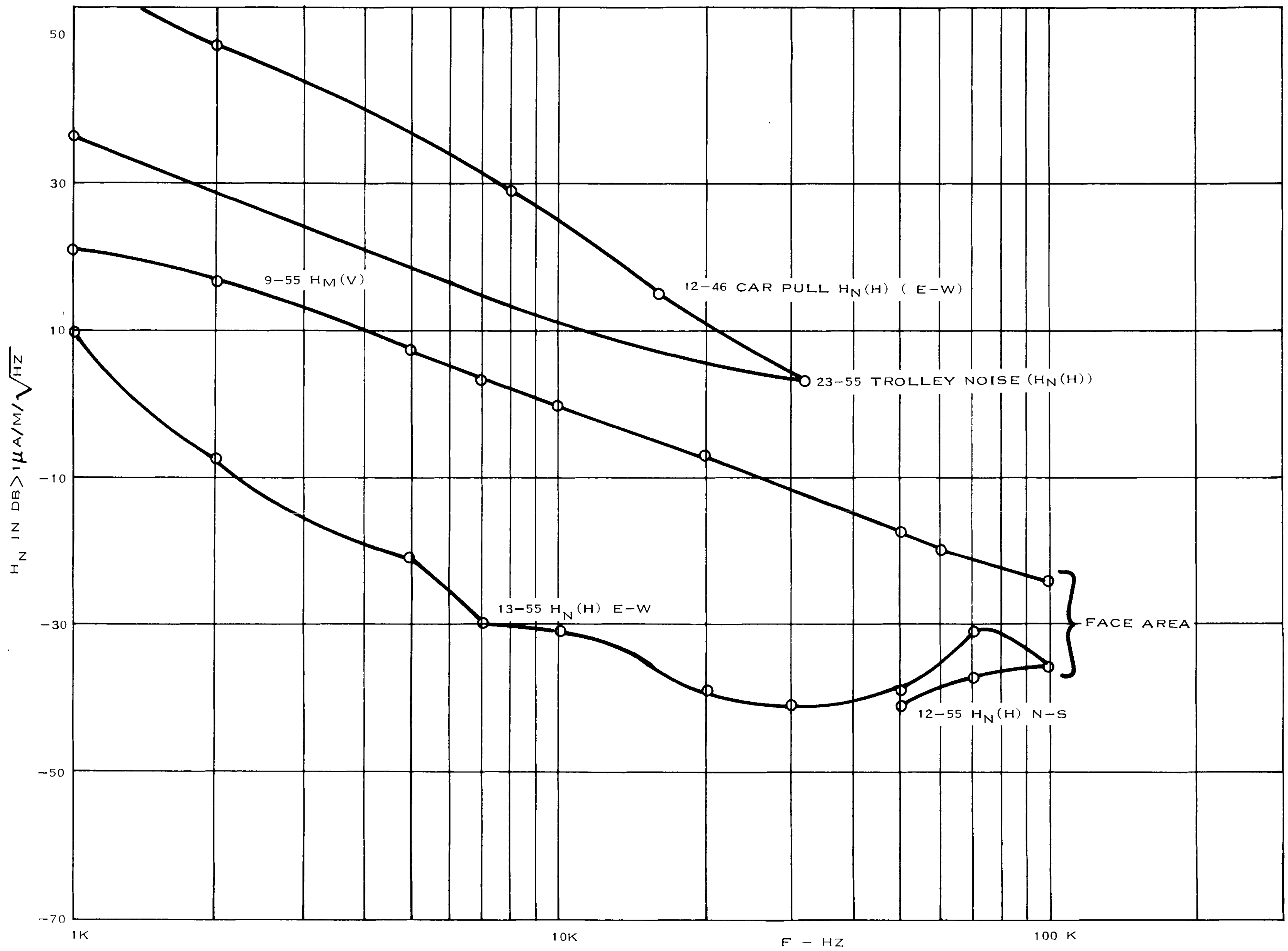

Figure 6-1. Robena Bensema Noise Spectrum Data/Trolley and Face Area Noise Levels.

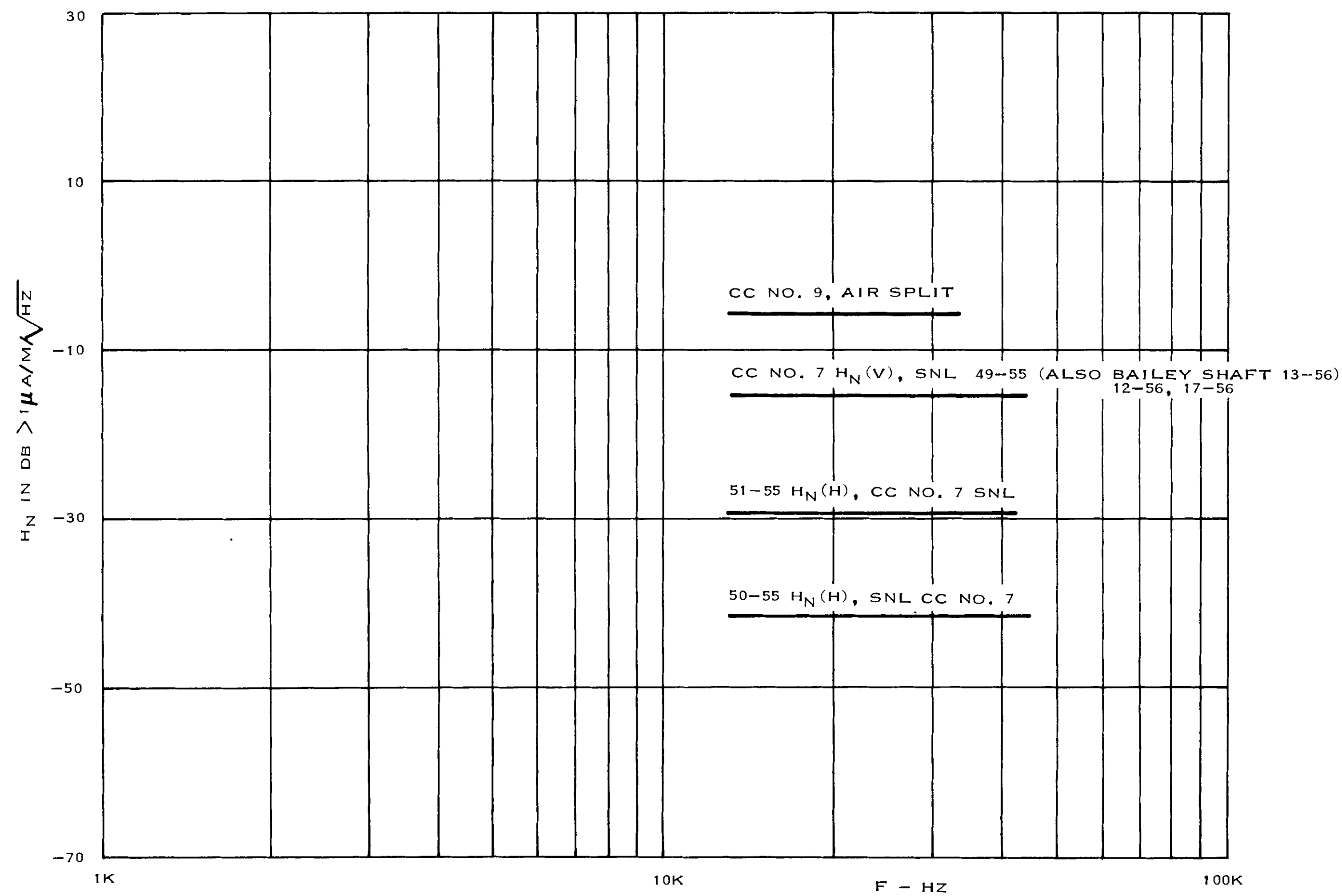

Figure 6-2. Robena Bensema Noise Spectrum Data/Noise Components Crosscuts 7 and 9.

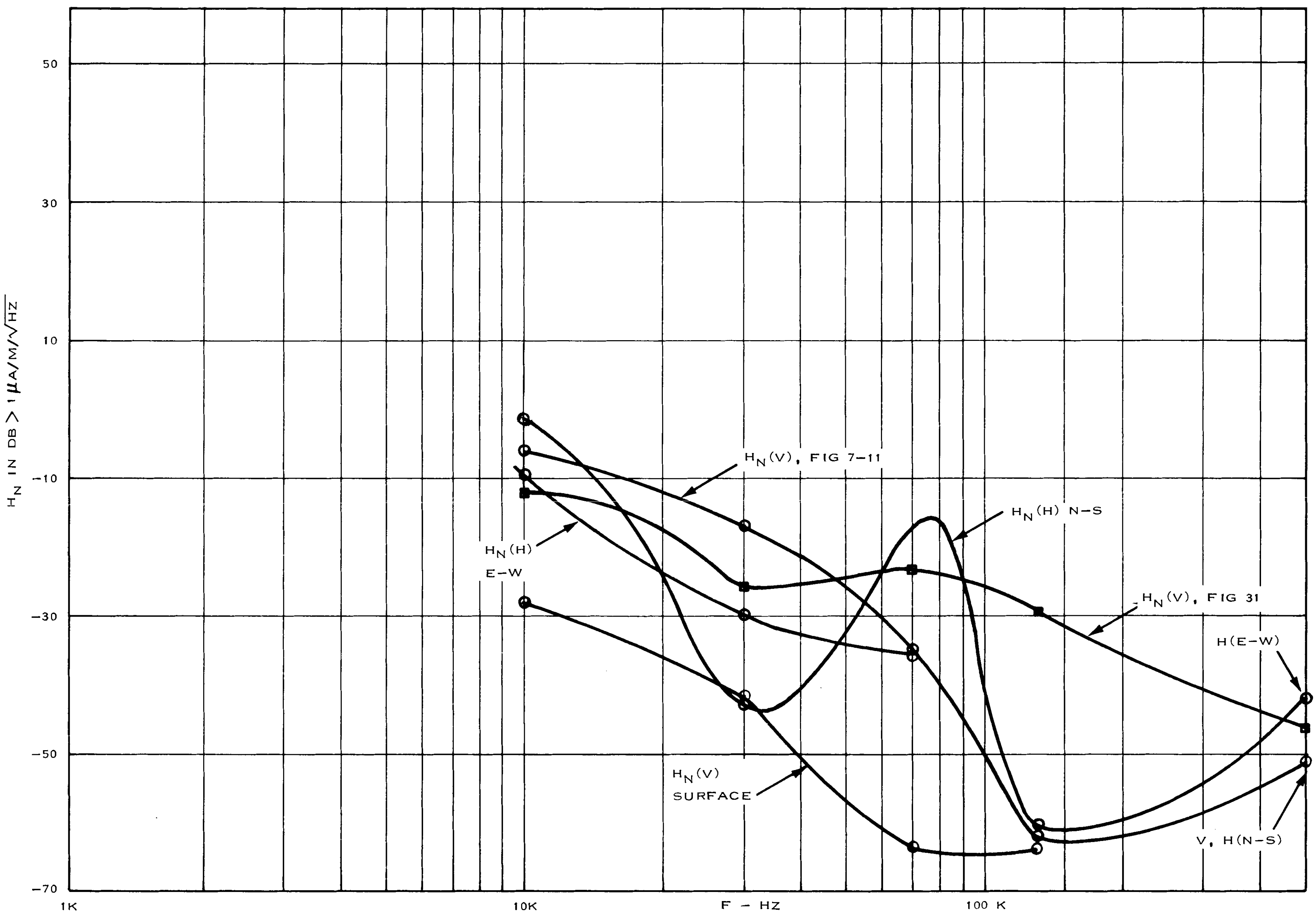

Figure 6-3. Robena Kandu APD-Data Spectrum (RMS).

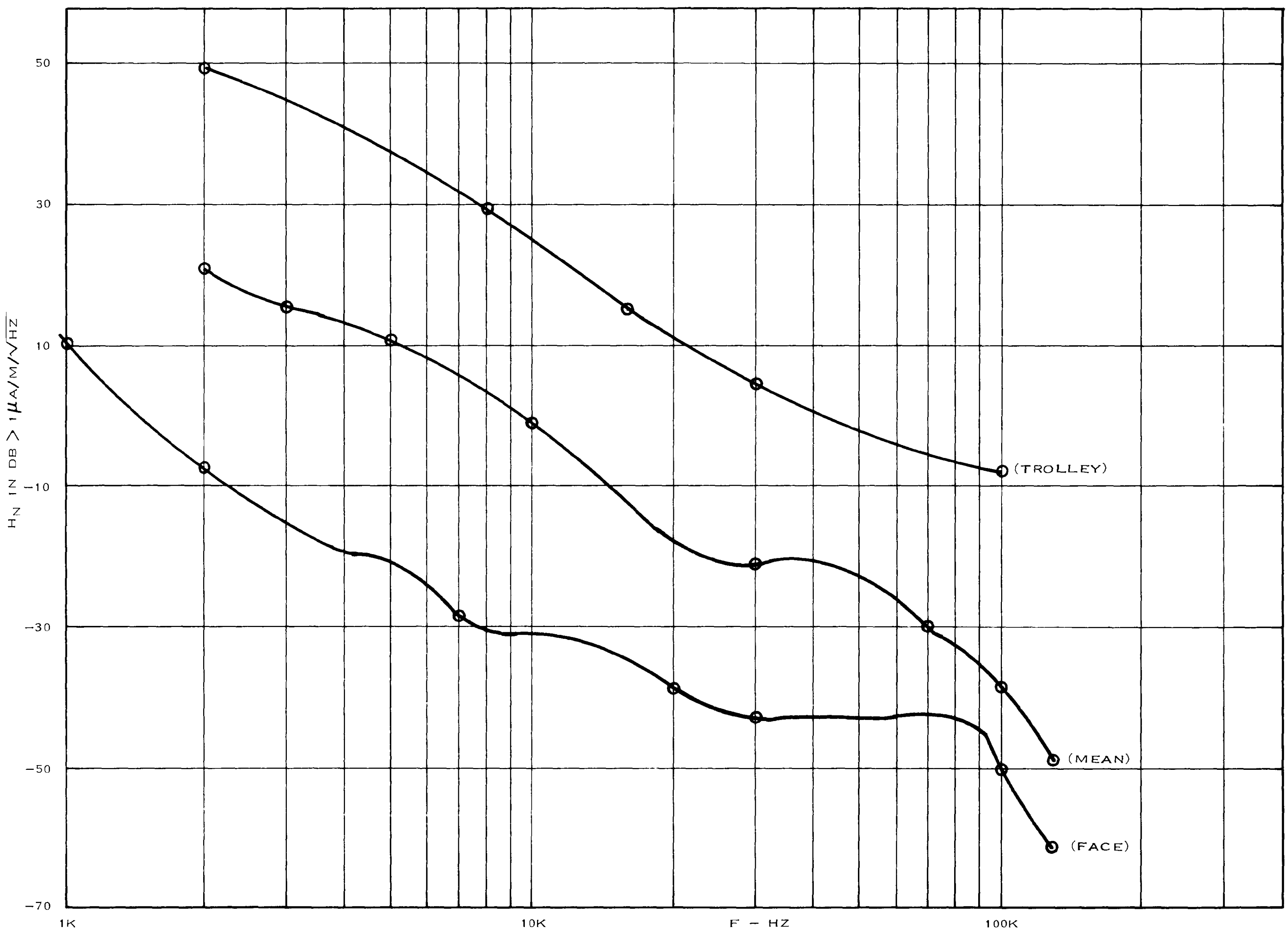

Figure 6-4. Robena $H_N(H)$ Extremes (RMS) Subsurface.

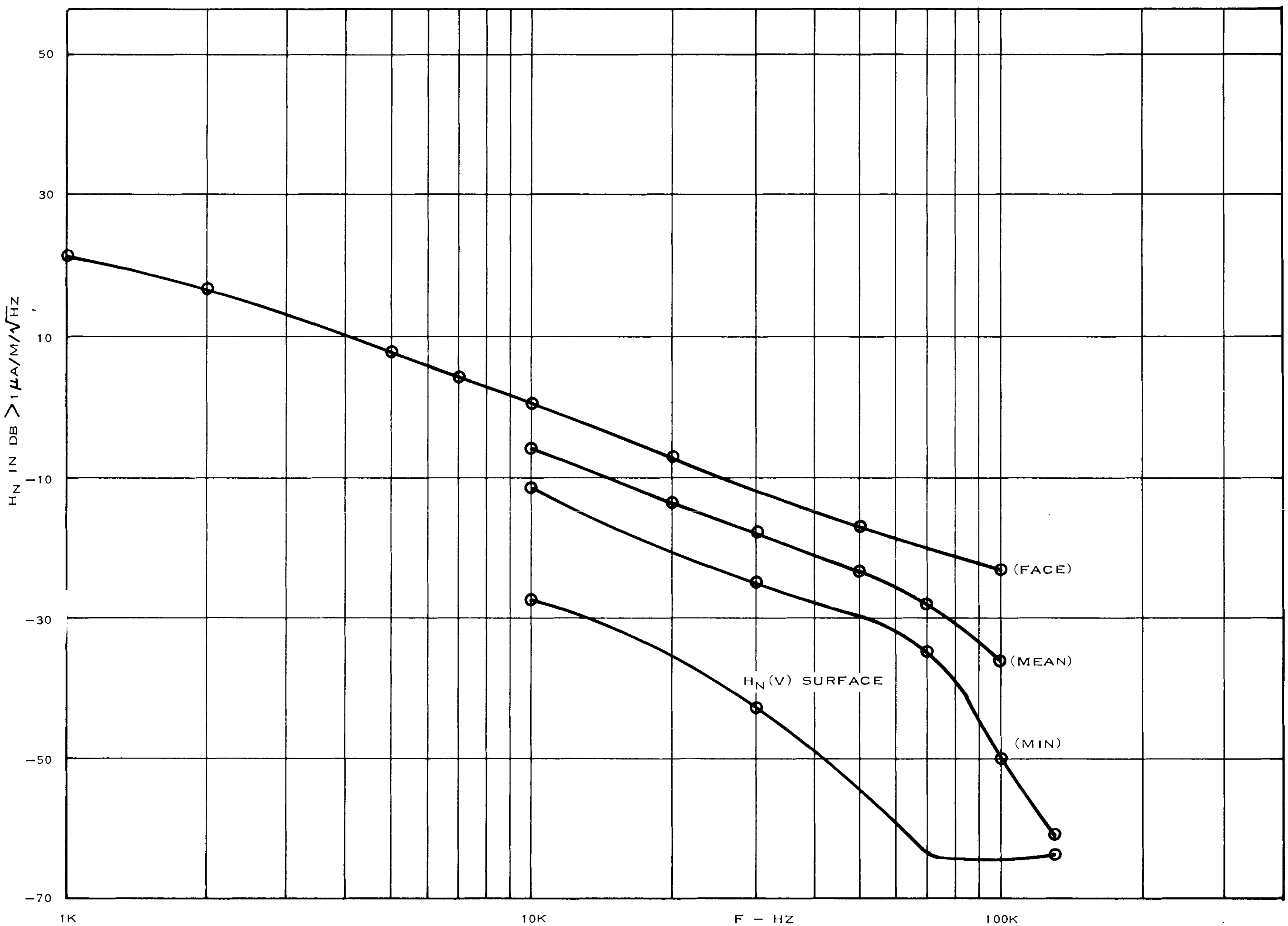

Figure 6-5. Robena $H_N(V)$ Extremes.

6.3 McELROY MINE

The McElroy mine is a dc mine with underground rectification and belt and rail haulage. Summaries of the equivalent background noise fields are shown in figures 6-6 through 6-15. Vertical noise fields in the face area and in location no. 2, which have a relatively small variation in the means, are shown in figure 6-6. The composite of this data is shown in figure 6-12 and can be considered to be a quasi-maximum average of face area noise. Kandu's APD equivalent of Bensema's figure 97-83 is also shown, but there is little correlation except at 10 kHz. Vertical noise fields for the head piece, middle of crosscut, and elevator shaft are shown in figure 6-7. There appears to be quite a bit of variance in these noise fields; however, considerably quieter fields are noted at the elevator shaft.

Figure 6-8 summarizes Kandu's APD measurements, showing about the same mean levels as in figure 6-7 at 10 kHz and for corresponding conditions in the Robena data, but with less variance. Figure 6-9 shows additional vertical field data at the head piece and arc welder. The 10-kHz peak for the head piece is an extremely high level for this frequency. An assortment of various locations and components is shown in figure 6-10.

The power entry is a maximal noise condition, while the site farthest from the power entry exhibits the quietest noise fields. Figure 6-11 shows additional high vertical noise fields in crosscuts and face areas. We note here the extension of high noise fields out to 50 kHz. Surface noise fields are shown in figure 6-12. These fields are relatively quiet and show a small degree of variance. The extremes and the means of the noise fields for the McElroy mine are shown in figure 6-14. The extremes for Robena are higher than those of McElroy, principally because of trolley noise, but the means are rather close except that McElroy exhibits higher levels between 12 and 50 kHz. McElroy also shows lower power-on minimums than Robena. Figure 6-15 shows the surface noise summary for McElroy and the correlation of McElroy data with Robena, Maxwell and Stone, and Geneva. The agreement is reasonably good with a relatively small degree of variance. Roof-bolt noise was not examined because of lack of calibrating data.

The conclusions that may be drawn with respect to the McElroy mine data are as follows:

a. Mean noise fields are about the same as Robena noise fields.
b. The surface noise fields lie between the mean and minimum subsurface noise fields, power-on.
c. There appears to be a high degree of correlation between the surface noise data for the McElroy and Robena mines.

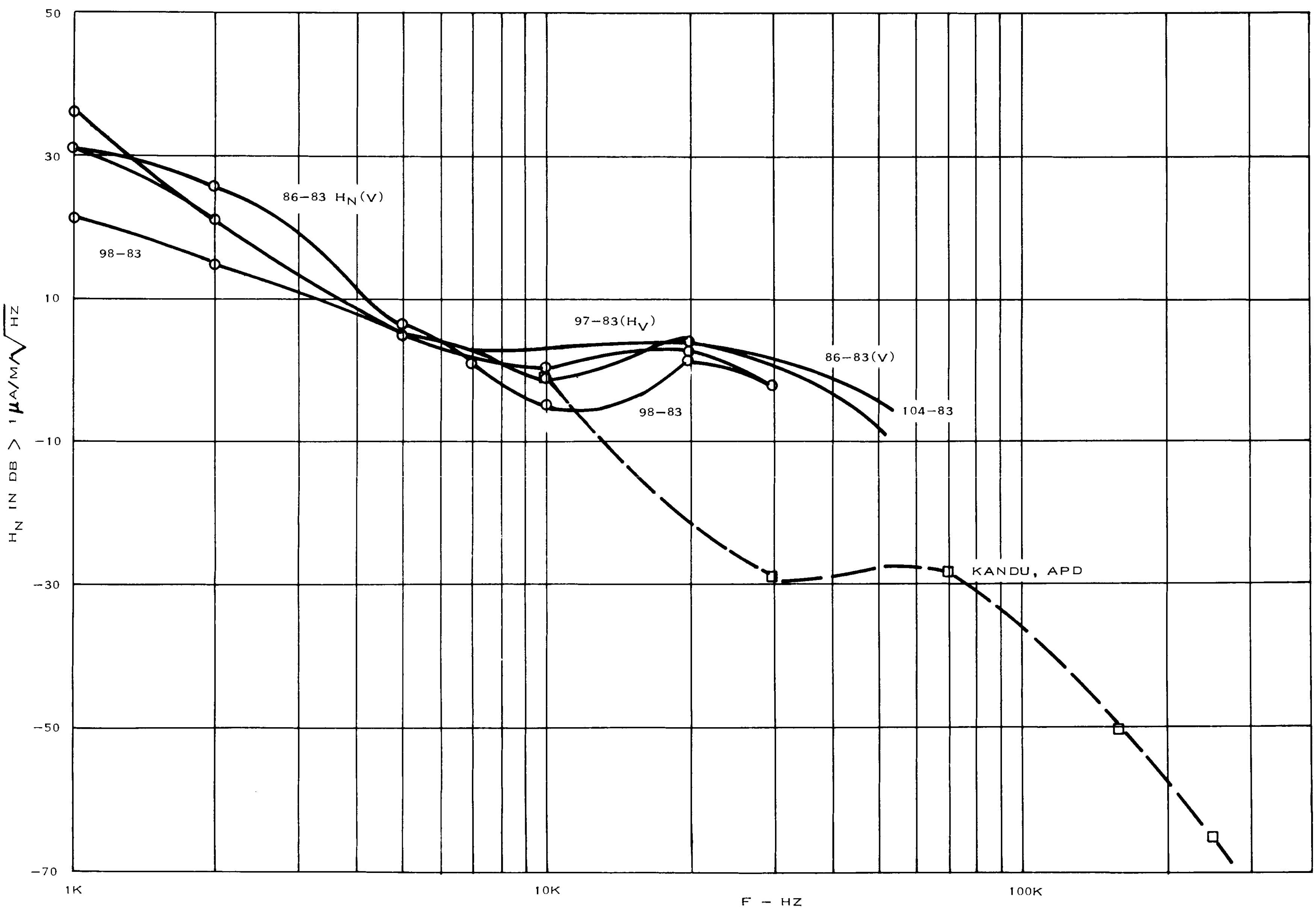

Figure 6-6. McElroy Spectrum Data/Vertical Noise Fields, Face Area, and Location No. 2.

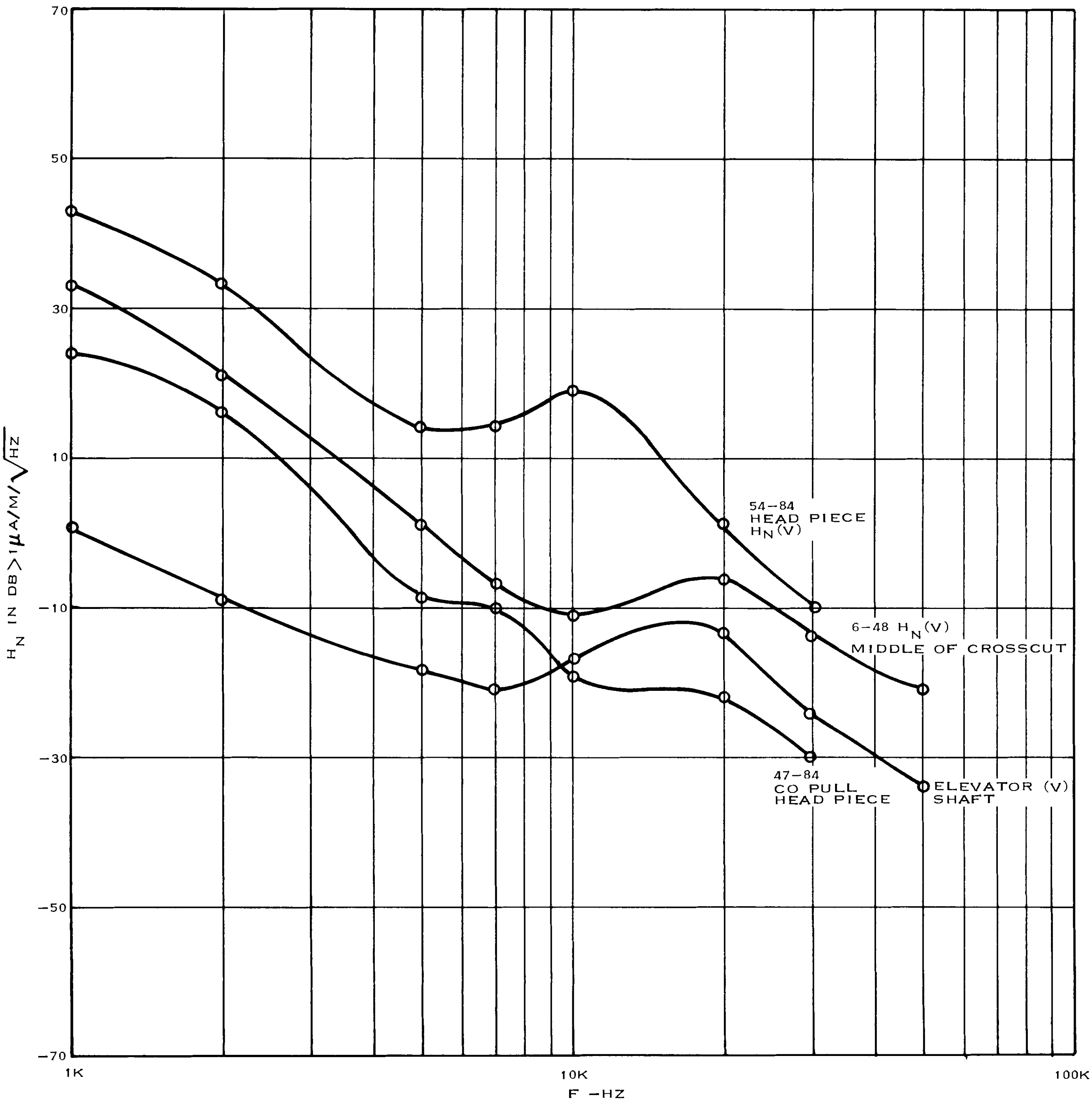

Figure 6-7. McElroy Spectrum Data/Vertical Noise Fields, Headpiece, Crosscut, and Shaft.

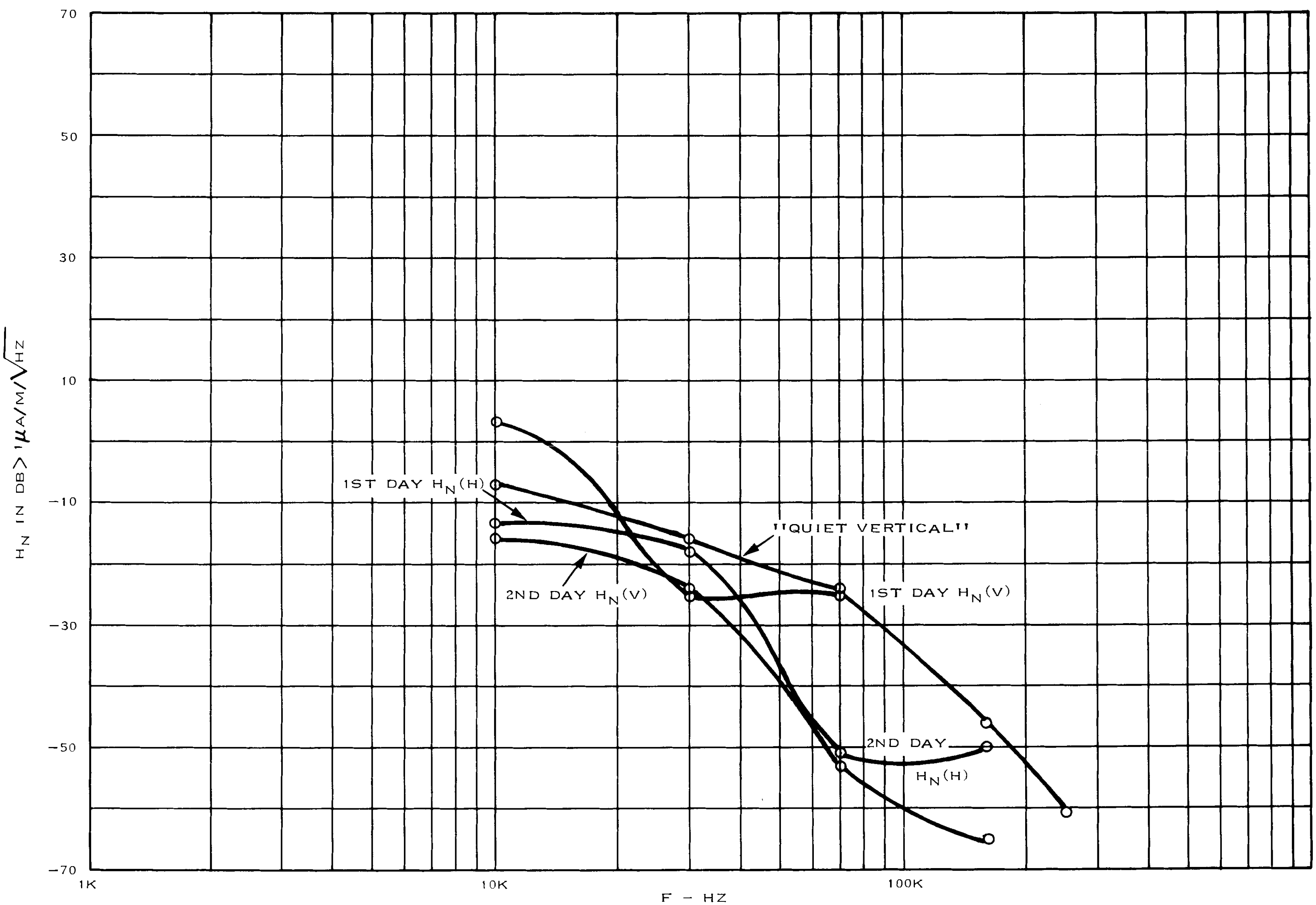

Figure 6-8. McElroy Spectrum Data/APD (RMS).

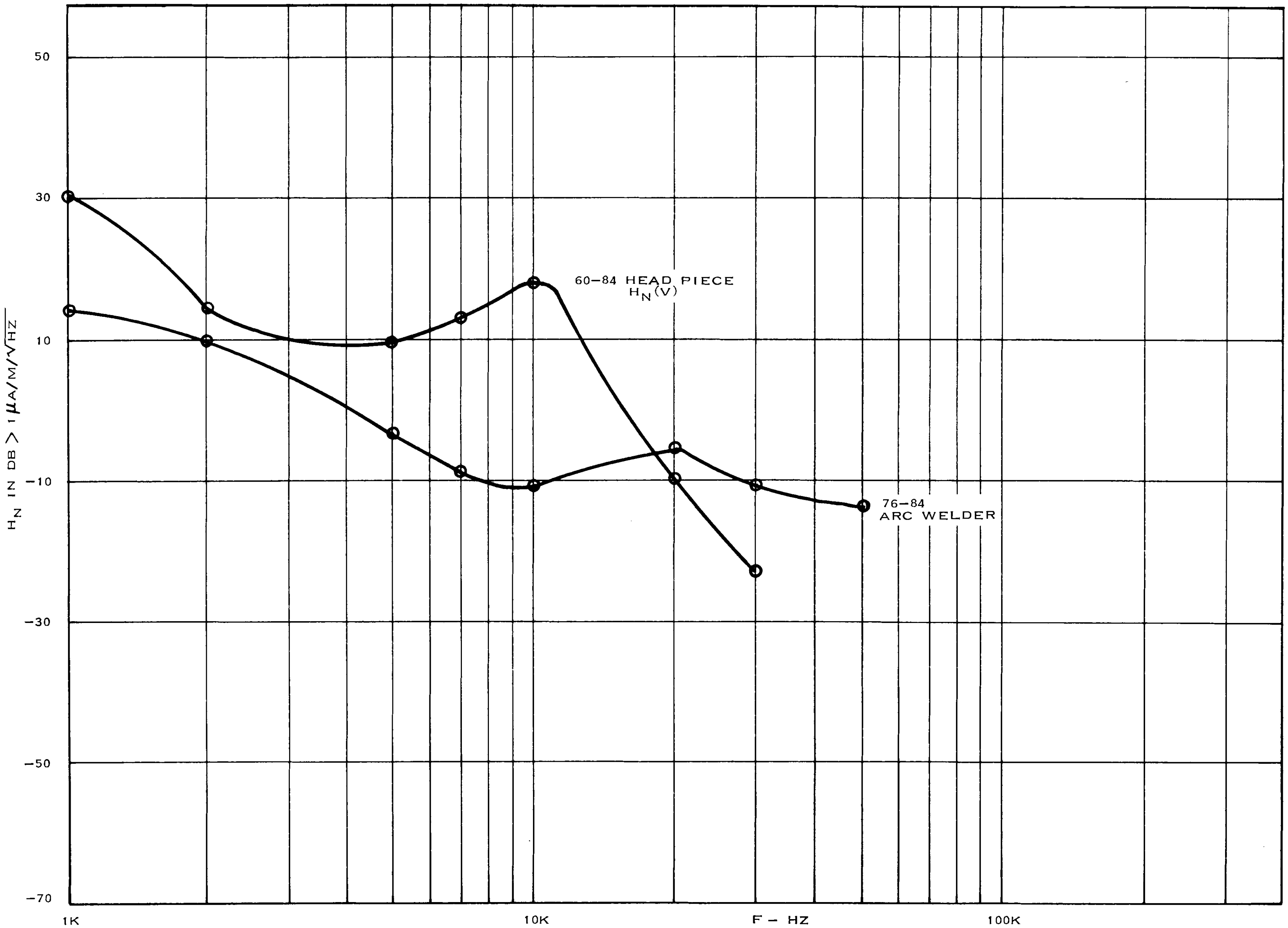

Figure 6-9. McElroy Spectrum Data/Additional Vertical Field Data.

