

RECOMMENDATION ITU-R P.368-7*

**GROUND-WAVE PROPAGATION CURVES FOR FREQUENCIES
BETWEEN 10 kHz AND 30 MHz**

(1951-1959-1963-1970-1974-1978-1982-1986-1990-1992)

The ITU Radiocommunication Assembly,

considering

that, in view of the complexity of the calculation, it is useful to have a set of ground-wave curves for a range of standard frequency values and ground characteristics,

recommends

1. that the curves of Annex 1, applied in the conditions specified below, should be used for the determination of ground-wave field strength at frequencies between 10 kHz and 30 MHz;
2. that, as a general rule, these curves should be used to determine field strength only when it is known that ionospheric reflections will be negligible in amplitude;
3. that these curves should not be used in those applications for which the receiving antenna is located well above the surface of the Earth;

Note 1 – That is, when $\epsilon_r \ll 60 \lambda \sigma$ the curves may be used up to a height $h = 1.2 \sigma^{1/2} \lambda^{3/2}$. Propagation curves for terminal heights up to 3 000 m and for frequencies up to 10 GHz can be found in the separately published ITU Handbook of Curves for Radio-Wave Propagation over the Surface of the Earth;

4. that these curves, plotted for homogeneous paths under the conditions established in Annex 1, may also be used to determine the field strength over mixed paths as indicated in Annex 2.

ANNEX 1

Propagation curves and conditions of validity (homogeneous paths)

The propagation curves in this Recommendation are calculated for the following assumptions:

- they refer to a smooth homogeneous spherical Earth;
- in the troposphere, the refractive index decreases exponentially with height, as described in Recommendation ITU-R P.453;
- both the transmitting and the receiving antennas are at ground level;

* Radiocommunication Study Group 3 made editorial amendments to this Recommendation in 2000 in accordance with Resolution ITU-R 44.

- the radiating element is a short vertical monopole. Assuming such a vertical antenna to be on the surface of a perfectly conducting plane Earth, and excited so as to radiate 1 kW, the field strength at a distance of 1 km would be 300 mV/m; this corresponds to a electromotive force of 300 V (see Recommendation ITU-R P.525);
- the curves are drawn for distances measured around the curved surface of the Earth;
- the curves give the value of the vertical field-strength component of the radiation field, i.e. that which can be effectively measured in the far-field region of the antenna.

Note 1 – The inverse-distance curve shown as a broken line in the figures, to which the curves are asymptotic at short distances, passes through the field value of 300 mV/m at a distance of 1 km. To refer the curves to other reference antennas, see Table 1 of Recommendation ITU-R P.341.

Note 2 – The curves were calculated using the computer program GRWAVE which is briefly described in Annex 3.

Note 3 – The basic transmission loss corresponding to the same conditions for which the curves were computed may be obtained from the value of field strength E (dB(μ V/m)) by using the following equation:

$$L_b \equiv A_t = 142.0 + 20 \log f_{\text{MHz}} - E \quad \text{dB}$$

For the influence of the environment on both the transmitting and the receiving antenna, refer to Recommendation ITU-R P.341.

Note 4 – The curves give the total field at distance, r , with an error less than 1 dB when kr is greater than about 10, where $k = 2\pi/\lambda$. Near-field (i.e. induction and static field) effects may be included by increasing the field strength (in decibels) by:

$$10 \log \left\{ 1 - \frac{1}{(kr)^2} + \frac{1}{(kr)^4} \right\}$$

This gives the total field within ± 0.1 dB for sea and wet ground, and within ± 1 dB for any ground conductivity greater than 10^{-3} S/m.

Note 5 – For either antenna, if the antenna site location is higher than the average terrain elevation along the path between the antennas, then the effective antenna height is the antenna height above the average terrain elevation along the path. This effective antenna height value should be compared to the computed value of antenna height limit in *recommends 3* to determine if the curves are valid for the path.

Figures 1 to 11 contain field-strength curves as a function of distance with frequency as a parameter.

FIGURE 1

Ground-wave propagation curves; Sea water, low salinity, $\sigma = 1 \text{ S/m}$, $\epsilon = 80$

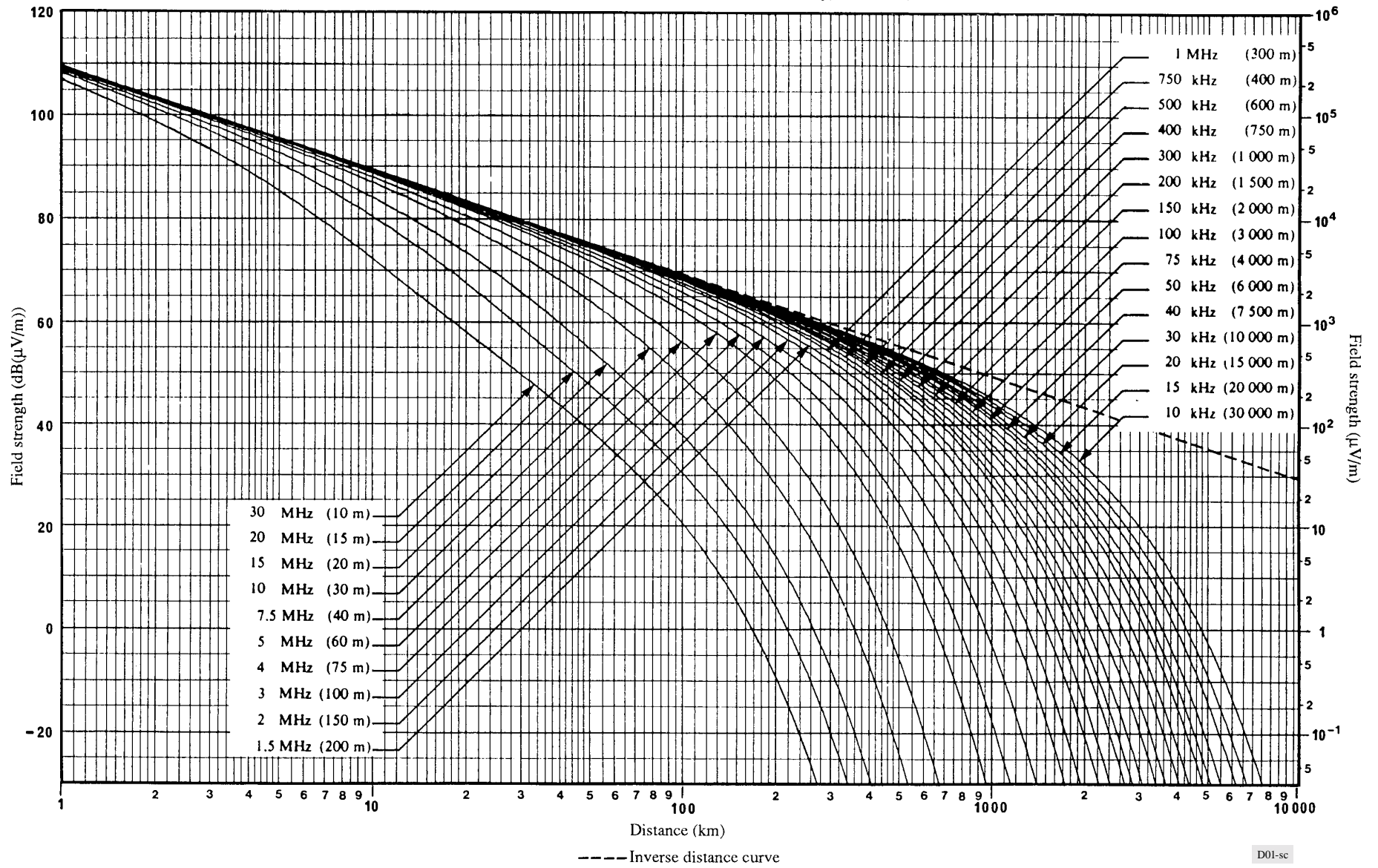


FIGURE 2

Ground-wave propagation curves; Sea water, average salinity, $\sigma = 5 \text{ S/m}$, $\epsilon = 70$

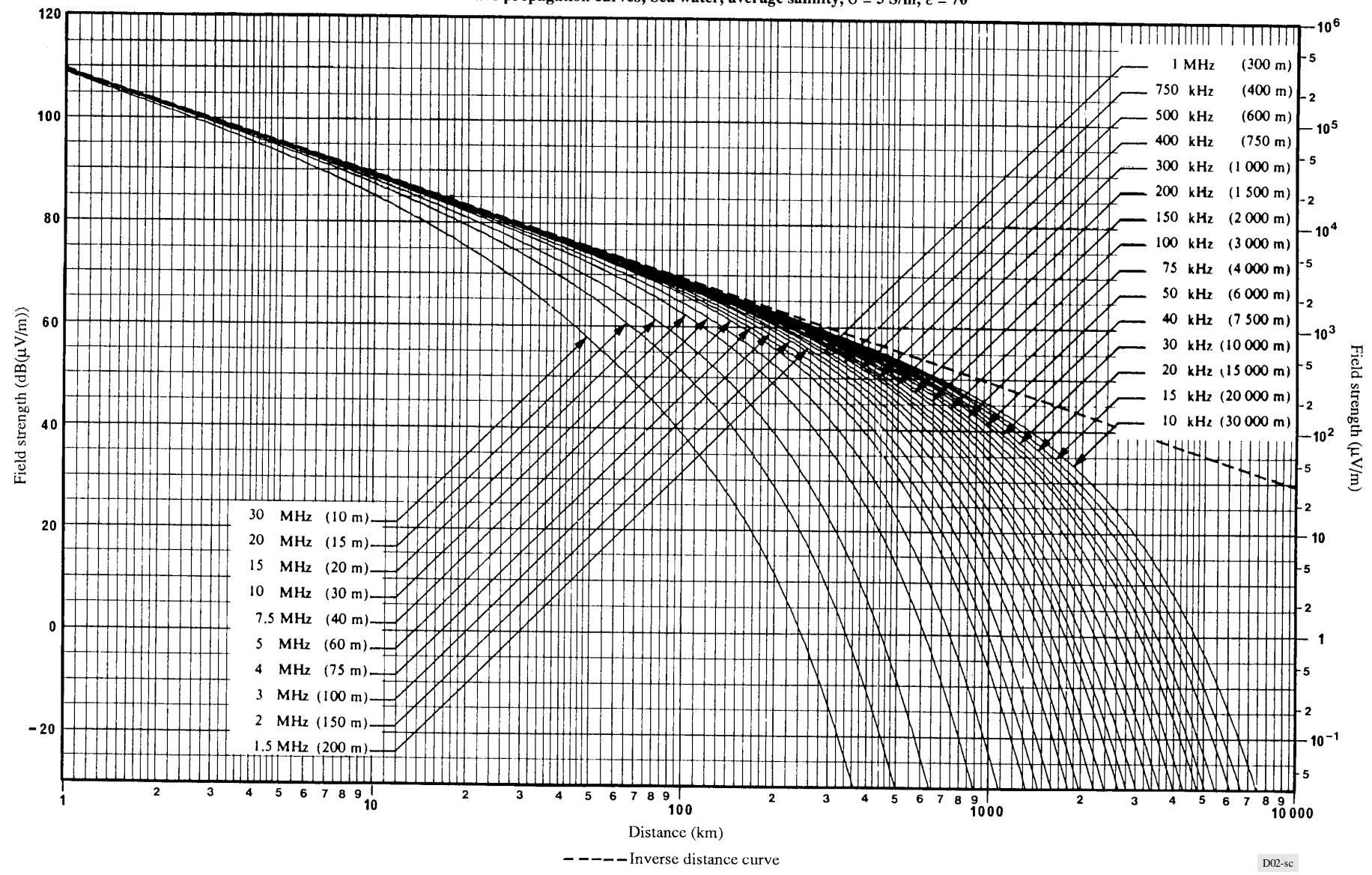


FIGURE 3

Ground-wave propagation curves; Fresh water, $\sigma = 3 \times 10^{-3}$ S/m, $\epsilon = 80$

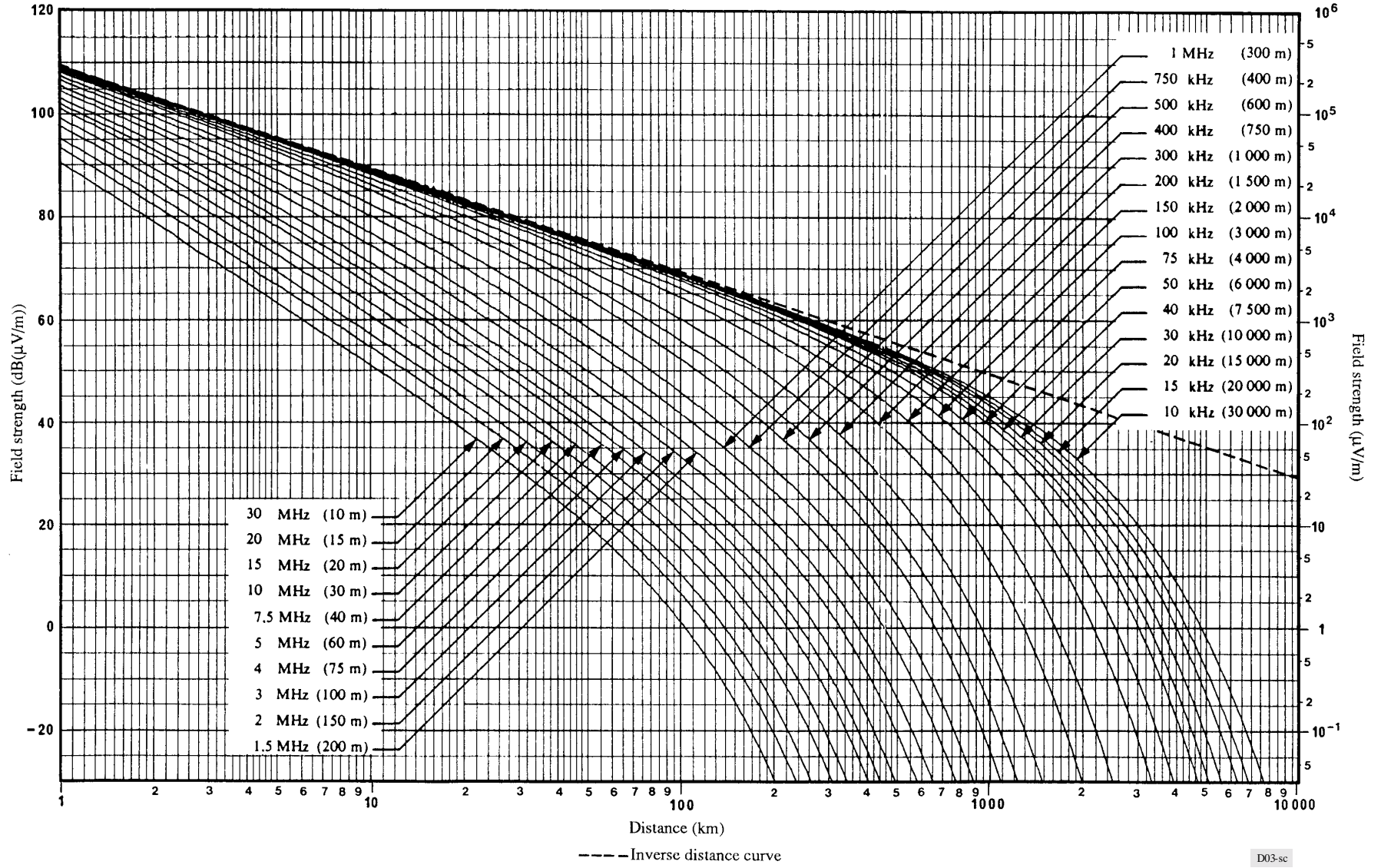


FIGURE 4

Ground-wave propagation curves; Land, $\sigma = 3 \times 10^{-2}$ S/m, $\epsilon = 40$