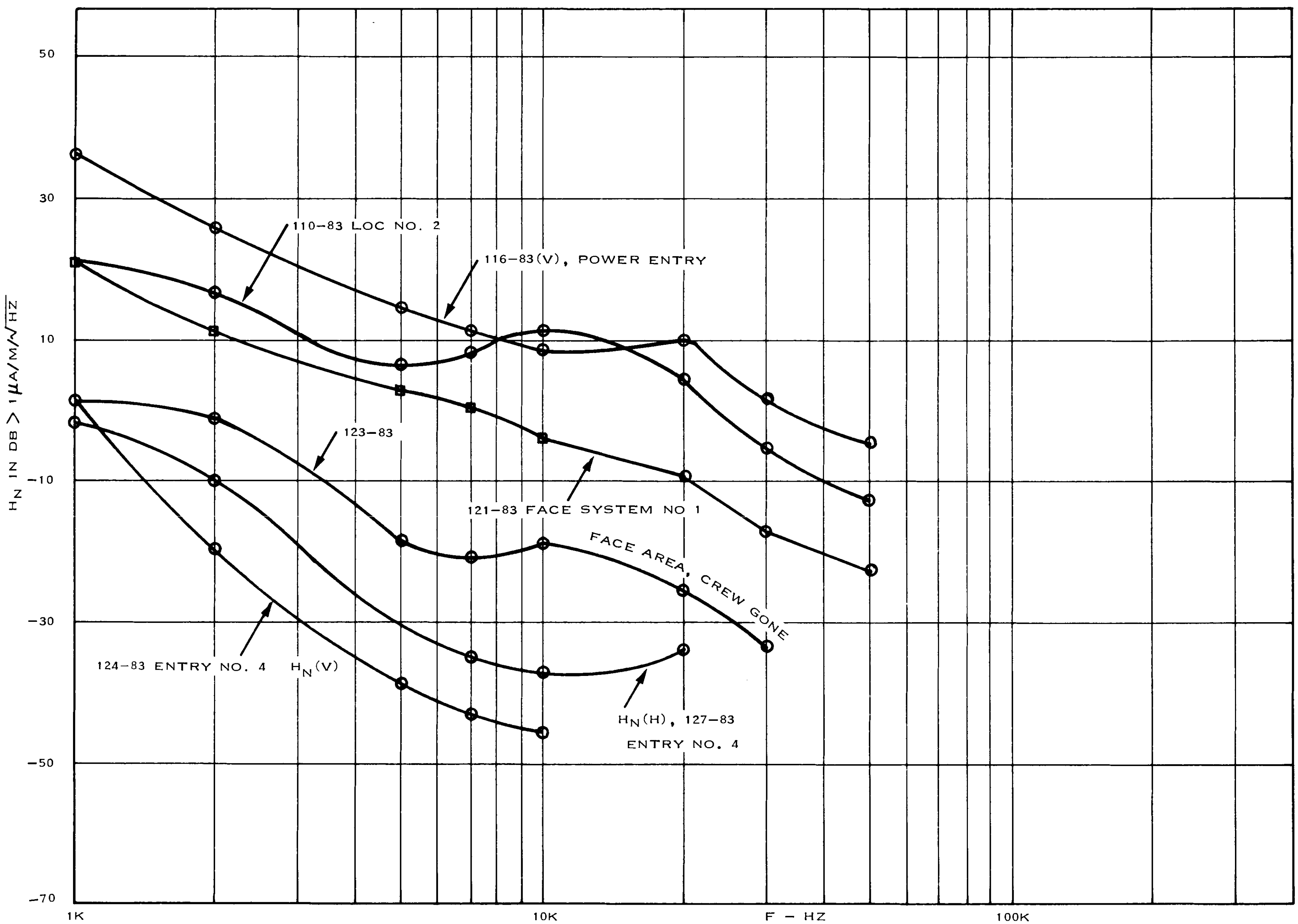

Figure 6-10. McElroy Spectrum Data/Various Locations and Components.

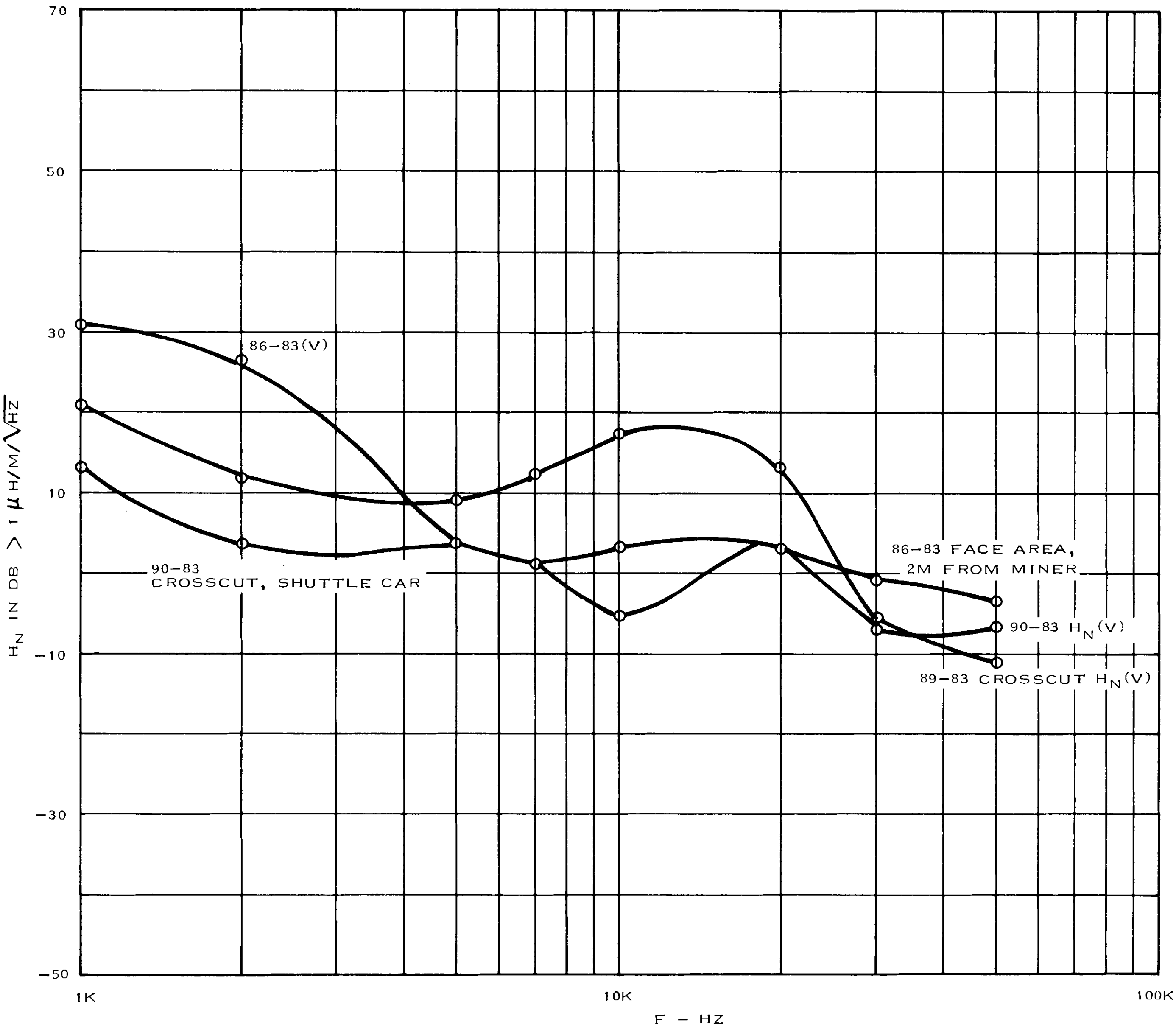

Figure 6-11. McElroy Spectrum Data/Additional High Vertical Noise Fields, Crosscuts and Face Areas.

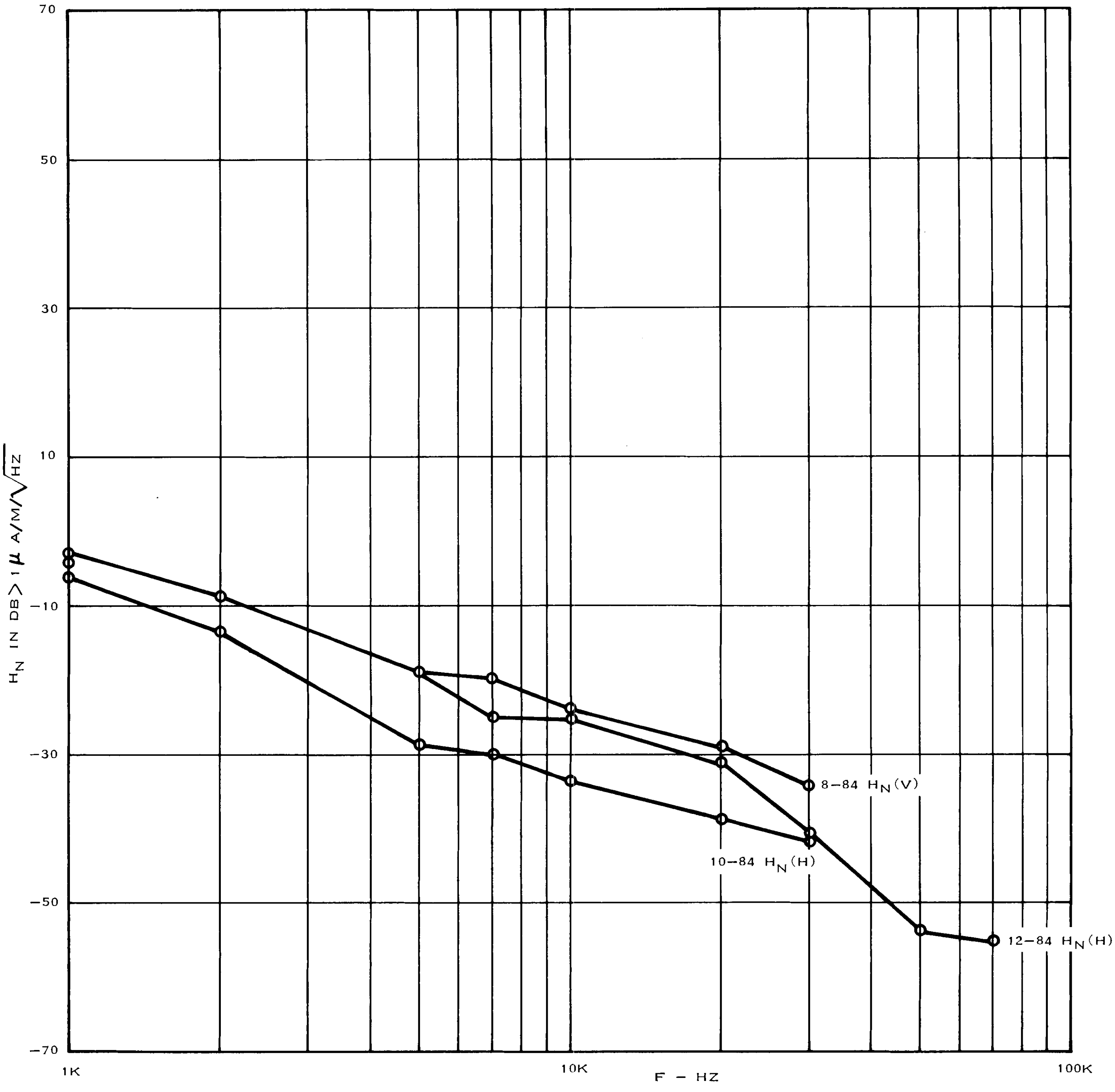

Figure 6-12. McElroy Surface Spectrum Data.

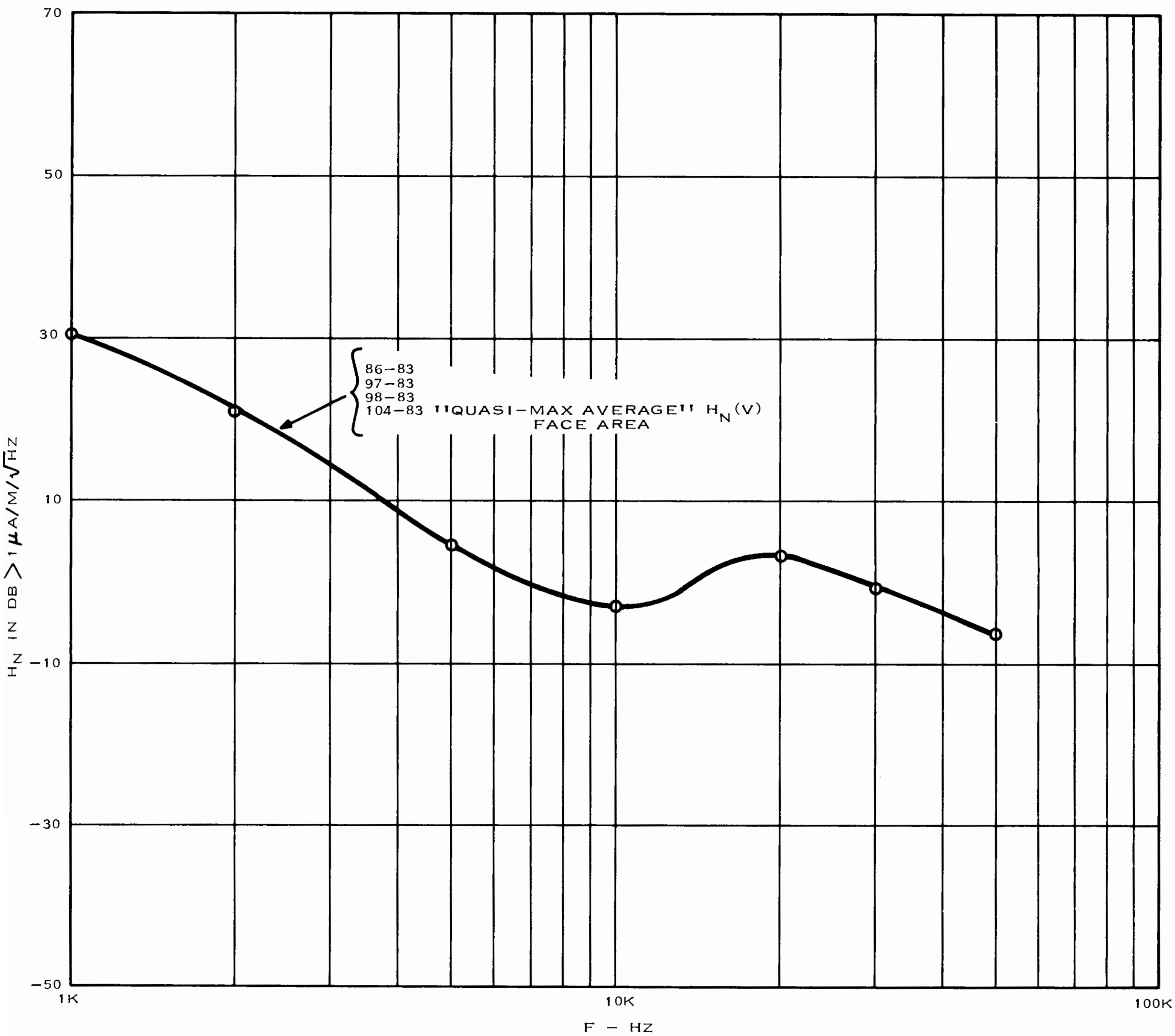

Figure 6-13. McElroy Spectrum Data.

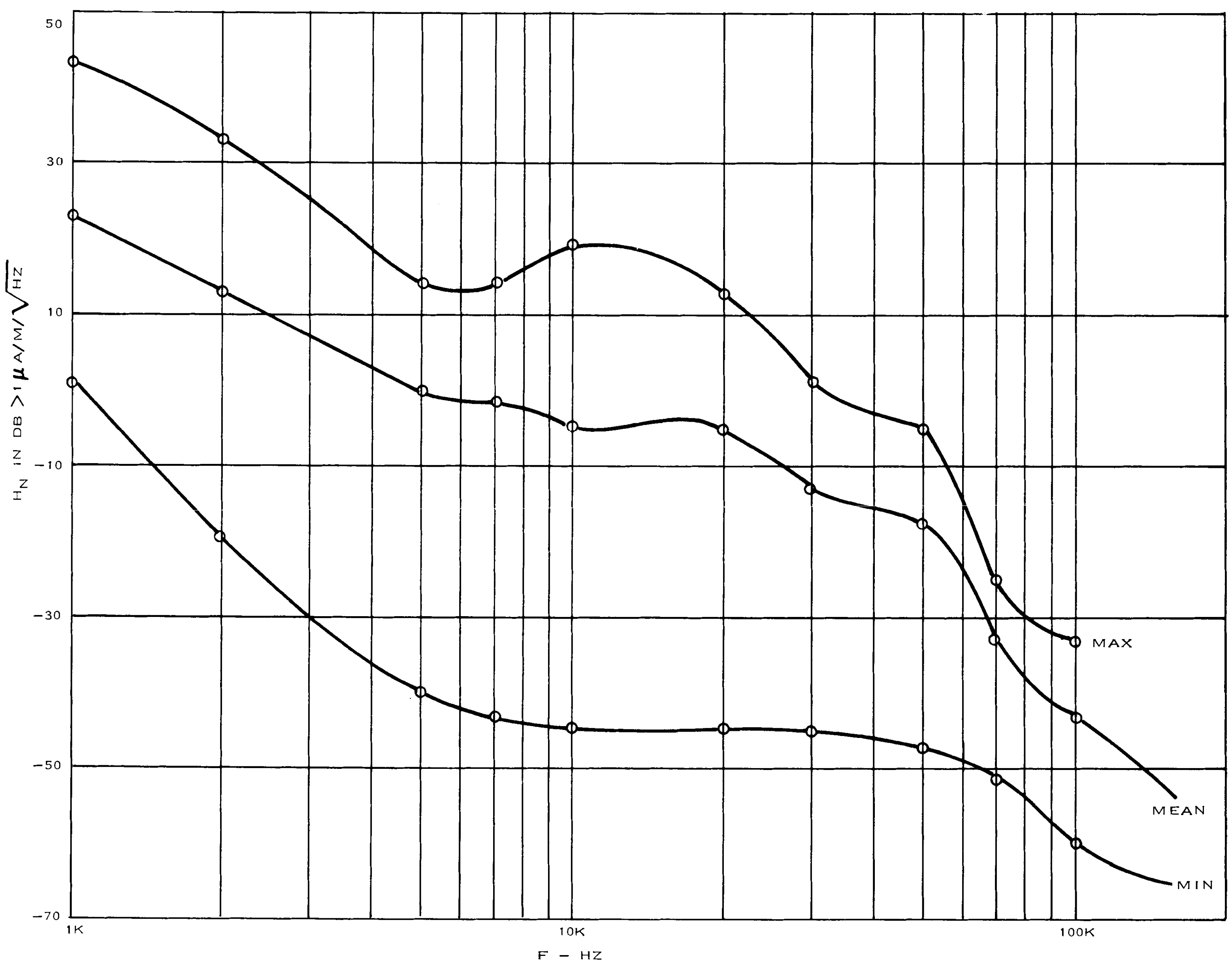

Figure 6-14. McElroy Spectrum Data/H_N Extremes.

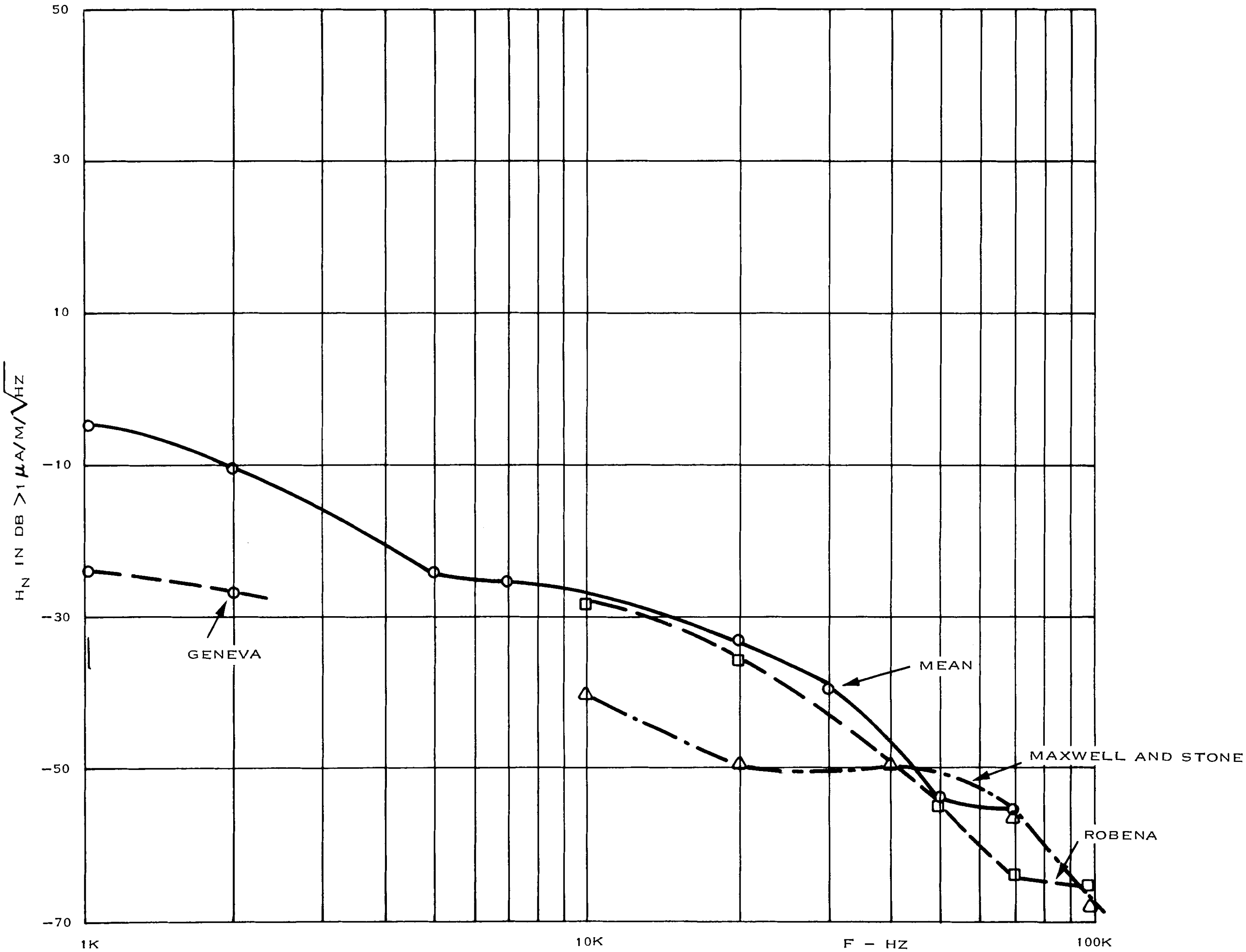

Figure 6-15. McElroy Surface Spectrum Data/Summary.

6.4 ITMAN MINE

The Itman mine is also a dc mine with underground rectification and belt and rail haulage. Summaries of the equivalent background noise fields are shown in figures 6-16 through 6-21. All magnetic field noise data correspond to the vertical component. Figure 6-16 shows noise levels for portal buses and in the Cabin Creek area. Figures 6-17 and 6-18 were recorded at the Farley Panel and Bensema's figure 39-85 (figure 6-17) is considered to be an especially good representative sample of noise 16 ft from the miner in the 10-kHz to 100-kHz region. Figure 6-19, 30 ft from miner, also exhibits very similar characteristics to the previous three figures with little variance. Figure 6-20, Kandu's APD data is also consistent with the previous data except for data from the 2nd day which exhibits anomalously high fields in the 50- to 100-kHz region. The extremes and the means of the Itman data are shown in figure 6-21. Note the small variance between the mean and the maximum. The sudden drop in the minimum level at 10 kHz is due to the inclusion of APD data.

The general conclusions which may be drawn with respect to Itman data are as follows:

a. The noise data is quite consistent with little variation in the medians.
b. The means are lower than either Robena or McElroy, particularly above 5 kHz.

Again, the roof-bolt noise was not examined, because of the lack of a calibration factor.

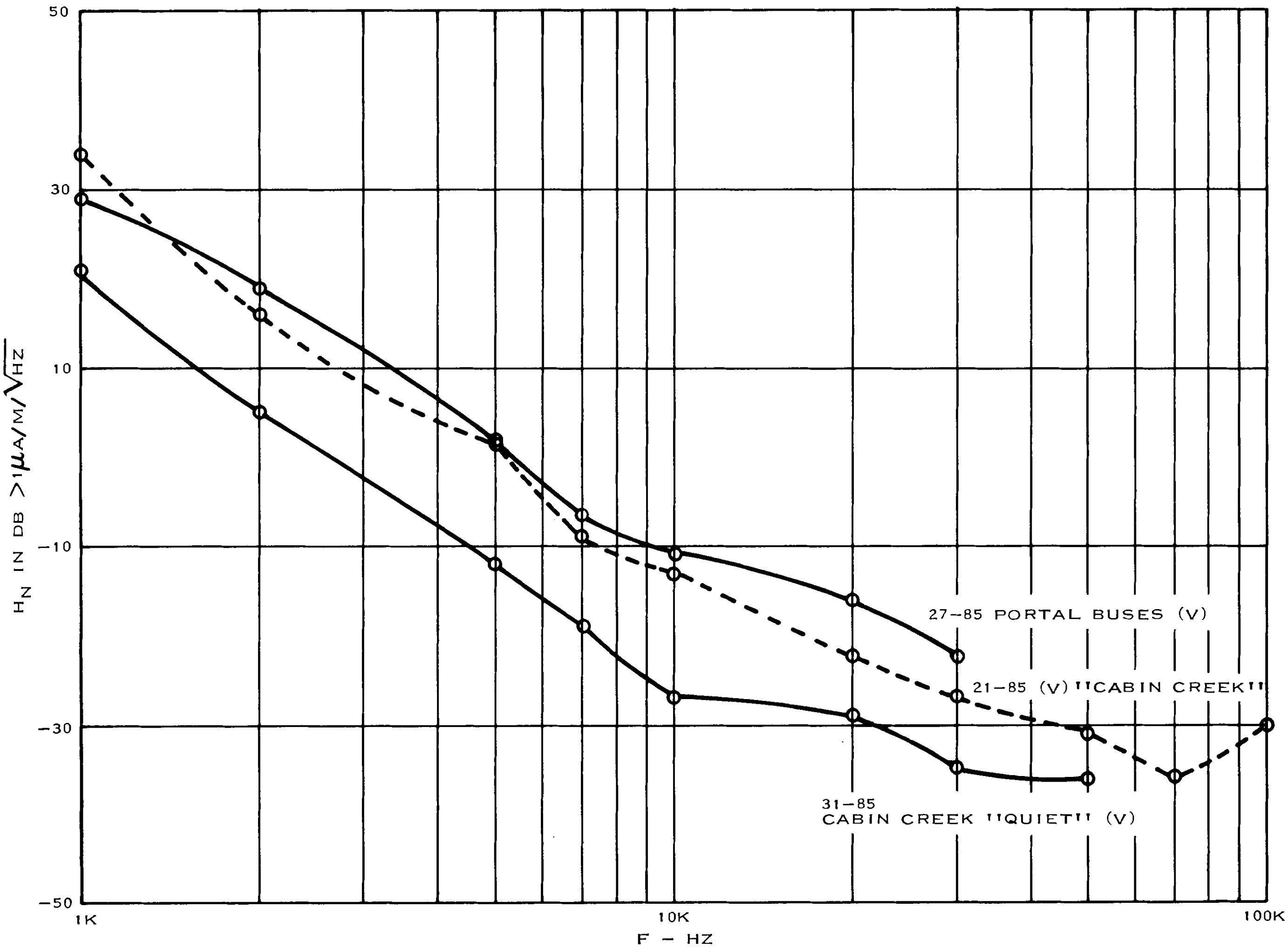

Figure 6-16. Itman Spectrum Data/Noise Levels - Portal Buses and Cabin Creek.

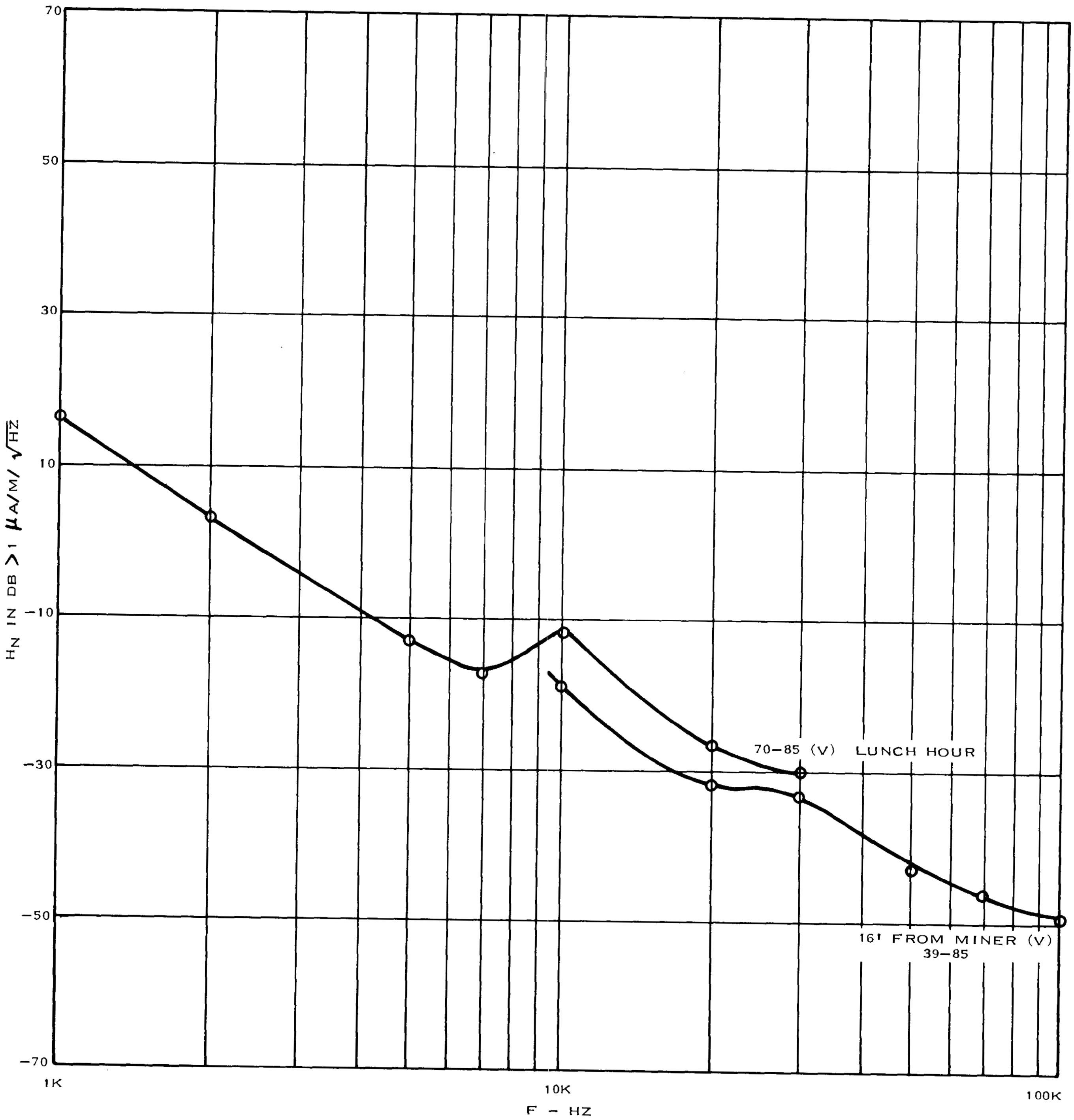

Figure 6-17. Itman Spectrum Data Farley Panel/Noise - 16 Ft From Miner.

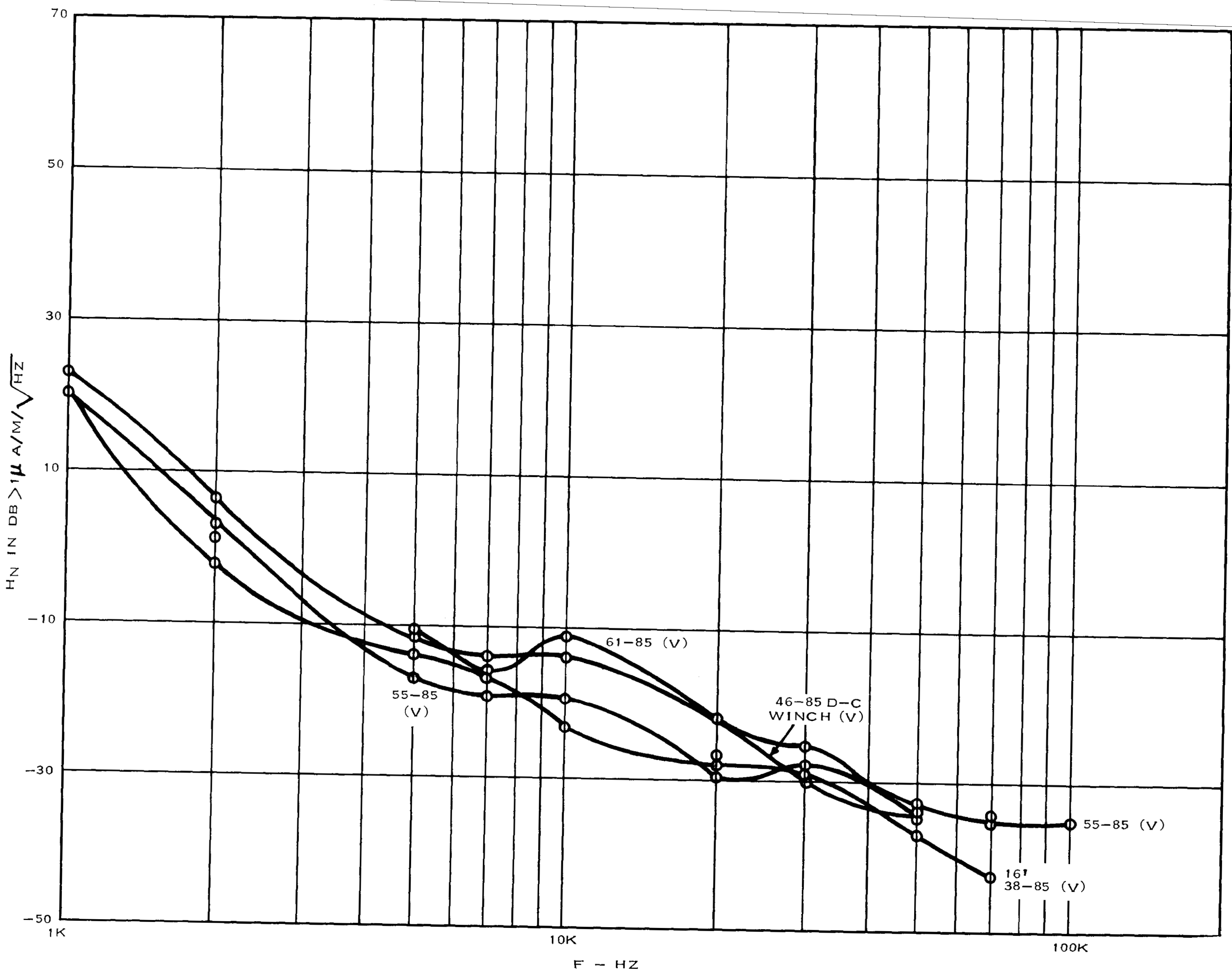

Figure 6-18. Itman Spectrum Data Farley Panel/Noise - 16 Ft From Miner - Continued.

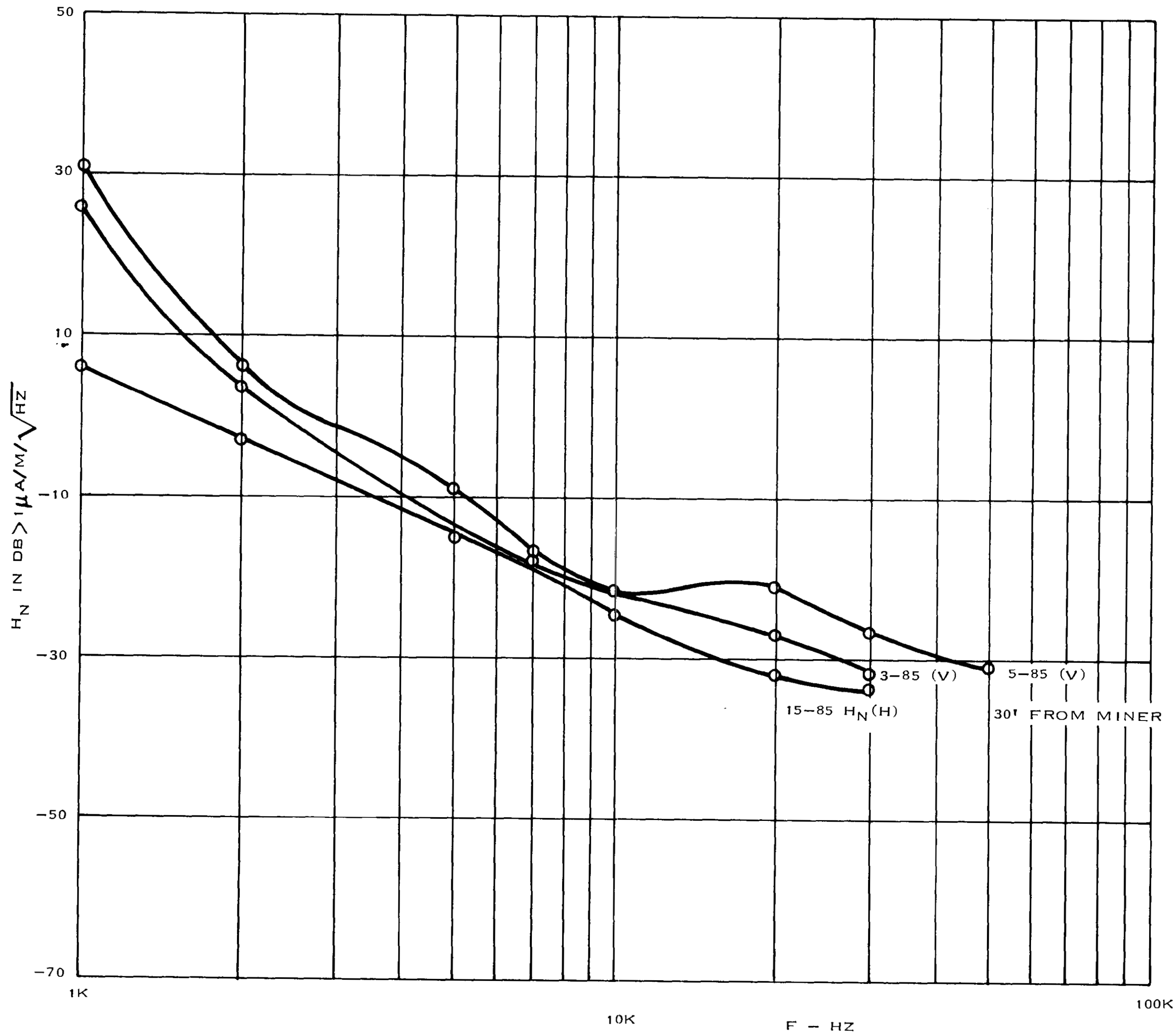

Figure 6-19. Itman Spectrum Data/30 Ft From Miner.

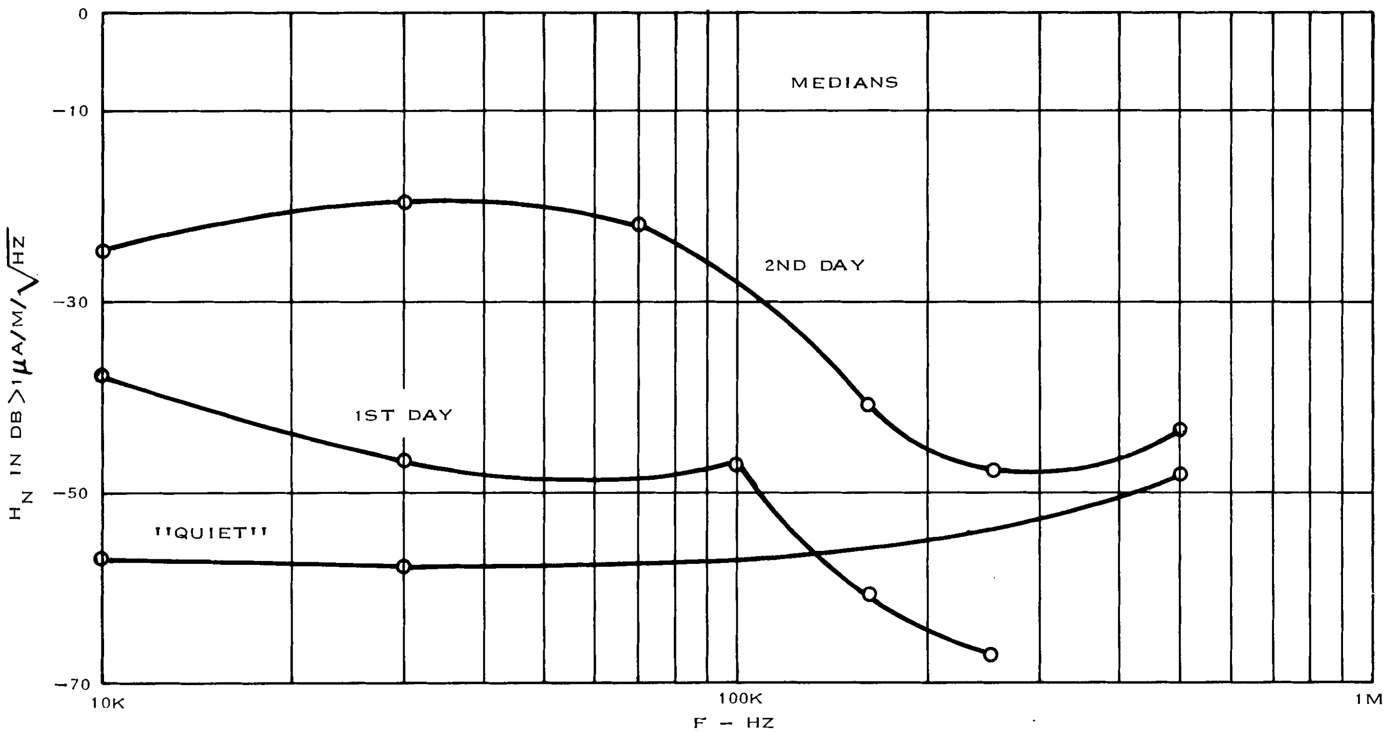

Figure 6-20. Itman Spectrum Data/APD.

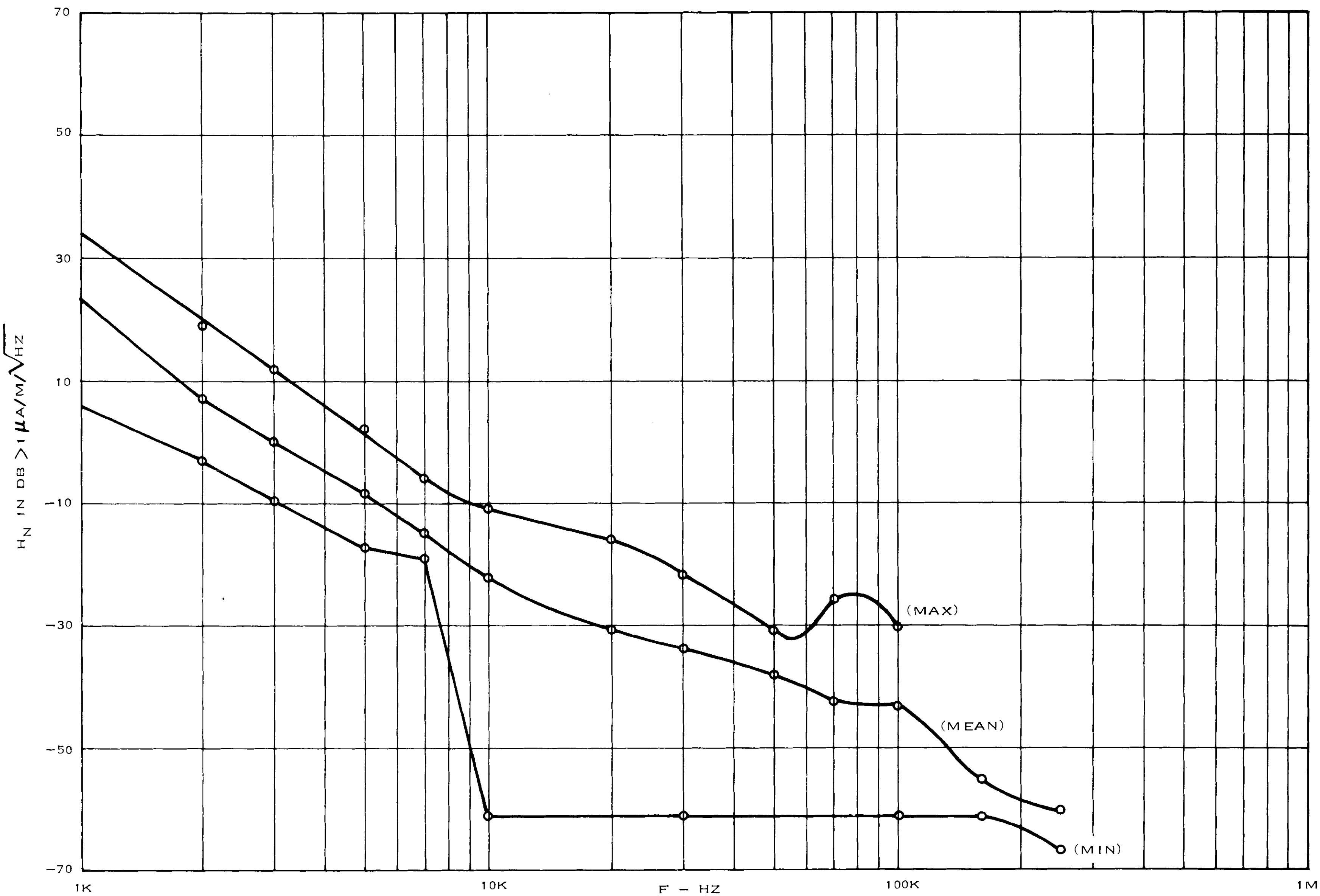

Figure 6-21. Itman Spectrum Data/Extremes.

6.5 GENEVA MINE

The Geneva mine is also a dc mine with underground rectification and belt and rail haulage. All measurements on hand for the Geneva mine are surface noise fields. Summaries of the equivalent background noise fields are shown in figures 6-22 through 6-25. These results show generally that there is a small variance in the means of the horizontal component, but very little variance in the mean of the vertical component. The surface fields measured at Geneva are the quietest of the four mines.

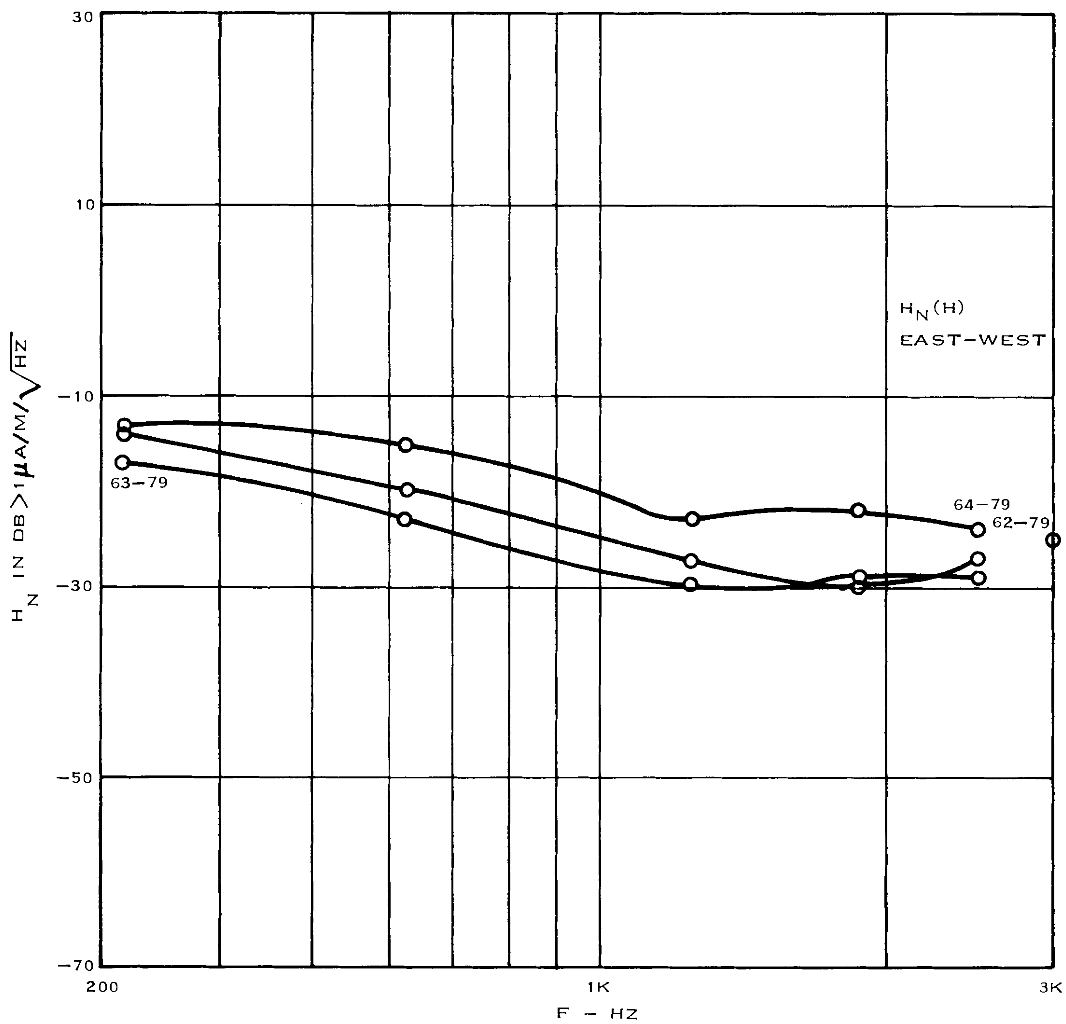

Figure 6-22. Geneva Spectrum Data/H_N(H) East-West.

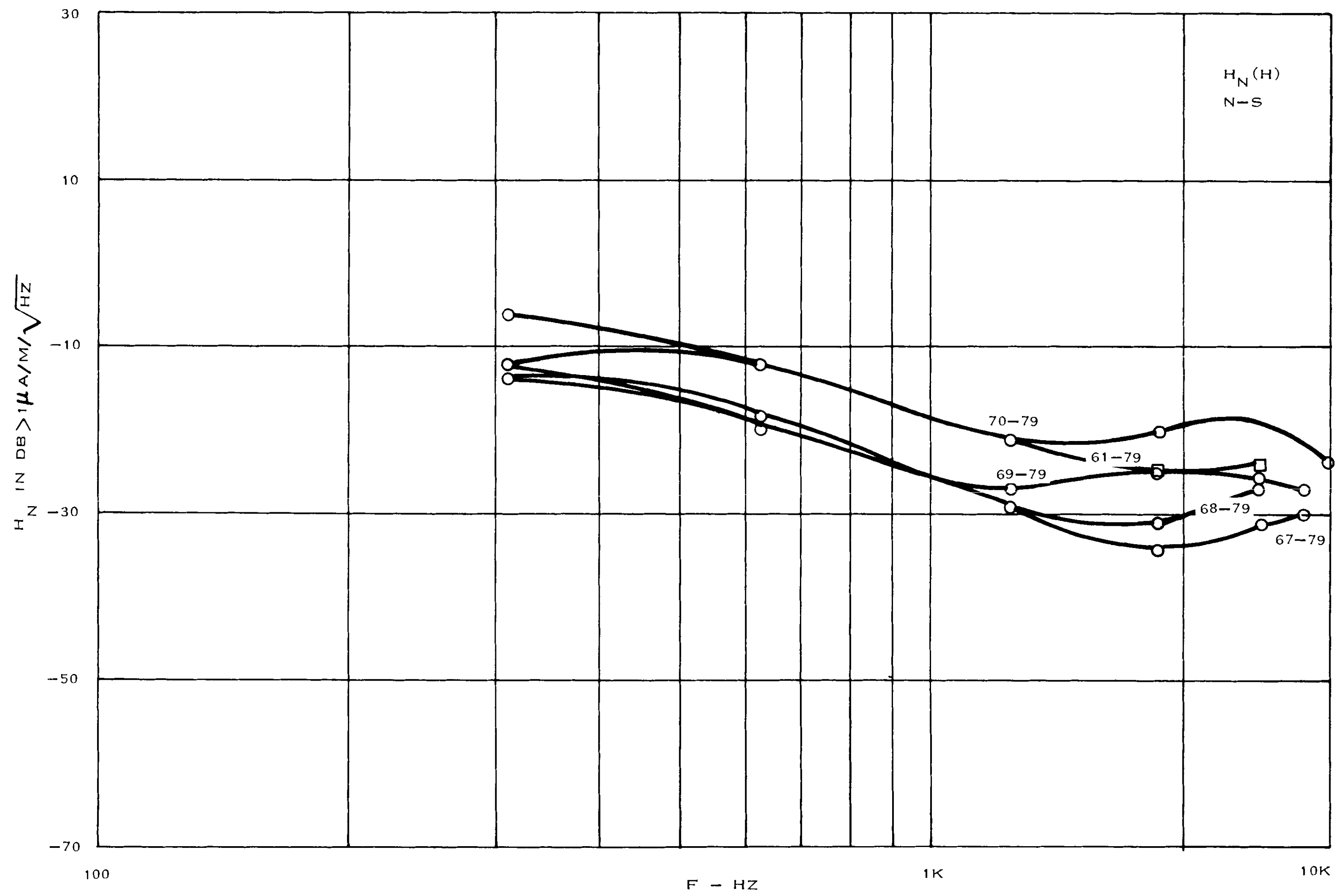

Figure 6-23. Geneva Spectrum Data/H_N(H) North-South.

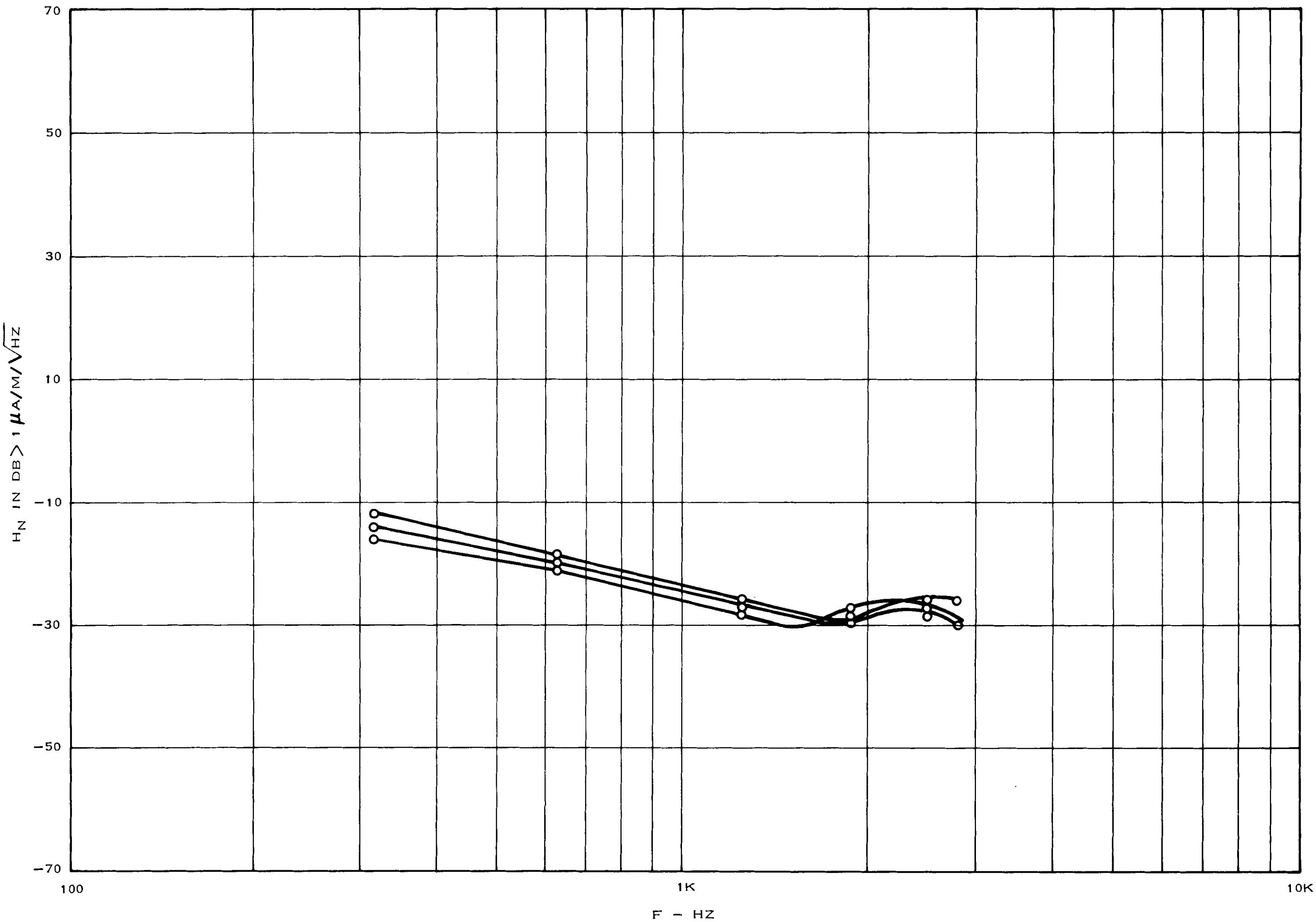

Figure 6-24. Geneva Spectrum Data/H_N(V).

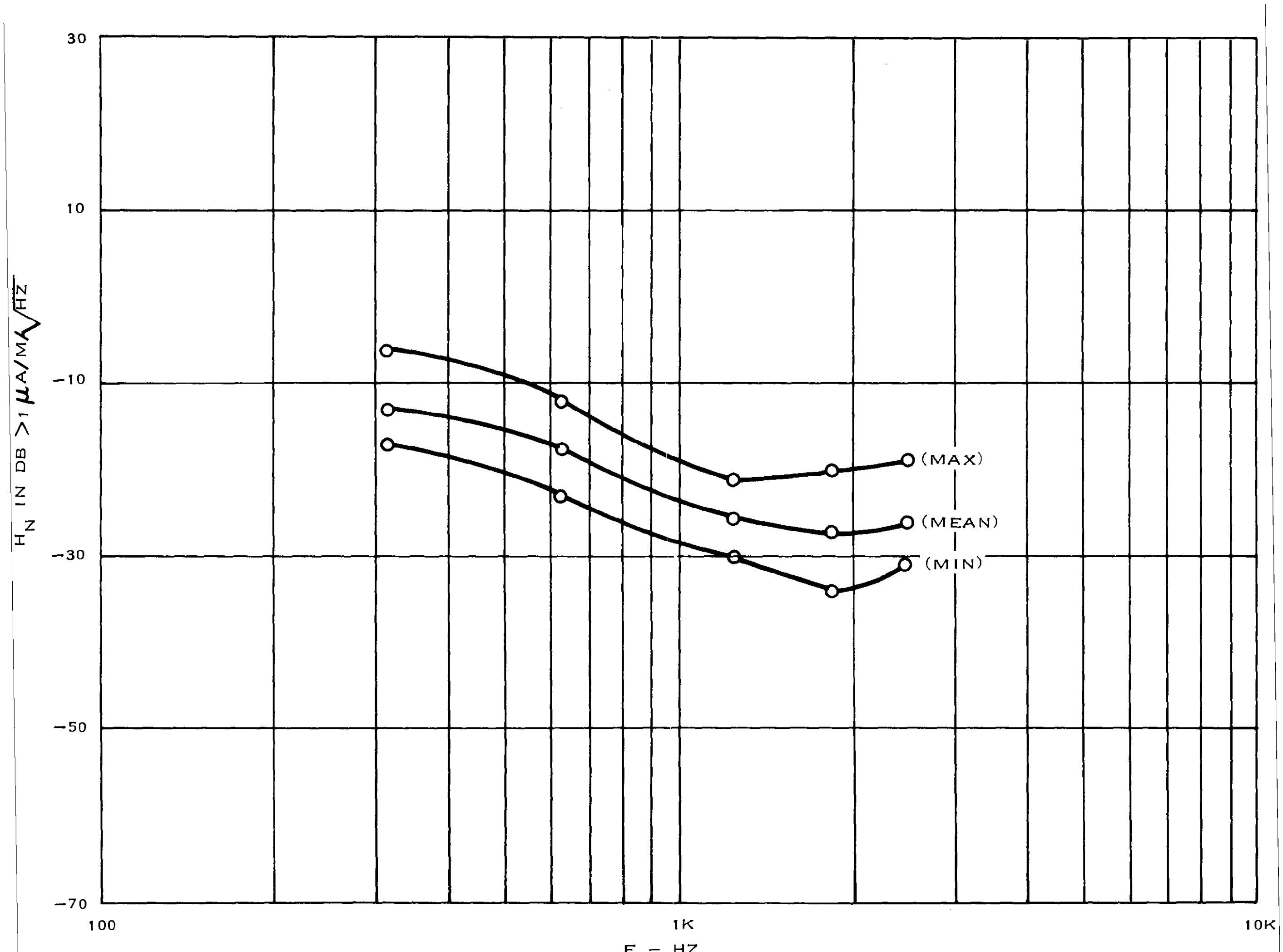

Figure 6-25. Geneva Spectrum/Data Extremes.

6.6 SUMMARY

The data from the above mentioned four mines by the NBS/ITS team is valuable data and is characteristic generally of noise conditions encountered under power-on conditions. Sufficient data has been reduced to represent various mine locations for 3 mine types, plus surface noise. Fourteen noise grades have been defined as follows:

NOISE GRADE

600 V dc mine	1.	Dc mine, maximum trolley
	2.	Dc mine, face area, mean
	3.	Dc mine, face area, minimum
Ac/dc mine	4.	Ac/dc mine, head piece, maximum
	5.	Ac/dc mine, face area, quasi-maximum
	6.	Ac/dc mine, mean noise
	7.	Ac/dc elevator shaft
	8.	Ac/dc power-on, quasi-minimum
Quieter ac/dc mine	9.	Ac/dc maximum (Itman)
	10.	Ac/dc mean
	11.	Ac/dc quasi-minimum
	12.	Surface noise - mean
	13.	Surface noise - power-on, minimum
	14.	Mean noise - all mines subsurface

The extremes and means of the four mines are shown in figure 6-26. The maximum level is that due to Robena trolley noise, while minimum levels are principally due to Itman. The mean has been determined by averaging all data and is given by the following:

$$H_N = 121.5 - 32.5 \log_{10} f \text{ (Hz)}$$

H_N is in dB>/μA/meter/ $\sqrt{\text{Hz}}$

The above relation and the application of the 14 noise grades should shed new light on optimal intramine frequencies. In the next section we shall give results of the S/N analysis for various paths and noise conditions.

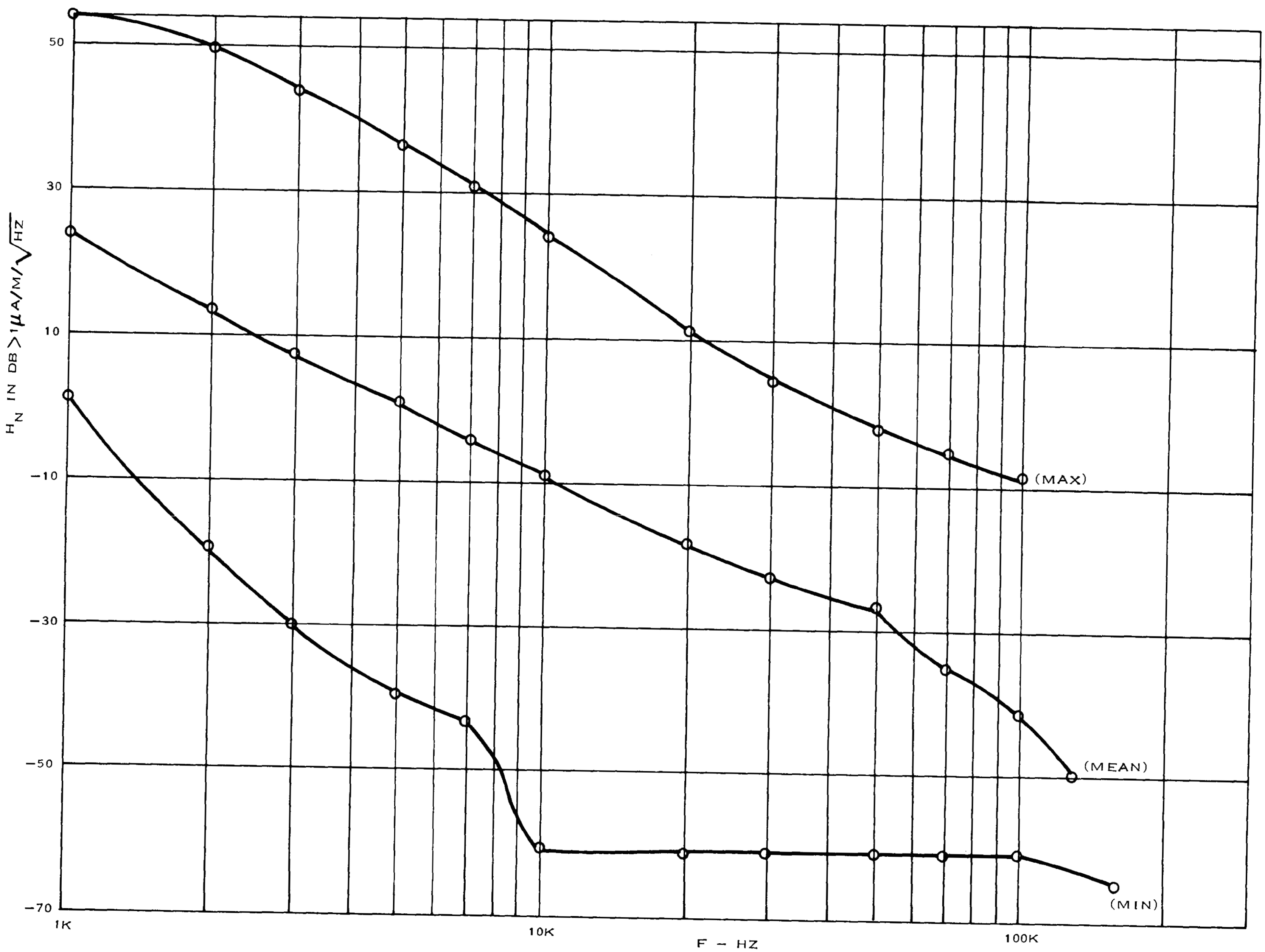

Figure 6-26. All Mines/Extremes.

6.7 RESULTS OF PROPAGATION PROGRAM ANALYSIS

Figure 6-27 shows the relationships of the electric and magnetic field components from transmit line and loop sources respectively in the spherical coordinate system for the computer printouts on the following pages.

The printouts incorporate the updated noise data with the communication propagation analysis program; for example, if we required the magnetic field component from a transmit line source at some perpendicular distance Y, from the source, we could read this component from the Hz (PHI=90) column at a specific transmitter depth and displacement. Such would be the case if the perpendicular magnetic field component were required for a receiving loop in the X-Y plane at some displacement from the transmit line source. For a horizontal surface loop to an underground horizontal loop antenna, the Hz (perpendicular field component) is taken from the Hz (VMD) column of the printout at the desired loop displacement and separation.

Although the depth of transmitter is a variable, as far as the printout is concerned, reciprocity still applies and transmit position and field sample points may be interchanged. All data is referenced to dB greater than 1 ampere/meter or 1 volt/meter.

To apply the data to a typical situation, one must first calculate a correction factor for that situation. See figure 6-27 for correction factor formulas. This factor is then added to the printout data to correct relative field intensity data to the actual power level, loop diameter, line source length or loop weight used. Subtracting the appropriate noise grade from the corrected field intensity data yields the S/N_0 ratio at the sample point in question. If it is necessary to know the open-circuit volts from a loop immersed in a known field, one can apply the equations from section 2 to the corrected field data from the computer printout.

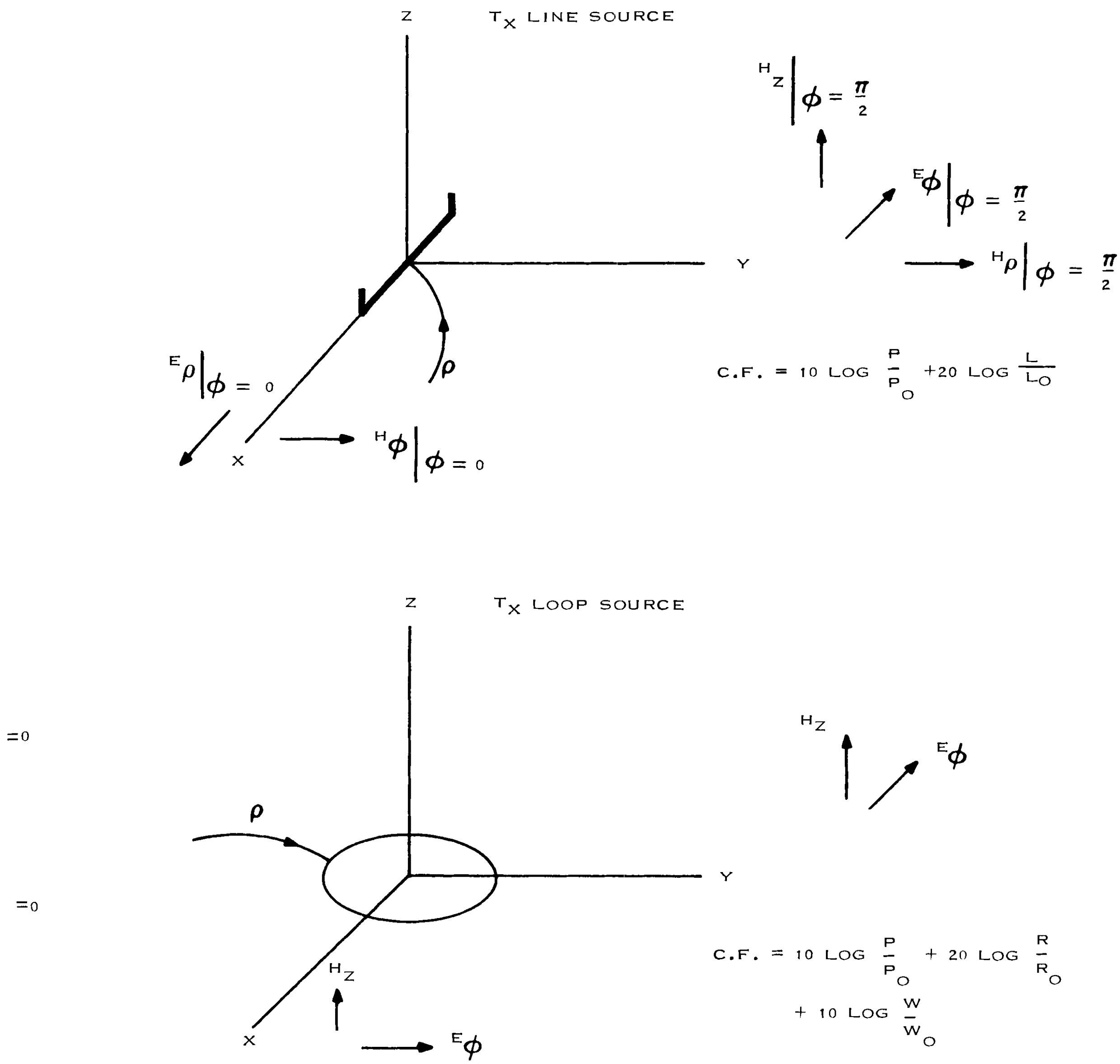

Figure 6-27. Vector Relationships of Electric and Magnetic Field Components for Printouts on Pages 6-34 Through 6-83.