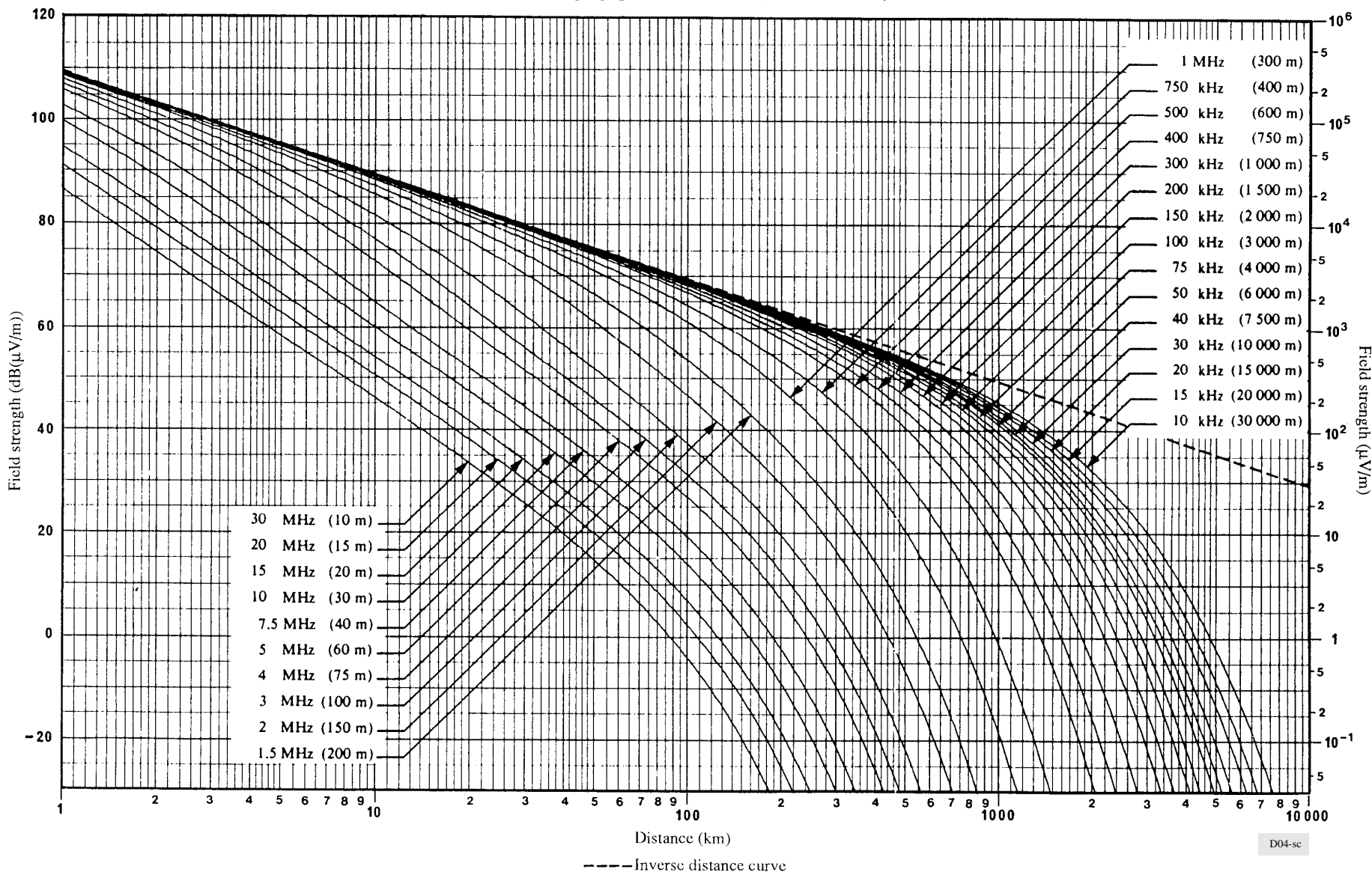


FIGURE 5

Ground-wave propagation curves; Wet ground, 10^{-2} S/M, $\epsilon = 30$

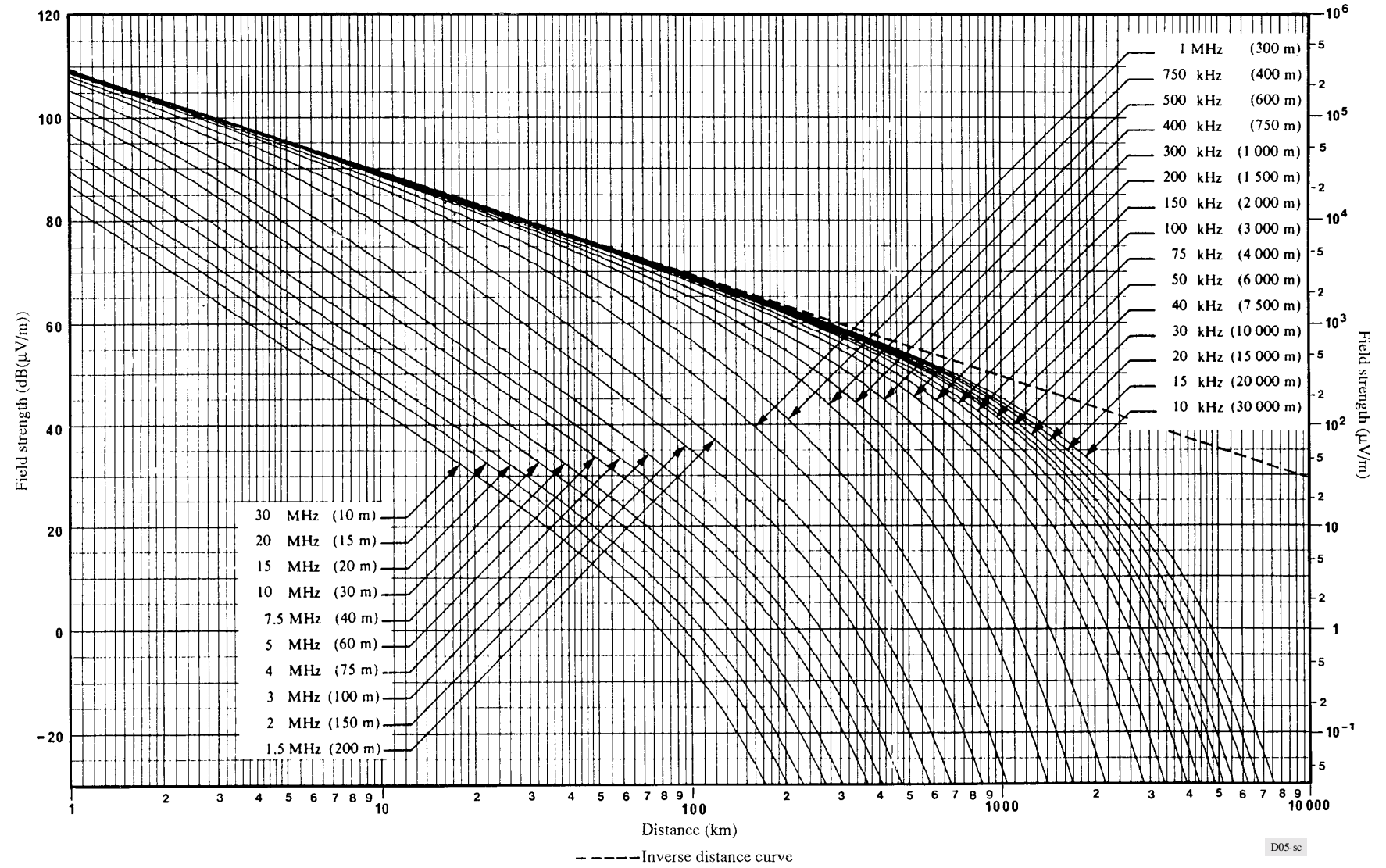
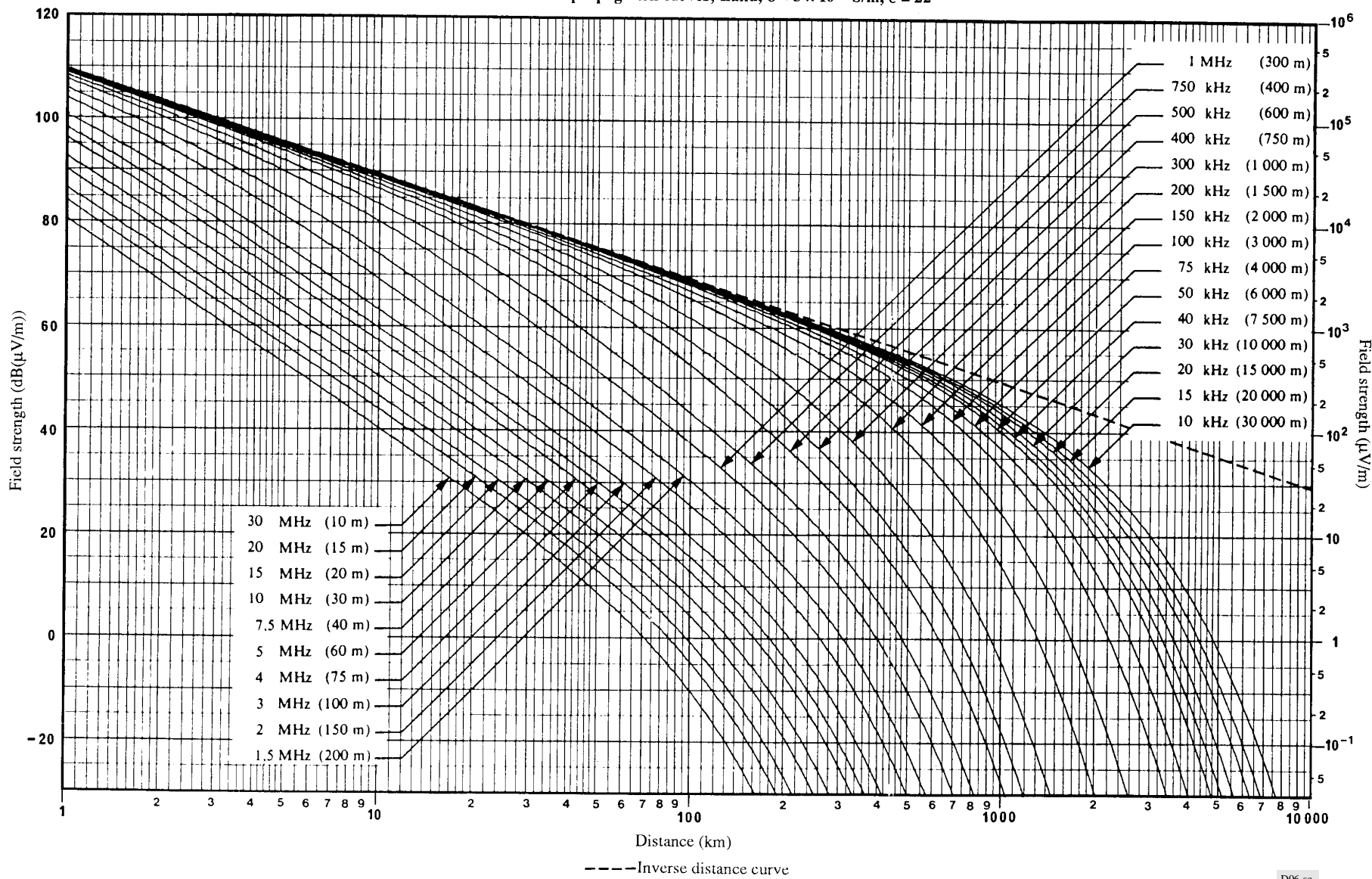


FIGURE 6

Ground-wave propagation curves; Land, $\sigma = 3 \times 10^{-3}$ S/m, $\epsilon = 22$



D06-sc

FIGURE 7

Ground-wave propagation curves; Medium dry ground, $\sigma = 10^{-3}$ S/m, $\epsilon = 15$

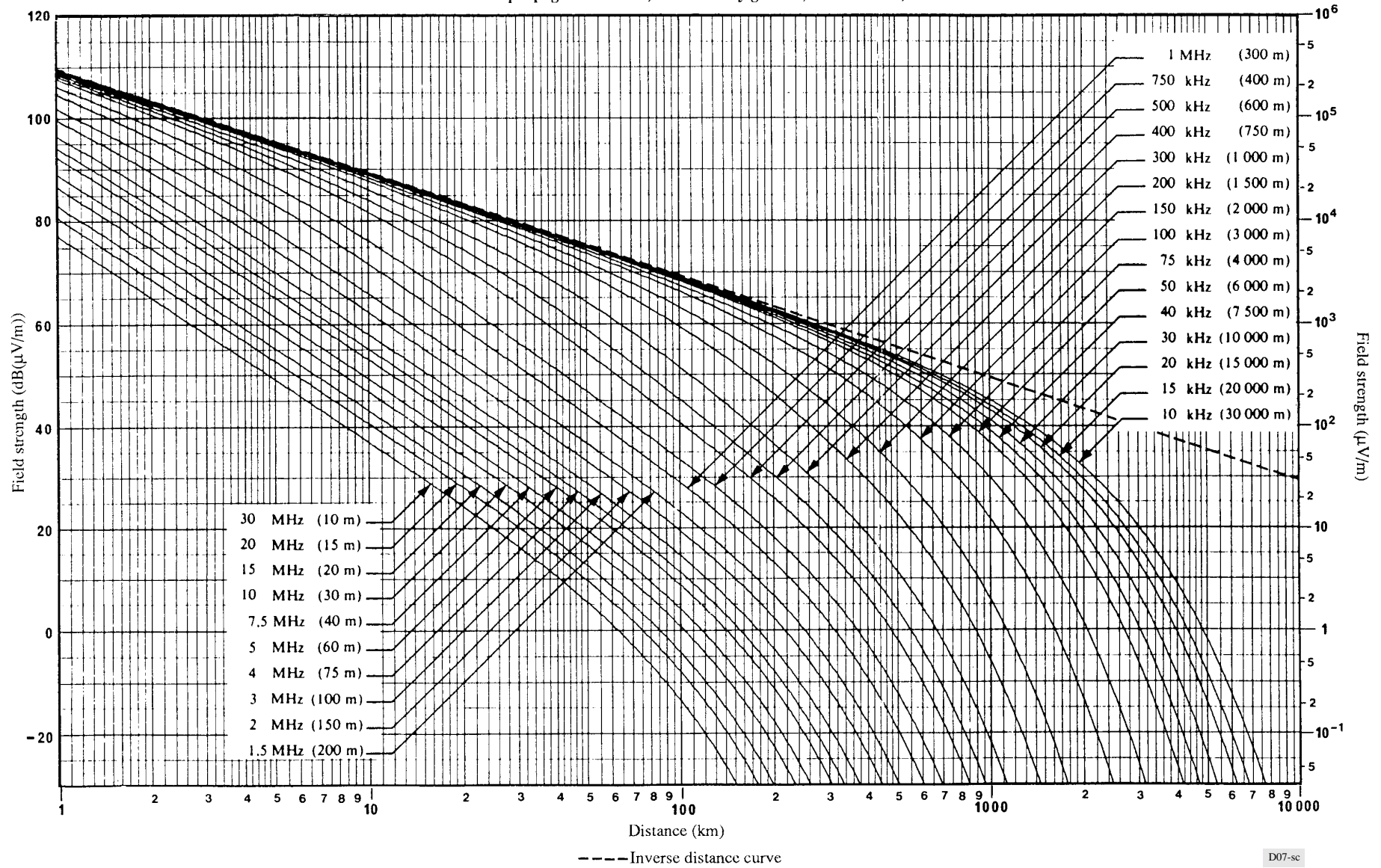


FIGURE 8

Ground-wave propagation curves; Dry ground, $\sigma = 3 \times 10^{-4}$ S/m, $\epsilon = 7$

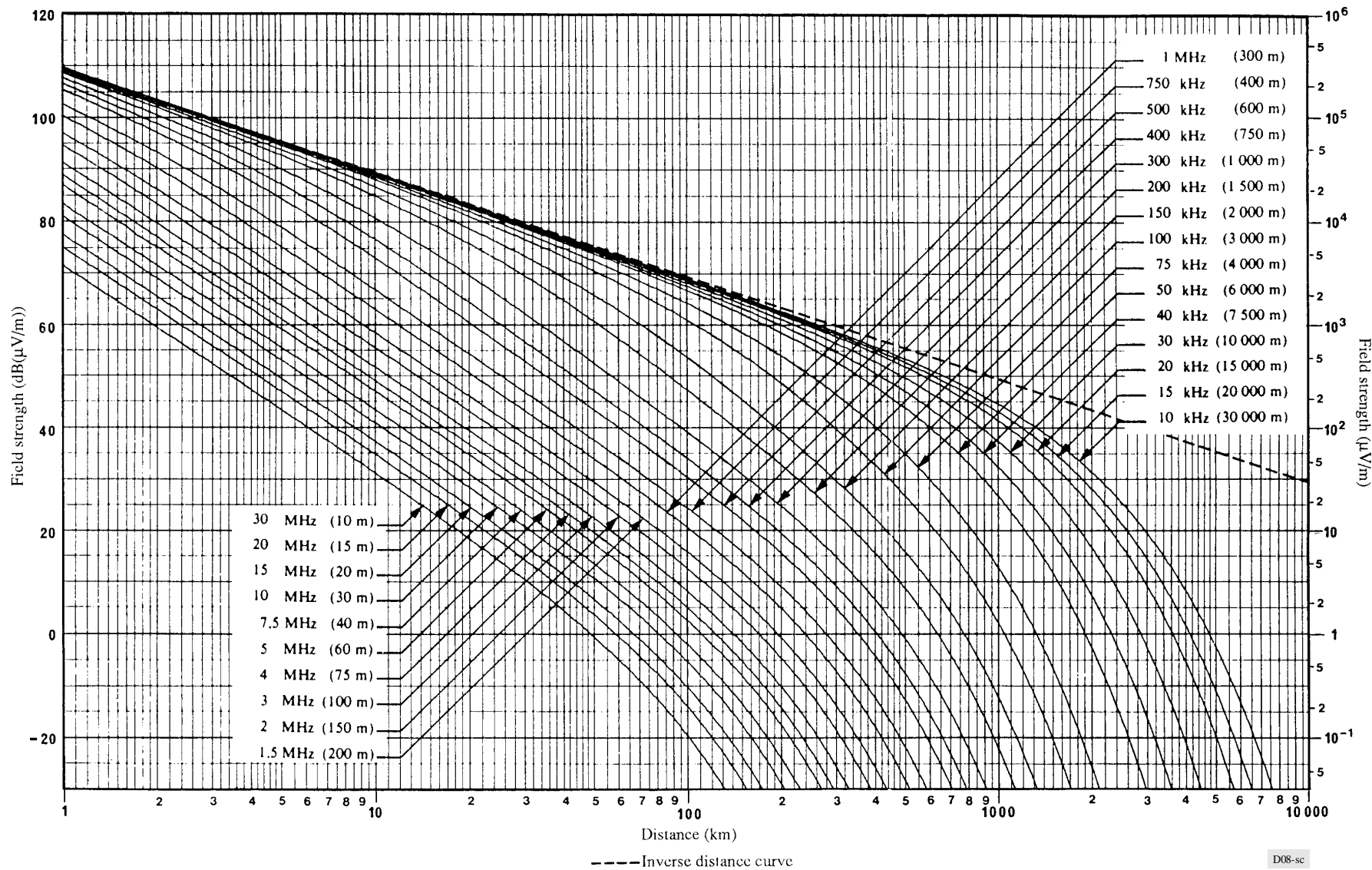


FIGURE 9

Ground-wave propagation curves; Very dry ground, $\sigma = 10^{-4}$ S/m, $\epsilon = 3$