FREQ= 1000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -66.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -99.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -110.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -77.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -90.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -97.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -86.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -97.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -114.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -96.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -91.00 DB .GT. 1A/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-16.07
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-16.07
25.00	.00	-29.86	-35.82	-116.99	-116.99	-47.92	-29.92	-44.04
25.00	.00	-29.86	-35.82	-116.99	-116.99	-47.92	-29.92	-44.04
50.00	.00	-48.02	-53.67	-116.99	-116.99	-60.06	-47.89	-56.12
50.00	.00	-48.02	-53.67	-116.99	-116.99	-60.06	-47.89	-56.12
100,00	.00	-66.58	-70.76	-116.99	-116.99	-72.60	-65.46	-68.42
100.00	.00	-66.58	-70.76	-116.99	-116.99	-72.60	-65.46	-68.42
200.00	.00	-86.70	-87.05	-116.99	-116.99	-86.70	-82.21	-81.63
200.00	.00	-86.70	-87.05	-116.99	-116.99	-86.70	-82.21	-81.63
400.00	.00	-111.21	-106.10	-116.99	-116.99	-105.19	-100.19	-97.88
400.00	.00	-111.21	-106.10	-116.99	-116.99	-105.19	-100.19	-97.88

FREQ= 1000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -66.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =    -99.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -110.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -77.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -90.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =    -97.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =    -86.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =    -97.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -114.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -125.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -144.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =    -96.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -91.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-48.70	-53.88	-56.73	-56.70	-80.14	-42.35	-98.56
5.00	50.00	12.10	6.08	-78.01	-77.98	-19.94	12.00	-76.38
25.00	.00	-57.03	-56.60	-59.78	-58.91	-68.96	-48.18	-85.50
25.00	50.00	-29.91	-35.82	-79.13	-78.35	-47.92	-29.90	-77.15
50.00	.00	-62.88	-62.54	-67.74	-63.77	-69.14	-63.73	-82.16
50.00	50.00	-48.19	-53.68	-82.48	-79.42	-60.03	-47.77	-78.19
100.00	.00	-67.25	-73.76	-86.94	-72.92	-75.37	-74.00	-82.12
100.00	50.00	-65.89	-70.78	-94.97	-82.62	-72.43	-65.11	-80.53
200.00	.00	-81.01	-87.85	-95.21	-84.57	-86.59	-83.96	-86.83
200.00	50.00	-82.75	-86.63	-101.51	-89.41	-85.91	-82.01	-86.17
400.00	.00	-103.99	-103.71	-104.24	-97.95	-102.50	-98.65	-102.14
400.00	50.00	-104.20	-103.60	-107.24	-100.44	-102.64	-99.26	-101.76

FREQ= 1000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -66.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -99.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -110.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -77.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -90.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -97.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -86.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -97.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -114.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -96.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -91.00 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-65.34	-70.91	-68.90	-68.89	-98.46	-60.72	-106.77
5.00	100.00	12.10	6.08	-91.33	-91.32	-19.94	12.00	-76.37
25.00	.00	-67.47	-71.61	-69.81	-69.54	-85.27	-62.31	-93.03
25.00	100.00	-29.87	-35.82	-91.63	-91.43	-47.92	-29.90	-77.14
50.00	.00	-74.37	-73.52	-72.42	-71.35	-81.46	-66.99	-88.14
50.00	100.00	-48.07	-53.65	-92.58	-91.76	-60.05	-47.75	-78.19
100.00	.00	-83.21	-78.96	-80.53	-76.50	-81.92	-83.32	-85.73
100.00	100.00	-66.81	-70.65	-96.18	-92.99	-72.53	-64.95	-80.53
200.00	.00	-86.97	-89.34	-101.28	-86.32	-89.20	-89.21	-88.66
200.00	100.00	-86.14	-86.45	-109.65	-96.76	-86.27	-81.64	-86.17
400.00	.00	-105.27	-104.44	-108.21	-99.90	-103.67	-100.31	-103.25
400.00	100.00	-106.71	-103.77	-116.09	-105.53	-103.34	-99.87	-101.77

FREQ= 1000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -66.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =    -99.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -110.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -77.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -90.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =    -97.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =    -86.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =    -97.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -114.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -125.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -144.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =    -96.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -91.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-82.14	-86.62	-82.70	-82.70	-118.16	-80.78	-118.23
5.00	200.00	12.10	6.08	-108.93	-108.93	-19.94	12.00	-76.37
25.00	.00	-82.61	-86.79	-82.96	-82.89	-104.41	-81.18	-104.40
25.00	200.00	-29.86	-35.82	-109.03	-108.97	-47.92	-29.90	-77.14
50.00	.00	-84.06	-87.31	-83.76	-83.46	-99.07	-82.51	-98.86
50.00	200.00	-48.02	-53.66	-109.32	-109.09	-60.06	-47.74	-78.19
100.00	.00	-89.60	-89.18	-86.70	-85.51	-95.52	-87.71	-94.68
100.00	200.00	-66.61	-70.73	-110.49	-109.55	-72.60	-64.84	-80.53
200.00	.00	-105.68	-94.75	-96.09	-91.49	-96.97	-102.13	-94.84
200.00	200.00	-86.89	-86.88	-114.98	-111.28	-86.65	-81.18	-86.17
400.00	.00	-112.27	-107.03	-115.74	-103.72	-107.36	-105.37	-107.68
400.00	200.00	-110.79	-104.99	-130.69	-116.84	-104.62	-99.91	-101.77

FREQ= 1000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =     -66.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =     -99.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =    -110.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =     -77.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =     -90.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =     -97.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =    -119.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =    -119.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =     -86.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =     -97.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =    -114.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =    -125.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =    -144.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =     -96.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =     -91.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-92.73	-96.42	-92.50	-92.50	-131.31	-94.28	-128.55
5.00	300.00	12.10	6.08	-123.43	-123.42	-19.94	12.00	-76.37
25.00	.00	-92.94	-96.50	-92.64	-92.60	-117.45	-94.41	-114.79
25.00	300.00	-29.86	-35.82	-123.48	-123.45	-47.92	-29.90	-77.14
50.00	.00	-93.57	-96.76	-93.04	-92.89	-111.78	-95.00	-109.12
50.00	300.00	-48.02	-53.67	-123.64	-123.52	-60.06	-47.74	-78.19
100.00	.00	-96.04	-97.76	-94.62	-94.03	-107.09	-97.53	-104.39
100.00	300.00	-66.58	-70.76	-124.27	-123.80	-72.61	-64.83	-80.53
200.00	.00	-105.17	-101.24	-100.23	-97.88	-105.72	-106.89	-103.23
200.00	300.00	-86.68	-87.07	-126.78	-124.88	-86.70	-81.12	-86.17
400.00	.00	-126.72	-110.92	-116.58	-107.98	-112.43	-112.12	-115.34
400.00	300.00	-111.29	-105.98	-136.23	-128.77	-105.15	-100.05	-101.77

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -71.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -103.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -128.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -87.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -99.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -129.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -139.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -100.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -113.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -123.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -130.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -147.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -95.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-10.05
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-10.05
25.00	.00	-29.89	-35.76	-116.99	-116.99	-47.95	-29.89	-38.03
25.00	.00	-29.89	-35.76	-116.99	-116.99	-47.95	-29.89	-38.03
50.00	.00	-48.17	-53.33	-116.99	-116.99	-60.22	-47.73	-50.18
50.00	.00	-48.17	-53.33	-116.99	-116.99	-60.22	-47.73	-50.18
100.00	.00	-67.29	-69.85	-116.99	-116.99	-73.31	-64.88	-62.78
100.00	.00	-67.29	-69.85	-116.99	-116.99	-73.31	-64.88	-62.78
200.00	.00	-89.10	-86.84	-116.99	-116.99	-89.10	-81.70	-77.11
200.00	.00	-89.10	-86.84	-116.99	-116.99	-89.10	-81.70	-77.11
400.00	.00	-117.72	-109.68	-116.99	-116.99	-111.70	-102.55	-96.49
400.00	.00	-117.72	-109.68	-116.99	-116.99	-111.70	-102.55	-96.49

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -71.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -103.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -128.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -87.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -99.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -129.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -139.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -100.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -113.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -123.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -130.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -147.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -95.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-47.95	-53.59	-56.71	-56.67	-80.25	-42.51	-87.41
5.00	50.00	12.10	6.08	-78.37	-78.34	-19.94	12.00	-64.41
25.00	.00	-57.52	-56.23	-60.04	-58.99	-69.10	-48.42	-74.51
25.00	50.00	-29.94	-35.76	-79.53	-78.74	-47.94	-29.84	-65.53
50.00	.00	-64.07	-61.95	-67.90	-63.99	-69.37	-64.36	-71.53
50.00	50.00	-48.37	-53.31	-82.95	-79.86	-60.17	-47.47	-67.08
100.00	.00	-67.40	-72.63	-88.21	-73.34	-75.97	-72.46	-72.59
100.00	50.00	-66.64	-69.63	-95.72	-83.25	-73.02	-64.38	-70.67
200.00	.00	-83.71	-86.63	-95.61	-85.64	-88.39	-83.40	-80.71
200.00	50.00	-84.91	-85.54	-102.48	-90.73	-87.84	-81.64	-79.79
400.00	.00	-107.30	-104.50	-106.91	-100.89	-107.70	-96.33	-115.17
400.00	50.00	-109.56	-105.45	-110.69	-103.95	-108.15	-98.50	-113.86

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -71.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -103.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -87.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -99.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -107.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -139.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -100.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -113.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -107.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -95.00 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-64.73	-69.83	-69.49	-69.48	-99.01	-61.42	-96.83
5.00	100.00	12.10	6.08	-93.29	-93.29	-19.94	12.00	-64.40
25.00	.00	-66.72	-70.49	-70.44	-70.16	-85.85	-63.06	-83.24
25.00	100.00	-29.89	-35.75	-93.63	-93.41	-47.95	-29.84	-65.52
50.00	.00	-72.84	-72.33	-73.17	-72.05	-82.14	-67.95	-78.61
50.00	100.00	-48.23	-53.29	-94.66	-93.79	-60.21	-47.42	-67.08
100.00	.00	-85.01	-77.64	-81.75	-77.50	-82.96	-84.09	-77.14
100.00	100.00	-67.53	-69.66	-98.60	-95.21	-73.23	-64.06	-70.67
200.00	.00	-89.70	-88.45	-102.44	-88.22	-91.43	-88.24	-83.32
200.00	100.00	-88.64	-85.88	-113.17	-99.66	-88.55	-81.18	-79.79
400.00	.00	-110.03	-106.21	-110.47	-103.94	-109.27	-98.81	-120.03
400.00	100.00	-112.89	-106.31	-119.51	-110.59	-109.22	-101.18	-113.92

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =     -71.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =    -103.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =    -128.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =     -87.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =     -99.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =    -107.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =    -129.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =    -139.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =    -100.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =    -113.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =    -123.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =    -130.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =    -147.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =    -107.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =     -95.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-82.06	-85.87	-84.94	-84.94	-120.26	-83.16	-111.72
5.00	200.00	12.10	6.08	-115.02	-115.02	-19.94	12.00	-64.40
25.00	.00	-82.54	-86.06	-85.23	-85.15	-106.53	-83.54	-98.06
25.00	200.00	-29.89	-35.76	-115.14	-115.07	-47.95	-29.83	-65.52
50.00	.00	-83.95	-86.62	-86.12	-85.79	-101.26	-84.93	-92.73
50.00	200.00	-48.17	-53.33	-115.48	-115.22	-60.22	-47.40	-67.08
100.00	.00	-89.28	-88.68	-89.41	-88.10	-98.01	-90.50	-89.34
100.00	200.00	-67.28	-69.86	-116.86	-115.81	-73.31	-63.93	-70.67
200.00	.00	-108.73	-95.04	-100.06	-94.96	-100.46	-101.51	-92.73
200.00	200.00	-89.15	-86.80	-122.18	-118.03	-89.09	-80.88	-79.79
400.00	.00	-118.16	-110.09	-118.49	-109.63	-113.88	-105.08	-123.66
400.00	200.00	-117.15	-108.74	-138.33	-125.33	-111.27	-102.91	-113.95

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -71.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -103.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -87.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -99.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -107.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -139.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -100.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -113.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -107.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -95.00 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-94.31	-97.38	-96.74	-96.73	-135.34	-98.66	-127.39
5.00	300.00	12.10	6.08	-133.91	-133.91	-19.94	12.00	-64.41
25.00	.00	-94.52	-97.48	-96.89	-96.85	-121.49	-98.72	-113.88
25.00	300.00	-29.89	-35.76	-133.98	-133.94	-47.95	-29.83	-65.52
50.00	.00	-95.18	-97.79	-97.36	-97.19	-115.88	-99.28	-108.45
50.00	300.00	-48.17	-53.33	-134.17	-134.04	-60.22	-47.40	-67.08
100.00	.00	-97.75	-98.98	-99.20	-98.53	-111.42	-101.92	-104.66
100.00	300.00	-67.29	-69.86	-134.95	-134.41	-73.31	-63.93	-70.67
200.00	.00	-107.30	-103.19	-105.80	-103.12	-110.86	-110.84	-107.94
200.00	300.00	-89.06	-86.86	-138.03	-135.86	-89.10	-80.90	-79.79
400.00	.00	-133.53	-115.35	-123.99	-115.54	-120.21	-112.99	-118.41
400.00	300.00	-117.61	-109.77	-149.53	-141.13	-111.74	-103.66	-113.95

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -82.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -113.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -106.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -115.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -118.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-2.09
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-2.09
25.00	.00	-29.99	-35.52	-116.99	-116.99	-48.05	-29.79	-30.12
25.00	.00	-29.99	-35.52	-116.99	-116.99	-48.05	-29.79	-30.12
50.00	.00	-48.70	-52.43	-116.99	-116.99	-60.74	-47.24	-42.49
50.00	.00	-48.70	-52.43	-116.99	-116.99	-60.74	-47.24	-42.49
100.00	.00	-69.27	-68.82	-116.99	-116.99	-75.29	-63.93	-55.99
100.00	.00	-69.27	-68.82	-116.99	-116.99	-75.29	-63.93	-55.99
200.00	.00	-94.92	-88.88	-116.99	-116.99	-94.92	-82.62	-73.10
200.00	.00	-94.92	-88.88	-116.99	-116.99	-94.92	-82.62	-73.10
400.00	.00	-132.12	-120.12	-116.99	-116.99	-126.10	-111.05	-98.28
400.00	.00	-132.12	-120.12	-116.99	-116.99	-126.10	-111.05	-98.28

FREQ= 2000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -71.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -103.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -128.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -87.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -99.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -129.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -139.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -100.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -113.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -123.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -130.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -147.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -107.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -95.00 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-94.31	-97.38	-96.74	-96.73	-135.34	-98.66	-127.39
5.00	300.00	12.10	6.08	-133.91	-133.91	-19.94	12.00	-64.41
25.00	.00	-94.52	-97.48	-96.89	-96.85	-121.49	-98.72	-113.88
25.00	300.00	-29.89	-35.76	-133.98	-133.94	-47.95	-29.83	-65.52
50.00	.00	-95.18	-97.79	-97.36	-97.19	-115.88	-99.28	-108.45
50.00	300.00	-48.17	-53.33	-134.17	-134.04	-60.22	-47.40	-67.08
100.00	.00	-97.75	-98.98	-99.20	-98.53	-111.42	-101.92	-104.66
100.00	300.00	-67.29	-69.86	-134.95	-134.41	-73.31	-63.93	-70.67
200.00	.00	-107.30	-103.19	-105.80	-103.12	-110.86	-110.84	-107.94
200.00	300.00	-89.06	-86.86	-138.03	-135.86	-89.10	-80.90	-79.79
400.00	.00	-133.53	-115.35	-123.99	-115.54	-120.21	-112.99	-118.41
400.00	300.00	-117.61	-109.77	-149.53	-141.13	-111.74	-103.66	-113.95

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -82.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -113.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -106.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -115.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -118.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-2.09
5.00	.00	12.10	6.08	-116.99	-116.99	-19.94	12.00	-2.09
25.00	.00	-29.99	-35.52	-116.99	-116.99	-48.05	-29.79	-30.12
25.00	.00	-29.99	-35.52	-116.99	-116.99	-48.05	-29.79	-30.12
50.00	.00	-48.70	-52.43	-116.99	-116.99	-60.74	-47.24	-42.49
50.00	.00	-48.70	-52.43	-116.99	-116.99	-60.74	-47.24	-42.49
100.00	.00	-69.27	-68.82	-116.99	-116.99	-75.29	-63.93	-55.99
100.00	.00	-69.27	-68.82	-116.99	-116.99	-75.29	-63.93	-55.99
200.00	.00	-94.92	-88.88	-116.99	-116.99	-94.92	-82.62	-73.10
200.00	.00	-94.92	-88.88	-116.99	-116.99	-94.92	-82.62	-73.10
400.00	.00	-132.12	-120.12	-116.99	-116.99	-126.10	-111.05	-98.28
400.00	.00	-132.12	-120.12	-116.99	-116.99	-126.10	-111.05	-98.28

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -82.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -113.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -106.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -115.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -118.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-47.35	-52.64	-57.12	-57.07	-80.64	-43.04	-73.42
5.00	50.00	12.10	6.08	-79.82	-79.79	-19.94	12.01	-48.64
25.00	.00	-55.83	-55.12	-60.56	-59.48	-69.58	-49.17	-60.89
25.00	50.00	-30.05	-35.50	-81.06	-80.23	-48.04	-29.61	-50.49
50.00	.00	-65.62	-60.48	-68.79	-64.70	-70.14	-65.55	-58.72
50.00	50.00	-48.93	-52.29	-84.75	-81.51	-60.67	-46.63	-53.17
100.00	.00	-69.63	-70.90	-89.61	-74.76	-77.74	-70.81	-62.48
100.00	50.00	-66.74	-68.08	-98.54	-85.46	-74.82	-63.36	-59.72
200.00	.00	-88.68	-86.66	-96.65	-88.92	-93.12	-81.70	-80.59
200.00	50.00	-90.32	-86.20	-104.86	-94.81	-92.88	-82.04	-78.75
400.00	.00	-108.36	-107.97	-113.48	-107.49	-120.37	-97.22	-109.08
400.00	50.00	-115.01	-113.56	-118.96	-112.70	-122.18	-101.20	-108.44

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -82.50 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -113.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -115.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -120.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -138.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -160.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -118.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -128.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -137.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -144.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -153.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-64.02	-68.24	-71.28	-71.27	-100.67	-63.38	-85.75
5.00	100.00	12.10	6.08	-98.54	-98.53	-19.94	12.01	-48.64
25.00	.00	-65.86	-68.92	-72.33	-72.02	-87.59	-65.09	-72.48
25.00	100.00	-29.99	-35.52	-98.94	-98.70	-48.05	-29.60	-50.49
50.00	.00	-71.29	-70.83	-75.37	-74.14	-84.13	-70.41	-68.49
50.00	100.00	-48.72	-52.41	-100.17	-99.20	-60.74	-46.51	-53.17
100.00	.00	-86.56	-76.60	-85.11	-80.37	-85.85	-83.89	-69.44
100.00	100.00	-69.42	-68.68	-104.89	-101.06	-75.25	-62.91	-59.72
200.00	.00	-96.04	-89.60	-104.32	-93.26	-97.08	-87.05	-86.38
200.00	100.00	-94.48	-87.79	-120.84	-107.09	-94.38	-82.49	-78.76
400.00	.00	-114.45	-113.31	-118.26	-113.06	-123.14	-101.01	-110.94
400.00	100.00	-126.16	-116.20	-129.56	-122.95	-123.04	-107.57	-108.42

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE =	-82.50 DB	.GT.	1A/M	NOISE GRADE =	1
NOISE =	-113.00 DB	.GT.	1A/M	NOISE GRADE =	2
NOISE =	-141.00 DB	.GT.	1A/M	NOISE GRADE =	3
NOISE =	-106.00 DB	.GT.	1A/M	NOISE GRADE =	4
NOISE =	-115.00 DB	.GT.	1A/M	NOISE GRADE =	5
NOISE =	-120.00 DB	.GT.	1A/M	NOISE GRADE =	6
NOISE =	-138.00 DB	.GT.	1A/M	NOISE GRADE =	7
NOISE =	-160.00 DB	.GT.	1A/M	NOISE GRADE =	8
NOISE =	-118.00 DB	.GT.	1A/M	NOISE GRADE =	9
NOISE =	-128.00 DB	.GT.	1A/M	NOISE GRADE =	10
NOISE =	-137.00 DB	.GT.	1A/M	NOISE GRADE =	11
NOISE =	-144.00 DB	.GT.	1A/M	NOISE GRADE =	12
NOISE =	-153.00 DB	.GT.	1A/M	NOISE GRADE =	13
NOISE =	-119.00 DB	.GT.	1A/M	NOISE GRADE =	14
NOISE =	-107.50 DB	.GT.	1V/M	NOISE GRADE =	15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-84.18	-87.16	-90.55	-90.54	-125.60	-88.94	-110.41
5.00	200.00	12.10	6.08	-128.90	-128.90	-19.94	12.01	-48.64
25.00	.00	-84.66	-87.39	-90.90	-90.80	-111.92	-89.21	-97.20
25.00	200.00	-29.99	-35.52	-129.05	-128.97	-48.05	-29.60	-50.49
50.00	.00	-86.15	-88.10	-91.98	-91.59	-106.82	-90.63	-92.62
50.00	200.00	-48.70	-52.43	-129.50	-129.19	-60.74	-46.50	-53.17
100.00	.00	-91.79	-90.72	-96.02	-94.49	-104.20	-96.55	-92.41
100.00	200.00	-69.26	-68.82	-131.31	-130.06	-75.29	-62.89	-59.73
200.00	.00	-113.70	-99.07	-109.24	-103.29	-108.83	-101.88	-109.75
200.00	200.00	-94.84	-88.94	-138.31	-133.34	-94.94	-82.93	-78.76
400.00	.00	-125.47	-120.93	-127.93	-123.31	-129.15	-109.72	-119.70
400.00	200.00	-131.11	-119.82	-154.25	-144.49	-126.03	-113.30	-108.43

FREQ= 5000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -82.50 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -113.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -115.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -120.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -138.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -160.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -118.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -128.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -137.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -144.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -153.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -119.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-100.39	-102.79	-106.56	-106.56	-144.85	-108.64	-137.22
5.00	300.00	12.10	6.08	-156.66	-156.66	-19.94	12.01	-48.64
25.00	.00	-100.64	-102.93	-106.76	-106.71	-131.04	-108.50	-123.11
25.00	300.00	-29.99	-35.52	-156.75	-156.71	-48.05	-29.60	-50.49
50.00	.00	-101.40	-103.35	-107.37	-107.17	-125.54	-108.89	-116.84
50.00	300.00	-48.70	-52.43	-157.02	-156.85	-60.74	-46.50	-53.17
100.00	.00	-104.39	-104.98	-109.75	-108.94	-121.55	-111.52	-110.53
100.00	300.00	-69.27	-68.82	-158.09	-157.43	-75.29	-62.89	-59.73
200.00	.00	-115.51	-110.79	-118.37	-115.09	-122.70	-117.39	-108.08
200.00	300.00	-94.93	-88.88	-162.33	-159.66	-94.92	-82.96	-78.76
400.00	.00	-137.01	-128.65	-138.41	-132.68	-137.75	-120.39	-157.98
400.00	300.00	-132.09	-120.17	-177.04	-167.89	-126.11	-114.24	-108.43

FREQ= 7000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =   -88.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =  -116.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =  -149.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =  -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =  -120.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =  -122.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =  -141.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =  -163.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =  -126.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =  -135.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =  -139.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =  -145.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =  -156.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =  -124.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =  -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.10	6.08	-116.99	-116.99	-19.95	12.00	.83
5.00	.00	12.10	6.08	-116.99	-116.99	-19.95	12.00	.83
25.00	.00	-30.07	-35.35	-116.99	-116.99	-48.13	-29.71	-27.24
25.00	.00	-30.07	-35.35	-116.99	-116.99	-48.13	-29.71	-27.24
50.00	.00	-49.05	-51.98	-116.99	-116.99	-61.09	-46.95	-39.76
50.00	.00	-49.05	-51.98	-116.99	-116.99	-61.09	-46.95	-39.76
100.00	.00	-70.47	-68.73	-116.99	-116.99	-76.49	-63.69	-53.82
100.00	.00	-70.47	-68.73	-116.99	-116.99	-76.49	-63.69	-53.82
200.00	.00	-98.16	-90.69	-116.99	-116.99	-98.16	-83.82	-72.49
200.00	.00	-98.16	-90.69	-116.99	-116.99	-98.16	-83.82	-72.49
400.00	.00	-139.72	-126.26	-116.99	-116.99	-133.70	-115.75	-98.88
400.00	.00	-139.72	-126.26	-116.99	-116.99	-133.70	-115.75	-98.88

FREQ= 7000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -88.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -116.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -149.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -106.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -122.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -135.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -139.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -156.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -124.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-47.04	-52.09	-57.42	-57.37	-80.91	-43.39	-68.63
5.00	50.00	12.09	6.08	-80.81	-80.77	-19.95	12.01	-42.87
25.00	.00	-55.07	-54.52	-60.94	-59.83	-69.92	-49.66	-56.28
25.00	50.00	-30.13	-35.32	-82.10	-81.25	-48.12	-29.44	-45.10
50.00	.00	-66.53	-59.83	-69.40	-65.21	-70.66	-65.92	-54.58
50.00	50.00	-49.29	-51.79	-85.96	-82.62	-61.02	-46.18	-48.40
100.00	.00	-70.99	-70.48	-90.17	-75.71	-78.85	-70.35	-59.96
100.00	50.00	-69.99	-67.83	-100.30	-86.91	-75.96	-63.15	-56.69
200.00	.00	-91.06	-67.59	-97.80	-90.94	-95.90	-80.95	-87.49
200.00	50.00	-93.40	-87.51	-106.60	-97.34	-95.80	-82.71	-84.20
400.00	.00	-109.16	-109.20	-116.55	-110.37	-126.50	-99.90	-124.29
400.00	50.00	-116.59	-117.26	-123.26	-117.07	-131.01	-104.61	-122.21

FREQ= 7000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =   -88.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =  -116.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =  -149.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =  -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =  -120.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =  -122.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =  -141.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =  -163.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =  -126.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =  -135.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =  -139.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =  -145.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =  -156.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =  -124.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =  -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-64.01	-67.90	-72.40	-72.39	-101.72	-64.57	-82.65
5.00	100.00	12.10	6.08	-101.58	-101.57	-19.95	12.01	-42.88
25.00	.00	-65.82	-68.60	-73.51	-73.19	-88.69	-66.30	-69.56
25.00	100.00	-30.07	-35.35	-102.01	-101.75	-48.13	-29.43	-45.10
50.00	.00	-71.17	-70.62	-76.72	-75.44	-85.37	-71.80	-65.98
50.00	100.00	-49.05	-51.97	-103.34	-102.31	-61.09	-46.05	-48.41
100.00	.00	-90.05	-76.78	-87.09	-82.10	-87.59	-83.56	-68.52
100.00	100.00	-70.55	-68.66	-108.47	-104.42	-76.47	-62.78	-56.69
200.00	.00	-98.97	-91.17	-105.70	-96.20	-100.32	-86.92	-103.34
200.00	100.00	-97.64	-89.69	-124.61	-111.32	-97.69	-84.02	-84.24
400.00	.00	-116.33	-116.52	-122.82	-117.29	-131.27	-104.31	-131.87
400.00	100.00	-131.95	-122.98	-135.60	-129.70	-130.72	-112.37	-122.23

FREQ= 7000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -88.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -116.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -149.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -120.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -122.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -163.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -126.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -135.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -139.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -145.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -156.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -124.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-85.97	-88.69	-93.70	-93.70	-128.64	-92.15	-115.58
5.00	200.00	12.10	6.08	-136.32	-136.32	-19.95	12.01	-42.88
25.00	.00	-86.48	-88.95	-94.09	-93.99	-114.99	-92.34	-102.95
25.00	200.00	-30.07	-35.35	-136.48	-136.40	-48.13	-29.43	-45.10
50.00	.00	-88.04	-89.74	-95.27	-94.86	-109.98	-93.73	-99.56
50.00	200.00	-49.05	-51.98	-136.99	-136.66	-61.09	-46.05	-48.41
100.00	.00	-93.96	-92.67	-99.71	-98.06	-107.69	-99.65	-109.51
100.00	200.00	-70.46	-68.73	-139.02	-137.67	-76.49	-62.81	-56.69
200.00	.00	-116.22	-102.10	-114.13	-107.88	-113.46	-103.08	-98.06
200.00	200.00	-98.10	-90.72	-146.85	-141.51	-98.17	-84.76	-64.24
400.00	.00	-129.48	-127.90	-133.99	-130.46	-137.79	-114.01	-129.43
400.00	200.00	-138.63	-126.19	-163.01	-154.76	-133.73	-119.75	-122.26

FREQ= 7000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -88.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -116.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -149.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -106.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -120.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -122.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -163.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -126.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -135.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -139.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -145.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -156.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -124.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -107.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-104.30	-106.49	-111.88	-111.88	-150.04	-114.01	-131.77
5.00	300.00	12.10	6.08	-168.53	-168.53	-19.95	12.01	-42.88
25.00	.00	-104.56	-106.65	-112.10	-112.05	-136.25	-113.73	-118.22
25.00	300.00	-30.07	-35.35	-168.63	-168.58	-48.13	-29.43	-45.10
50.00	.00	-105.39	-107.13	-112.78	-112.57	-130.82	-114.00	-112.69
50.00	300.00	-49.05	-51.98	-168.94	-168.76	-61.09	-46.05	-48.41
100.00	.00	-108.62	-108.99	-115.44	-114.56	-127.06	-116.58	-108.69
100.00	300.00	-70.47	-68.73	-170.15	-169.43	-76.49	-62.81	-56.69
200.00	.00	-120.64	-115.64	-125.07	-121.52	-129.09	-120.82	-112.86
200.00	300.00	-98.17	-90.69	-174.97	-172.07	-98.16	-84.76	-84.24
400.00	.00	-142.06	-136.79	-145.99	-141.96	-147.24	-125.96	-131.68
400.00	300.00	-139.74	-126.27	-190.80	-181.88	-133.70	-120.37	-122.26

FREQ= 10000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -95.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -101.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -142.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.09	6.09	-116.99	-116.99	-19.95	12.01	3.93
5.00	.00	12.09	6.09	-116.99	-116.99	-19.95	12.01	3.93
25.00	.00	-30.20	-35.10	-116.99	-116.99	-48.26	-29.59	-24.20
25.00	.00	-30.20	-35.10	-116.99	-116.99	-48.26	-29.59	-24.20
50.00	.00	-49.57	-51.49	-116.99	-116.99	-61.61	-46.59	-36.96
50.00	.00	-49.57	-51.49	-116.99	-116.99	-61.61	-46.59	-36.96
100.00	.00	-72.12	-68.96	-116.99	-116.99	-78.14	-63.63	-51.79
100.00	.00	-72.12	-68.96	-116.99	-116.99	-78.14	-63.63	-51.79
200.00	.00	-102.45	-93.45	-116.99	-116.99	-102.45	-85.88	-72.50
200.00	.00	-102.45	-93.45	-116.99	-116.99	-102.45	-85.88	-72.50
400.00	.00	-149.54	-134.54	-116.99	-116.99	-143.52	-119.69	-98.81
400.00	.00	-149.54	-134.54	-116.99	-116.99	-143.52	-119.69	-98.81

FREQ= 10000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -95.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -101.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -142.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-46.70	-51.45	-57.87	-57.83	-81.34	-43.91	-63.83
5.00	50.00	12.09	6.09	-82.24	-82.20	-19.95	12.01	-36.78
25.00	.00	-54.30	-53.85	-61.51	-60.37	-70.43	-50.34	-51.75
25.00	50.00	-30.24	-35.06	-83.61	-82.73	-48.25	-29.19	-39.50
50.00	.00	-67.71	-59.19	-70.30	-65.96	-71.43	-66.12	-50.69
50.00	50.00	-49.81	-51.28	-87.70	-84.22	-61.54	-45.67	-43.65
100.00	.00	-72.87	-70.35	-90.75	-77.08	-80.41	-69.89	-58.45
100.00	50.00	-71.69	-67.92	-102.66	-88.98	-77.57	-63.16	-54.39
200.00	.00	-93.33	-89.35	-99.73	-93.69	-99.76	-80.62	-91.64
200.00	50.00	-97.49	-89.81	-109.21	-100.85	-99.78	-84.01	-94.66
400.00	.00	-110.59	-110.46	-119.74	-113.46	-131.54	-104.46	-121.78
400.00	50.00	-119.11	-119.64	-128.19	-121.93	-142.98	-110.42	-121.55

FREQ= 10000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -95.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -101.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -142.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-64.29	-67.84	-73.97	-73.96	-103.20	-66.20	-80.28
5.00	100.00	12.09	6.09	-105.66	-105.65	-19.95	12.01	-36.78
25.00	.00	-66.11	-68.60	-75.16	-74.82	-90.24	-67.95	-67.45
25.00	100.00	-30.19	-35.10	-106.13	-105.86	-48.26	-29.17	-39.51
50.00	.00	-71.46	-70.76	-78.59	-77.24	-87.10	-73.63	-64.46
50.00	100.00	-49.56	-51.50	-107.60	-106.51	-61.62	-45.56	-43.65
100.00	.00	-91.71	-77.49	-89.77	-84.48	-89.98	-83.30	-69.70
100.00	100.00	-72.12	-68.97	-113.25	-108.93	-78.15	-62.99	-54.40
200.00	.00	-101.87	-93.79	-107.98	-100.20	-104.71	-87.43	-89.49
200.00	100.00	-101.78	-92.63	-129.36	-116.96	-102.09	-86.57	-94.58
400.00	.00	-119.11	-119.26	-128.17	-121.94	-140.84	-110.06	-123.04
400.00	100.00	-137.75	-133.71	-143.69	-138.16	-141.14	-119.69	-121.51

FREQ= 10000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -95.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -120.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -151.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -101.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -123.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -125.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -137.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -165.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -131.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -142.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -181.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -147.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -160.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -129.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -107.50 DB .GT. 1V/M  NOISE GRADE = 15
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DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-88.71	-91.18	-97.91	-97.91	-132.72	-96.41	-127.14
5.00	200.00	12.09	6.09	-145.96	-145.96	-19.95	12.01	-36.78
25.00	.00	-89.25	-91.47	-98.34	-98.23	-119.10	-96.47	-111.72
25.00	200.00	-30.20	-35.10	-146.15	-146.06	-48.26	-29.17	-39.51
50.00	.00	-90.91	-92.37	-99.65	-99.20	-114.20	-97.80	-103.51
50.00	200.00	-49.57	-51.49	-146.73	-146.37	-61.61	-45.56	-43.65
100.00	.00	-97.24	-95.70	-104.59	-102.79	-112.34	-103.59	-95.47
100.00	200.00	-72.12	-68.96	-149.03	-147.57	-78.14	-63.04	-54.40
200.00	.00	-119.58	-106.54	-120.41	-113.96	-119.58	-105.43	-99.37
200.00	200.00	-102.44	-93.46	-157.90	-152.12	-102.46	-87.53	-94.59
400.00	.00	-135.34	-136.89	-142.42	-138.92	-149.90	-120.81	-130.20
400.00	200.00	-148.53	-134.62	-174.76	-168.20	-143.62	-128.47	-121.50

FREQ= 10000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -95.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -120.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -101.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -123.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -142.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -147.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -129.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -107.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-109.75	-111.74	-118.84	-118.84	-156.87	-121.00	-136.00
5.00	300.00	12.09	6.09	-183.80	-183.79	-19.95	12.01	-36.78
25.00	.00	-110.04	-111.92	-119.09	-119.03	-143.10	-120.52	-122.86
25.00	300.00	-30.20	-35.10	-183.91	-183.86	-48.26	-29.17	-39.51
50.00	.00	-110.95	-112.48	-119.86	-119.63	-137.75	-120.63	-117.98
50.00	300.00	-49.57	-51.49	-184.26	-184.07	-61.61	-45.56	-43.65
100.00	.00	-114.50	-114.63	-122.86	-121.90	-134.30	-123.16	-116.68
100.00	300.00	-72.12	-68.96	-185.66	-184.88	-78.14	-63.04	-54.40
200.00	.00	-127.66	-122.35	-133.75	-129.91	-137.44	-125.70	-132.90
200.00	300.00	-102.45	-93.45	-191.20	-188.04	-102.45	-87.53	-94.59
400.00	.00	-149.91	-148.29	-156.16	-154.05	-159.83	-134.18	-153.78
400.00	300.00	-149.56	-134.54	-208.12	-199.93	-143.52	-128.62	-121.50

FREQ= 20000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -108.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -127.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -159.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -117.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -133.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -136.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -169.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -116.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.09	6.11	-116.99	-116.99	-19.96	12.01	9.94
5.00	.00	12.09	6.11	-116.99	-116.99	-19.96	12.01	9.94
25.00	.00	-30.63	-34.36	-116.99	-116.99	-48.70	-29.18	-18.41
25.00	.00	-30.63	-34.36	-116.99	-116.99	-48.70	-29.18	-18.41
50.00	.00	-51.20	-50.75	-116.99	-116.99	-63.24	-45.87	-31.91
50.00	.00	-51.20	-50.75	-116.99	-116.99	-63.24	-45.87	-31.91
100.00	.00	-76.85	-70.81	-116.99	-116.99	-82.67	-64.55	-49.01
100.00	.00	-76.85	-70.81	-116.99	-116.99	-82.67	-64.55	-49.01
200.00	.00	-114.04	-102.04	-116.99	-116.99	-114.04	-92.98	-74.20
200.00	.00	-114.04	-102.04	-116.99	-116.99	-114.04	-92.98	-74.20
400.00	.00	-175.25	-157.24	-116.99	-116.99	-169.23	-125.07	-98.65
400.00	.00	-175.25	-157.24	-116.99	-116.99	-169.23	-125.07	-98.65

FREQ= 20000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -108.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -127.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -159.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -117.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -133.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -136.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -169.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -116.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-46.19	-50.27	-59.37	-59.32	-82.72	-45.51	-55.73
5.00	50.00	12.09	6.11	-86.54	-86.50	-19.96	12.03	-24.99
25.00	.00	-53.23	-52.77	-63.32	-62.10	-72.08	-52.34	-44.40
25.00	50.00	-30.65	-34.34	-88.12	-87.14	-48.69	-28.44	-29.08
50.00	.00	-70.49	-58.53	-73.06	-68.32	-73.80	-65.81	-45.34
50.00	50.00	-51.36	-50.61	-92.83	-89.00	-63.21	-44.85	-35.64
100.00	.00	-77.98	-71.53	-92.27	-81.21	-85.03	-68.98	-62.26
100.00	50.00	-76.41	-69.72	-108.77	-95.04	-82.33	-64.42	-54.67
200.00	.00	-96.40	-95.23	-106.23	-100.99	-111.09	-82.94	-86.85
200.00	50.00	-108.11	-98.11	-117.52	-110.88	-110.97	-89.49	-84.31
400.00	.00	-114.33	-113.94	-126.32	-119.98	-140.27	-113.02	-141.05
400.00	50.00	-126.47	-125.77	-138.47	-132.04	-151.68	-125.51	-140.28