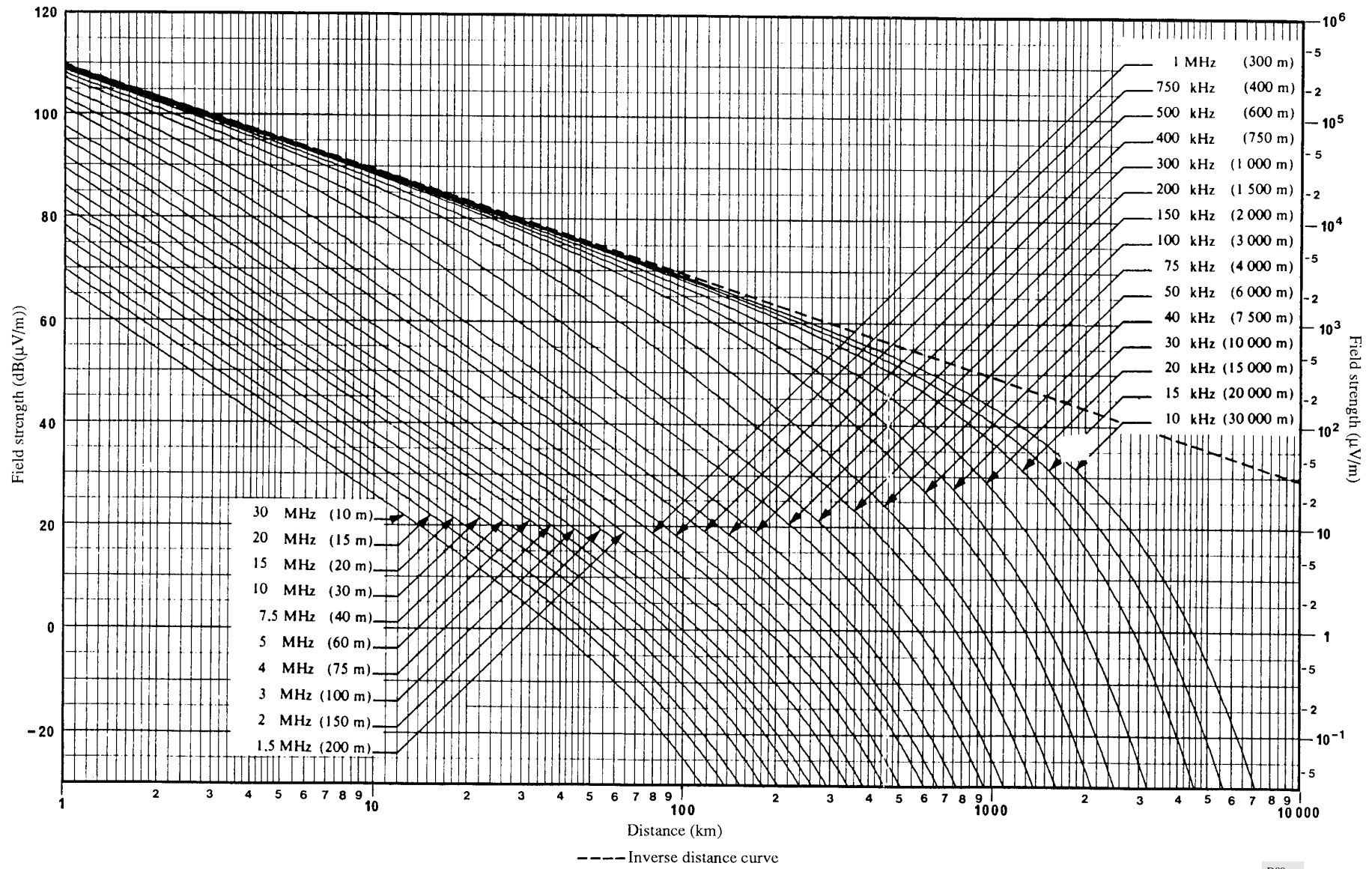


FIGURE 10

Ground-wave propagation curves; Fresh water ice, -1°C , $\sigma = 3 \times 10^{-5} \text{ S/m}$, $\epsilon = 3$

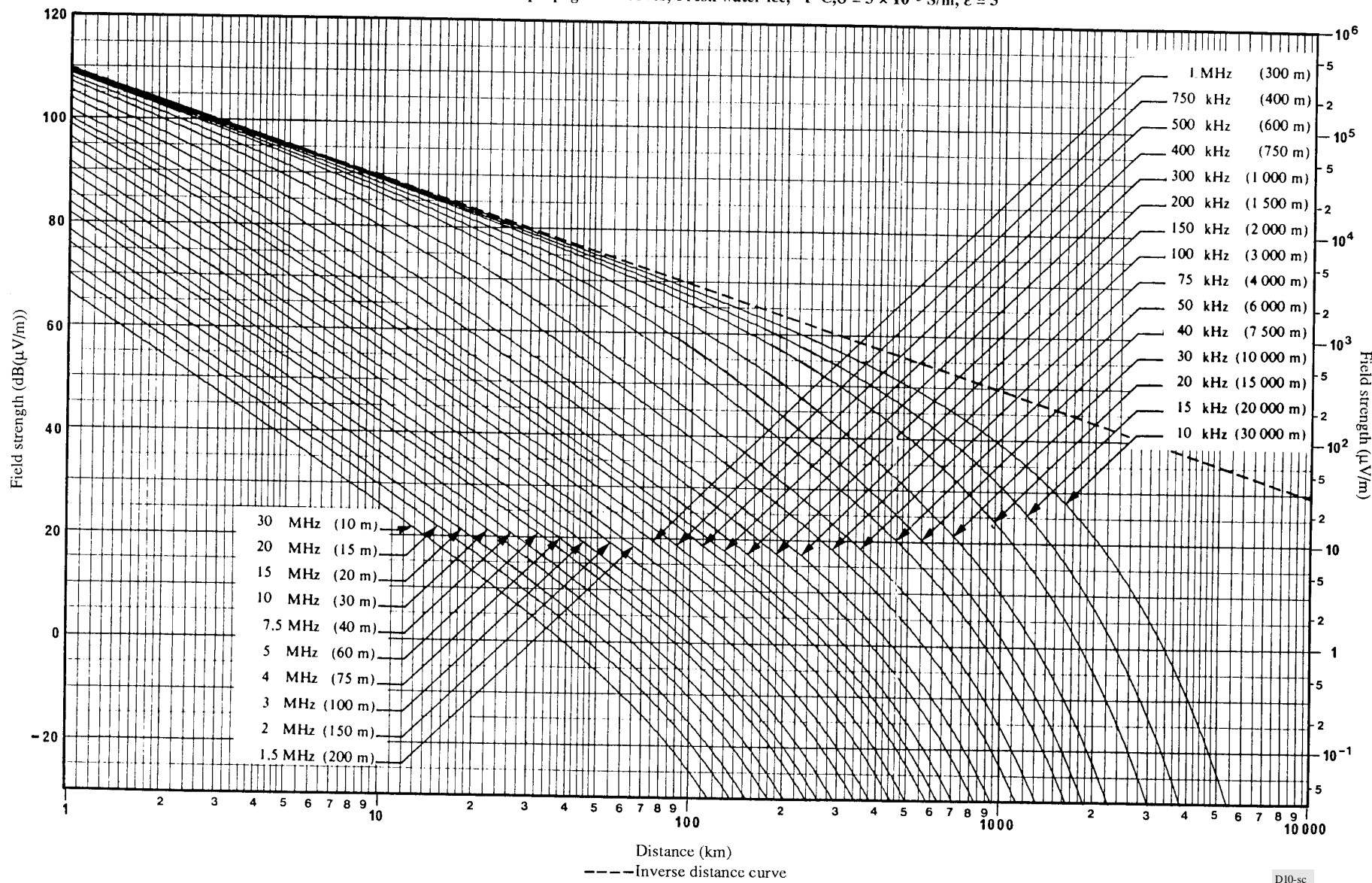
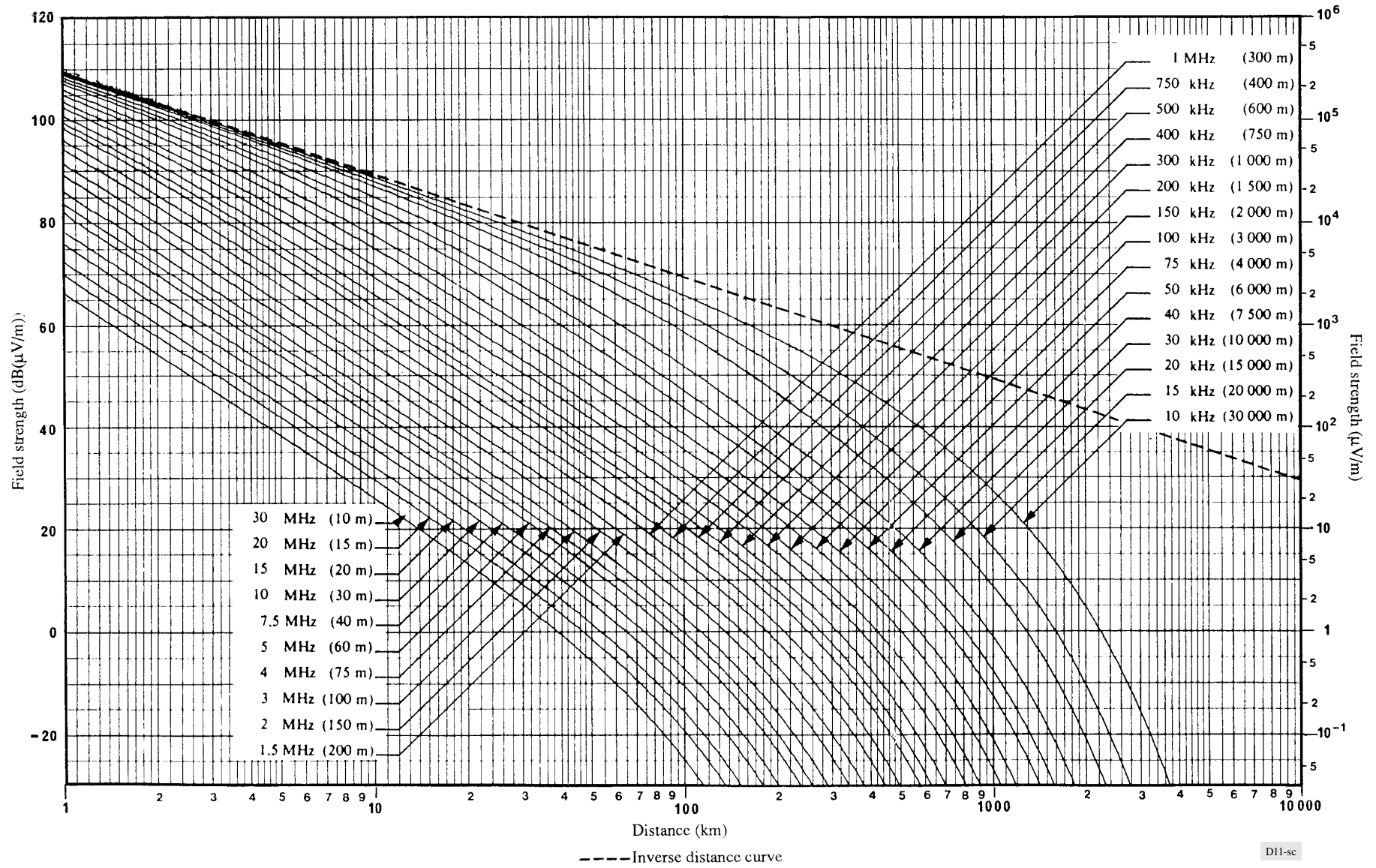


FIGURE 11

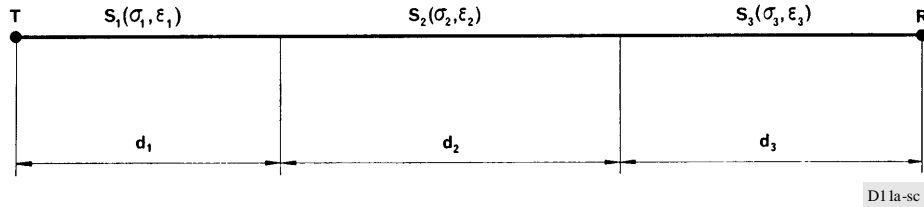
Ground-wave propagation curves; Fresh water ice, -10°C , $\sigma = 10^{-5}\text{ S/m}$, $\epsilon = 3$



Application to mixed paths (inhomogeneous paths)

1. Figures 14 to 50 of this Annex may be used for the determination of propagation over mixed paths (non-homogeneous smooth Earth) as follows:

Such paths may be made up of sections S_1, S_2, S_3 , etc., of lengths d_1, d_2, d_3 , etc., having conductivity and permittivity $\sigma_1, \epsilon_1; \sigma_2, \epsilon_2; \sigma_3, \epsilon_3$, etc., as shown below for three sections:



The Millington method used in this Annex for determining propagation over mixed paths is the most accurate available and satisfies the reciprocity condition. The method assumes that the curves are available for the different types of terrain in the sections S_1, S_2, S_3 , etc., assumed to be individually homogeneous, all drawn for the same source T defined, for instance, by a given inverse-distance curve. The values may then finally be scaled up for any other source.

For a given frequency, the curve appropriate to the section S_1 is then chosen and the field $E_1(d_1)$ in dB(μ V/m) at the distance d_1 is then noted. The curve for the section S_2 is then used to find the fields $E_2(d_1)$ and $E_2(d_1 + d_2)$ and, similarly, with the curve for the section S_3 , the fields $E_3(d_1 + d_2)$ and $E_3(d_1 + d_2 + d_3)$ are found, and so on.

A received field strength E_R is then defined by:

$$E_R = E_1(d_1) - E_2(d_1) + E_2(d_1 + d_2) - E_3(d_1 + d_2) + E_3(d_1 + d_2 + d_3) \quad (1)$$

The procedure is then reversed, and calling R the transmitter and T the receiver, a field E_T is obtained, given by:

$$E_T = E_3(d_3) - E_2(d_3) + E_2(d_3 + d_2) - E_1(d_3 + d_2) + E_1(d_3 + d_2 + d_1) \quad (2)$$

The required field is given by $\frac{1}{2}[E_R + E_T]$, the extension to more sections being obvious.

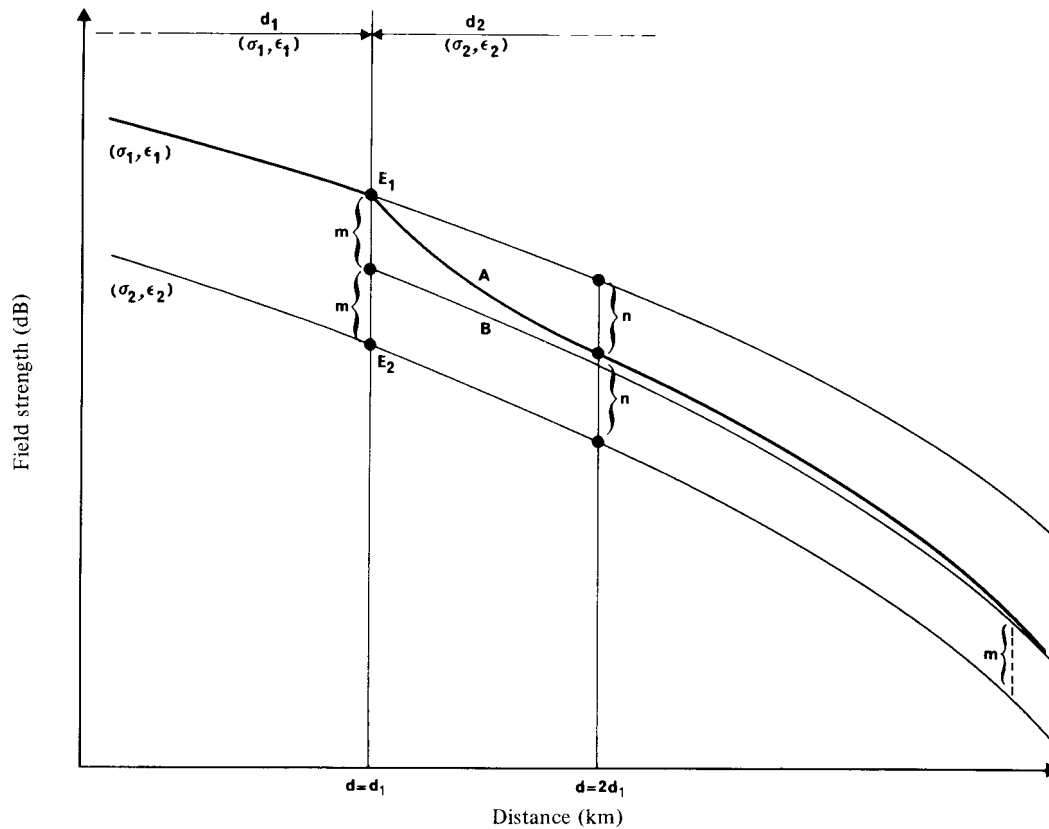
The method can in principle be extended to phase changes if the corresponding curves for phase as a function of distance over a homogeneous earth are available. Such information would be necessary for application to navigational systems. The method is generally easy to use, particularly with the aid of a computer.

2. For planning purposes where the coverage of a certain transmitter is needed, a graphical procedure, based on the same method, is convenient for a rough and quick estimation of the distance at which the field strength has a certain value.

A short description of the graphical method is given here.

Figure 12 applies to a path having two different sections characterized by the values σ_1, ϵ_1 and σ_2, ϵ_2 , and extending for distances d_1 and d_2 , respectively. It is supposed that the modulus of the complex permittivity (dielectric constant) $|\epsilon'(\sigma_1, \epsilon_1)|$ is greater than $|\epsilon'(\sigma_2, \epsilon_2)|$. For the distances $d > d_1$ the field-strength curve obtained by the Millington method (§ 1) lies between the curves corresponding to the two different electrical properties $E(\sigma_1, \epsilon_1)$ and $E(\sigma_2, \epsilon_2)$. At the distance $d = 2d_1$, where d_1 is the distance from the transmitter to the border separating the two sections, the curve goes through the mid-point between the curves $E(\sigma_1, \epsilon_1)$ and $E(\sigma_2, \epsilon_2)$ provided that the field strength is labelled linearly in decibels. In addition, the same curve approaches an asymptote, which differs by m dB from the curve $E(\sigma_2, \epsilon_2)$ as indicated in Fig. 12, where m is half the difference in decibels between the two curves $E(\sigma_1, \epsilon_1)$ and $E(\sigma_2, \epsilon_2)$ at $d = d_1$. The point at $d = 2d_1$ and the asymptote make it easy to draw the resulting field-strength curve.

FIGURE 12
Comparison of results



A: Calculated field-strength curve
B: Asymptote

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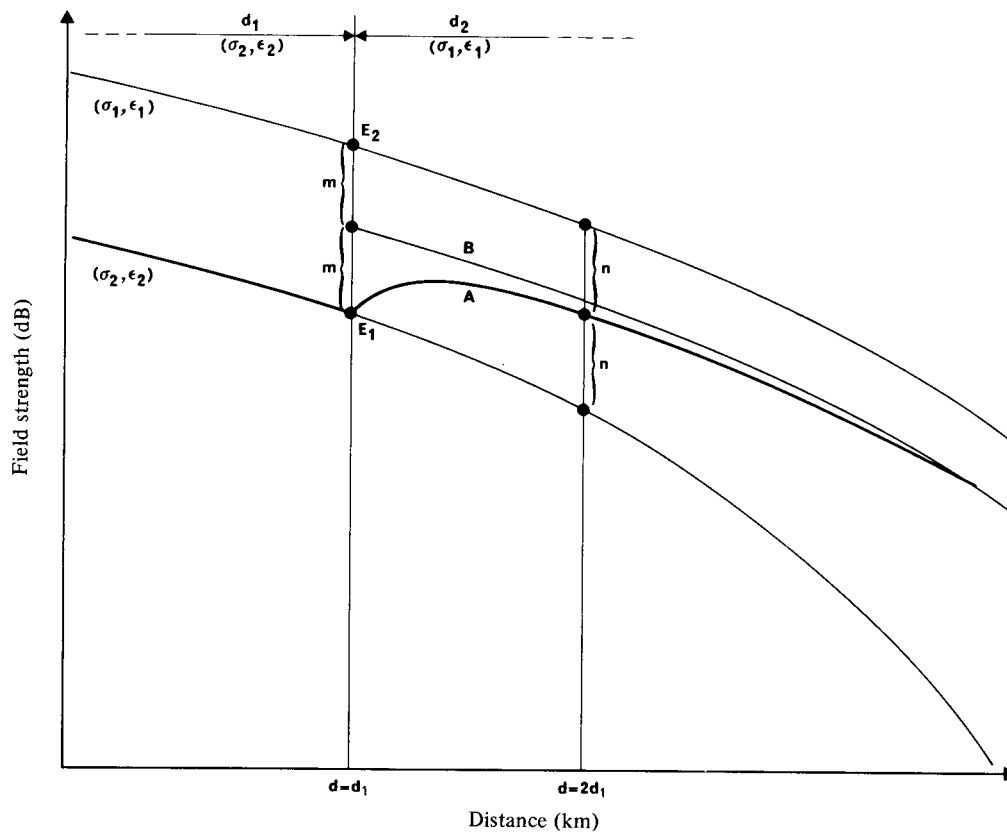
Figure 13 shows the curve for a two-section path with electrical constants changing from σ_2, ϵ_2 to σ_1, ϵ_1 where the modulus of the complex permittivity $|\epsilon'(\sigma_1, \epsilon_1)| > |\epsilon'(\sigma_2, \epsilon_2)|$. The above-mentioned procedure can be applied here bearing in mind that the asymptote is now parallel to the curve of the $E(\sigma_1, \epsilon_1)$.

For paths consisting of more than two sections, each change can be considered separately in the same way as the first change. The resulting curve has to be a continuous curve, and the portions of curves are displaced parallel to the extrapolated curve at the end of the previous section.

The accuracy of the graphical method is dependent on the difference in slope of the field-strength curves, and is therefore to an extent dependent on the frequency. For the LF band, the difference between the method described in § 1 and this approximate method is normally negligible, but for the highest part of the MF band the differences in most cases will not exceed 3 dB.

Figures 14 to 50 contain field-strength curves as a function of distance with the electrical characteristics of the ground as a parameter.

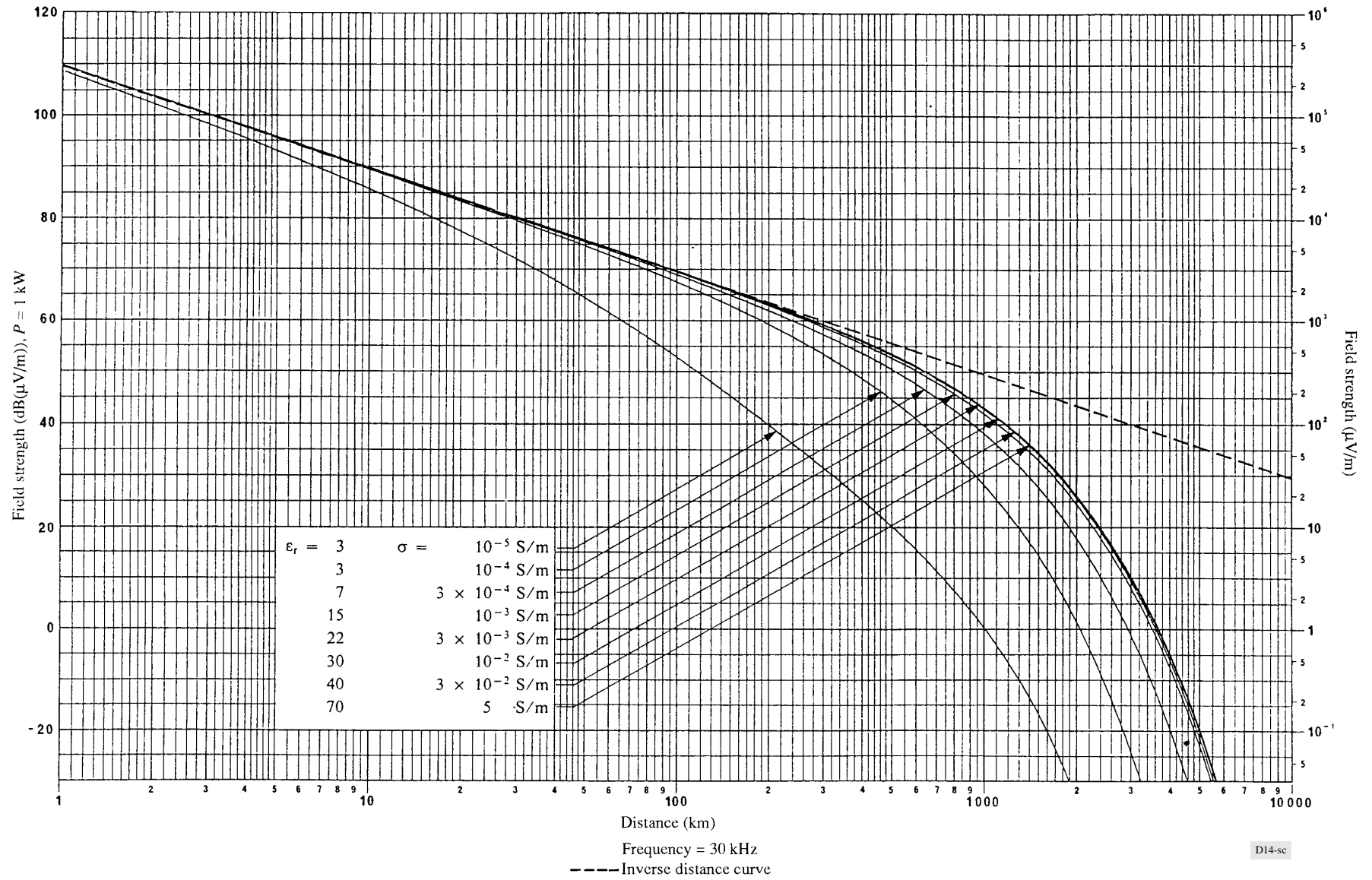
FIGURE 13
Comparison of results



A: Calculated field-strength curve
B: Asymptote

FIGURE 14

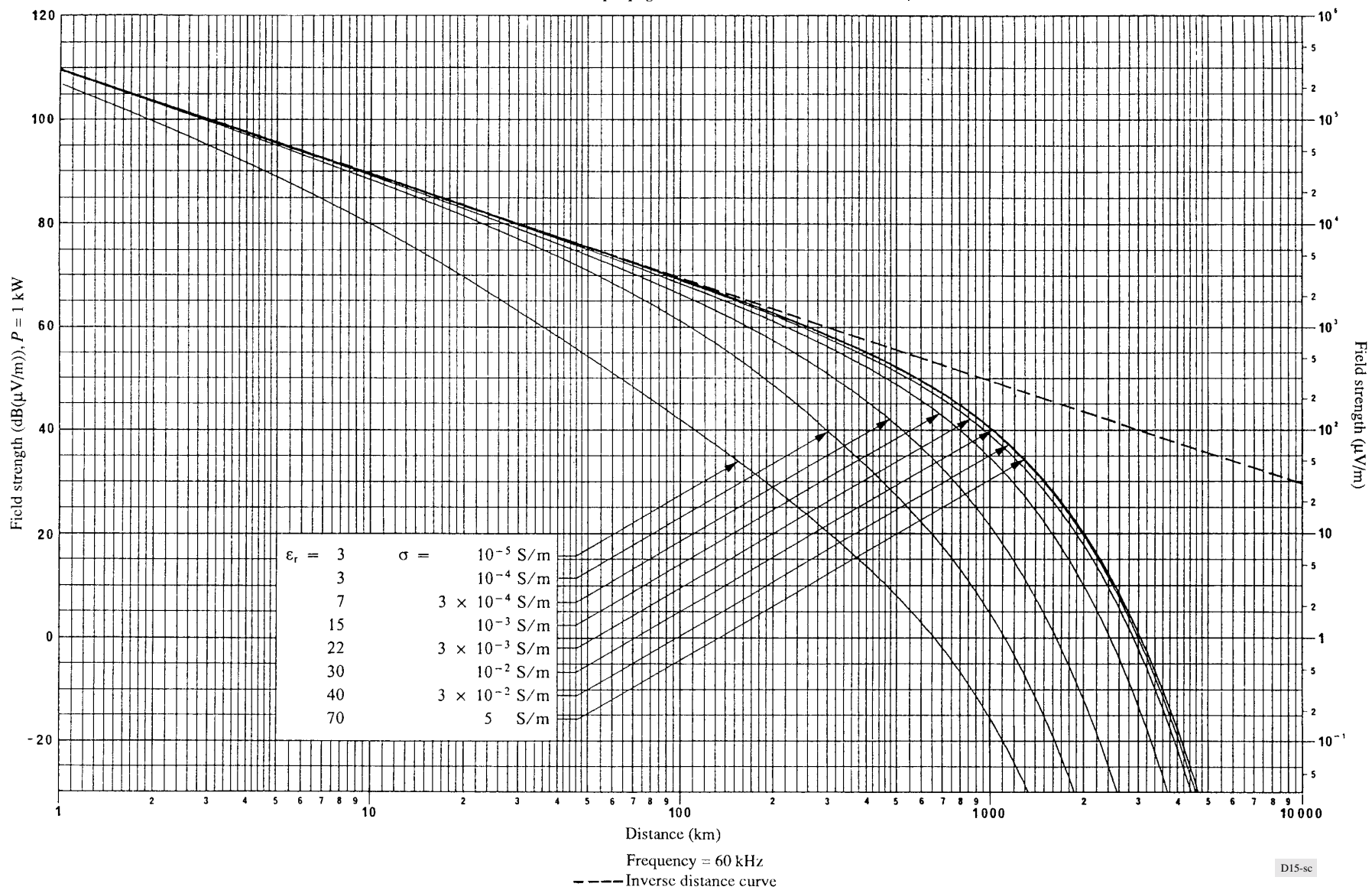
Ground-wave propagation for different values of σ and ϵ_r



D14-sc

FIGURE 15

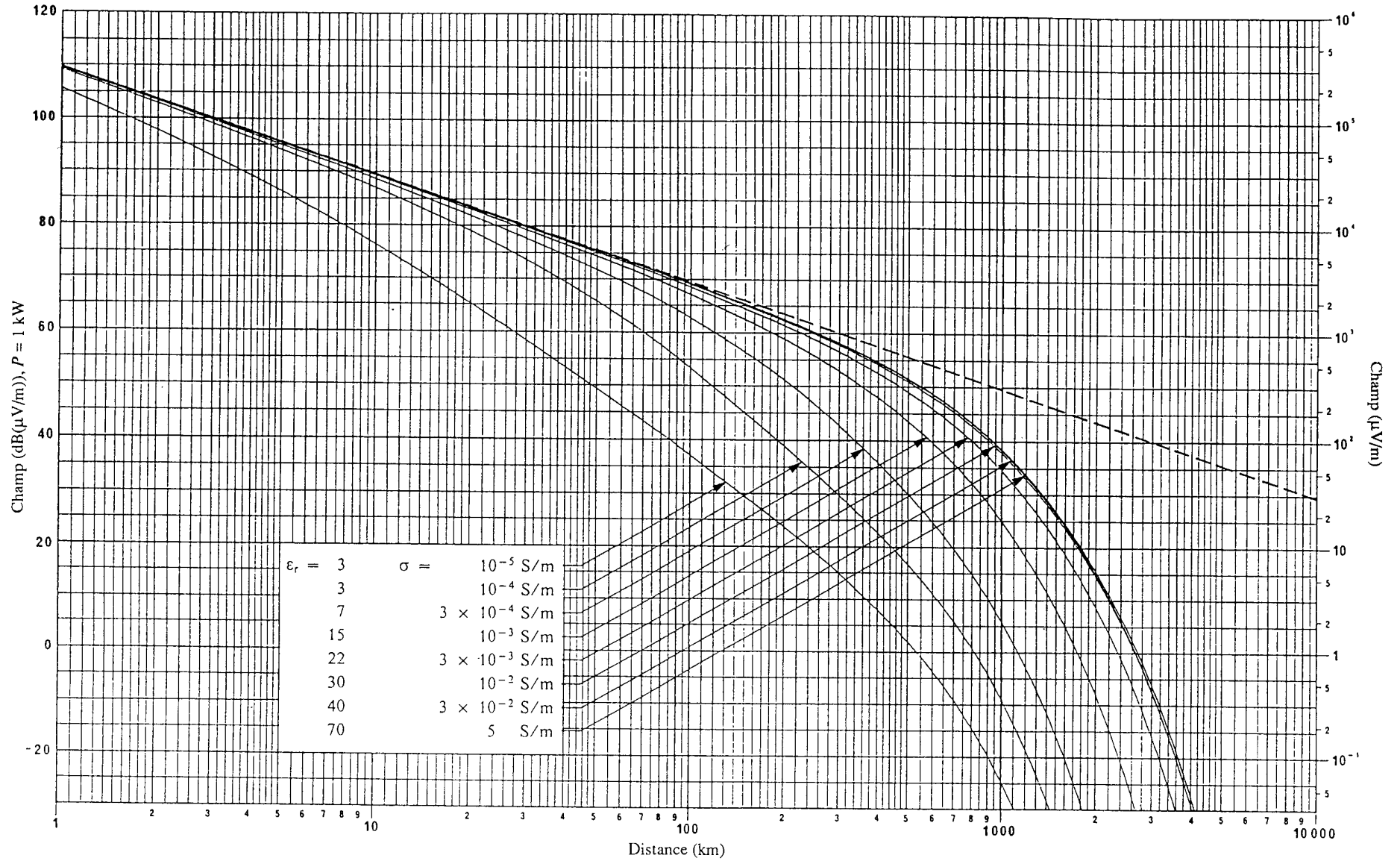
Ground-wave propagation for different values of σ and ϵ_r