FREQ= 20000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -108.50 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -127.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -159.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -119.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -117.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -125.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -133.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -165.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -136.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -169.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -116.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-66.17	-69.12	-78.54	-78.52	-107.56	-70.87	-80.35
5.00	100.00	12.09	6.11	-116.86	-116.84	-19.96	12.03	-24.99
25.00	.00	-68.08	-70.03	-79.93	-79.54	-94.77	-72.56	-68.49
25.00	100.00	-30.63	-34.36	-117.44	-117.13	-48.70	-28.44	-29.08
50.00	.00	-73.72	-72.65	-83.97	-82.43	-92.14	-78.48	-68.29
50.00	100.00	-51.19	-50.76	-119.25	-118.00	-63.24	-44.82	-35.64
100.00	.00	-95.60	-80.99	-97.18	-91.23	-96.77	-83.80	-85.65
100.00	100.00	-76.77	-70.87	-126.24	-121.27	-82.89	-64.86	-54.68
200.00	.00	-107.42	-102.84	-115.88	-111.24	-117.09	-91.64	-95.58
200.00	100.00	-113.02	-101.74	-142.18	-132.41	-113.97	-95.22	-84.33
400.00	.00	-126.48	-125.87	-138.50	-132.03	-152.07	-125.65	-142.77
400.00	100.00	-150.80	-153.16	-163.03	-156.45	-172.05	-145.65	-140.45

FREQ= 20000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -108.50 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =    -127.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =    -159.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -119.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -117.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =    -125.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =    -133.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =    -165.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =    -136.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =    -151.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =    -181.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =    -153.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =    -169.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =    -138.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -116.50 DB .GT. 1V/M  NOISE GRADE = 15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-97.22	-99.27	-109.33	-109.33	-143.88	-107.87	-115.87
5.00	200.00	12.09	6.11	-171.35	-171.35	-19.96	12.03	-24.99
25.00	.00	-97.85	-99.65	-109.87	-109.74	-130.36	-107.53	-102.89
25.00	200.00	-30.63	-34.36	-171.59	-171.49	-48.70	-28.44	-29.08
50.00	.00	-99.81	-100.83	-111.51	-110.99	-125.75	-108.65	-98.81
50.00	200.00	-51.20	-50.75	-172.35	-171.92	-63.24	-44.83	-35.64
100.00	.00	-107.28	-105.21	-117.73	-115.60	-124.99	-113.52	-101.62
100.00	200.00	-76.85	-70.81	-175.34	-173.62	-82.87	-64.89	-54.68
200.00	.00	-129.44	-119.87	-136.36	-130.41	-136.09	-114.38	-112.44
200.00	200.00	-114.04	-102.04	-186.70	-180.08	-114.04	-96.12	-84.33
400.00	.00	-150.91	-150.31	-163.30	-156.32	-181.35	-144.59	-156.30
400.00	200.00	-174.75	-157.32	-207.20	-203.70	-169.28	-151.63	-140.44

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FREQ=  20000.00 HZ  COND.=    .01 MHOS/M  EPS=  10.00 POWER=    10.00 WATTS  XMIT LOOP WEIGHT=     6.00 KG

XMIT LOOP RADIUS=    20.00 M  LINE SOURCE LENGTH=   100.00 M  DEPTH OF TRANSMITTER=   300.00

        LINE SOURCE CONTACT RESISTANCE =   100.00 OHMS

        NOISE =    -108.50 DB .GT. 1A/M  NOISE GRADE =   1
        NOISE =    -127.00 DB .GT. 1A/M  NOISE GRADE =   2
        NOISE =    -159.00 DB .GT. 1A/M  NOISE GRADE =   3
        NOISE =    -119.00 DB .GT. 1A/M  NOISE GRADE =   4
        NOISE =    -117.00 DB .GT. 1A/M  NOISE GRADE =   5
        NOISE =    -125.00 DB .GT. 1A/M  NOISE GRADE =   6
        NOISE =    -133.00 DB .GT. 1A/M  NOISE GRADE =   7
        NOISE =    -165.00 DB .GT. 1A/M  NOISE GRADE =   8
        NOISE =    -136.00 DB .GT. 1A/M  NOISE GRADE =   9
        NOISE =    -151.00 DB .GT. 1A/M  NOISE GRADE =  10
        NOISE =    -181.00 DB .GT. 1A/M  NOISE GRADE =  11
        NOISE =    -153.00 DB .GT. 1A/M  NOISE GRADE =  12
        NOISE =    -169.00 DB .GT. 1A/M  NOISE GRADE =  13
        NOISE =    -138.00 DB .GT. 1A/M  NOISE GRADE =  14
        NOISE =    -116.50 DB .GT. 1V/M  NOISE GRADE =  15
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DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-125.26	-126.91	-137.32	-137.31	-175.07	-139.47	-147.41
5.00	300.00	12.09	6.11	-223.45	-223.45	-19.96	12.03	-24.99
25.00	.00	-125.62	-127.16	-137.64	-137.57	-161.37	-138.43	-134.16
25.00	300.00	-30.63	-34.36	-223.60	-223.54	-48.70	-28.44	-29.08
50.00	.00	-126.74	-127.91	-138.63	-138.35	-156.22	-138.13	-129.07
50.00	300.00	-51.20	-50.75	-224.07	-223.83	-63.24	-44.83	-35.64
100.00	.00	-131.14	-130.81	-142.52	-141.36	-153.56	-140.57	-127.12
100.00	300.00	-76.85	-70.81	-225.93	-225.00	-82.87	-64.89	-54.68
200.00	.00	-147.10	-141.36	-156.44	-152.11	-159.60	-140.61	-164.61
200.00	300.00	-114.04	-102.04	-233.28	-229.52	-114.04	-96.12	-84.33
400.00	.00	-173.74	-178.38	-184.63	-181.65	-196.55	-159.58	-171.16
400.00	300.00	-175.25	-157.24	-252.60	-247.31	-169.23	-151.32	-140.44

FREQ= 50000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -122.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -154.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -172.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -179.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -118.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.05	6.18	-116.99	-116.99	-19.99	12.04	17.89
5.00	.00	12.05	6.18	-116.99	-116.99	-19.99	12.04	17.89
25.00	.00	-31.93	-33.13	-116.99	-116.99	-49.99	-28.28	-11.18
25.00	.00	-31.93	-33.13	-116.99	-116.99	-49.99	-28.28	-11.18
50.00	.00	-55.32	-51.25	-116.99	-116.99	-67.36	-45.68	-26.62
50.00	.00	-55.32	-51.25	-116.99	-116.99	-67.36	-45.68	-26.62
100.00	.00	-87.57	-77.60	-116.99	-116.99	-93.59	-69.60	-48.79
100.00	.00	-87.57	-77.60	-116.99	-116.99	-93.59	-69.60	-48.79
200.00	.00	-138.63	-122.66	-116.99	-116.99	-138.63	-103.29	-74.61
200.00	.00	-138.63	-122.66	-116.99	-116.99	-138.63	-103.29	-74.61
400.00	.00	-227.99	-206.00	-116.99	-116.99	-221.97	-133.09	-98.66
400.00	.00	-227.99	-206.00	-116.99	-116.99	-221.97	-133.09	-98.66

FREQ= 50000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =    -122.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =    -137.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =    -163.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =    -138.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =    -126.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =    -137.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =    -154.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =    -167.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =    -151.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =    -158.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =    -181.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =    -172.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =    -179.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =    -148.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =    -118.50 DB .GT. 1V/M  NOISE GRADE = 15
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DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-46.83	-50.04	-63.30	-63.24	-86.42	-49.56	-49.48
5.00	50.00	12.05	6.18	-96.72	-96.68	-19.99	12.10	-9.60
25.00	.00	-53.83	-53.02	-67.98	-66.58	-76.40	-56.90	-40.25
25.00	50.00	-31.91	-33.15	-98.72	-97.59	-49.99	-27.20	-16.77
50.00	.00	-74.71	-60.19	-79.74	-74.24	-79.76	-65.17	-48.36
50.00	50.00	-55.28	-51.29	-104.75	-100.24	-67.38	-45.28	-29.52
100.00	.00	-85.47	-77.94	-97.89	-91.14	-95.98	-70.14	-63.19
100.00	50.00	-86.78	-76.94	-120.75	-109.11	-93.32	-70.66	-60.42
200.00	.00	-103.27	-102.78	-119.51	-112.75	-132.71	-96.94	-105.40
200.00	50.00	-123.46	-126.12	-137.61	-131.68	-137.11	-107.71	-101.19
400.00	.00	-121.66	-120.52	-137.75	-130.50	-155.30	-122.20	-168.61
400.00	50.00	-141.20	-139.66	-157.16	-149.68	-174.37	-142.79	-182.25

FREQ= 50000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -122.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -138.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -154.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -151.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -172.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -179.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -118.50 DB .GT. 1V/M NOISE GRADE = 15

'(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-72.91	-75.20	-89.05	-89.03	-117.74	-81.39	-86.31
5.00	100.00	12.05	6.18	-140.99	-140.97	-19.99	12.10	-9.60
25.00	.00	-75.14	-76.45	-90.85	-90.38	-105.31	-82.72	-72.76
25.00	100.00	-31.93	-33.13	-141.79	-141.41	-49.99	-27.21	-16.77
50.00	.00	-81.78	-80.08	-96.15	-94.26	-103.75	-88.31	-69.15
50.00	100.00	-55.32	-51.25	-144.28	-142.75	-67.36	-45.32	-29.52
100.00	.00	-104.03	-91.95	-112.85	-106.41	-112.06	-89.48	-81.68
100.00	100.00	-87.57	-77.60	-153.86	-147.82	-93.59	-71.69	-60.43
200.00	.00	-121.87	-123.60	-136.79	-132.12	-147.85	-108.46	-125.10
200.00	100.00	-137.75	-122.77	-171.58	-165.97	-138.73	-116.84	-101.20
400.00	.00	-141.20	-139.66	-157.16	-149.68	-174.36	-142.79	-185.34
400.00	100.00	-179.65	-177.73	-195.59	-188.04	-209.77	-179.04	-184.31

FREQ= 50000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE =	-122.00 DB .GT. 1A/M	NOISE GRADE =	1
NOISE =	-137.00 DB .GT. 1A/M	NOISE GRADE =	2
NOISE =	-163.00 DB .GT. 1A/M	NOISE GRADE =	3
NOISE =	-138.00 DB .GT. 1A/M	NOISE GRADE =	4
NOISE =	-126.00 DB .GT. 1A/M	NOISE GRADE =	5
NOISE =	-137.00 DB .GT. 1A/M	NOISE GRADE =	6
NOISE =	-154.00 DB .GT. 1A/M	NOISE GRADE =	7
NOISE =	-167.00 DB .GT. 1A/M	NOISE GRADE =	8
NOISE =	-151.00 DB .GT. 1A/M	NOISE GRADE =	9
NOISE =	-158.00 DB .GT. 1A/M	NOISE GRADE =	10
NOISE =	-181.00 DB .GT. 1A/M	NOISE GRADE =	11
NOISE =	-172.00 DB .GT. 1A/M	NOISE GRADE =	12
NOISE =	-179.00 DB .GT. 1A/M	NOISE GRADE =	13
NOISE =	-148.00 DB .GT. 1A/M	NOISE GRADE =	14
NOISE =	-118.50 DB .GT. 1V/M	NOISE GRADE =	15

ISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-117.70	-119.30	-133.73	-133.72	-167.92	-132.16	-132.59
5.00	200.00	12.05	6.18	-223.71	-223.71	-19.99	12.10	-9.60
25.00	.00	-118.54	-119.87	-134.48	-134.32	-154.60	-130.84	-120.07
25.00	200.00	-31.93	-33.13	-224.07	-223.93	-49.99	-27.21	-16.77
50.00	.00	-121.13	-121.62	-136.79	-136.12	-150.58	-131.68	-117.21
50.00	200.00	-55.32	-51.25	-225.16	-224.62	-67.36	-45.32	-29.52
100.00	.00	-131.01	-128.16	-145.53	-142.83	-152.07	-133.70	-131.14
100.00	200.00	-87.57	-77.60	-229.52	-227.35	-93.59	-71.68	-60.43
200.00	.00	-154.65	-151.94	-168.15	-166.12	-171.53	-139.44	-142.30
200.00	200.00	-138.63	-122.66	-244.94	-237.86	-138.63	-116.74	-101.20
400.00	.00	-179.64	-177.96	-195.57	-188.05	-212.37	-179.88	-217.78
400.00	200.00	-227.77	-206.00	-273.43	-265.05	-221.97	-200.08	-184.37

FREQ= 50000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =   -122.00 DB .GT. 1A/M  NOISE GRADE =   1
NOISE =   -137.00 DB .GT. 1A/M  NOISE GRADE =   2
NOISE =   -163.00 DB .GT. 1A/M  NOISE GRADE =   3
NOISE =   -138.00 DB .GT. 1A/M  NOISE GRADE =   4
NOISE =   -126.00 DB .GT. 1A/M  NOISE GRADE =   5
NOISE =   -137.00 DB .GT. 1A/M  NOISE GRADE =   6
NOISE =   -154.00 DB .GT. 1A/M  NOISE GRADE =   7
NOISE =   -167.00 DB .GT. 1A/M  NOISE GRADE =   8
NOISE =   -151.00 DB .GT. 1A/M  NOISE GRADE =   9
NOISE =   -158.00 DB .GT. 1A/M  NOISE GRADE =  10
NOISE =   -181.00 DB .GT. 1A/M  NOISE GRADE =  11
NOISE =   -172.00 DB .GT. 1A/M  NOISE GRADE =  12
NOISE =   -179.00 DB .GT. 1A/M  NOISE GRADE =  13
NOISE =   -148.00 DB .GT. 1A/M  NOISE GRADE =  14
NOISE =   -118.50 DB .GT. 1V/M  NOISE GRADE =  15
```

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-159.78	-161.07	-175.78	-175.78	-213.20	-177.75	-199.50
5.00	300.00	12.05	6.18	-304.10	-304.10	-19.99	12.10	-9.60
25.00	.00	-160.28	-161.44	-176.24	-176.15	-199.63	-175.50	-187.62
25.00	300.00	-31.93	-33.13	-304.32	-304.25	-49.99	-27.21	-16.77
50.00	.00	-161.84	-162.58	-177.69	-177.32	-194.88	-174.72	-173.90
50.00	300.00	-55.32	-51.25	-305.02	-304.72	-67.36	-45.32	-29.52
100.00	.00	-167.95	-167.02	-183.33	-181.83	-193.80	-176.63	-163.02
100.00	300.00	-87.57	-77.60	-307.79	-306.60	-93.59	-71.68	-60.43
200.00	.00	-188.40	-183.63	-202.33	-198.56	-205.80	-176.98	-180.74
200.00	300.00	-138.63	-122.66	-318.57	-313.95	-138.63	-116.74	-101.20
400.00	.00	-218.21	-215.94	-234.24	-226.32	-249.08	-223.17	-232.64
400.00	300.00	-227.99	-206.00	-345.49	-343.95	-221.97	-200.08	-184.37

FREQ= 70000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -171.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -146.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -175.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -155.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -123.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	12.03	6.24	-116.99	-116.99	-20.01	12.07	20.80
5.00	.00	12.03	6.24	-116.99	-116.99	-20.01	12.07	20.80
25.00	.00	-32.73	-32.78	-116.99	-116.99	-50.60	-27.93	-8.74
25.00	.00	-32.73	-32.78	-116.99	-116.99	-50.80	-27.93	-8.74
50.00	.00	-57.66	-52.18	-116.99	-116.99	-69.70	-46.15	-25.31
50.00	.00	-57.66	-52.18	-116.99	-116.99	-69.70	-46.15	-25.31
100.00	.00	-93.29	-81.87	-116.99	-116.99	-99.31	-73.19	-49.73
100.00	.00	-93.29	-81.87	-116.99	-116.99	-99.31	-73.19	-49.73
200.00	.00	-151.31	-133.89	-116.99	-116.99	-151.31	-105.86	-74.56
200.00	.00	-151.31	-133.89	-116.99	-116.99	-151.31	-105.86	-74.56
400.00	.00	-254.70	-231.26	-116.99	-116.99	-248.68	-136.01	-98.66
400.00	.00	-254.70	-231.26	-116.99	-116.99	-248.68	-136.01	-98.66

FREQ= 70000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -171.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -146.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -175.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -155.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -123.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-47.78	-50.71	-65.57	-65.51	-88.59	-51.84	-49.67
5.00	50.00	12.03	6.24	-102.27	-102.22	-20.01	12.16	-4.02
25.00	.00	-54.97	-53.99	-70.65	-69.15	-78.89	-59.29	-42.19
25.00	50.00	-32.72	-32.79	-104.48	-103.27	-50.80	-26.85	-12.92
50.00	.00	-76.59	-61.95	-83.40	-77.58	-83.12	-65.43	-65.48
50.00	50.00	-57.58	-52.25	-111.16	-106.34	-69.73	-46.23	-29.78
100.00	.00	-88.12	-82.45	-101.86	-96.60	-102.11	-72.28	-66.86
100.00	50.00	-92.33	-81.47	-127.08	-116.74	-99.18	-74.98	-58.63
200.00	.00	-107.02	-105.95	-124.55	-117.55	-137.47	-105.17	-117.42
200.00	50.00	-129.94	-135.40	-147.29	-140.41	-152.53	-120.45	-119.47
400.00	.00	-125.87	-123.48	-143.31	-134.90	-161.51	-128.84	-172.89
400.00	50.00	-148.65	-146.16	-166.07	-157.61	-184.12	-151.33	-194.17

FREQ= 70000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

```
NOISE =   -126.00 DB .GT. 1A/M  NOISE GRADE =  1
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  2
NOISE =   -163.00 DB .GT. 1A/M  NOISE GRADE =  3
NOISE =   -141.00 DB .GT. 1A/M  NOISE GRADE =  4
NOISE =   -131.00 DB .GT. 1A/M  NOISE GRADE =  5
NOISE =   -153.00 DB .GT. 1A/M  NOISE GRADE =  6
NOISE =   -158.00 DB .GT. 1A/M  NOISE GRADE =  7
NOISE =   -171.00 DB .GT. 1A/M  NOISE GRADE =  8
NOISE =   -146.00 DB .GT. 1A/M  NOISE GRADE =  9
NOISE =   -163.00 DB .GT. 1A/M  NOISE GRADE = 10
NOISE =   -181.00 DB .GT. 1A/M  NOISE GRADE = 11
NOISE =   -175.00 DB .GT. 1A/M  NOISE GRADE = 12
NOISE =   -186.00 DB .GT. 1A/M  NOISE GRADE = 13
NOISE =   -155.00 DB .GT. 1A/M  NOISE GRADE = 14
NOISE =   -123.50 DB .GT. 1V/M  NOISE GRADE = 15
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DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-77.14	-79.24	-94.70	-94.68	-123.27	-87.00	-84.29
5.00	100.00	12.03	6.24	-153.52	-153.50	-20.01	12.16	-4.02
25.00	.00	-79.57	-80.66	-96.71	-96.21	-111.02	-88.07	-72.43
25.00	100.00	-32.73	-32.78	-154.43	-154.02	-50.80	-26.85	-12.92
50.00	.00	-86.77	-84.80	-102.64	-100.58	-110.01	-93.19	-72.87
50.00	100.00	-57.66	-52.18	-157.26	-155.60	-69.70	-46.26	-29.78
100.00	.00	-108.90	-98.57	-120.69	-114.53	-120.21	-93.96	-91.13
100.00	100.00	-93.30	-81.87	-168.05	-161.61	-99.31	-75.95	-58.63
200.00	.00	-129.74	-129.30	-147.37	-140.35	-167.09	-120.25	-123.35
200.00	100.00	-150.71	-133.98	-187.72	-183.45	-151.38	-128.27	-119.43
400.00	.00	-148.65	-146.16	-166.07	-157.61	-184.12	-151.33	-194.88
400.00	100.00	-194.17	-191.61	-211.59	-203.05	-229.55	-196.27	-208.04

FREQ= 70000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -171.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -146.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -175.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -155.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -123.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-128.88	-130.34	-146.35	-146.34	-180.42	-144.67	-151.13
5.00	200.00	12.03	6.24	-250.31	-250.30	-20.01	12.16	-4.02
25.00	.00	-129.82	-131.00	-147.21	-147.03	-167.19	-142.87	-136.65
25.00	200.00	-32.73	-32.78	-250.71	-250.57	-50.80	-26.85	-12.92
50.00	.00	-132.73	-133.03	-149.85	-149.12	-163.47	-143.68	-129.80
50.00	200.00	-57.66	-52.18	-251.98	-251.39	-69.70	-46.26	-29.78
100.00	.00	-143.81	-140.67	-159.82	-156.90	-166.09	-144.49	-129.26
100.00	200.00	-93.29	-81.87	-257.01	-254.64	-99.31	-75.95	-58.63
200.00	.00	-169.30	-170.55	-184.74	-184.96	-190.32	-154.06	-154.42
200.00	200.00	-151.31	-133.89	-273.99	-267.32	-151.31	-127.96	-119.43
400.00	.00	-194.17	-191.53	-211.59	-203.05	-229.41	-196.23	-232.35
400.00	200.00	-254.50	-231.26	-302.79	-293.83	-248.68	-225.33	-207.97

FREQ= 70000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -126.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -141.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -131.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -153.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -158.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -171.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -146.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -175.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -155.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -123.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-177.96	-179.14	-195.41	-195.41	-232.72	-197.24	-198.50
5.00	300.00	12.03	6.24	-344.77	-344.77	-20.01	12.16	-4.02
25.00	.00	-178.53	-179.57	-195.95	-195.85	-219.22	-194.43	-186.51
25.00	300.00	-32.73	-32.78	-345.03	-344.95	-50.80	-26.85	-12.92
50.00	.00	-180.31	-180.92	-197.62	-197.21	-214.67	-193.57	-184.63
50.00	300.00	-57.66	-52.18	-345.84	-345.51	-69.70	-46.26	-29.78
100.00	.00	-187.28	-186.12	-204.12	-202.47	-214.38	-194.89	-192.16
100.00	300.00	-93.29	-81.87	-349.06	-347.76	-99.31	-75.95	-58.63
200.00	.00	-209.54	-206.10	-225.23	-222.58	-229.49	-197.01	-198.76
200.00	300.00	-151.31	-133.89	-361.42	-356.56	-151.31	-127.96	-119.43
400.00	.00	-239.62	-236.90	-256.99	-248.49	-274.12	-239.60	-265.76
400.00	300.00	-254.70	-231.26	-393.82	-386.22	-248.68	-225.33	-207.97

FREQ= 100000.00 HZ CUND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -170.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -164.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -135.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	11.99	6.33	-116.99	-116.99	-20.05	12.11	23.88
5.00	.00	11.99	6.33	-116.99	-116.99	-20.05	12.11	23.88
25.00	.00	-33.87	-32.58	-116.99	-116.99	-51.93	-27.62	-6.34
25.00	.00	-33.87	-32.58	-116.99	-116.99	-51.93	-27.62	-6.34
50.00	.00	-60.80	-53.81	-116.99	-116.99	-72.64	-47.19	-24.44
50.00	.00	-60.80	-53.81	-116.99	-116.99	-72.64	-47.19	-24.44
100.00	.00	-100.73	-87.77	-116.99	-116.99	-106.75	-78.04	-50.61
100.00	.00	-100.73	-87.77	-116.99	-116.99	-106.75	-78.04	-50.61
200.00	.00	-167.53	-148.56	-116.99	-116.99	-167.53	-108.99	-74.58
200.00	.00	-167.53	-148.56	-116.99	-116.99	-167.53	-108.99	-74.58
400.00	.00	-288.59	-263.60	-116.99	-116.99	-282.57	-139.11	-98.66
400.00	.00	-288.59	-263.60	-116.99	-116.99	-282.57	-139.11	-98.66

FREQ= 100000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -170.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -180.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -164.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -135.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-49.41	-52.06	-68.64	-68.57	-91.54	-54.89	-53.23
5.00	50.00	11.99	6.33	-109.52	-109.47	-20.05	12.26	1.83
25.00	.00	-56.93	-55.72	-74.21	-72.60	-82.26	-62.34	-51.07
25.00	50.00	-33.86	-32.58	-112.01	-110.70	-51.93	-26.66	-9.43
50.00	.00	-78.98	-64.74	-88.17	-82.03	-87.60	-66.36	-51.32
50.00	50.00	-60.73	-53.86	-119.51	-114.31	-72.86	-47.88	-33.42
100.00	.00	-91.90	-89.02	-107.65	-103.62	-110.41	-76.11	-103.59
100.00	50.00	-99.66	-87.62	-135.57	-126.72	-106.76	-81.13	-66.73
200.00	.00	-111.76	-110.15	-130.70	-123.21	-144.57	-110.57	-134.87
200.00	50.00	-138.72	-137.10	-158.09	-150.30	-170.54	-146.85	-127.36
400.00	.00	-130.18	-126.90	-149.14	-139.85	-168.50	-134.76	-176.66
400.00	50.00	-157.38	-154.03	-176.35	-167.00	-195.57	-161.70	-203.83

FREQ= 100000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -170.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -180.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -164.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -135.50 DB .GT. 1A/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-82.99	-84.89	-102.06	-102.04	-130.49	-94.27	-92.13
5.00	100.00	11.99	6.33	-169.58	-169.57	-20.05	12.26	1.83
25.00	.00	-85.66	-86.54	-104.34	-103.79	-118.48	-95.01	-83.23
25.00	100.00	-33.87	-32.58	-170.64	-170.18	-51.93	-26.66	-9.43
50.00	.00	-93.60	-91.35	-111.06	-108.81	-118.16	-99.31	-106.19
50.00	100.00	-60.80	-53.81	-173.90	-172.08	-72.84	-47.89	-33.42
100.00	.00	-115.78	-107.62	-130.52	-125.12	-130.83	-100.63	-92.03
100.00	100.00	-100.73	-87.76	-186.10	-179.28	-106.75	-81.84	-66.73
200.00	.00	-139.04	-136.91	-158.36	-150.19	-172.41	-139.50	-141.49
200.00	100.00	-167.19	-148.60	-209.10	-204.85	-167.56	-142.88	-127.33
400.00	.00	-157.38	-154.03	-176.35	-167.00	-195.56	-161.70	-203.73
400.00	100.00	-211.78	-208.28	-230.75	-221.32	-249.85	-215.70	-244.15

FREQ= 100000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -170.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -180.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -164.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -135.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-143.50	-144.82	-162.51	-162.50	-196.44	-160.66	-158.46
5.00	200.00	11.99	6.33	-284.08	-284.07	-20.05	12.26	1.83
25.00	.00	-144.57	-145.60	-163.50	-163.30	-183.34	-158.28	-147.23
25.00	200.00	-33.87	-32.58	-284.55	-284.39	-51.93	-26.66	-9.43
50.00	.00	-147.89	-148.00	-166.55	-165.75	-180.00	-159.14	-149.25
50.00	200.00	-60.80	-53.81	-286.03	-285.38	-72.84	-47.89	-33.42
100.00	.00	-160.45	-157.04	-178.04	-174.89	-184.05	-158.83	-147.64
100.00	200.00	-100.73	-87.77	-291.89	-289.29	-106.75	-81.84	-66.73
200.00	.00	-189.24	-197.39	-206.70	-206.79	-215.38	-173.91	-175.10
200.00	200.00	-167.53	-148.56	-310.57	-304.85	-167.53	-142.63	-127.33
400.00	.00	-211.79	-208.28	-230.75	-221.32	-249.70	-215.65	-255.69
400.00	200.00	-288.40	-263.60	-339.47	-329.92	-282.58	-257.68	-242.53

FREQ= 100000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -128.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -170.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -144.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -137.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -163.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -180.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -164.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -181.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -161.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -135.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-201.41	-202.48	-220.40	-220.40	-257.59	-222.03	-219.95
5.00	300.00	11.99	6.33	-396.25	-396.24	-20.05	12.26	1.83
25.00	.00	-202.07	-203.00	-221.03	-220.92	-244.17	-218.56	-208.12
25.00	300.00	-33.87	-32.58	-396.55	-396.46	-51.93	-26.66	-9.43
50.00	.00	-204.13	-204.59	-222.97	-222.53	-239.89	-217.71	-206.87
50.00	300.00	-60.80	-53.81	-397.50	-397.14	-72.84	-47.89	-33.42
100.00	.00	-212.16	-210.77	-230.56	-228.74	-240.60	-218.18	-211.31
100.00	300.00	-100.73	-87.77	-401.28	-399.85	-106.75	-81.84	-66.73
200.00	.00	-236.69	-235.58	-254.22	-253.73	-259.82	-223.37	-248.32
200.00	300.00	-167.53	-148.56	-415.49	-410.51	-167.53	-142.63	-127.33
400.00	.00	-266.20	-262.54	-285.17	-275.63	-304.01	-269.31	-303.77
400.00	300.00	-288.59	-263.60	-449.91	-438.60	-282.57	-257.68	-242.53

FREQ= 200000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= .00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -177.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -178.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -183.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -176.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -149.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	11.84	6.67	-116.99	-116.99	-20.20	12.27	29.83
5.00	.00	11.84	6.67	-116.99	-116.99	-20.20	12.27	29.83
25.00	.00	-37.19	-33.12	-116.99	-116.99	-55.25	-27.58	-2.50
25.00	.00	-37.19	-33.12	-116.99	-116.99	-55.25	-27.58	-2.50
50.00	.00	-69.35	-59.39	-116.99	-116.99	-81.39	-51.49	-24.68
50.00	.00	-69.35	-59.39	-116.99	-116.99	-81.39	-51.49	-24.68
100.00	.00	-120.25	-104.28	-116.99	-116.99	-126.27	-85.23	-50.52
100.00	.00	-120.25	-104.28	-116.99	-116.99	-126.27	-85.23	-50.52
200.00	.00	-209.28	-187.30	-116.99	-116.99	-209.28	-115.03	-74.58
200.00	.00	-209.28	-187.30	-116.99	-116.99	-209.28	-115.03	-74.58
400.00	.00	-374.95	-346.95	-116.99	-116.99	-368.93	-145.13	-98.66
400.00	.00	-374.95	-346.95	-116.99	-116.99	-368.93	-145.13	-98.66

FREQ= 200000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 50.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -177.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -178.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -183.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -176.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -149.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-54.97	-57.14	-77.07	-77.00	-99.72	-63.15	-55.89
5.00	50.00	11.84	6.67	-128.71	-128.65	-20.20	12.60	12.96
25.00	.00	-63.53	-61.83	-83.91	-82.03	-91.53	-70.04	-44.79
25.00	50.00	-37.19	-33.11	-131.89	-130.36	-55.25	-27.19	-5.37
50.00	.00	-85.59	-73.65	-100.51	-94.11	-99.79	-71.19	-57.51
50.00	50.00	-69.35	-59.38	-141.37	-135.38	-81.39	-53.47	-36.02
100.00	.00	-104.08	-104.82	-124.99	-119.39	-135.56	-90.10	-102.03
100.00	50.00	-119.38	-104.40	-159.29	-153.23	-126.37	-98.47	-76.90
200.00	.00	-123.20	-119.85	-145.17	-135.84	-161.35	-124.37	-156.32
200.00	50.00	-161.56	-157.78	-183.50	-174.06	-196.76	-160.43	-159.39
400.00	.00	-132.62	-134.60	-154.59	-150.53	-182.01	-144.27	-184.16
400.00	50.00	-170.94	-172.92	-192.92	-188.87	-220.65	-186.12	-222.80

FREQ= 200000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 100.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -177.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -178.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -183.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -176.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -149.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-99.42	-100.99	-121.46	-121.43	-149.62	-113.30	-102.37
5.00	100.00	11.84	6.67	-211.06	-211.04	-20.20	12.60	12.96
25.00	.00	-102.73	-103.22	-124.41	-123.74	-138.21	-113.28	-92.91
25.00	100.00	-37.19	-33.12	-212.46	-211.92	-55.25	-27.19	-5.37
50.00	.00	-112.55	-109.72	-133.09	-130.41	-139.67	-115.24	-108.14
50.00	100.00	-69.35	-59.39	-216.78	-214.61	-81.39	-53.46	-36.02
100.00	.00	-136.29	-133.33	-155.74	-153.40	-159.04	-120.94	-118.18
100.00	100.00	-120.25	-104.28	-231.91	-224.96	-126.27	-98.36	-76.90
200.00	.00	-161.53	-158.00	-183.48	-174.07	-199.24	-161.28	-193.01
200.00	100.00	-209.03	-187.30	-261.31	-250.75	-209.28	-181.37	-159.52
400.00	.00	-170.94	-172.92	-192.92	-188.87	-220.65	-186.12	-222.80
400.00	100.00	-247.72	-249.55	-269.69	-265.56	-207.24	-262.59	-299.64

FREQ= 200000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 200.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -177.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -178.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -183.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -176.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -149.50 DB .GT. 1V/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-182.13	-183.23	-204.14	-204.13	-237.84	-201.77	-190.81
5.00	200.00	11.84	6.67	-370.22	-370.21	-20.20	12.60	12.96
25.00	.00	-183.55	-184.32	-205.47	-205.23	-225.05	-198.20	-178.61
25.00	200.00	-37.19	-33.12	-370.86	-370.67	-55.25	-27.19	-5.37
50.00	.00	-187.90	-187.64	-209.57	-208.58	-222.67	-199.21	-177.22
50.00	200.00	-69.35	-59.39	-372.87	-372.09	-81.39	-53.46	-36.02
100.00	.00	-203.93	-200.31	-224.64	-221.28	-230.39	-197.93	-194.50
100.00	200.00	-120.25	-104.28	-380.77	-377.67	-126.27	-98.36	-76.90
200.00	.00	-239.76	-234.08	-262.52	-250.48	-276.53	-231.86	-233.67
200.00	200.00	-209.28	-187.30	-403.97	-401.22	-209.28	-181.38	-159.52
400.00	.00	-247.72	-249.55	-269.69	-265.56	-297.24	-262.59	-299.38
400.00	200.00	-374.55	-346.96	-423.24	-418.93	-368.93	-341.02	-327.10

FREQ= 200000.00 HZ COND.= .01 MHOS/M EPS= 10.00 POWER= 10.00 WATTS XMIT LOOP WEIGHT= 6.00 KG

XMIT LOOP RADIUS= 20.00 M LINE SOURCE LENGTH= 100.00 M DEPTH OF TRANSMITTER= 300.00

LINE SOURCE CONTACT RESISTANCE = 100.00 OHMS

NOISE = -130.00 DB .GT. 1A/M NOISE GRADE = 1
NOISE = -148.00 DB .GT. 1A/M NOISE GRADE = 2
NOISE = -190.00 DB .GT. 1A/M NOISE GRADE = 3
NOISE = -150.00 DB .GT. 1A/M NOISE GRADE = 4
NOISE = -145.00 DB .GT. 1A/M NOISE GRADE = 5
NOISE = -177.00 DB .GT. 1A/M NOISE GRADE = 6
NOISE = -167.00 DB .GT. 1A/M NOISE GRADE = 7
NOISE = -186.00 DB .GT. 1A/M NOISE GRADE = 8
NOISE = -160.00 DB .GT. 1A/M NOISE GRADE = 9
NOISE = -178.00 DB .GT. 1A/M NOISE GRADE = 10
NOISE = -183.00 DB .GT. 1A/M NOISE GRADE = 11
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 12
NOISE = -198.00 DB .GT. 1A/M NOISE GRADE = 13
NOISE = -176.00 DB .GT. 1A/M NOISE GRADE = 14
NOISE = -149.50 DB .GT. 1A/M NOISE GRADE = 15

DISP(M)	DEPTH(M)	ERHO(PHI=0)	EPHI(PHI=90)	HRHO(PHI=90)	HPHI(PHI=0)	HZ(PHI=90)	HZ(VMD)	EPH(VMD)
5.00	.00	-262.35	-263.24	-284.34	-284.34	-321.32	-285.36	-276.61
5.00	300.00	11.84	6.67	-527.06	-527.05	-20.20	12.60	12.96
25.00	.00	-263.23	-263.96	-285.20	-285.06	-308.11	-280.57	-263.56
25.00	300.00	-37.19	-33.12	-527.47	-527.37	-55.25	-27.19	-5.37
50.00	.00	-265.99	-266.19	-287.84	-287.29	-304.48	-280.04	-259.03
50.00	300.00	-69.35	-59.39	-528.78	-528.35	-81.39	-53.46	-36.02
100.00	.00	-276.67	-274.85	-298.09	-295.93	-307.74	-278.71	-265.54
100.00	300.00	-120.25	-104.28	-533.94	-532.21	-126.27	-98.36	-76.90
200.00	.00	-309.22	-324.90	-330.14	-331.79	-339.14	-293.90	-326.90
200.00	300.00	-209.28	-187.30	-551.94	-547.73	-209.28	-181.38	-159.52
400.00	.00	-324.49	-326.18	-346.47	-342.24	-373.83	-339.04	-375.96
400.00	300.00	-374.95	-346.95	-576.75	-572.28	-368.93	-341.02	-327.10

Analysis of Mine Communications Propagation Programs

In paragraph 7.1 "User's Guide for the Mine Communication's Propagation Programs," computer programs are presented for the complete analysis of specific through-the-earth electromagnetic links. These links include the following:

a. Communications between a VMD on the surface and a submerged VMD.
b. Communications between an infinite line source on the surface and a submerged line source or VMD.
c. Intramine communications between submerged horizontal electric dipoles (HED), between HED and VMD, or VMD to VMD.
d. Intramine communications from an infinite line source.

7.1 USER'S GUIDE FOR THE MINE COMMUNICATION'S PROPAGATION PROGRAMS

In the course of the analytical work which was accomplished under subcontract Purchase Order No. C-684420 to Collins Radio Group for their Bureau of Mines project, several basic computer programs were written. These programs were generated for the following specific tasks:

a. Communications between a vertical magnetic dipole (VMD) on the surface and a submerged VMD.*
b. Communications between an infinite line source on the surface and a submerged line source or VMD.*
c. Intramine communications between submerged horizontal electric dipoles (HED), between HED and VMD, or VMD to VMD.**
d. Intramine communications from a submerged infinite line source.

The first program is employed for most up-link or down-link paths. It computes the H-fields on the surface from a submerged VMD at various displacements, or the subsurface H-fields from a VMD on the surface. It will also compute the subsurface E- and H-fields of interest from an infinite line source on the surface.

The results are displayed for various receiving point depths and displacements in terms of signal-to-noise spectral density.

*With preliminary noise grades.
**Includes updated noise grades defined in section 6.

The input requirements are as follows:

FORTRAN NOTATION	MEANING
PT	Transmitter power in watts
W1	Weight of transmit loop, kg
AC	Circular mils area of loop wire
A1	Radius of transmit loop, meters
A2	Radius of receive loop, meters
SIG	Overburden conductivity mhos/meter
RNF	Receiver noise figure, dB
NOISE	Noise grade; 1, 2, or 3*
LINK	= 1 up-link, = 2 down-link
IT	If IT = 1, a large diameter surface XMIT is used
ITYPE	= 1, vertical H-fields from VMD
	= 2, vertical H-fields from infinite line source
	= 3, horizontal H-fields from infinite line source
	= 4, E-fields from infinite line source
LL	Number of frequencies to be skipped.

7.2 PROGRAM NUMBER ONE

The printed output first consists of a 2-dimensional array of Wait's functions used to compute the fields. After a listing of the basic input parameters, the noise power density, the minimum receive loop turns and the Q of the transmit and receive loops are presented. A 2-dimensional (depth and displacement) array of S/N_0 is then printed out.

*Preliminary noise grades.

```
      COMPLEX SUM,FUN,DOODLE,ZAP
      DIMENSION UN(2,16),FREQ(16),DN(3,16),KLINK(2),QX(11,12),QS(11,12)
      DATA FREQ/100.,200.,300.,500.,700.,1000.,2000.,3000.,5000.,7000.,
     110000.,20000.,30000.,50000.,70000.,100000./,KLINK/4H  UP,4HDOWN/
      DATA (UN(1,I),I=1,16)/46.5,31.0,19.0,6.0,0.0,-6.0,-13.0,-18.5,-24.
     15,-28.5,-33.0,-41.0,-46.0,-50.0,-53.5,-57.0/,(UN(2,I),I=1,16)/30.,
     26.0,-6.0,-17.0,-25.0,-30.0,-37.5,-40.0,-40.0,-40.0,-40.0,-49.0,-50
     3.0,-53.0,-58.0,-68.0/,(DN(1,I),I=1,16)/59.0,54.5,51.0,45.0,42.5,40
     4.0,31.0,21.0,1.5,-3.5,-15.0,-29.0,-34.0,-43.0,-65.0,-73.0/,(DN(2,I
     5),I=1,16)/47.0,31.0,19.0,12.0,11.0,11.0,11.0,6.0,-9.0,-22.0,-32.0,
     6-46.0,-55.0,-64.0,-69.0,-73.0/,(DN(3,I),I=1,16)/30.0,6.0,-6.0,-17.
     70,-25.0,-30.0,-37.0,-40.0,-46.0,-45.0,-48.0,-54.5,-59.0,-72.0,-75.
     80,-76.0/
      EXTERNAL FUN
      PI=3.141592654
    1 READ 2,PT,W1,AC,A1,A2,SIG,RNF,NOISE,LINK,IT,ITYPE,LL
    2 FORMAT(7F10.2,5I2)
      IF(PT.LT..0001) CALL EXIT
      MINK=KLINK(LINK)
      IF(ITYPE.GT.1) GO TO 20
      N=0
      IF(LINK.EQ.2.AND.IT.EQ.1) N=1
   20 DO 12 I=1,16,LL
      FRE=FREQ(I)
      IF(LINK.GT.1) GO TO 3
      HN=UN(NOISE,I)
      GO TO 4
    3 HN=DN(NOISE,I)
    4 CONTINUE
      DUM=HN
      HN=10.**((HN-120.)/20.)
      RFN=10.**(RNF/10.)
      IF(ITYPE.GT.1) GO TO 21
      QL1=(1.515*FRE*ALOG10(96.5*A1)*W1*1.E-3)/A1
   21 NT=(4.41*RFN*1.E-8)/(FRE**2*HN**2*AC*A2**3)+1
      TN=NT
      W2=(A2*TN*AC)/(2.78*1.E+4)
      QL2=(1.515*FRE*ALOG10(96.5*A2)*W2*1.E-3)/A2
   17 PNOD=10.*ALOG10(4.*PI**4*6.52*W2)-230.+DUM+20.*ALOG10(FRE*A2)
      DO 7 J=1,12
      H=.05+.05*FLOAT(J-1)
      SIGM=SIG*1000.
      X=.086*SQRT(FRE*SIGM)*H
      DO 7 K=1,11
      D=.5*FLOAT(K-1)/H
      A=(A1/H)*1.E-3
      TEMP=1.E-6
      SUM=(0.,0.)
      G=0.
      F=1.
      DO 5 L=1,10
      ZAP=DOODLE(1,G,F,X,D,A,N,ITYPE,FUN)
      SUM=SUM+ZAP
      IF(CABS(ZAP).LT..001*TEMP) GO TO 6
      TEMP=CABS(ZAP)
      G=F
      F=3.*G
    5 CONTINUE
```

```
    6 Q=CABS(SUM)
      IF(Q.LE.0.)Q=1.E-10
      IF(ITYPE.GT.1) GO TO 22
      SNR=-40.+10.*ALOG10(65.2*W1)-10.*ALOG10(16.*PI**2)+20.*ALOG10(A1*Q
     1)-DUM-60.*ALOG10(H)+10.*ALOG10(PT)
      GO TO 28
   22 SNR=20.*ALOG10(Q/H)-DUM+10.*ALOG10(PT/100.)+60.
C CAUTION FOR ITYPE 4 SUBSURFACE LINE SOURCE NOISE FIELDS ARE ONLY APPRO
C XIMATE
      IF(ITYPE.EQ.4)SNR=SNR+20.*ALOG10(H*FRE)-109.5
   28 QS(K,J)=Q
    7 QX(K,J)=SNR
      PRINT 19
   19 FORMAT(1H1,//,40X,'WATTS Q FUNCTION',//)
      PRINT 18,QS
   18 FORMAT(1X,11F11.6/)
      IF(ITYPE.GT.1) GO TO 24
      PRINT 8,FRE,PT,W1,W2,A1,A2,SIG,MINK,NOISE,RNF
    8 FORMAT(1H1,10X,'FREQ.=',F8.0,' HZ  TRANSMITTER POWER ',F8.0,'WATTS
     1  XMIT LOOP WEIGHT ',F6.2,' KG  RCVE LOOP WEIGHT ',F6.2,' KG ',//,
     210X,'XMIT LOOP RADIUS  ',F6.2,' M   RCVE LOOP RADIUS ',F6.2,' M
     3COND. ',F6.2,'  MHOS/M  ',A4,'LINK  NOISE=',I2,' RCVR NF=',F4.0,'
     4DB')
      PRINT 13,PNOD,NT,QL1,QL2
   13 FORMAT(//,10X,'NOISE POWER DENSITY ',F7.1,' DBW,  RCVE LOOP TURNS
     1 ',I4,' XMIT LOOP Q ',F8.2,',RCVE LOOP Q ',F8.2)
      GO TO 27
   24 PRINT 25,FRE,PT,SIG,MINK,NOISE,RNF
   25 FORMAT(1H1,10X,'FREQ.=',F8.0,' HZ  TRANS POWER ',F8.0,' WATTS  CON
     1D. ',F6.2,' MHOS/M  ',A4,'LINK  NOISE=',I2,'  RCVR NF=',F4.0,' DB'
     2)
      PRINT 26
   26 FORMAT(//,40X,'LINE SOURCE DOWNLINK')
   27 PRINT 9
    9 FORMAT(///,20X,'RECEIVED SIGNAL TO NOISE SPECTRAL DENSITY',//,40X,
     1'DISPLACEMENT-KM',/,' DEPTH(KM)    .00     .05     .10     .15     .20
     2    .25     .30     .35     .40     .45     .50 ',/)
      DO 10 L=1,12
      H=.05+.05*FLOAT(L-1)
   10 PRINT 11,H,(QX(M,L),M=1,11)
   11 FORMAT(1X,F6.2,2X,11F7.1/)
   12 CONTINUE
      GO TO 1
      END

OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

```
      COMPLEX FUNCTION DOODLE(N,A,B,C,D,E,K,L,FUN)
      DIMENSION Y(32),W(32)
      COMPLEX FUN
      DATA (W(I),I=1,16)/3.5093050E-3,8.1371974E-3,1.26960327E-2,
     1 1.71369314E-2,2.14179490E-2,2.54990296E-2,2.93420467E-2,
     2 3.29111114E-2,3.61728971E-2,3.90969479E-2,4.16559621E-2,
     3 4.38260465E-2,4.55869390E-2,4.69221995E-2,4.78193600E-2,
     4 4.82700443E-2/
      DATA (Y(I),I=1,29)/1.3680691E-3,7.19424422E-3,1.76188722E-2,
     2 3.25469620E-2,5.18394221E-2,7.53161931E-2,1.02758102E-1,
     3 1.33908940E-1,1.68477866E-1,2.06142121E-1,2.46550045E-1,
     4 2.89324361E-1,3.34065698E-1,3.80356318E-1,4.27764019E-1,
     5 4.75846167E-1,5.24153832E-1,5.72235980E-1,6.19643681E-1,
     5 6.65934301E-1,7.10675638E-1,7.53449954E-1,7.93857878E-1,
     6 8.31522133E-1,8.66091059E-1,8.97241897E-1,9.24683806E-1,
     7 9.48160577E-1,9.67453037E-1/
      DATA (Y(I),I=30,32)/9.82381127E-1,9.92805756E-1,9.98631931E-1/
      DOODLE=(0.,0.)
      XX = A
      H=(B-A)/(FLOAT(N))
      DO 5 I=1,16
      J=33-I
    5 W(J)=W(I)
   30 DO 1 J=1,N
      DO 2 I=1,32
      X=XX+H*Y(I)
    2 DOODLE=DOODLE+W(I)*FUN(X,C,D,E,K,L)
    1 XX=XX+H
      DOODLE=H*DOODLE
      RETURN
      END
```

F UNIVAC 1108 FORTRAN V COMPILATION.   0 *DIAGNOSTIC* MESSAGE(S)

```
      COMPLEX FUNCTION FUN(X,H,D,G,K,L)
      COMPLEX Q
      DOUBLE PRECISION XD,HD,C,E,U,V,W,Z,T
      XD=X**2
      HD=H**2
      CALL CDSQRT(XD,HD,C,E)
      U=DEXP(-C)*DCOS(E)
      V=-DEXP(-C)*DSIN(E)
      W=DBLE(X)+C
      CALL DCDI22(U,V,W,E,Z,T)
      Q=CMPLX(SNGL(Z),SNGL(T))
      GO TO (1,2,3,4),L
    1 FUN=X**3*Q*BSSL(X*D,1)
      IF(K.EQ.0.OR.X.LT.1.E-6)RETURN
      FUN=FUN*2.*BSSL(X*G,3)/(X*G)

      RETURN
    2 FUN=2.*X*Q*SIN(X*D)
      RETURN
    3 FUN=2.*Q*CMPLX(SNGL(C),SNGL(E))*COS(X*D)
      RETURN
    4 FUN=2.*Q*COS(X*D)
      RETURN
      END
```

F UNIVAC 1108 FORTRAN V COMPILATION.   *DIAGNOSTIC* MESSAGE(S)

```
NE DCDI22      ENTRY POINT 000034

USED (BLOCK, NAME, LENGTH)

)01    *CODE     000050
)00    *DATA     000010
)02    *BLANK    000000


 REFERENCES (BLOCK, NAME)

)03    NERR3$


ASSIGNMENT FOR VARIABLES (BLOCK, TYPE, RELATIVE LOCATION, NAME)

000000 INJP$


 *           SUBROUTINE DCDI22(A,B,C,D,X,Y)
 *           DOUBLE PRECISION A,B,C,D,X,Y
 *           X=C*C+D*D
 *           Y=(B*C-A*D)/X
 *           X=(A*C+B*D)/X
 *           RETURN
 *           END

OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)


 *           SUBROUTINE CDSQRT(A,B,C,D)
 *           DOUBLE PRECISION A,B,C,D,Z2,ZSR,F
 *           Z2=A*A+B*B
 *           ZSR=DSQRT(Z2)
 *           C=DSQRT(0.5D0*(A+ZSR))
 *           F=ZSR-A
 *           F=DMAX1(0.D0,ZSR-A)
 *           D=DSIGN(1.0D0,B)*DSQRT(0.5D0*F)
 *           RETURN
 *           END

OF UNIVAC 1108 FORTRAN V COMPILATION.      0 *DIAGNOSTIC* MESSAGE(S)
```

7.3 PROGRAM NUMBER TWO

The second program is used for most intramine paths. It computes the five field components of interest emanating from a submerged HED and the two field components due to a submerged VMD. These components are calculated on the surface and at the transmitter depth for various displacements. The input requirements are as follows:

FORTRAN NOTATION	MEANING
PT	Transmitter power in watts
W1	Weight of the transmitting VMD, kg
A1	Radius of transmitting VMD, meters
L1	Length of transmitting HED meters
FRX	Frequency in Hz
EPS	Relative dielectric constant of overburden
SIG	Conductivity of overburden mhos/meter
RS	Contact resistance of submerged HED
DS	Depth of transmitter, meters
NOISE	Noise grade (subsurface) 1, 2, or 3
LT	The number of displacements in 100-meter increments from the transmitter.

The format for this data is (9F8.2, 2I2). An arbitrary number of these cards may be inputted for whatever combination of parameters are desired. The last card in the data deck is blank. The frequencies selected must be one of the following: 1 KHZ, 2 KHZ, 3 KHZ, 5 KHZ, 10 KHZ, 20 KHZ, 50 KHZ, 70 KHZ, 100 KHZ.

The field components computed are

$$E_\rho\Big|_{\phi = 0^\circ};\quad E_\phi\Big|_{\phi = \pi/2};\quad H_\rho\Big|_{\phi = \pi/2};\quad H_\phi\Big|_{\phi = 0};\quad \text{and}\quad H_z\Big|_{\phi = \pi/2}$$

For the transmitting VMD, the field components are Hz and E_ϕ.

The output format first displays the basic input data and the noise fields for the three noise grades. The above seven field components are then printed out for the indicated displacement for receiving points located at the surface and at the transmitter depth.

```
      REAL L1
      COMPLEX A,G1,G12,K,H,EP,EPH,HPH,HZ,HZV,GAM,U,T,BET,ALP,TEB,PLA
      DIMENSION FREQ(19),DN(15,17),Q(10),H(10),P(25),FEP(8,10)
     1,FEPH(8,10),FHPH(8,10),FHP(8,10),FHZ(8,10),FHZV(8,10)
      DIMENSION FEPHV(8,10),DP(2),DX(6)
      DATA FREQ/100.,200.,300.,500.,700.,1000.,2000.,3000.,5000.,7000.,
     110000.,20000.,30000.,50000.,70000.,1.E+5,2.E+5,3.35E+5,4.E+5/
      DATA((DN(I,J),J=1,17),I=1,15)/88.,78.,72.,64.,59.,54.,49.,45.,37.5
     1,32.,25.,11.5,4.5,-2.,-6.,-8.,-10.,45.,38.,33.,28.,25.,21.,17.,13.
     2,7.,4.,0.,-7.,-12.,-17.,-21.,-24.,-28.,51.,39.,31.,22.,16.,10.,-8.
     3,-15.,-21.,-29.,-31.,-39.,-43.,-43.,-43.,-50.,-70.,88.,74.,66.,56.
     4,49.,43.,33.,23.,14.,14.,19.,1.,-10.,-18.,-21.,-24.,-30.,68.,57.,
     550.,42.,36.,30.,21.,14.,5.,0.,-3.,3.,0.,-6.,-11.,-17.,-25.,57.,46.
     6,40.,33.,28.,23.,13.,7.,0.,-2.,-5.,-5.,-13.,-17.,-33.,-43.,-57.,30
     7.,21.,16.,10.,5.,1.,-9.,-14.,-18.,-21.,-17.,-13.,-24.,-34.,-38.,-4
     81.,-47.,57.,44.,33.,19.,10.,1.,-19.,-30.,-40.,-43.,-45.,-45.,-45.,
     9-47.,-51.,-60.,-66.,81.,67.,58.,48.,41.,34.,20.,12.,2.,-6.,-11.,
     X-15.,-22.,-31.,-26.,-30.,-40.,67.,54.,46.,36.,29.,23.,7.,0.,-6.,
     1-15.,-22.,-31.,-34.,-38.,-43.,-44.,-58.,38.,29.,22.,15.,10.,6.,-3.
     2,-9.,-17.,-19.,-61.,-61.,-61.,-61.,-61.,-61.,-63.,21.,13.,8.,3.,
     3-1.,-5.,-10.,-16.,-24.,-25.,-27.,-33.,-39.,-52.,-55.,-66.,-78.,-7.
     3,-12.,-15.,-19.,-21.,-24.,-27.,-29.,-33.,-36.,-40.,-49.,-52.,-59.,
     4-66.,-70.,-78.,56.5,46.5,41.,33.5,29.,24.,13.,6.,1.,-4.,-9.,-18.,
     5-23.,-28.,-35.,-41.,-56.,42.,40.,38.,36.,33.,29.,25.,19.5,12.5,
     612.5,12.5,3.5,2.5,1.5,-3.5,-15.5,-29.5/
      DATA DX/5.,25.,50.,100.,200.,400./
      PI=3.141592654
      EO=(1./(36.*PI))*1.E-9
      C=2.99796E+8
      UO=4.*PI*1.E-7
    1 READ 2,PT,WI,AI,L1,FRX,EPS,SIG,RS,DS,NOISE,LT
    2 FORMAT(9F8.2,2I2)
      IF(PT.LT..0001) CALL EXIT
      DO 16 I=1,19
 THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
      IF(FRX.NE.FREQ(I)) GO TO 16
      FRE=FRX
      W=2.*PI*FRE
      G12=UO*W*(0.,1.)*(SIG+(0.,1.)*EPS*EO*W)
      CUR=SQRT(PT/RS)
      GO=-(W/C)**2
      G1=CSQRT(G12)
      CURM=0.5*AI*SQRT(WI*PT*6.52E+3)
      K=(SIG+(0.,1.)*EPS*EO*W)/((0.,1.)*EO*W)
      A=(CUR*L1)/(4.*PI*(SIG+(0.,1.)*EPS*EO*W))
      B=(CUR*L1)/(4.*PI)
      CK=CURM/(4.*PI)
      T=-(0.,1.)*UO*W*CURM/(4.*PI)
      DP(1)=0.
      DP(2)=DS
      DO 12 J=1,2
      Z=DP(J)
      DO 12 L=1,LT
      RHO=DX(L)
      GAM=G12*RHO**2
      D=(Z+DS)/RHO
      R=SQRT(RHO**2+(Z-DS)**2)
      ZO=W*RHO/C
      DELO=ZO*(1.-1./SQRT(2.))
      DELK=ZO*CABS(1.-CSQRT(K/(K+1.)))
      P(1)=0.
      P(2)=ZO-DELO
      P(3)=ZO-DELK
```

```
      P(4)=ZO+DELK
      P(5)=ZO+DELO
      P(6)=RHO*SQRT(-REAL(G12))
      P(7)=2.*P(6)
      P(8)=3.*P(6)
      P(9)=4.*P(6)
      P(10)=6.*P(6)
      P(11)=16.*P(6)
      DO 98 LK=12,20
   98 P(LK)=3.*P(LK-1)
      DO 99 LL=1,10
   99 H(LL)=(0.,0.)
      IF(Z.GT.1..AND.DS.GT.1.) GO TO 997
      BET=1.-(1.+G1*R+4.*G12*R**2/9.+G1*G12*R**3/9.)*CEXP(-G1*R)
      TEB=18.*CK*BET/(G12*RHO**5)
      FHZV(J,L)=20.*ALOG10(CABS(TEB))
      ALP=1.-(1.+G1*R+G12*R**2/3.)*CEXP(-G1*R)
      PLA=6.*T*ALP/(G12*RHO**4)
      FEPHV(J,L)=20.*ALOG10(CABS(PLA))
      GO TO 71
  997 DO 7 M=1,19
      G=P(M)
      E=P(M+1)
      CALL HMO(1,G,E,D,70,K,GAM,0)
      DO 15 II=1,10
   15 H(II)=H(II)+O(II)
    7 CONTINUE
   71 CONTINUE
C     COMPUTE PRIMARY FIELDS
      EP=-A*CEXP(-G1*R)*(1.+G1*R+G12*R**2-(RHO/R)**2*(3.+3.*G1*R+G12*R**
     12))/R**3
      EPH=A*CEXP(-G1*R)*(G12*R**2+G1*R+1.)/R**3
      EPHV=T*CEXP(-G1*R)*RHO*(G1*R+1.)/R**3
      HPH=-B*CEXP(-G1*R)*(G1*R+1.)*SQRT(1.-(RHO/R)**2)/R**2
      IF(CABS(HPH).LT.1.E-9)HPH=(1.E-9,1.E-9)
      HZ=B*CEXP(-G1*R)*RHO*(G1*R+1.)/R**3
      HZV=CK*CEXP(-G1*R)*(-1.-G1*R-G12*R**2+(1.-(RHO/R)**2)*(3.*(1.+G1*R
     1)+G12*R**2))/R**3
      FEP(J,L)=20.*ALOG10(CABS(EP+A*(H(1)-H(2))/RHO**3+2.*A*(H(3)-H(4))/
     1(GO*RHO**5)))
      FEPH(J,L)=20.*ALOG10(CABS(EPH-A*G12*H(5)/RHO+A*H(2)/RHO**3+2.*A*H(
     14)/RHO**5))
      FHPH(J,L)=20.*ALOG10(CABS(HPH+B*H(6)/RHO**2+2.*B*(H(8)-H(7))/(GO*
     1RHO**4)))
      FHP(J,L)=20.*ALOG10(CABS(HPH+B*H(6)/RHO**2+2.*B*H(7)/(GO*RHO**4)))
      FHZ(J,L)=20.*ALOG10(CABS(HZ-B*H(9)/RHO**2))
      IF(Z.LE.1..AND.DS.LE.1.) GO TO 12
      FHZV(J,L)=20.*ALOG10(CABS(HZV-CK*H(10)/RHO**3))
      FEPHV(J,L)=20.*ALOG10(CABS(EPHV-T*H(2)/RHO**3))
   12 CONTINUE
      PRINT 30
   30 FORMAT(1H1)
      PRINT 17,FRE,SIG,EPS,PT,W1,A1,L1,DS,RS
   17 FORMAT(//,10X,'FREQ= ',F9.2,' HZ  COND.= ',F6.2,' MHOS/M  EPS= ',
     1F6.2,' POWER= ',F8.2,' WATTS  XMIT LOOP WEIGHT= ',F8.2,' KG',//,
     210X,'XMIT LOOP RADIUS= ',F8.2,' M  LINE SOURCE LENGTH= ',F8.2,' M
     3 DEPTH OF TRANSMITTER= ',F8.2,//,20X,'LINE SOURCE CONTACT RESISTAN
     1CE = ',F8.2,' OHMS',//)
       IF(I.GT.17) GO TO 221
       DO 79 NOISE=1,15
```

```
      HN=DM(NOISE,I)-120.
   79 PRINT 22,HN,NOISE
   22 FORMAT(20X,'NOISE = ',F10.2,' DB .GT. 1A/M  NOISE GRADE =',I4)
  221 PRINT 18
   18 FORMAT(//)
      PRINT 19
   19 FORMAT(2X,'DISP(M)   DEPTH(M)   ERHO(PHI=0)    EPHI(PHI=90)   HRHO(PHI
     1=90)   HPHI(PHI=0)    HZ(PHI=90)    HZ(VMD)    EPH(VMD)',//)
      DO 13 N=1,LT
      DISP=DX(N)
      DO 20 NN=1,2
      DPTH=DP(NN)
   20 PRINT 21,DISP,DPTH,FEP(NN,N),FEPH(NN,N),FHPH(NN,N),FHP(NN,N),FHZ(
     1NN,N),FHZV(NN,N),FEPHV(NN,N)
   21 FORMAT(2F9.2,7F13.2,/)
   13 CONTINUE
   16 CONTINUE
      GO TO 1
      END

PILATION:              1 DIAGNOSTICS.


      SUBROUTINE HMO          ENTRY POINT 000161


      SUBROUTINE HMO(N,A,B,D,ZO,K,G12,R)
      COMPLEX R,S,K,G12
      DIMENSION Y(32),W(32),R(10),S(10)
      DATA (W(I),I=1,16)/3.5093050E-3,8.1371974E-3,1.26960327E-2,
     1 1.71369314E-2,2.14179490E-2,2.54990296E-2,2.93420467E-2,
     2 3.29111114E-2,3.61728971E-2,3.90969479E-2,4.16559621E-2,
     3 4.38260465E-2,4.5586939E-2,4.692219954E-2,4.78193600E-2,
     4 4.82700443E-2/
      DATA (Y(I),I=1,29)/1.3680691E-3,7.19424422E-3,1.76188722E-2,
     2 3.25469620E-2,5.18394221E-2,7.53161931E-2,1.02758102E-1,
     3 1.33908940E-1,1.68477866E-1,2.06142121E-1,2.46550045E-1,
     4 2.89324361E-1,3.34065698E-1,3.80356318E-1,4.27764019E-1,
     5 4.75846167E-1,5.24153832E-1,5.72235980E-1,6.19643681E-1,
     5 6.65934301E-1,7.10675638E-1,7.53449954E-1,7.93857878E-1,
     6 8.31522133E-1,8.66091059E-1,8.97241897E-1,9.24683806E-1,
     7 9.48160577E-1,9.67453037E-1/
      DATA (Y(I),I=30,32)/9.823811278E-1,9.92805756E-1,9.98631931E-1/
      DO 8 I=1,10
    8 R(I)=(0.,0.)
      XX=A
      H=(B-A)/FLOAT(N)
      DO 5 I=1,16
      J=33-I
    5 W(J)=W(I)
      DO 1 J=1,N
      DO 2 I=1,32
      X=XX+H*Y(I)
      CALL FUN(X,D,ZO,K,G12,S)
      DO 6 M=1,10
    6 R(M)=R(M)+W(I)*S(M)
    2 CONTINUE
```

```
1 XX=XX+H
  DO 7 L=1,10
7 R(L)=H*R(L)
  RETURN
  END
```

END OF COMPILATION: NO DIAGNOSTICS.

```
      SUBROUTINE FUN(X,D,ZO,K,G12,S)
      COMPLEX K,S,G12,U,UO,R,T,E
      DIMENSION S(10)
      U=CSQRT(X**2+G12)
      Y=X**2-ZO**2
      IF(Y.LT.0.) UO=CMPLX(0.,SQRT(ABS(Y)))
      IF(Y.GE.0.) UO=CMPLX(SQRT(Y),0.)
      R=(UO-U)/(U+K*UO)
      T=(UO-U)/(UO+U)
      IF(X.LT.1.E+5) GO TO 1
      A=0.
      B=0.
      GO TO 2
    1 A=BSSL(X,1)
      B=BSSL(X,3)
    2 E=CEXP(-U*D)
      S(1)=A*T*E*U*X
      S(2)=B*T*E*X**2/U
      S(3)=A*R*E*U*X**3
      S(4)=B*R*E*U*X**2
      S(5)=A*T*E*X/U
      S(6)=A*T*E*X
      S(7)=B*R*E*X**2
      S(8)=A*R*E*X**3
      S(9)=B*T*E*X**2/U
      S(10)=A*T*E*X**3
      RETURN
      END
```

7.4 PROGRAM NUMBER THREE

The third program in the series pertains principally to the submerged infinite line source. It computes the E-field parallel to the line source, the vertical H-field and the horizontal H-field normal to the line source. The input requirements are as follows:

FORTRAN NOTATION	MEANING
PT	Transmitter power, watts
FRX	Frequency, Hz
EPS	Relative dielectric constant
SIG	Overburden conductivity, mhos/meter
RS	Line source contact resistance, ohms
DS	Line source depth
NOISE	Noise grade: 1, 2, and 3
LT	The number of displacement increments to be computed

The basic input parameters are first printed out after which is displayed the noise fields for the three noise grades. The three field components of interest are then printed out at the surface and at the transmitter depth. These are repeated for each displacement. The last data card is left blank.

```
*          COMPLEX G1,G12,H,GAM,Q
*          DIMENSION UN(2,16),FREQ(16),DN(3,16),Q(3),H(3),P(15),FEX(8,10),
*         1FHY(8,10),FHZ(8,10),KLINK(2)
*          DATA FREQ/100.,200.,300.,500.,700.,1000.,2000.,3000.,5000.,7000.,
*         110000.,20000.,30000.,50000.,70000.,100000./,KLINK/4H  UP,4HDOWN/
*          DATA (UN(1,I),I=1,16)/46.5,31.0,19.0,6.0,0.0,-6.0,-13.0,-18.5,-24.
*         15,-28.5,-33.0,-41.0,-46.0,-50.0,-53.5,-57.0/,(UN(2,I),I=1,16)/30.,
*         26.0,-6.0,-17.0,-25.0,-30.0,-37.5,-40.0,-40.0,-40.0,-40.0,-49.0,-50
*         3.0,-53.0,-58.0,-68.0/,(DN(1,I),I=1,16)/59.0,54.5,51.0,45.0,42.5,40
*         4.0,31.0,21.0,1.5,-3.5,-15.0,-29.0,-34.0,-43.0,-65.0,-73.0/,(DN(2,I
*         5),I=1,16)/47.0,31.0,19.0,12.0,11.0,11.0,11.0,6.0,-9.0,-22.0,-32.0,
*         6-46.0,-55.0,-64.0,-69.0,-73.0/,(DN(3,I),I=1,16)/30.0,6.0,-6.0,-17.
*         70,-25.0,-30.0,-37.0,-40.0,-46.0,-45.0,-48.0,-54.5,-59.0,-72.0,-75.
*         80,-76.0/
*          PI=3.141592654
*          E0=(1./(36.*PI))*1.E-9
*          C=2.99796E+8
*          U0=4.*PI*1.E-7
*        1 READ 2,PT,FRY,EPS,SIG,RS,DS,NOISE,LT
*        2 FORMAT(6F8.2,2I2)
*          IF(PT.LT..0001) CALL EXIT
*          DO 16 I=1,16
GNOSTIC.   THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
*          IF(FRY.NE.FREQ(I)) GO TO 16
*          FRE=FRY
*          W=2.*PI*FRE
*          G12=U0*W*(0.,1.)*(SIG+(0.,1.)*EPS*E0*W)
*          CUR=SQRT(PT/RS)
*          G0=-(W/C)**2
*          G1=CSQRT(G12)
*          GAM=G12*DS**2
*          Z0=W*DS/C
*          DELO=Z0*(1.-1./SQRT(2.))
*          P(1)=0.
*          P(2)=Z0-DELO
*          P(3)=Z0+DELO
*          P(4)=DS*SQRT(-REAL(G12))
*          P(5)=2.*P(4)
*          P(6)=3.*P(4)
*          P(7)=4.*P(4)
*          P(8)=6.*P(4)
*          P(9)=18.*P(4)
*          DO 98 LK=10,13
*       98 P(LK)=3.*P(LK-1)
*          DO 12 J=1,2
*          Z=60.*FLOAT(J-1)
*          IF(J.EQ.2)Z=DS
*          ZZ=Z/DS
*          DO 12 L=1,LT
*          RHO=100.*FLOAT(L-1)
*          D=RHO/DS
*          DO 99 LL=1,3
*       99 H(LL)=(0.,0.)
*          DO 7 M=1,12
*          G=P(M)
*          E=P(M+1)
*          CALL DOUBLE(1,G,E,ZZ,Z0,D,GAM,Q)
*          DO 15 II=1,3
*       15 H(II)=H(II)+Q(II)
*        7 CONTINUE
*          FEX(J,L)=20.*ALOG10(U0*W*CUR*CABS(H(1))/(2.*PI))
*          FHY(J,L)=20.*ALOG10(CUR*CABS(H(2))/(2.*PI*DS))
```

```
*          IF(CABS(H(3)).LT.1.E-14)H(3)=(1.E-14,1.E-14)
*          IF(CABS(H(3)).GT.1.E+14)H(3)=(1.E+14,1.E+14)
*          FHZ(J,L)=20.*ALOG10(CUR*CABS(H(3))/(2.*PI*DS))
*       12 CONTINUE
*          PRINT 30
*       30 FORMAT(1H1)
*          PRINT 17,FRE,SIG,EPS,PT,DS,RS
*       17 FORMAT(//,10X,'FREQ= ',F9.2,' HZ  COND.= ',F6.3,' MHOS/M  EPS= ',
*         1F6.2,' POWER= ',F8.2,'  DEPTH OF TRANSMITTER= ',F8.2,//,20X,'LINE
*         2SOURCE CONTACT RESISTANCE= ',F8.2,' OHMS',//)
*          DO 79 NOISE=1,3
*          HN=DN(NOISE,I)-120.
*       79 PRINT 22,HN,NOISE
*       22 FORMAT(20X,'NOISE = ',F10.2,' DB .GT. 1A/M  NOISE GRADE = ',I4,/)
*          DO 13 N=1,LT
*          DISP=100.*FLOAT(N-1)
*          PRINT 18,DISP
*       18 FORMAT(//,10X,'THE FIELD COMPONENTS IN DB GT 1V/M OR 1A/M FOR A DI
*         1SPLACEMENT OF ',F8.2,' METERS',//)
*          PRINT 19
*       19 FORMAT(2X,'DEPTH(M)        EX              HY              HZ',//)
*          DO 20 NN=1,2
*          DPTH=50.*FLOAT(NN-1)
*          IF(NN.EQ.2)DPTH=DS
*       20 PRINT 21,DPTH,FEX(NN,N),FHY(NN,N),FHZ(NN,N)
*       21 FORMAT(F8.2,3F13.2,/)
*       13 CONTINUE
*       14 CONTINUE
*          GO TO 1
*          END

OF UNIVAC 1108 FORTRAN V COMPILATION.        1 *DIAGNOSTIC* MESSAGE(S)
*          SUBROUTINE DOUBLE(N,A,B,D,Z0,T,G12,R)
*          COMPLEX R,S,G12
*          DIMENSION Y(32),W(32),R(3),S(3)
*          DATA (W(I),I=1,16)/3.5093050E-3,8.1371974E-3,1.26960327E-2,
*         1 1.71369314E-2,2.14179490E-2,2.54990296E-2,2.93420467E-2,
*         2 3.29111114E-2,3.61728971E-2,3.90969479E-2,4.16559621E-2,
*         3 4.38260465E-2,4.55869390E-2,4.69221995E-2,4.78193600E-2,
*         4 4.82700443E-2/
*          DATA (Y(I),I=1,29)/1.3680691E-3,7.19424422E-3,1.76188722E-2,
*         2 3.25469620E-2,5.18394221E-2,7.53161931E-2,1.02758102E-1,
*         3 1.33908940E-1,1.68477866E-1,2.06142121E-1,2.46550045E-1,
*         4 2.89324361E-1,3.34065698E-1,3.80356318E-1,4.27764019E-1,
*         5 4.75846167E-1,5.24153832E-1,5.72235980E-1,6.19643681E-1,
*         5 6.65934301E-1,7.10675638E-1,7.53449954E-1,7.93857878E-1,
*         6 8.31522133E-1,8.66091059E-1,8.97241897E-1,9.24683806E-1,
*         7 9.48160577E-1,9.67453037E-1/
*          DATA (Y(I),I=30,32)/9.82381127E-1,9.92805756E-1,9.98631931E-1/
*          DO 8 I=1,3
*        8 R(I)=(0.,0.)
*          XX=A
*          H=(B-A)/FLOAT(N)
*          DO 5 I=1,16
*          J=33-I
*        5 W(J)=W(I)
```

```
*           DO 1  I=1,N
*           DO 2  I=1,32
*           X=XX+H*Y(I)
*           CALL FUN(X,D,Z0,R,G12,S)
*           DO 6  M=1,3
*         6 P(M)=P(M)+W(I)*S(M)
*         2 CONTINUE
*         1 XX=XX+H
*           DO 7  L=1,3
*         7 P(L)=H*P(L)
*           RETURN
*           END

OF UNIVAC 1108 FORTRAN V COMPILATION.        0 *DIAGNOSTIC* MESSAGE(S)