D15-sc

FIGURE 16

Propagation de l'onde de sol pour différentes valeurs de σ et ϵ_r



Fréquence: 90 kHz

----- Inverse de la distance

D16-sc

FIGURE 17

Ground-wave propagation for different values of σ and ϵ_r

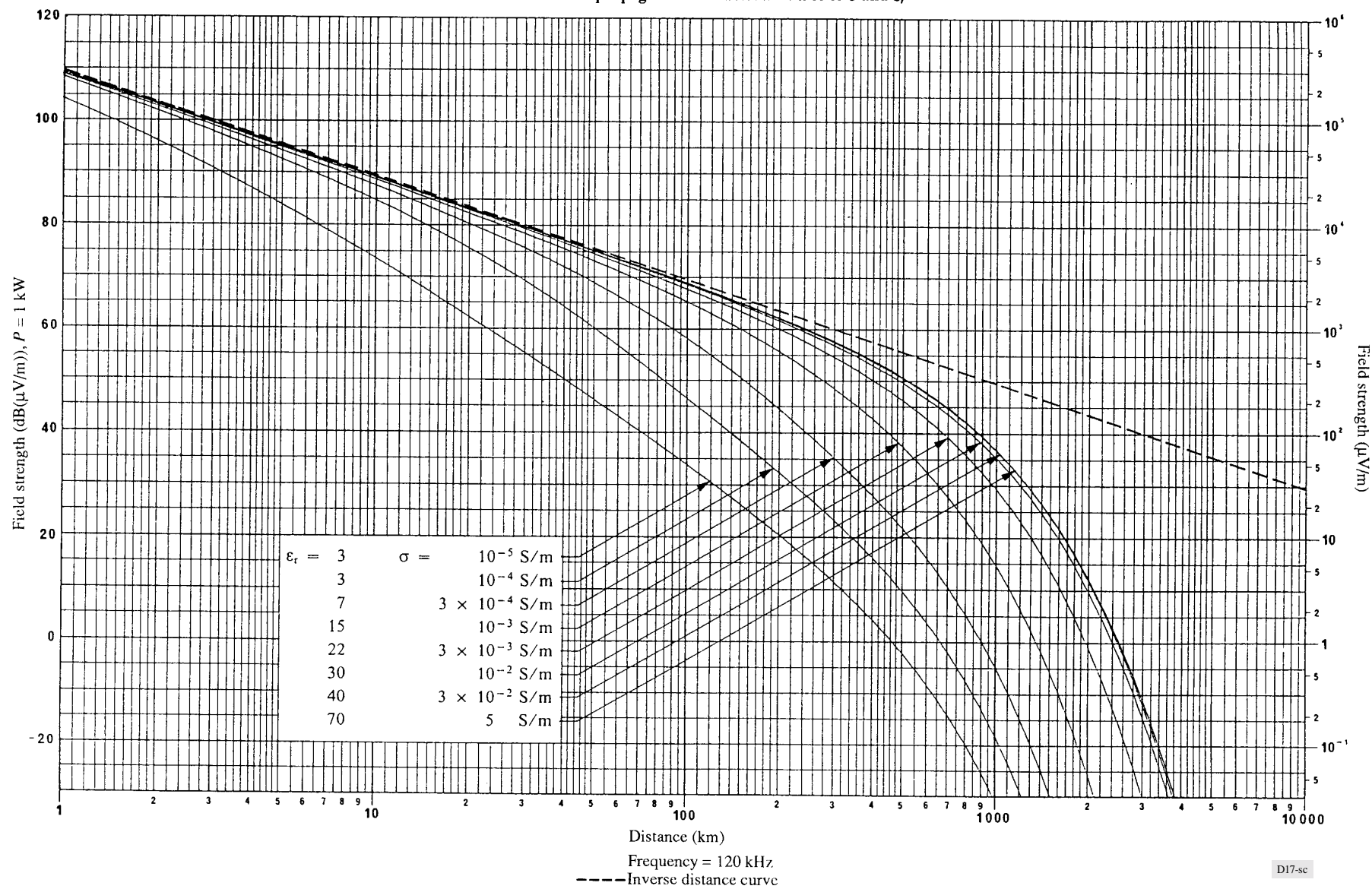
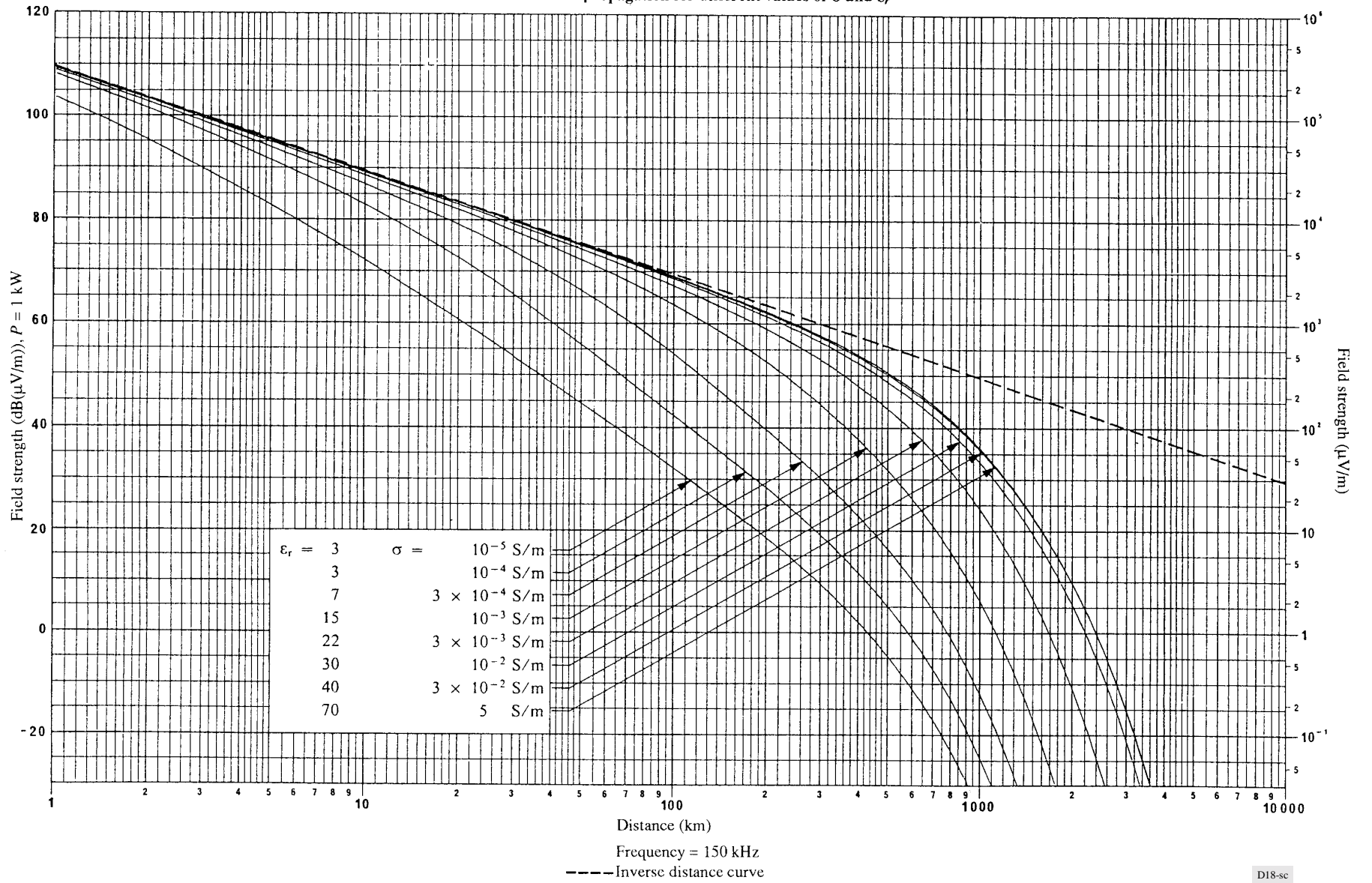


FIGURE 18

Ground-wave propagation for different values of σ and ϵ_r



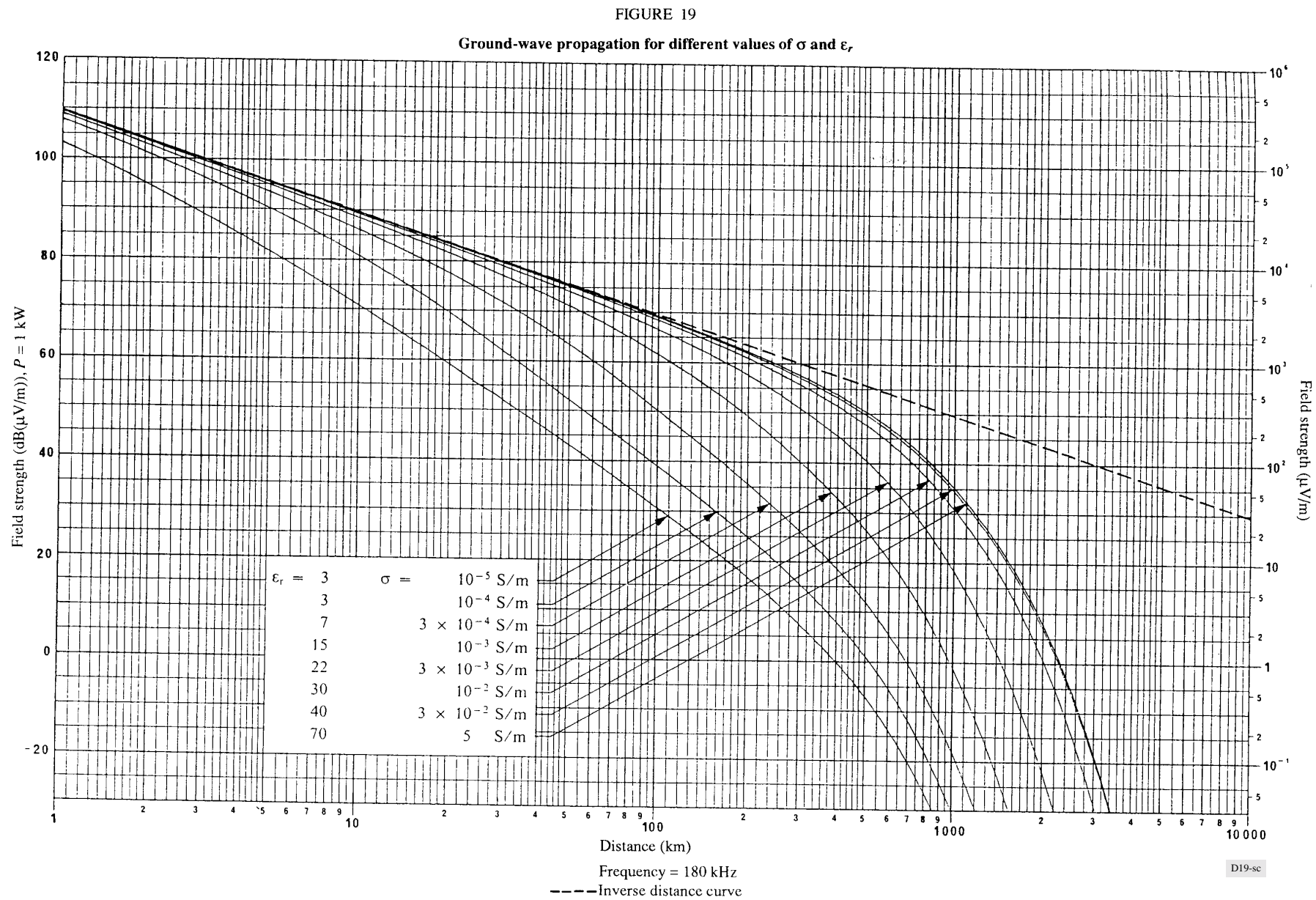
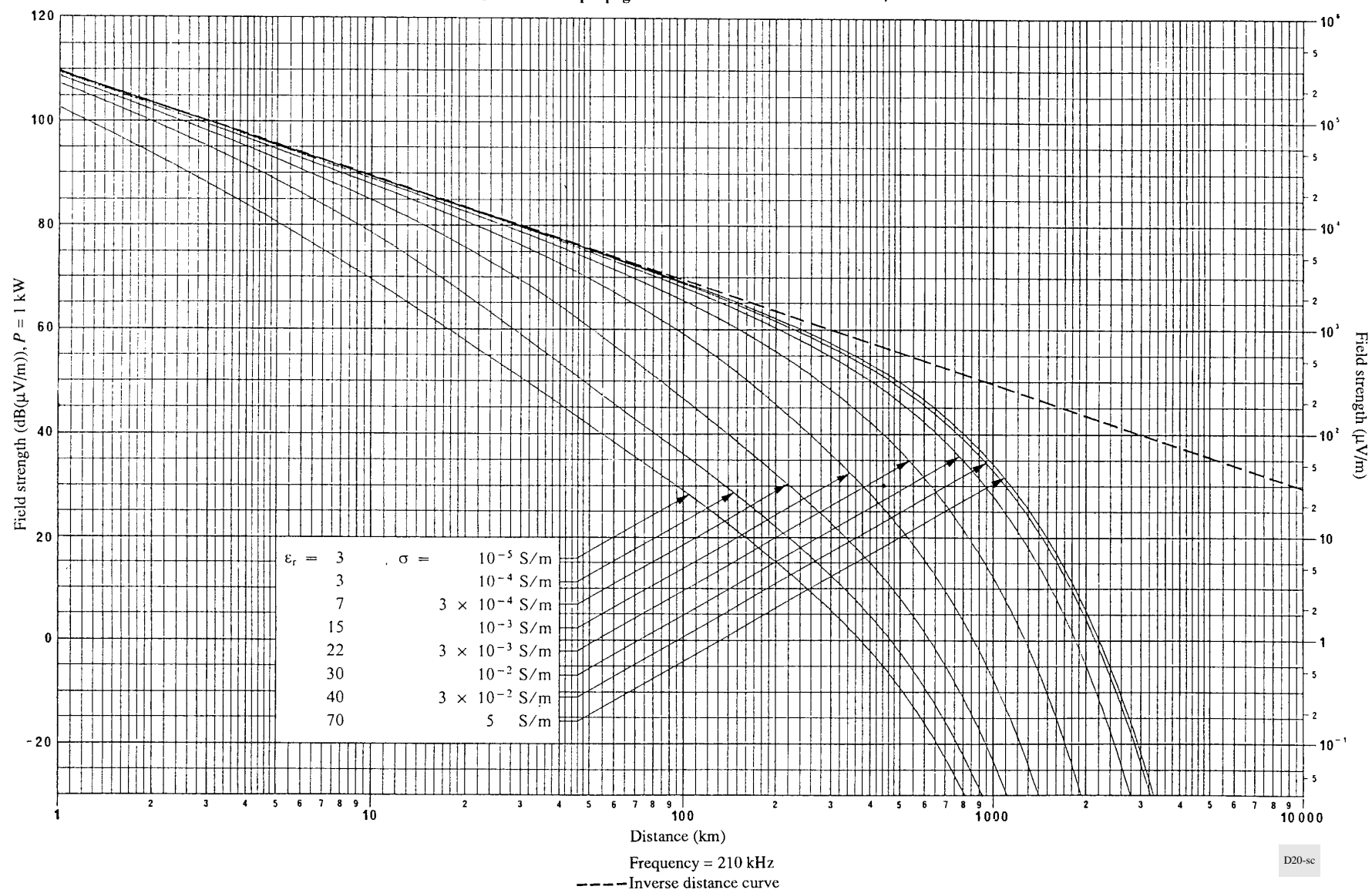