            SUBROUTINE FUN(X,D,Z0,R,G12,S)
            COMPLEX G12,S,U,U0,E,F,T
            DIMENSION S(3)
            U=CSQRT(X**2+G12)
            Y=X**2-Z0**2
            IF(Y.LT.0.)U0=CMPLX(0.,SQRT(ABS(Y)))
            IF(Y.GE.0.)U0=CMPLX(SQRT(Y),0.)
            T=(U-U0)/(U+U0)
            IF(D.GT.1.)A=1.
            IF(D.LE.1.)A=-1.
            C=0.
NOSTIC*     THE TEST FOR EQUALITY BETWEEN NON-INTEGERS MAY NOT BE MEANINGFUL.
            IF(D.NE.1.)C=A
            E=CEXP(-U*ABS(D-1.))
            F=CEXP(-U*(D+1.))
            S(1)=COS(X*R)*(E+T*F)/U
            S(2)=COS(X*R)*(E*C+T*F)
            S(3)=SIN(X*R)*(E*A+T*F)*X/U
            RETURN
            END
```

7.5 THEORETICAL PREDICTIONS FOR IN-MINE PROPAGATION

From the analysis programs described in paragraph 7.1, a computer printout was obtained and its results listed in paragraph 6.7. These results incorporated the latest NBS noise data listed in paragraph 6.6.

The received signal strengths for various antenna configurations are combined with the specified noise grades and an equivalent S/N_0 is calculated. These resulting signal-to-noise ratios are plotted for various antenna configurations and displacements in figures 7-1 through 7-16 for a transmitted power of 10 watts into the specified transmitting antenna. It should be noted that a 37-dB S/N_0 ratio is the minimum requirement for communication of normal speech assuming 75-percent word intelligibility and a 1-Hz normalized bandwidth. From these experimental results, predictions are drawn concerning optimum usable frequency versus maximum transmission displacement for various antenna configurations. Figures 7-1 through 7-16 are the basis for these predictions.

The predictions that follow assume a noise grade 14 (mean noise-all mines subsurface) and an input power of 10 watts.

a. Loop (VMD) to loop (VMD) provides highest S/N_0 ratio.
b. For 20-meter radius transmit loop, a maximum of approximately 225 meters/740 ft separation can be achieved. (This assumes a minimum of 37 dB S/N_0 ratio for adequate information transfer with an optimum frequency of 10 kHz to 20 kHz.) At lesser separations, the 100-kHz to 200-kHz range provides the higher signal-to-noise ratios.
c. For 8-inch/0.3032-meter diameter transmit loop, a maximum of approximately 80 meters/263 ft separation can be achieved at an optimum frequency of 70 to 100 kHz (37 dB S/N_0 ratio was minimum).
d. For 100-meter/328-ft line source transmitter, a maximum of 200 meters/656 ft can be achieved at a frequency of 10 kHz. At separations below 500 ft, however, the 100-kHz frequency range provides the higher S/N_0 ratio.
e. For up-link and down-link propagation, maximum transmit depth for 13.58 meter/44.68 foot radius loop was 175 meters/574 ft at a frequency of 10 kHz, and for the line source transmit, maximum depth was 225 m/730 ft at a frequency of 10 kHz (37 dB S/N_0 ratio was minimum).

Predictions for transmission from a loop to line source could not be made because reliable E-field noise data was not available for this mode of propagation. In the experimental measurements presented in volume 4 (Experimental Measurements), line source to loop transmission is included.

Figures 7-17 through 7-19 show typical mine entries and crosscuts with lf and vlf theoretical predictions illustrated. Darkened areas indicate loss of transmission.

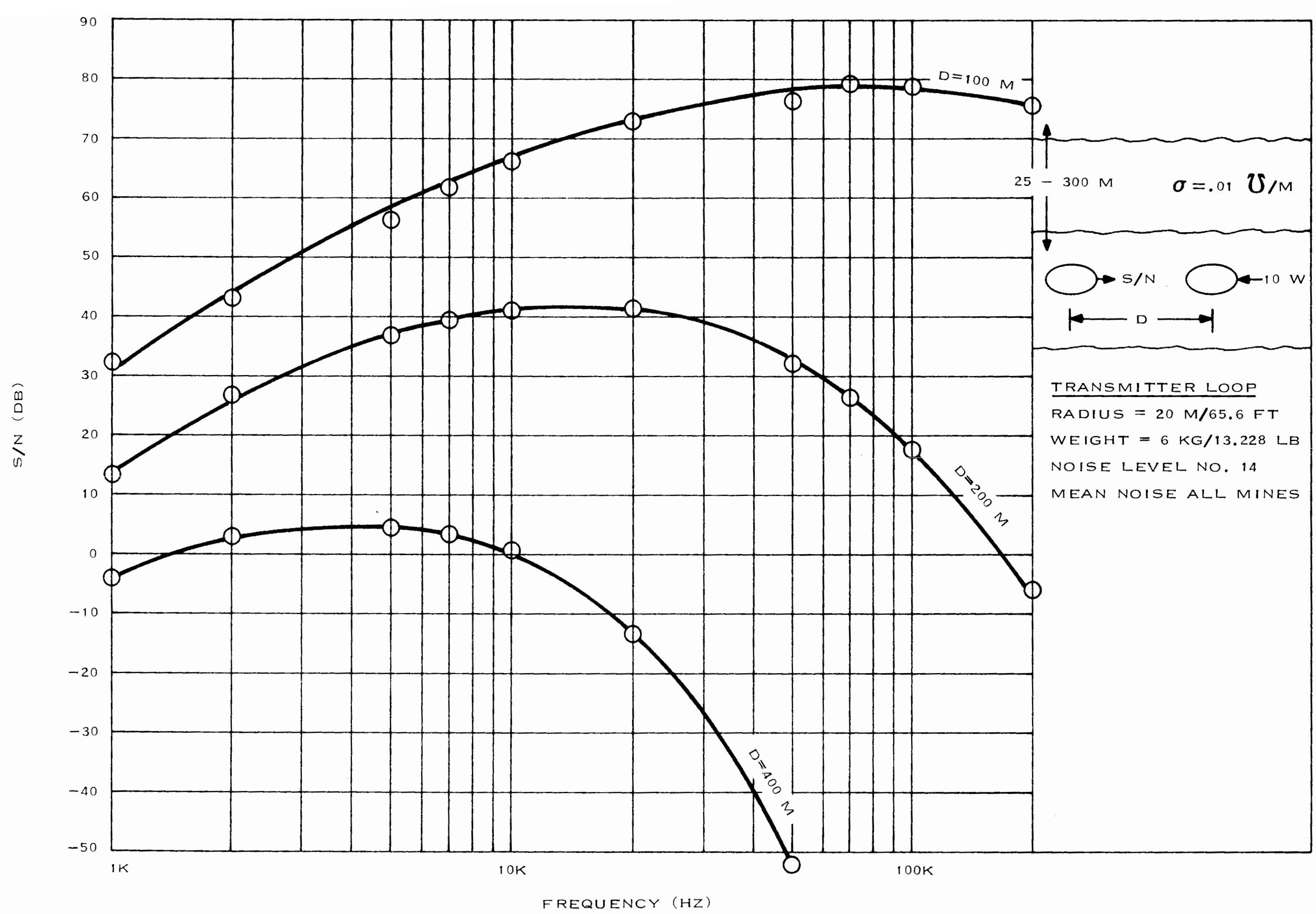

Figure 7-1. Loop-to-Loop Lateral Transmission for Varying Displacements.

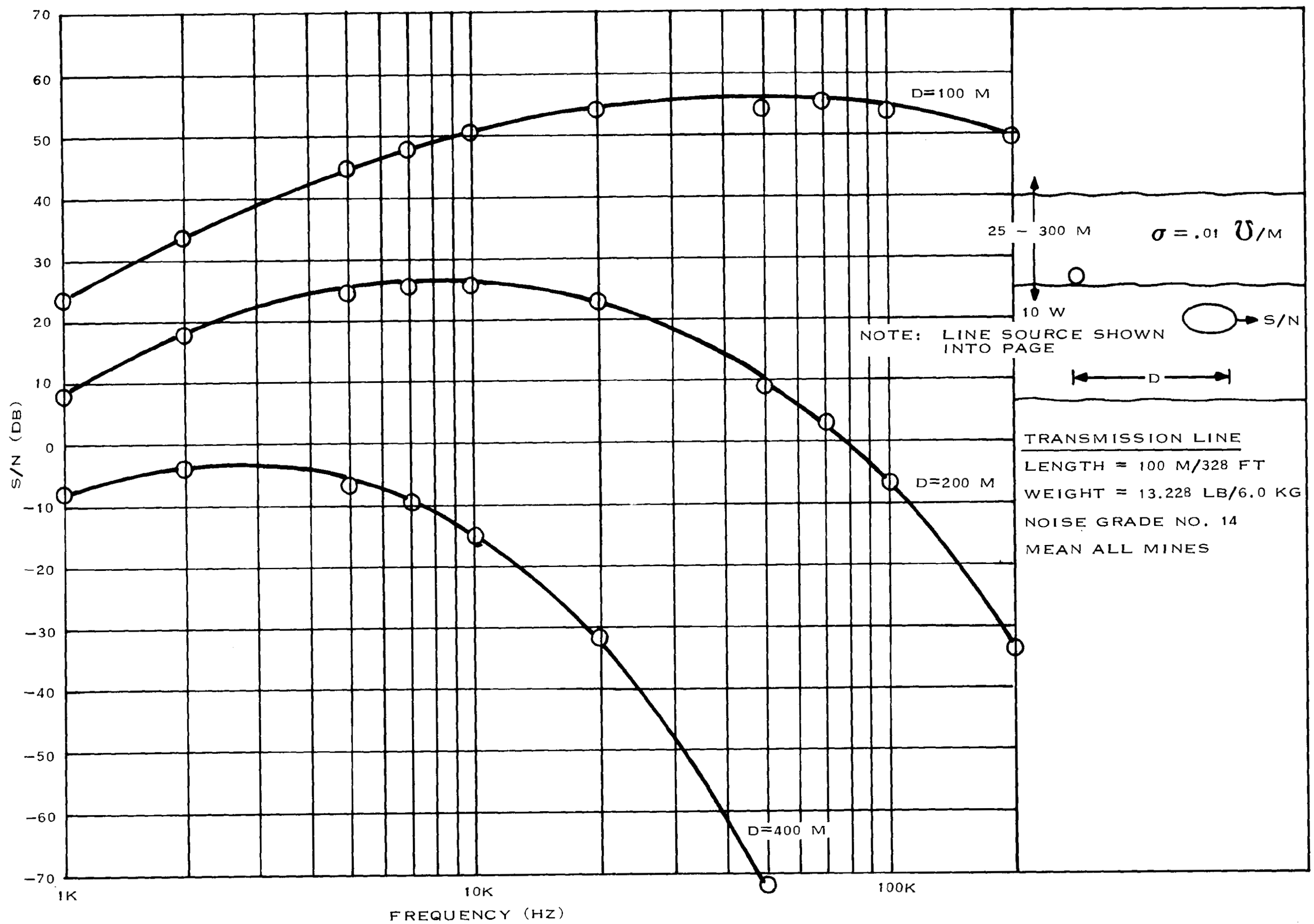

Figure 7-2. Line Source-to-Loop Lateral Transmission for Varying Displacements.

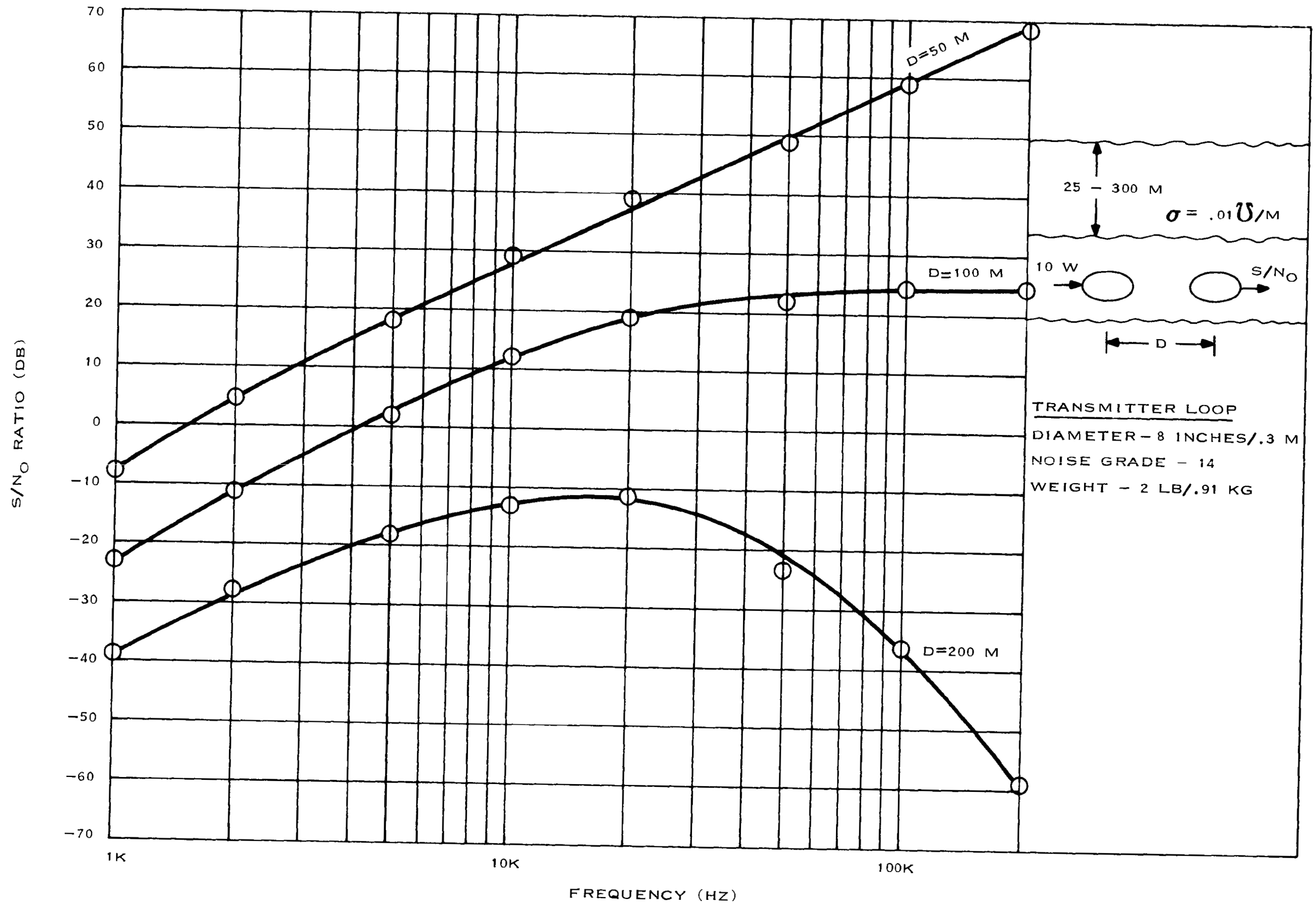

Figure 7-3. Loop-to-Loop S/N Ratio for Various Displacements - Noise Grade 14.

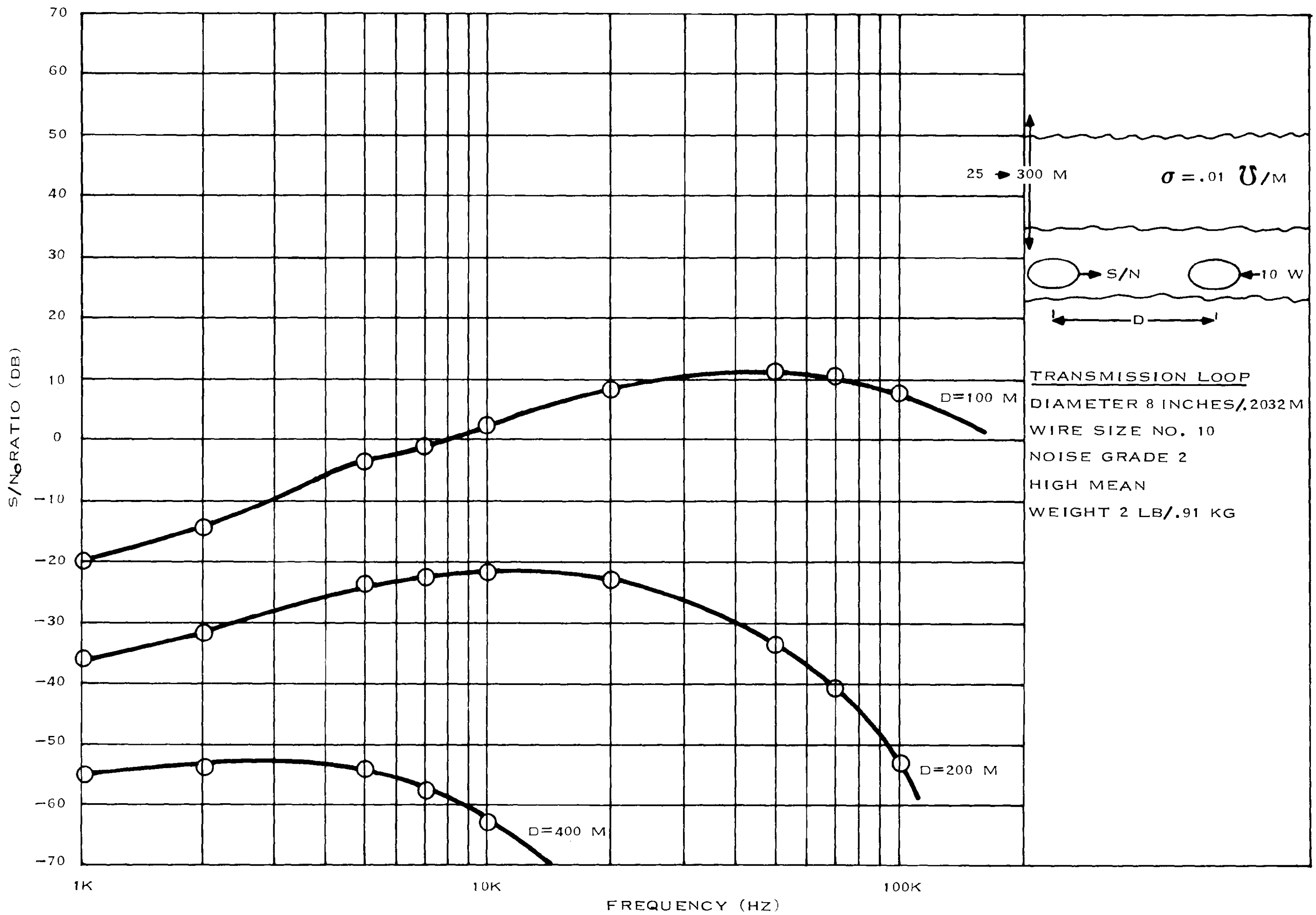

Figure 7-4. Loop-to-Loop S/N Ratio for Various Displacements - Noise Grade 2.

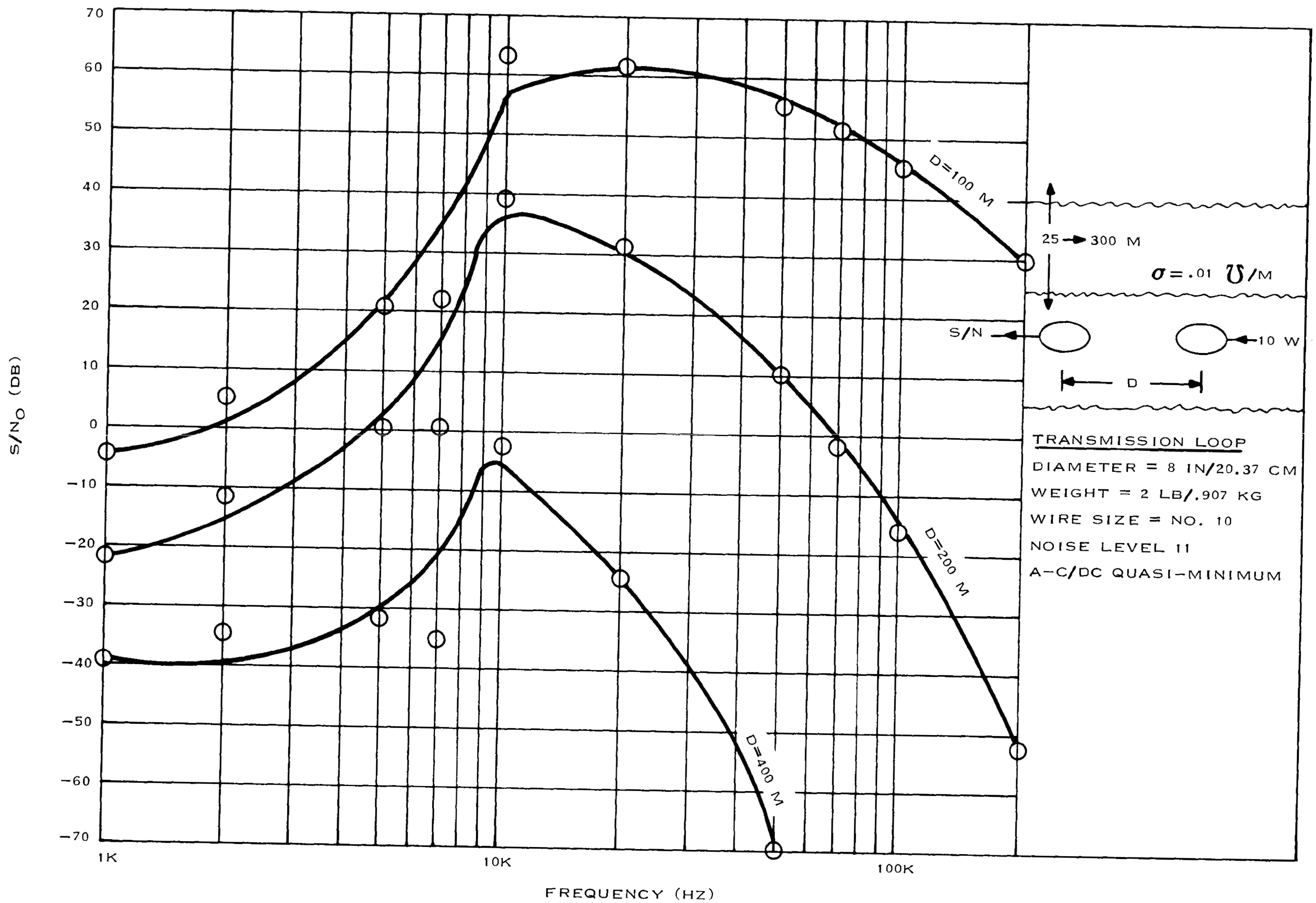

Figure 7-5. Loop-to-Loop Lateral Transmission for Varying Displacements.

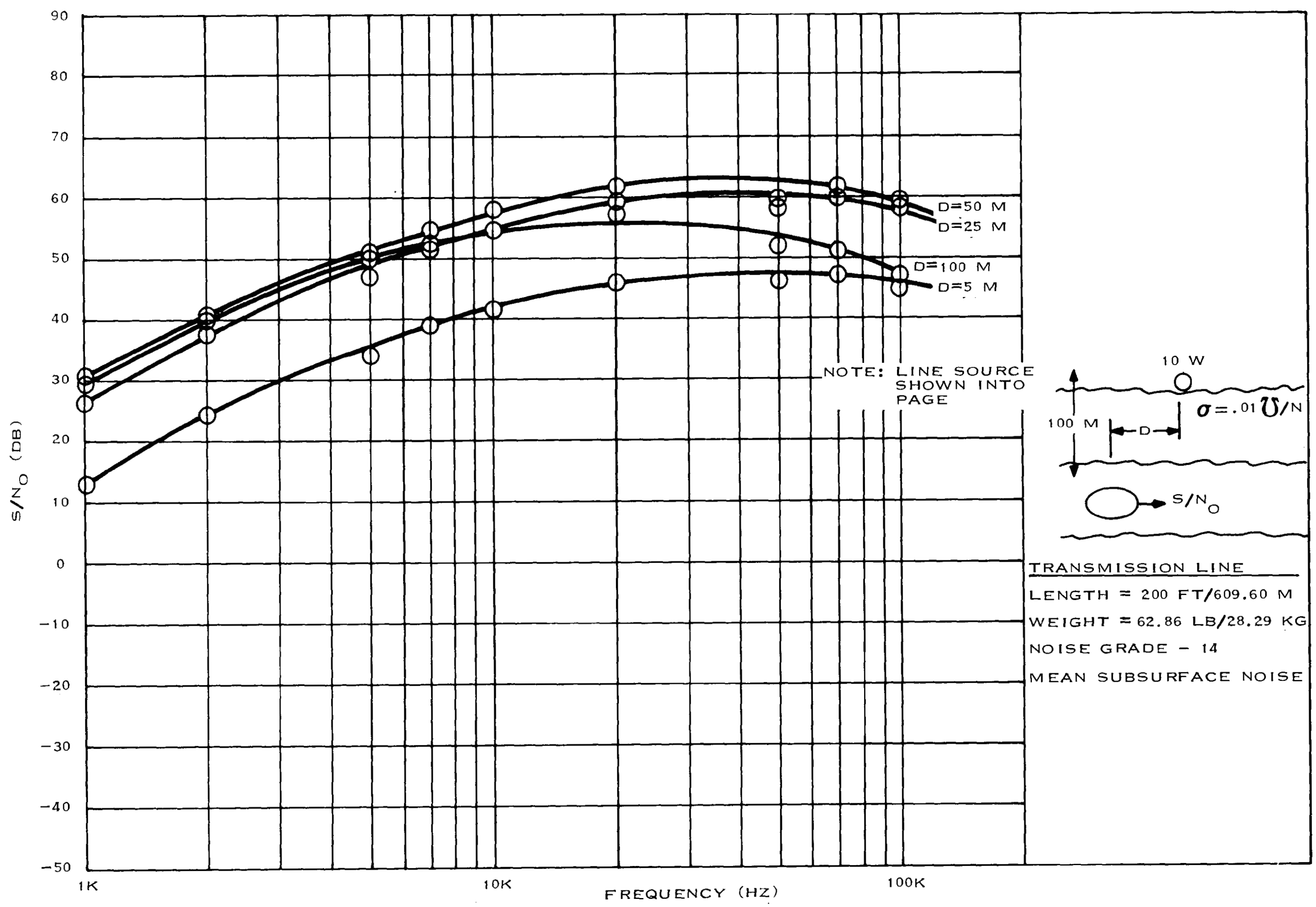

Figure 7-6. Line Source-to-Loop S/N Ratio for Various Displacements Down-Link.

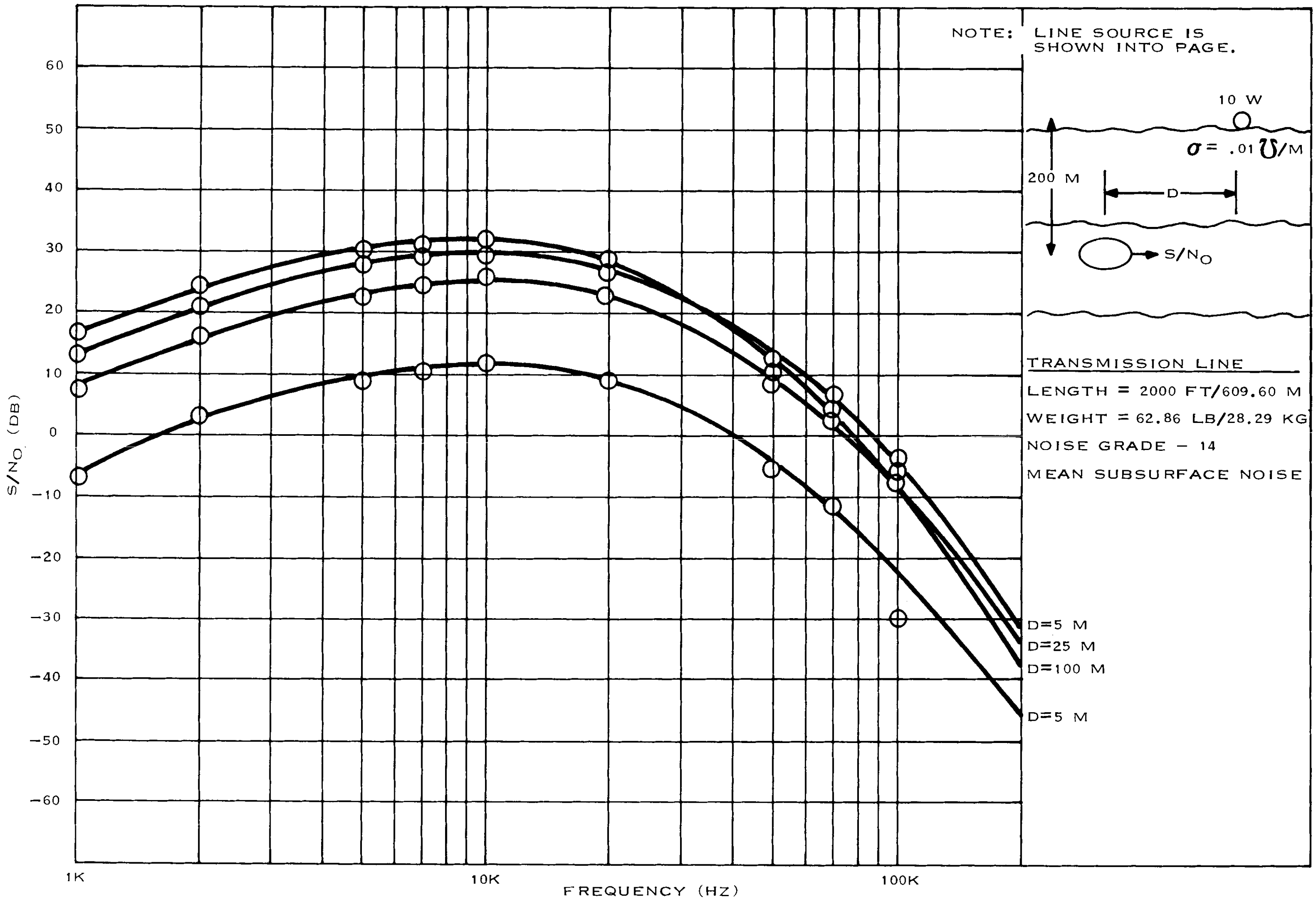

Figure 7-7. Line Source-to-Loop S/N Ratio for Various Displacements Down-Link.

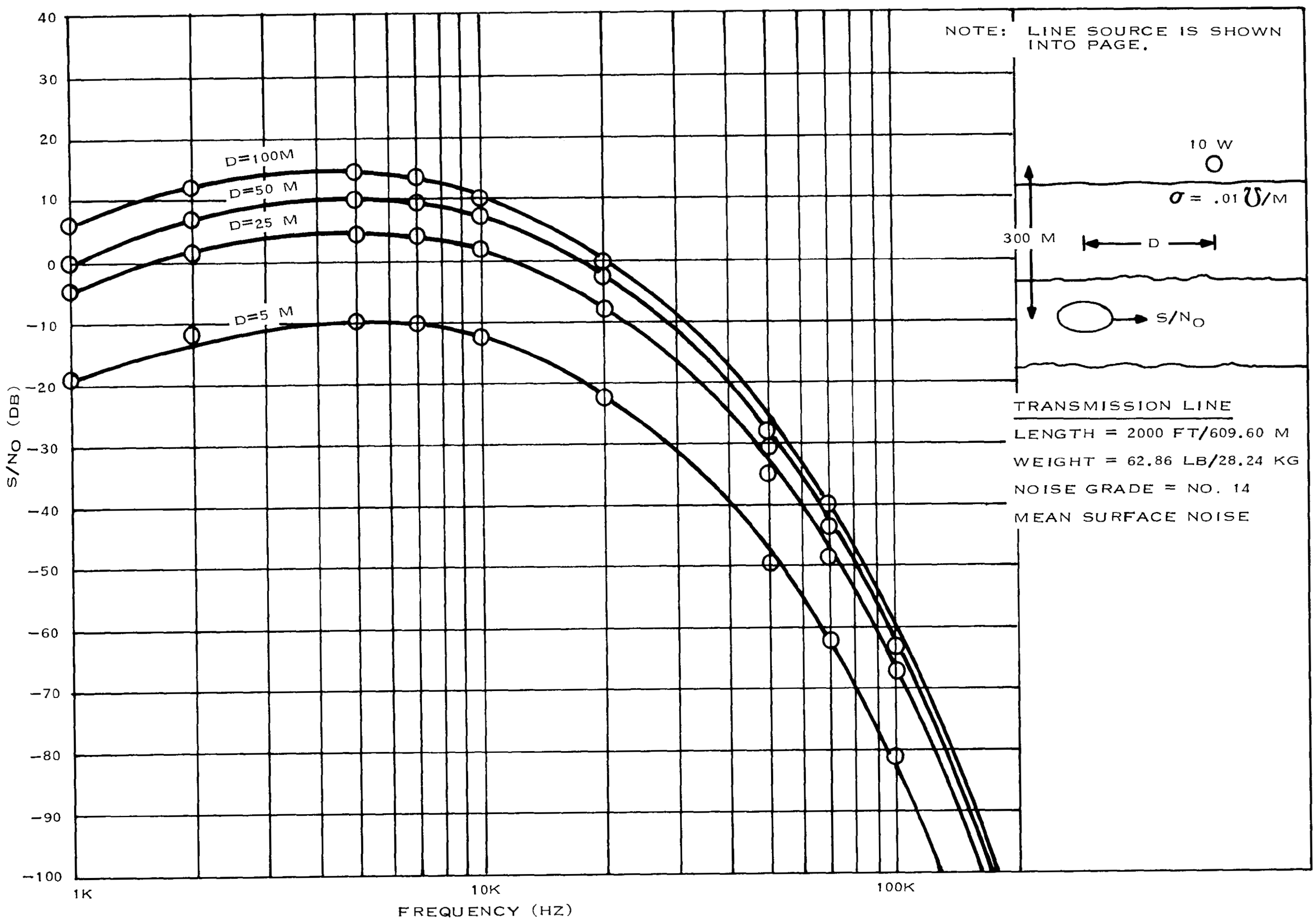

Figure 7-8. Line Source-to-Loop S/N_0 Ratio for Various Displacements Down-Link.

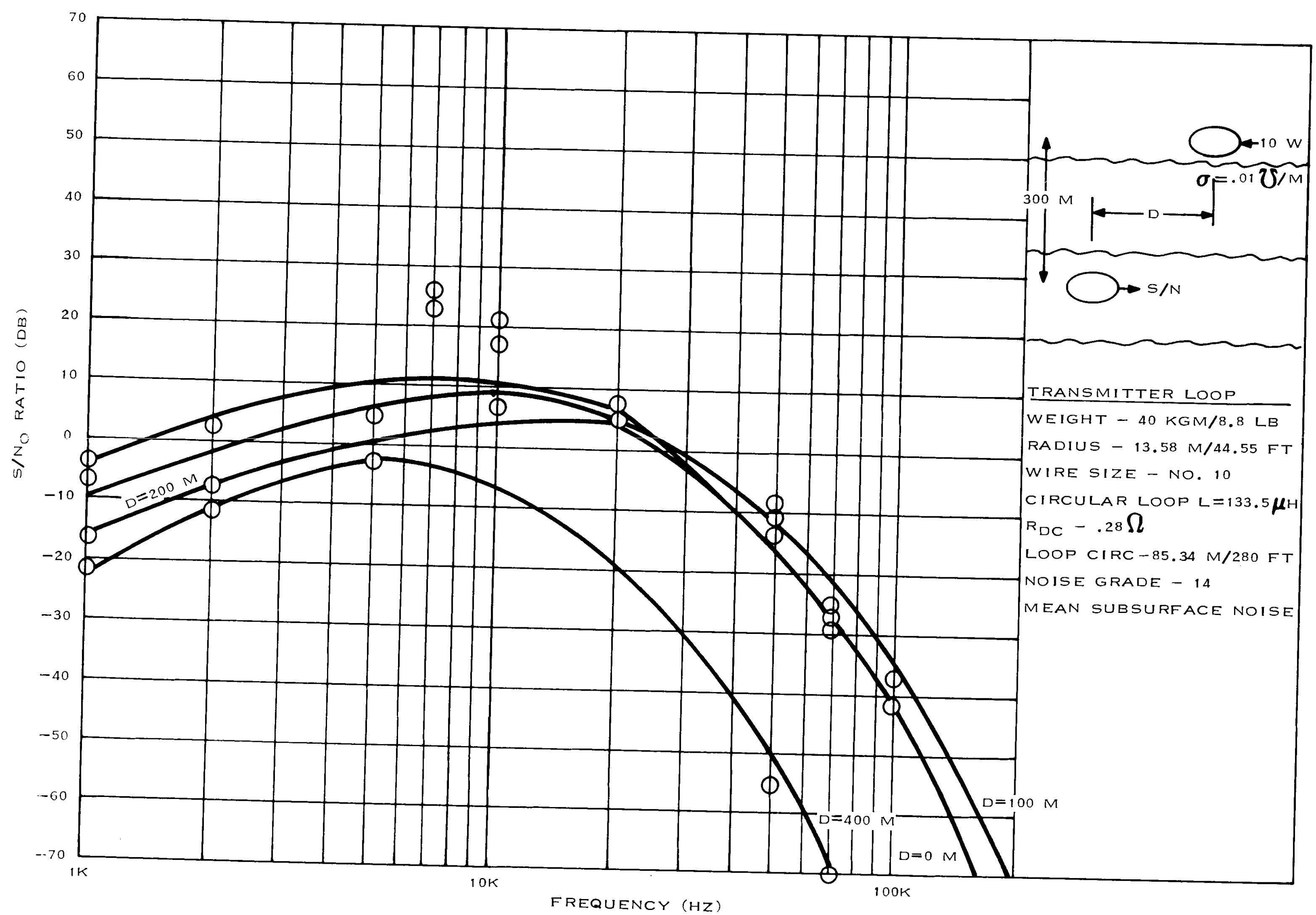

Figure 7-9. Down-Link Loop-to-Loop S/N Ratio for Various Displacements.

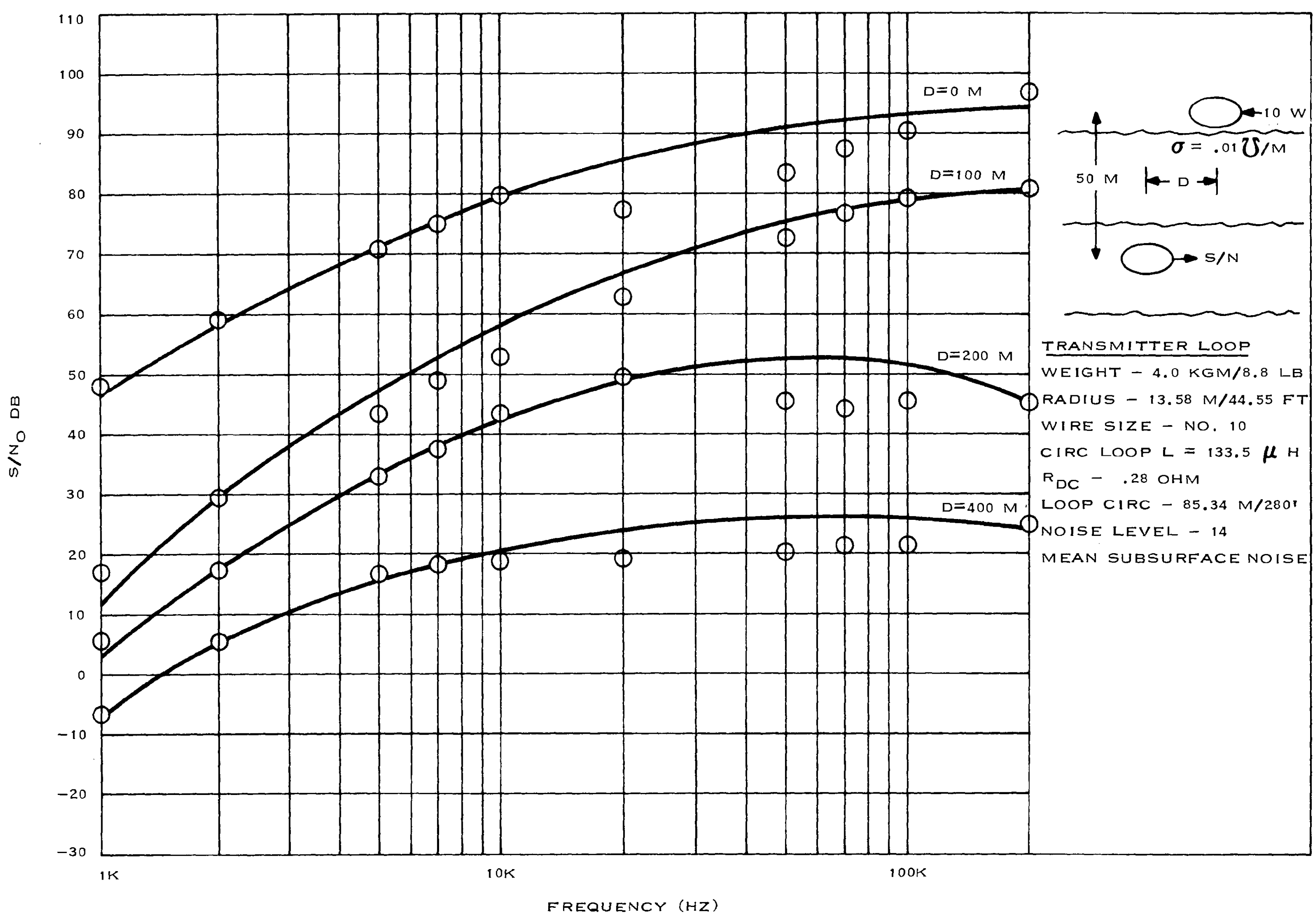

Figure 7-10. Down-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

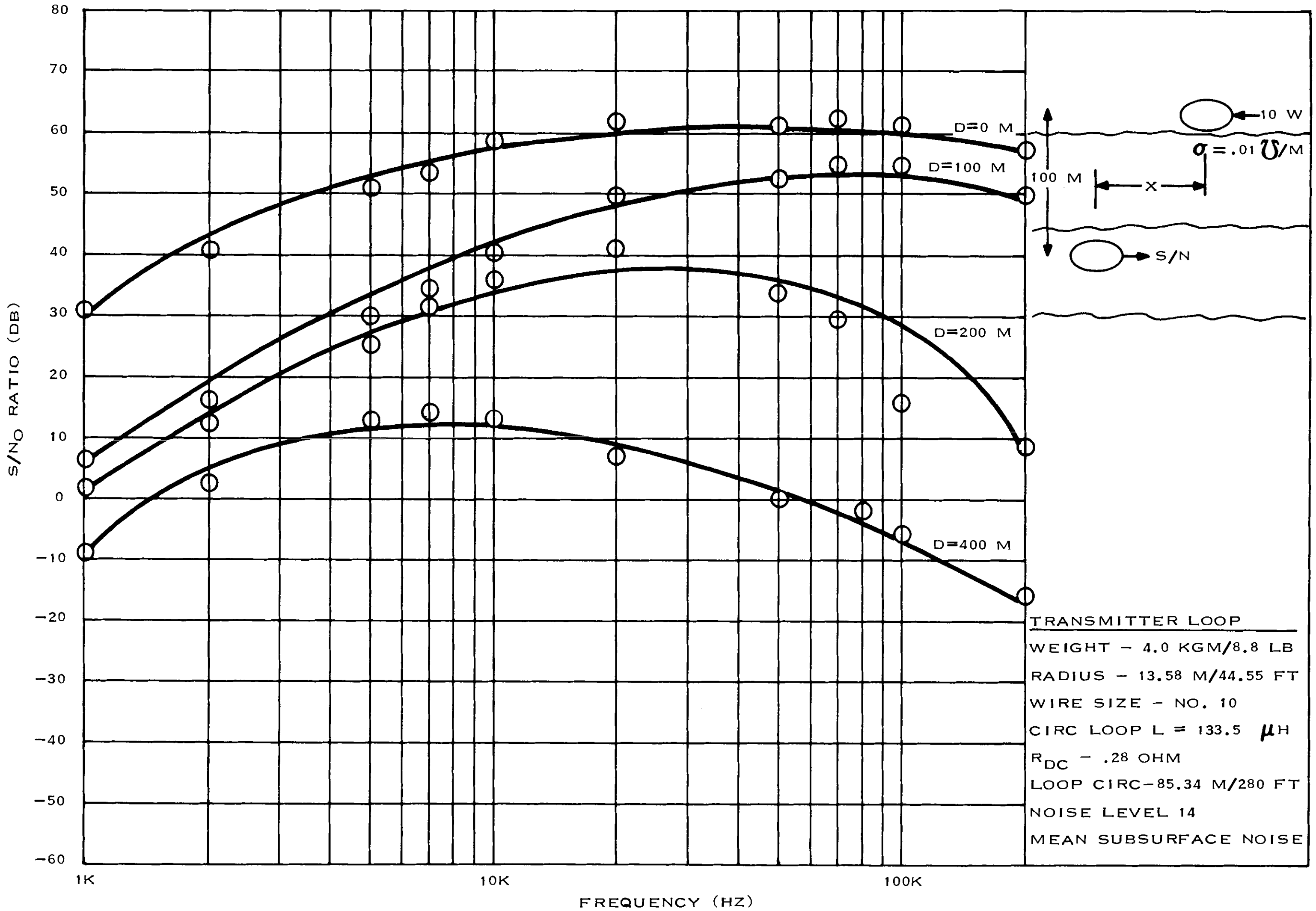

Figure 7-11. Down-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

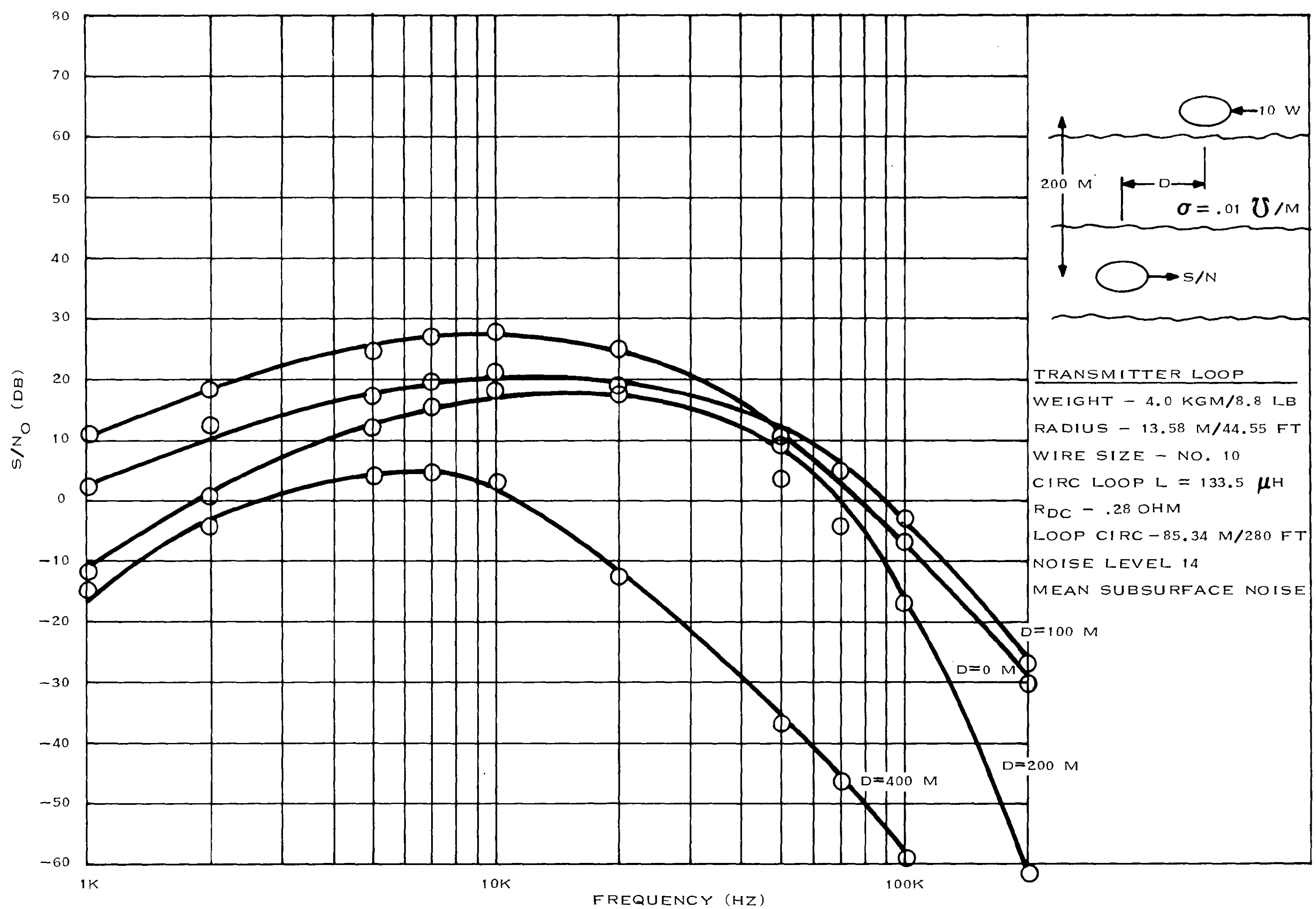

Figure 7-12. Down-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

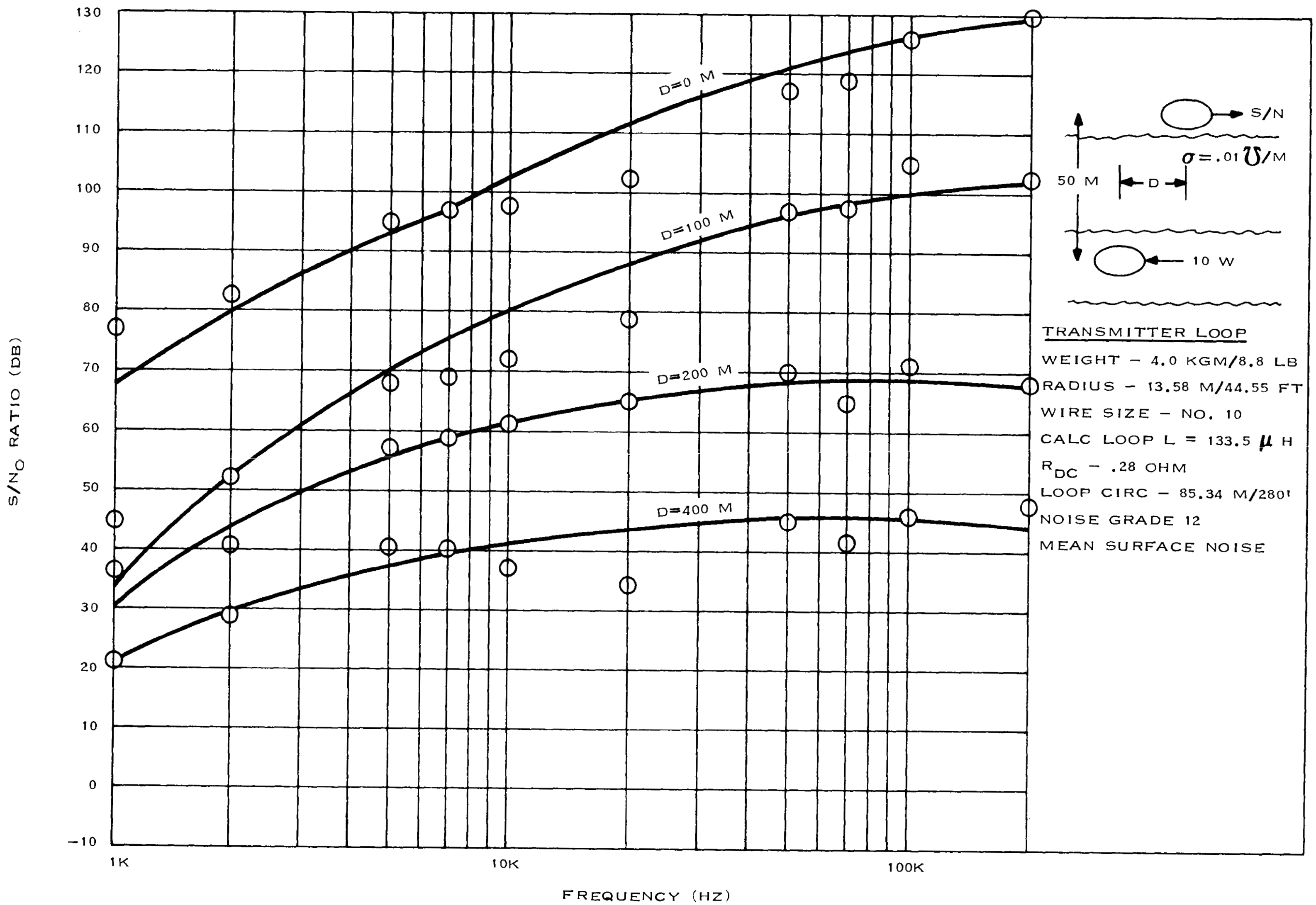

Figure 7-13. Up-Link Loop-to-Loop S/N Ratio for Various Displacements.

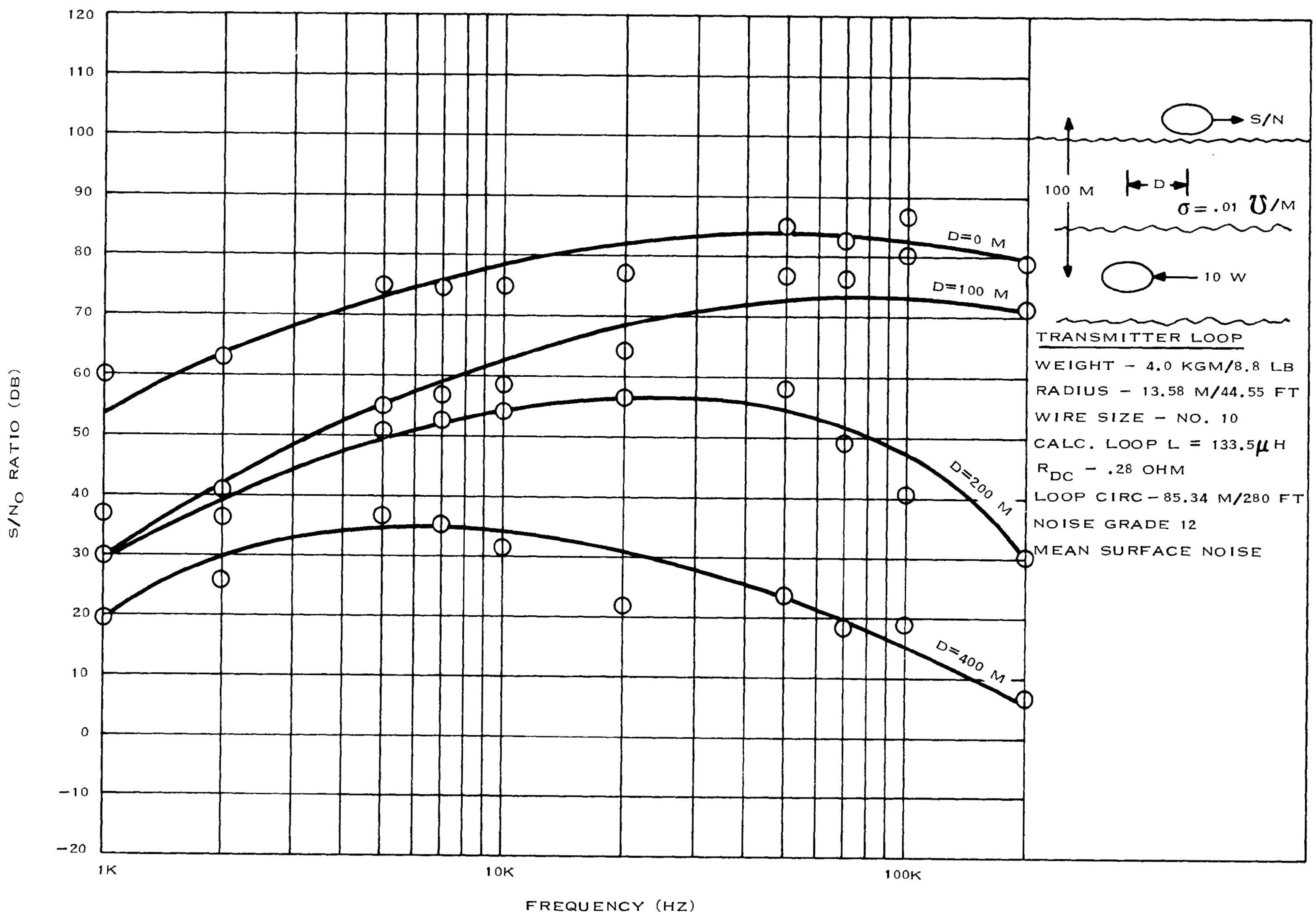

Figure 7-14. Up-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

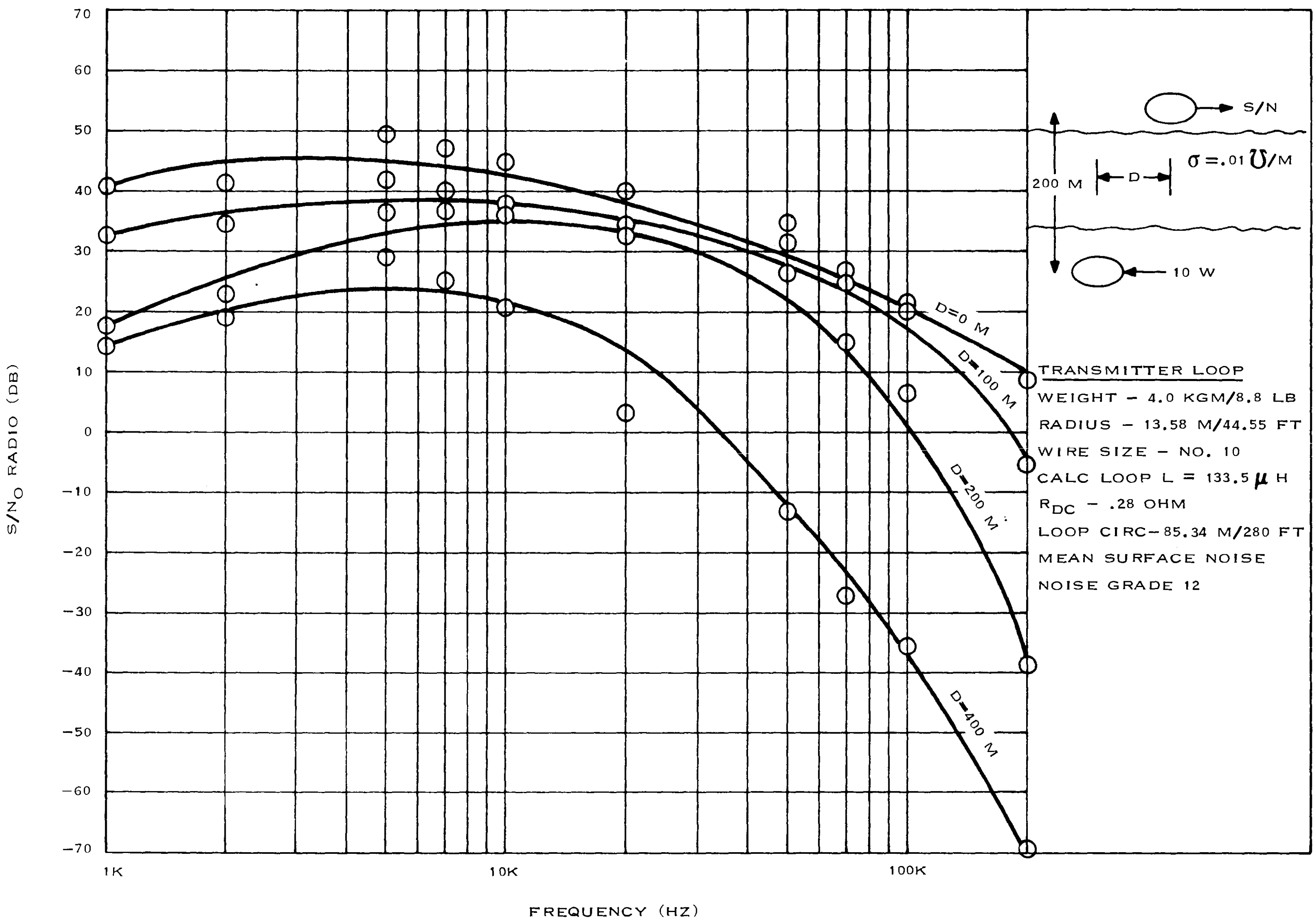

Figure 7-15. Up-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

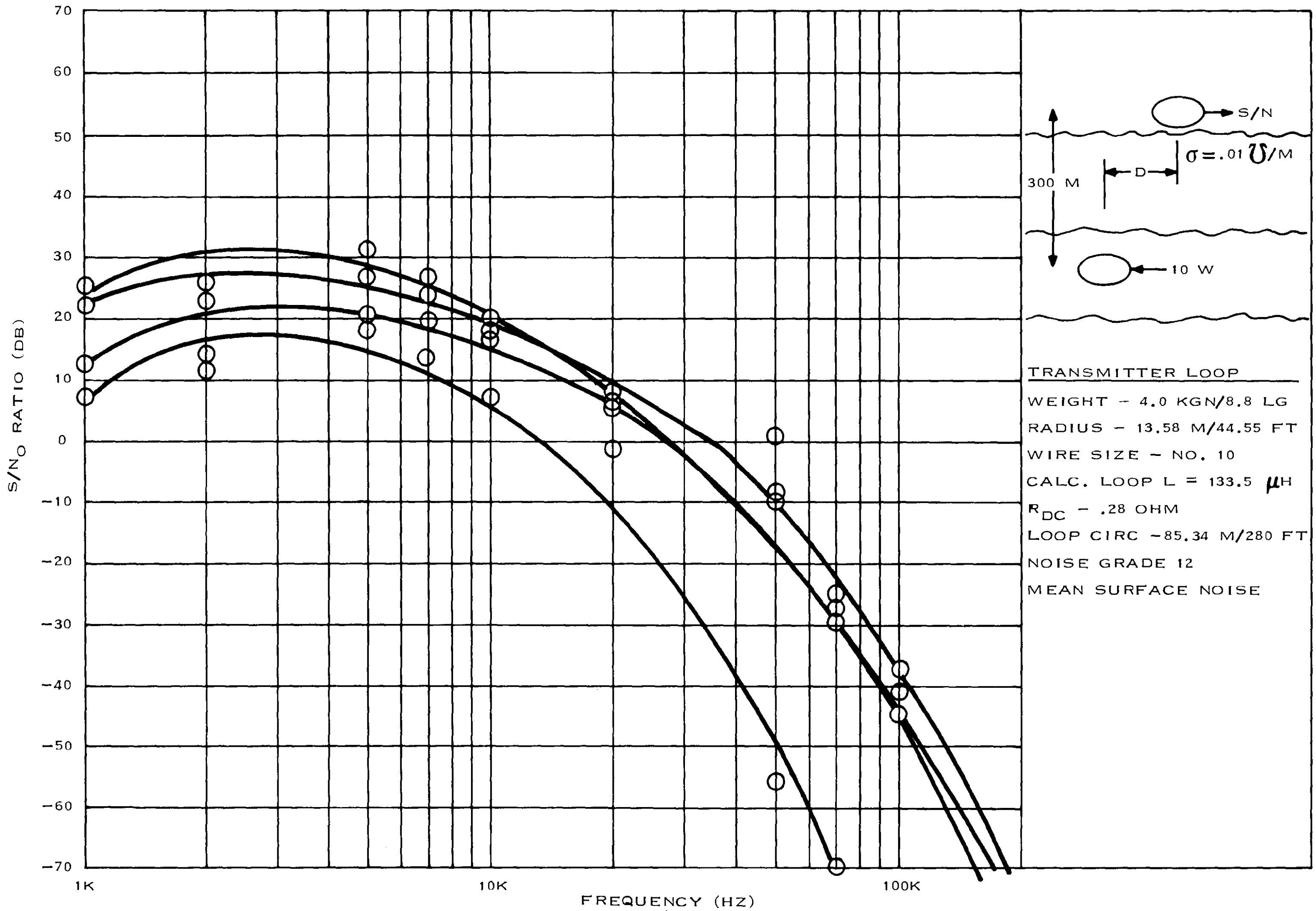

Figure 7-16. Up-Link Loop-to-Loop S/N Ratio for Various Displacements - Continued.

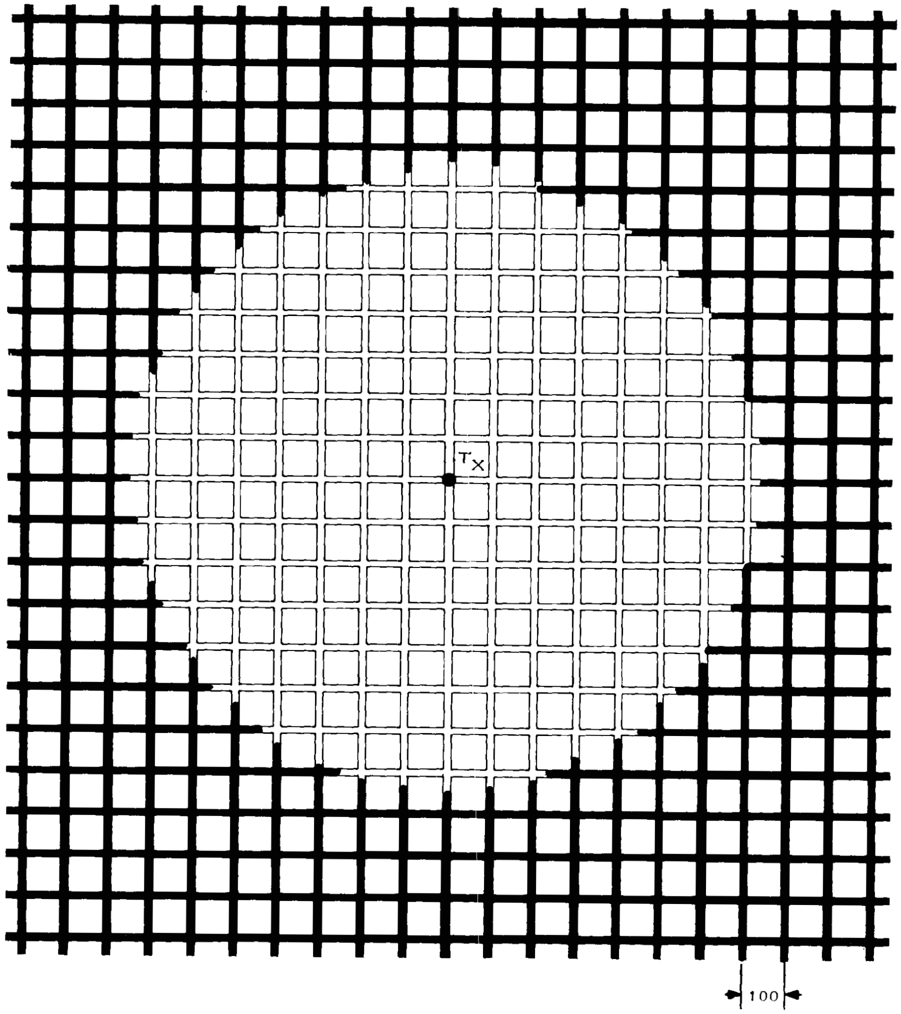

Figure 7-17. LF Propagation (Theoretical - Fixed Station - NG 14).

7.5.1 LF Propagation (Theoretical-Fixed Station - NG 14)

20-meter radius loop (fixed station) to loop transmission
VMD to VMD
Frequency - 10 to 20 kHz
37-dB minimum S/N_0
10-watt input
Darkened areas indicate loss of transmission

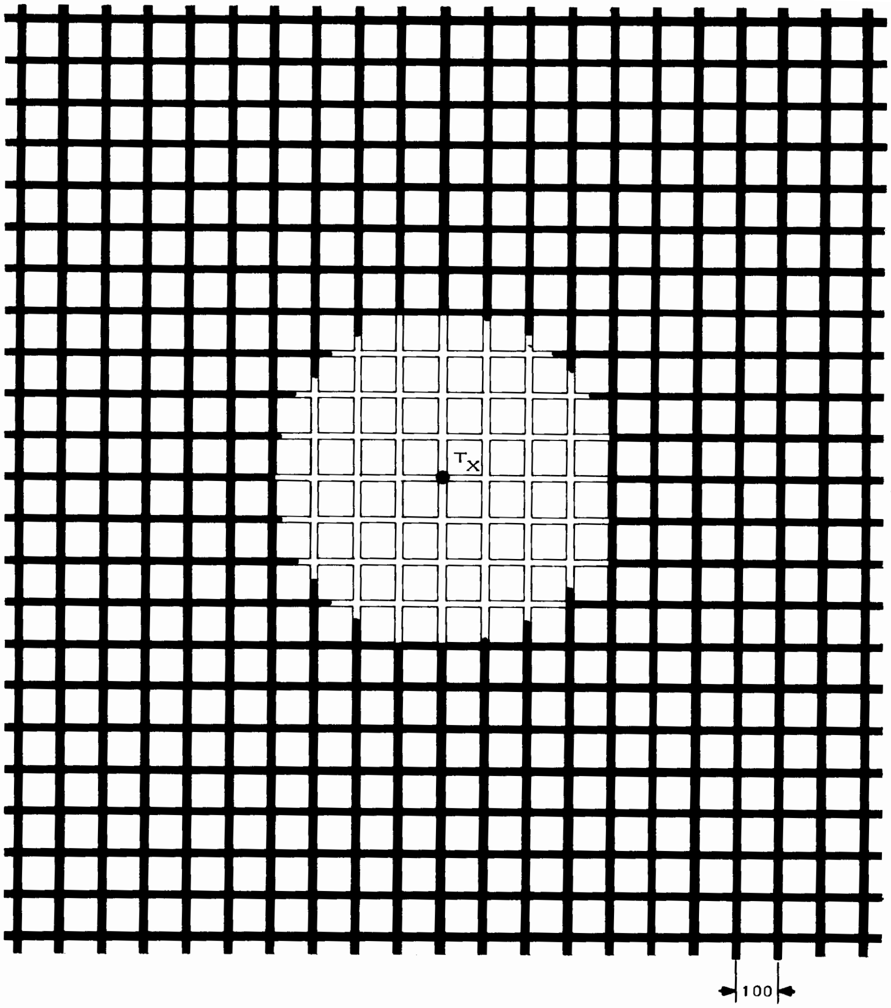

Figure 7-18. LF Propagation (Theoretical - Portable - NG 14).

7.5.2 LF Propagation (Theoretical - Portable - NG 14)

8-inch-diameter loop (portable) to loop transmission
VMD to VMD
Frequency - 70 to 100 kHz
37-dB minimum S/N_0
10-watt input
Darkened areas indicate loss of transmission

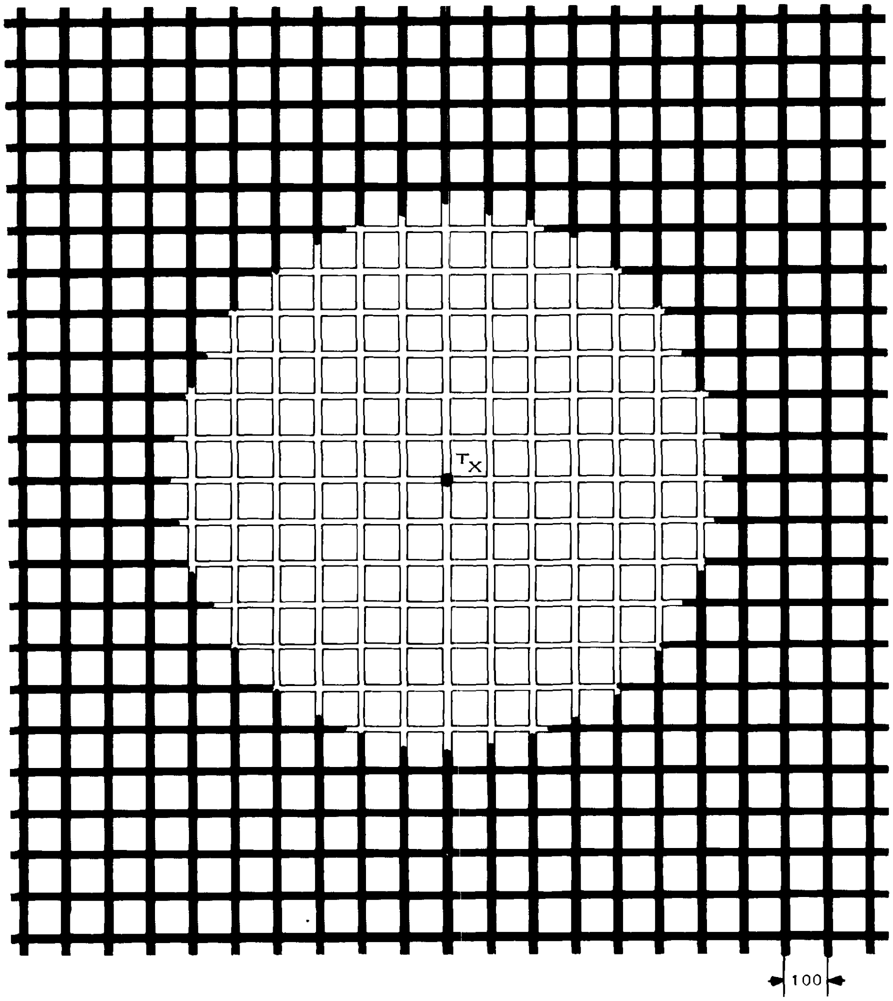

Figure 7-19. LF Propagation (Theoretical - NG 14).

7.5.3 LF Propagation (Theoretical - NG 14)

100-meter line source to loop transmission
VMD to VMD
Frequency - 10 kHz
37-dB minimum S/N_0
10-watt input
Darkened areas indicate loss of transmission

7.6 SUMMARY

These reports, analyses, and propagation predictions provide a theoretical data base from which expected signal strengths and subsequent signal-to-noise ratios can be calculated. It is stressed that outdated noise data was employed in the early reports and discussions. However, the predictions made in paragraph 7.5 were based upon the more recent NBS noise data.

Also, because of recent in-mine tests, there appears to be a gap between the propagation predictions and the experimental results as frequencies increase beyond 50 kHz. Additional experimental work needs to be completed to obtain reliable predictions for the higher ranges of frequencies.