FIGURE 20

Ground-wave propagation for different values of σ and ϵ_r



D20-sc

FIGURE 21

Ground-wave propagation for different values of σ and ϵ_r

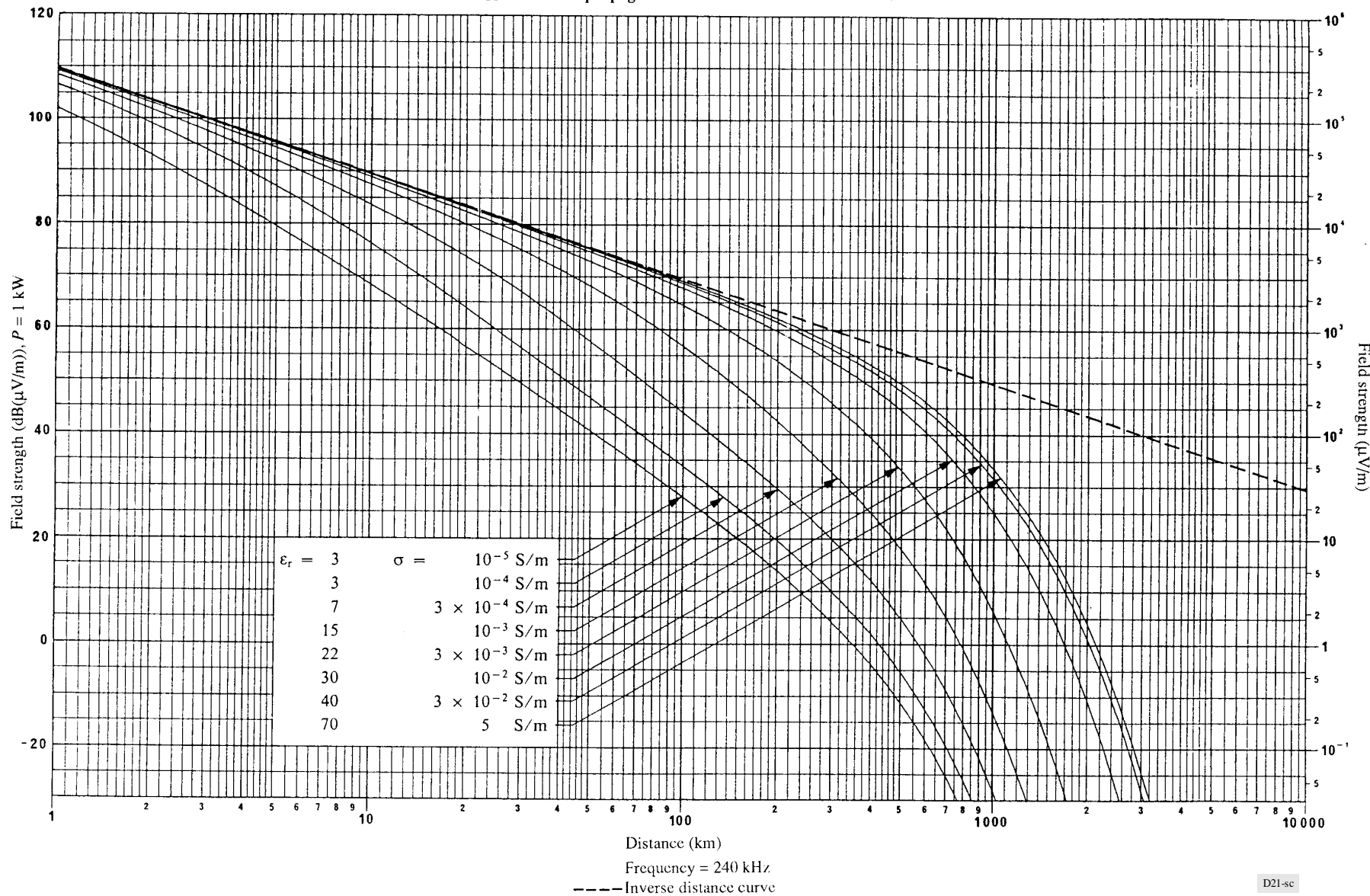


FIGURE 22

Ground-wave propagation for different values of σ and ϵ_r

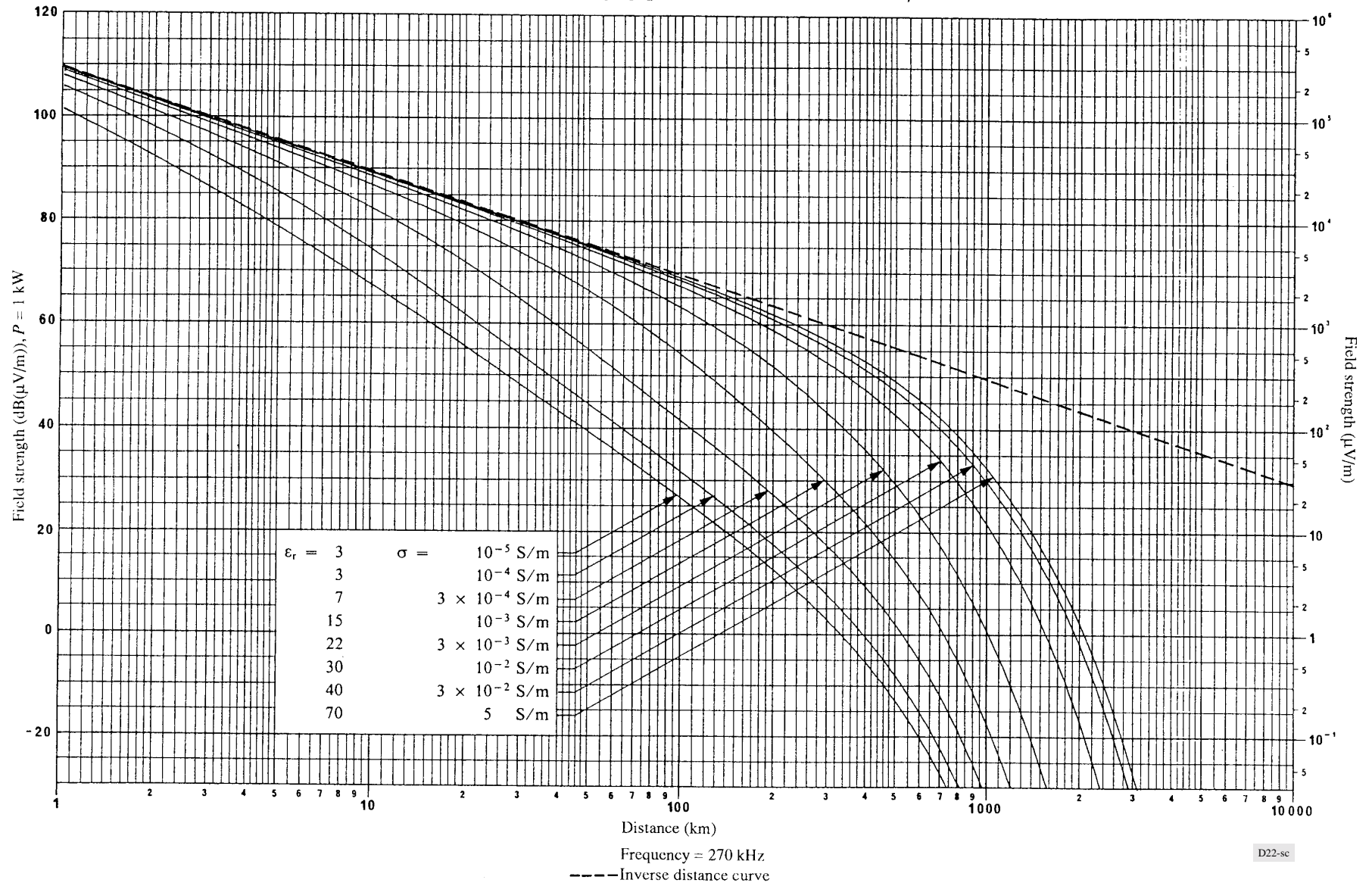


FIGURE 23

Ground-wave propagation for different values of σ and ϵ_r

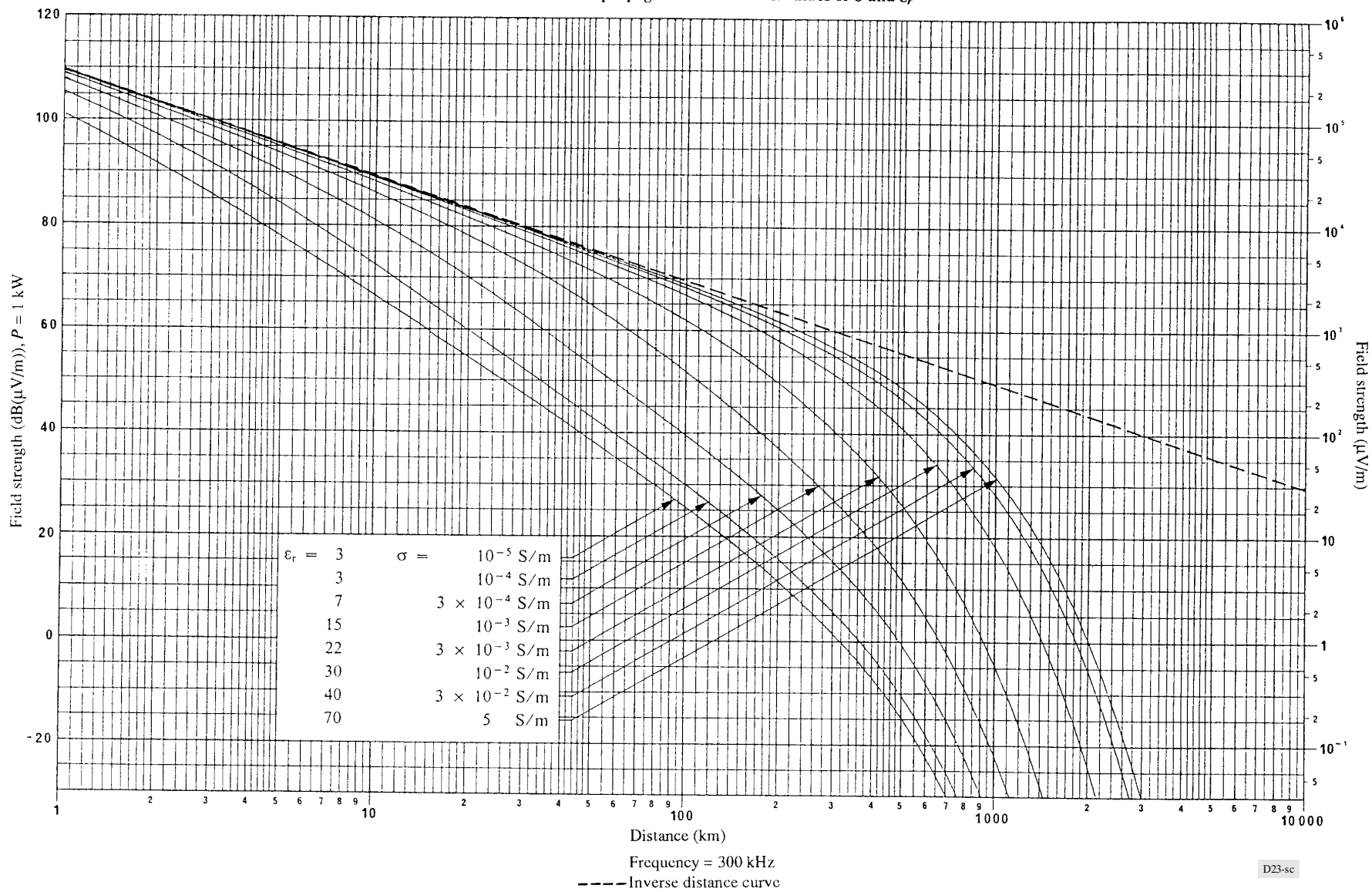


FIGURE 24

Ground-wave propagation for different values of σ and ϵ_r

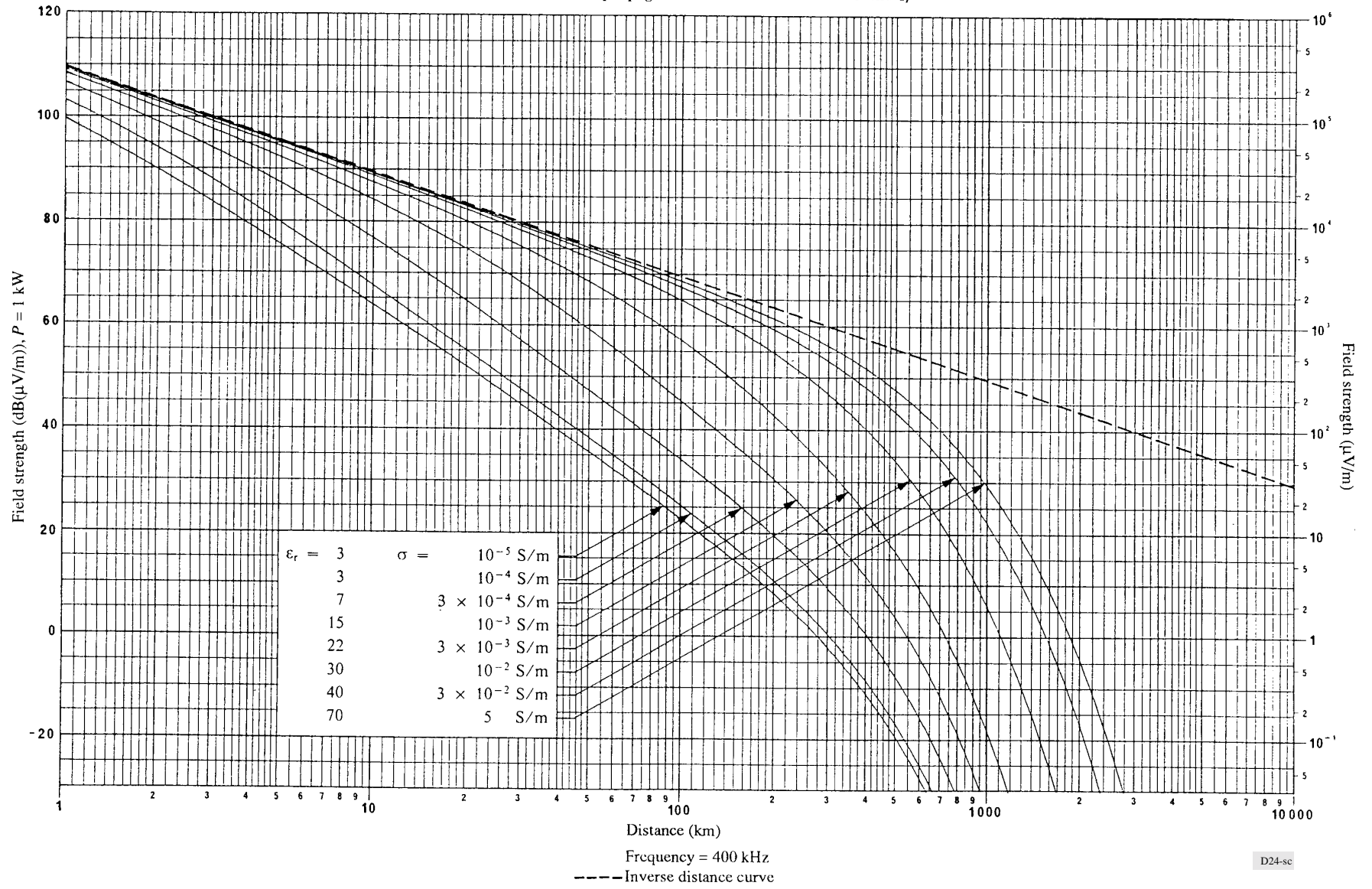


FIGURE 25
Ground-wave propagation for different values of σ and ϵ_r

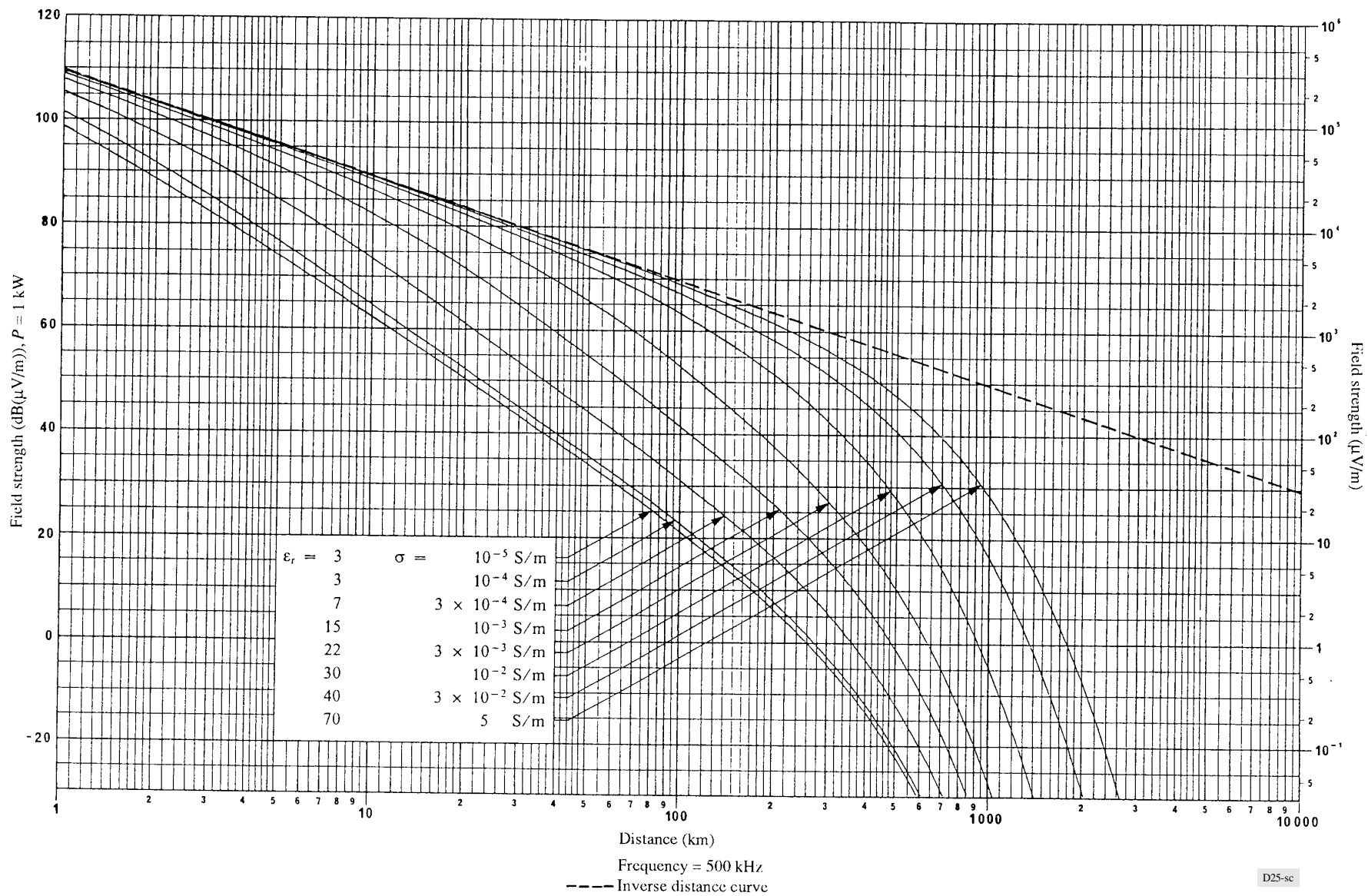
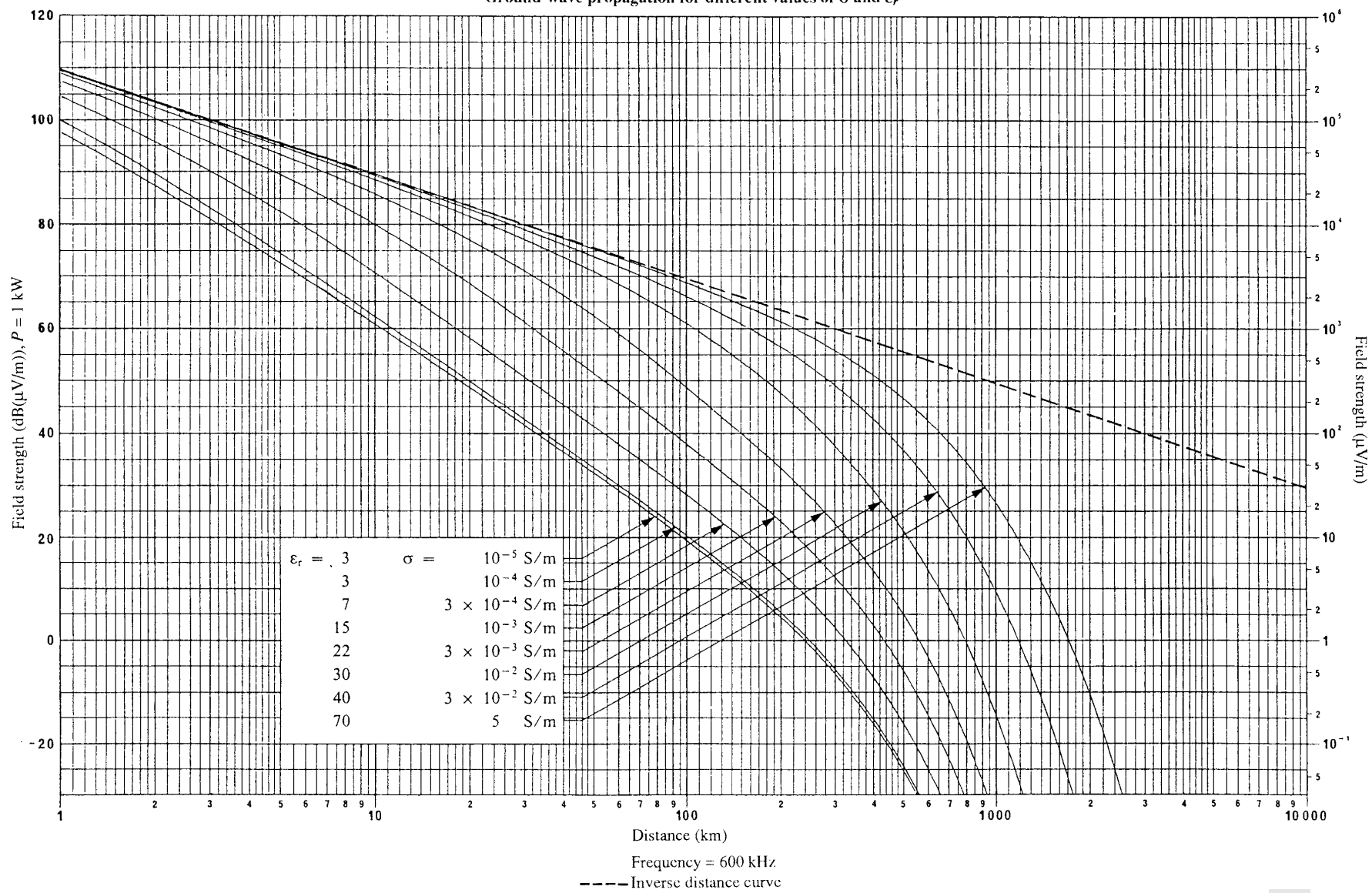


FIGURE 26

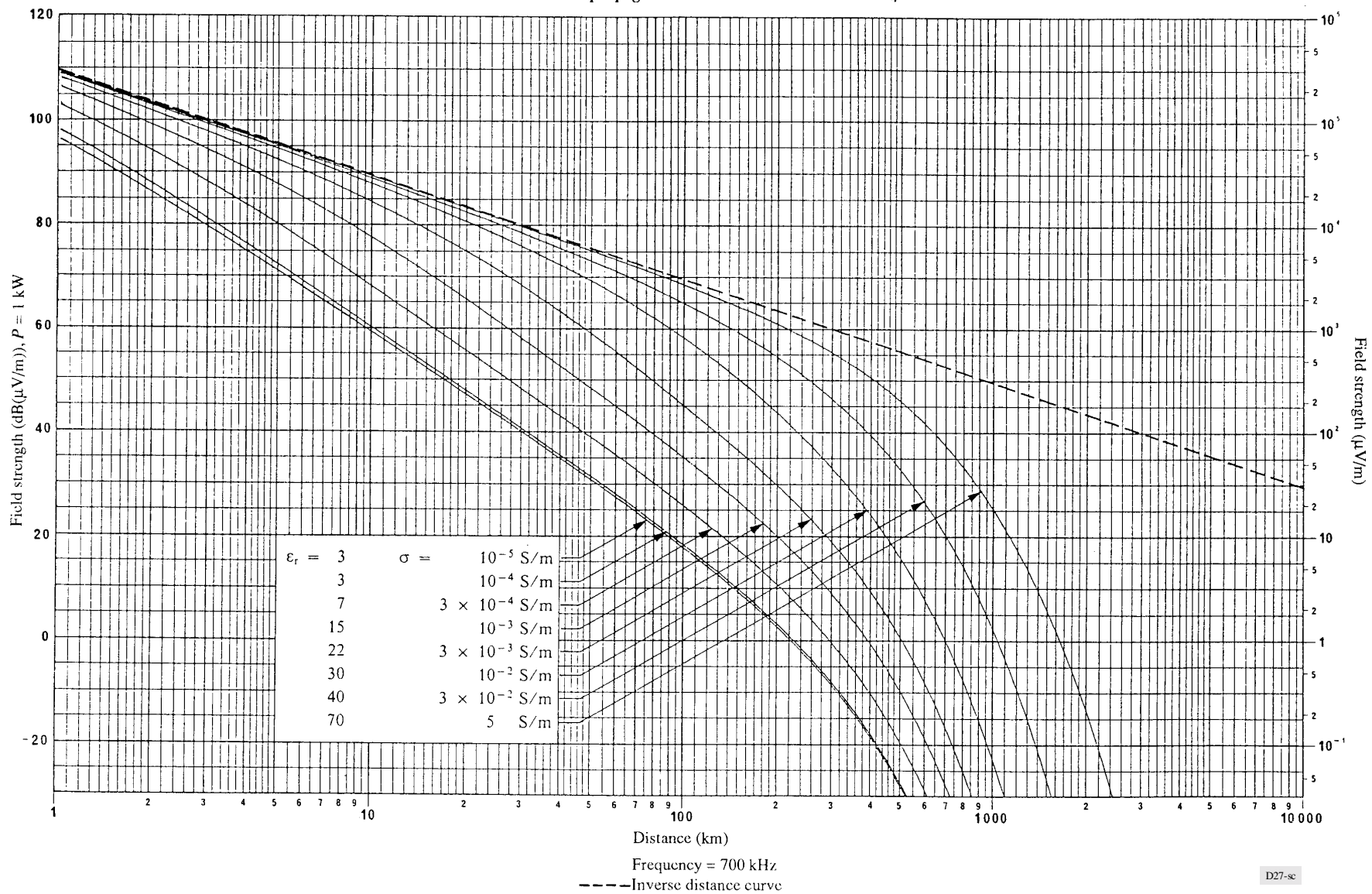
Ground-wave propagation for different values of σ and ϵ_r



D26-sc

FIGURE 27

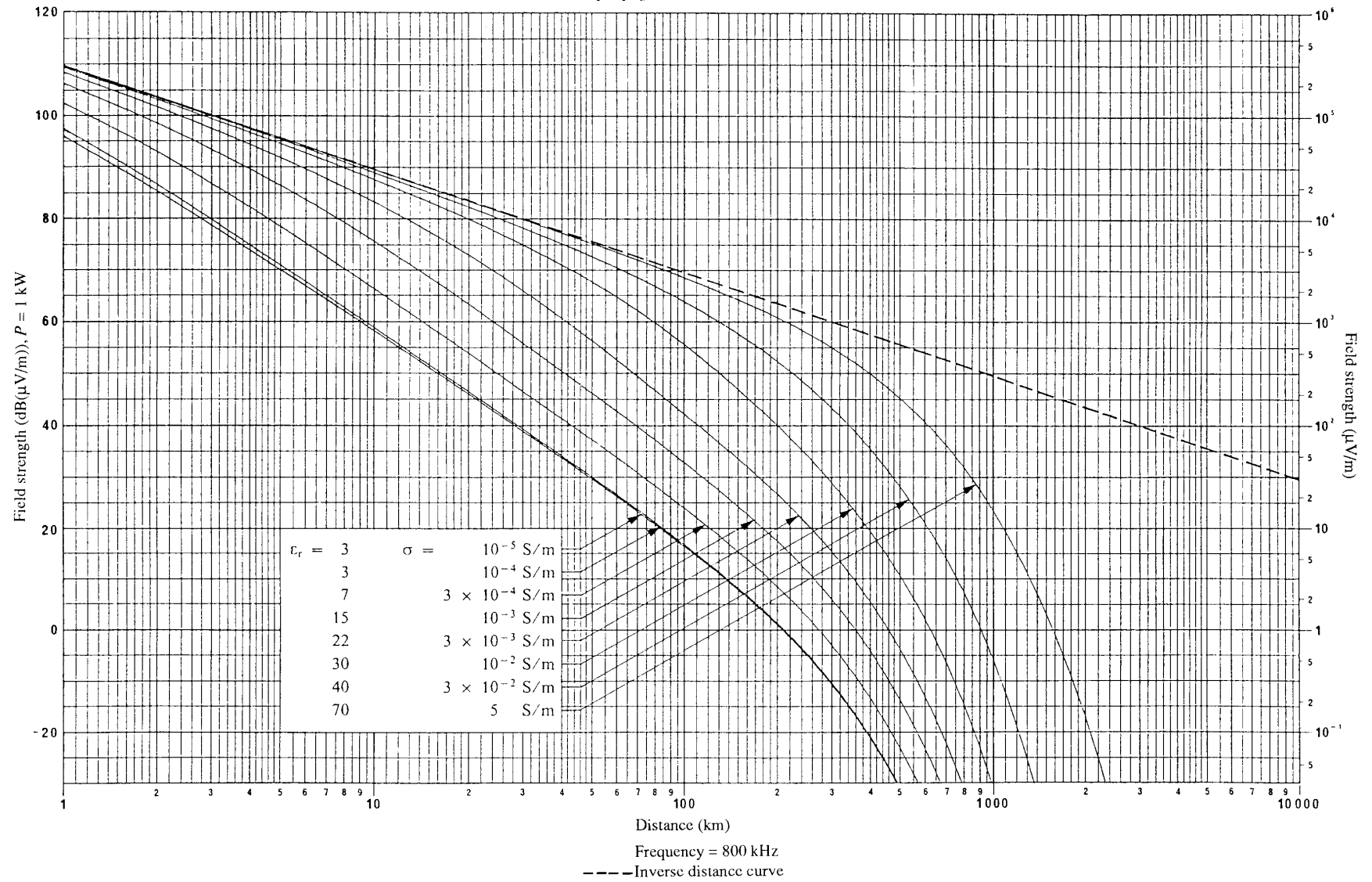
Ground-wave propagation for different values of σ and ϵ_r



D27-sc

FIGURE 28

Ground-wave propagation for different values of σ and ϵ_r



D28-sc

FIGURE 29

Ground-wave propagation for different values of σ and ϵ_r

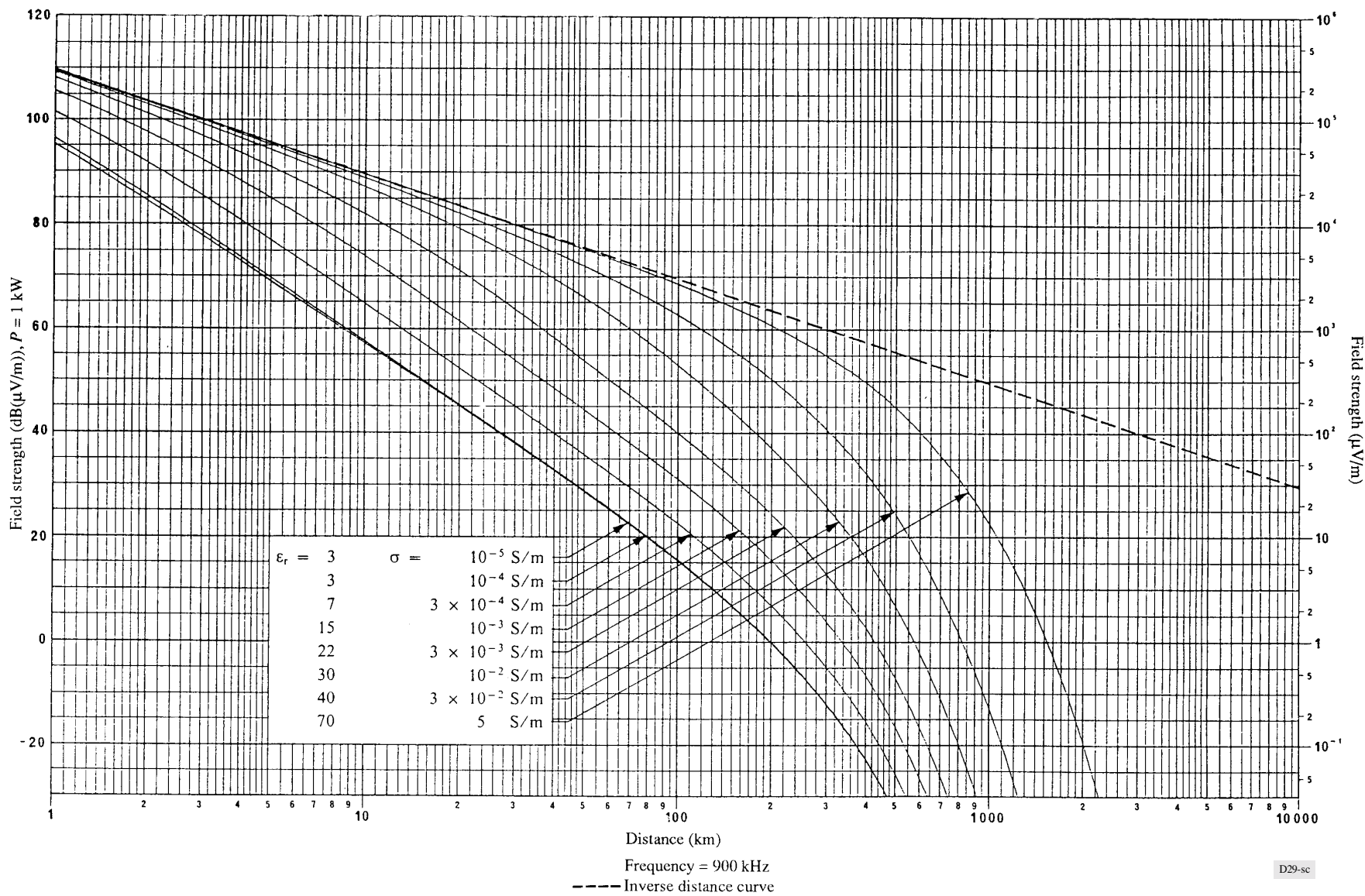
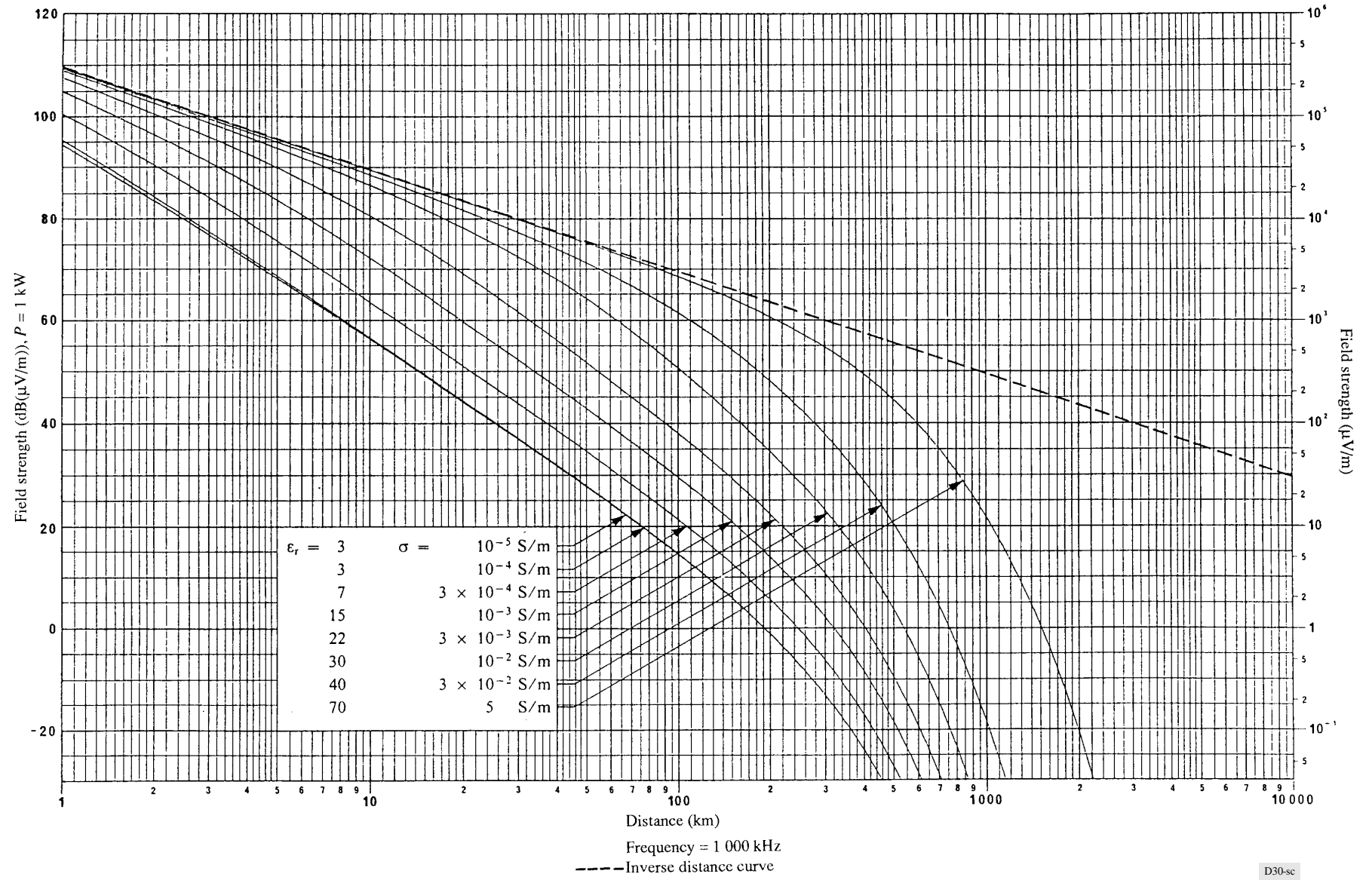


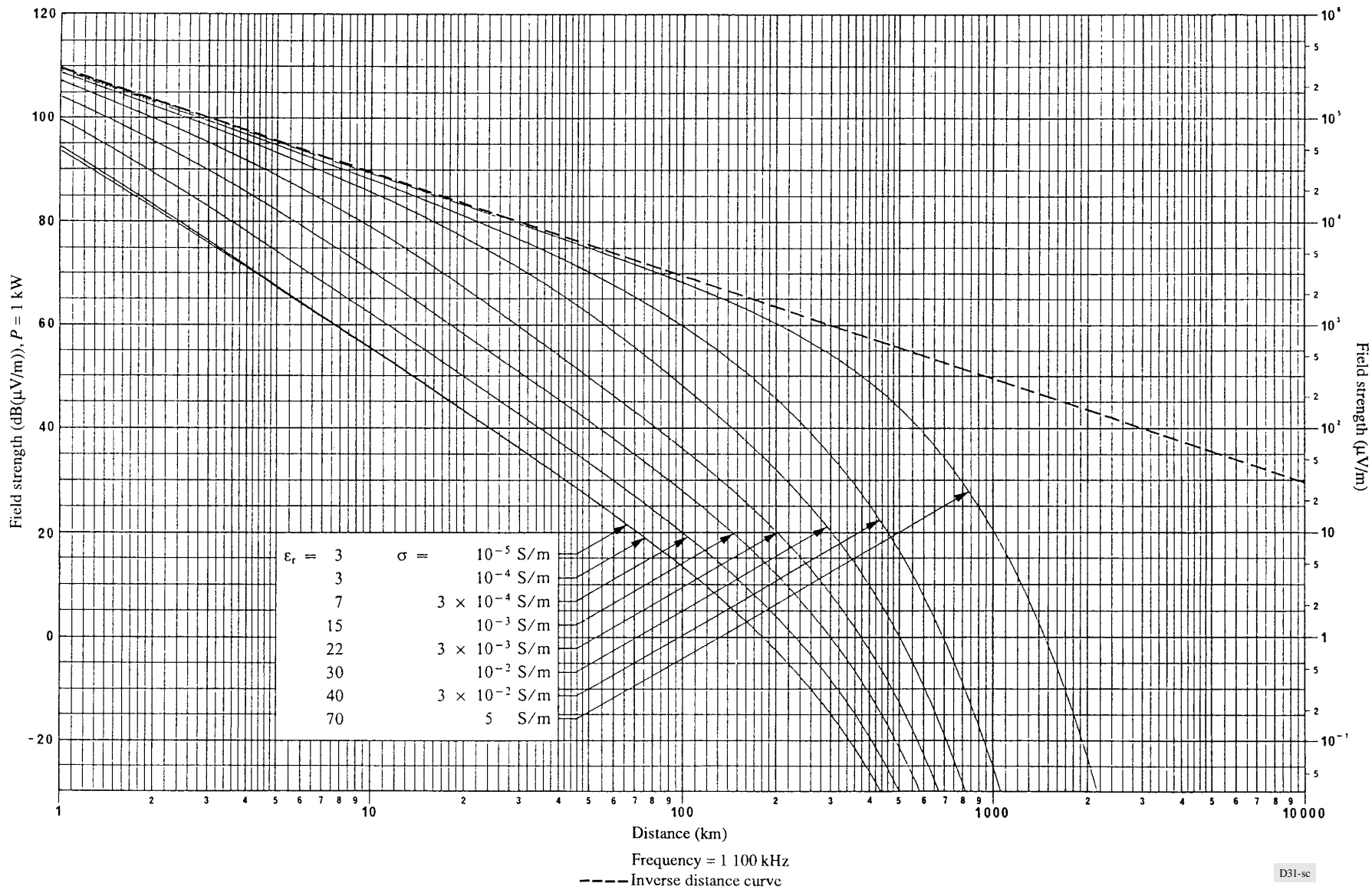
FIGURE 30

Ground-wave propagation for different values of σ and ϵ_r



D30-sc

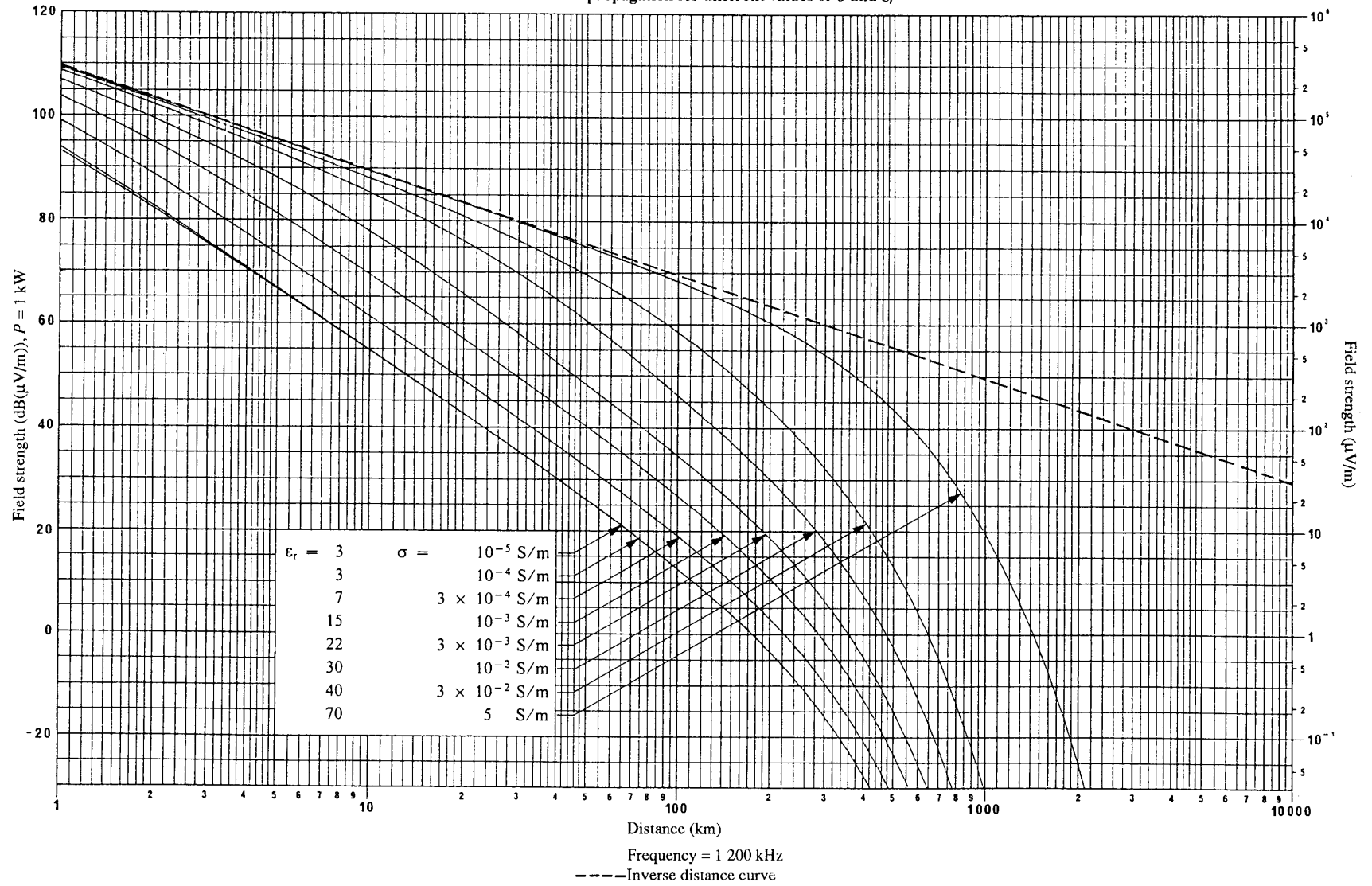
FIGURE 31
Ground-wave propagation for different values of σ and ϵ_r



D31-sc

FIGURE 32

Ground-wave propagation for different values of σ and ϵ_r .



D32-sc

FIGURE 33

Ground-wave propagation for different values of σ and ϵ_r

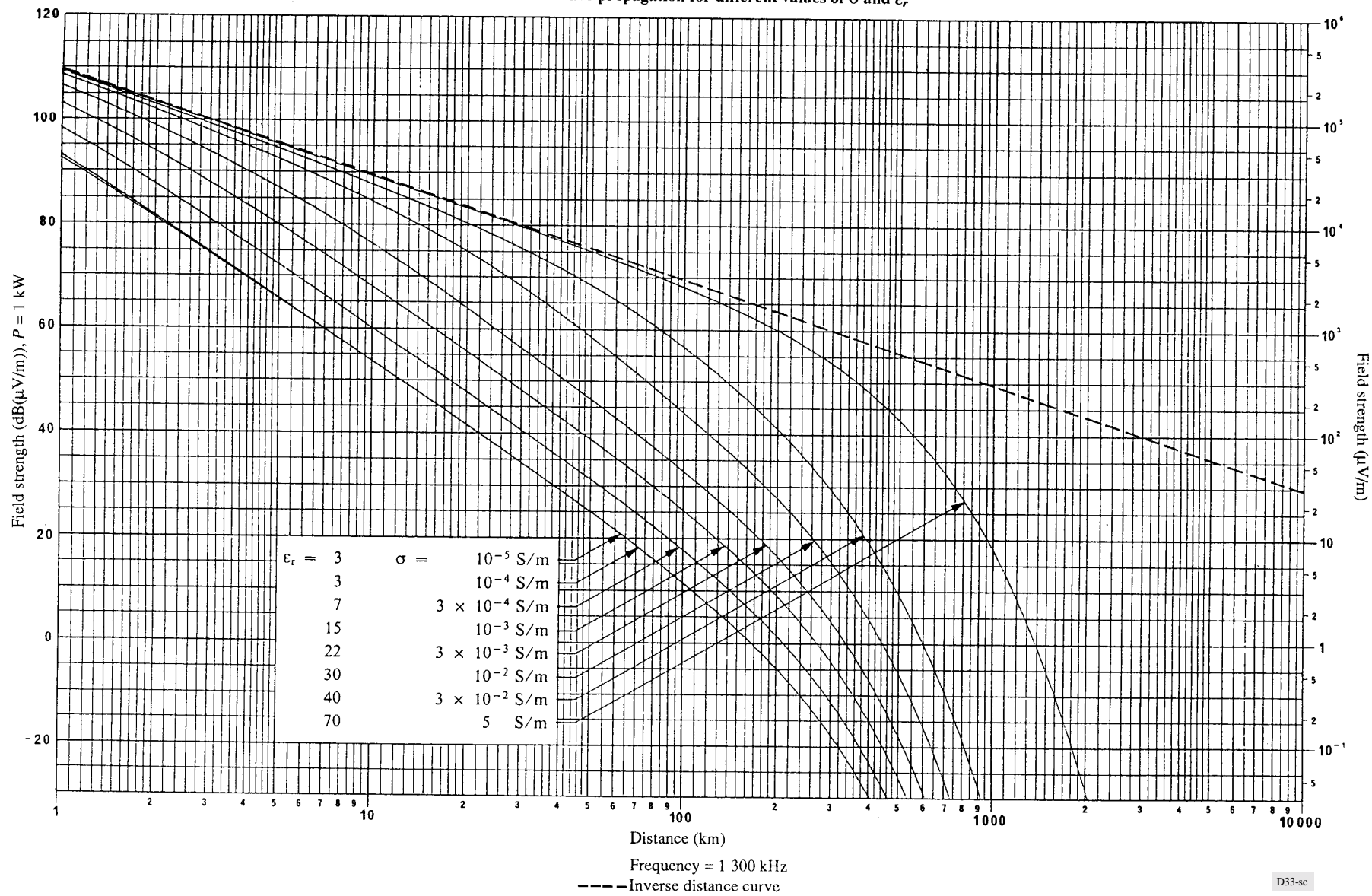
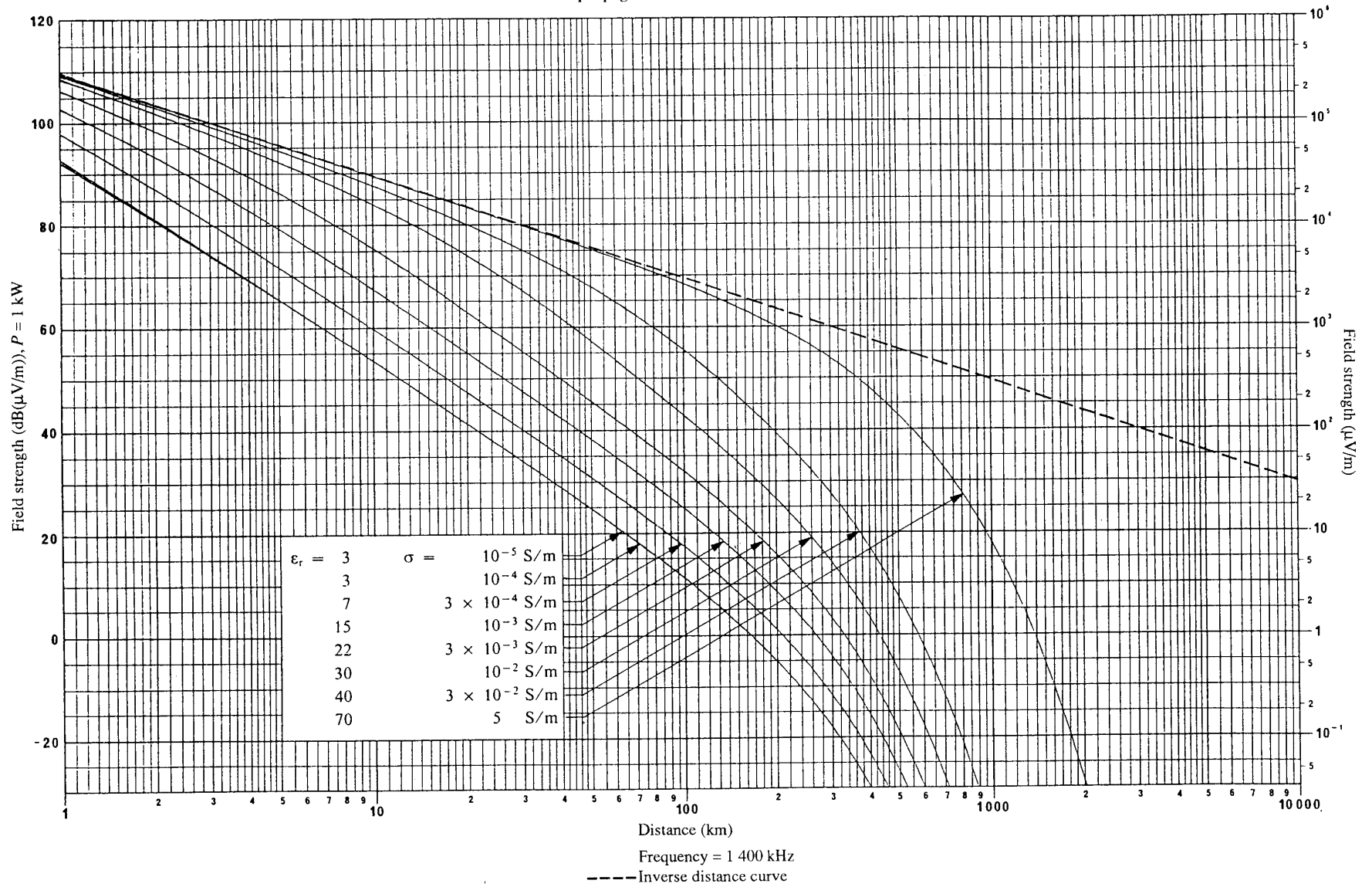


FIGURE 34

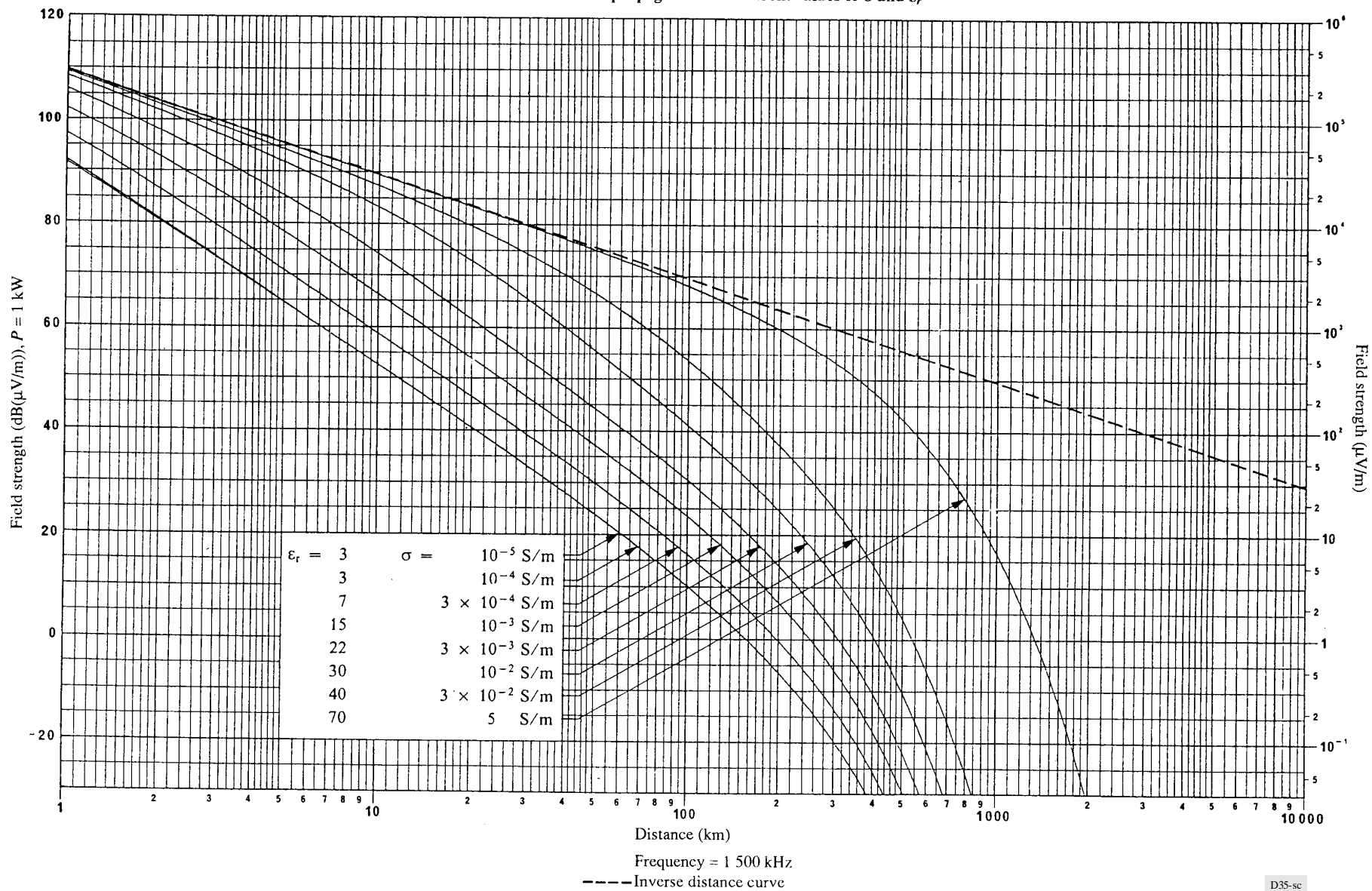
Ground-wave propagation for different values of σ and ϵ_r



D34-sc

FIGURE 35

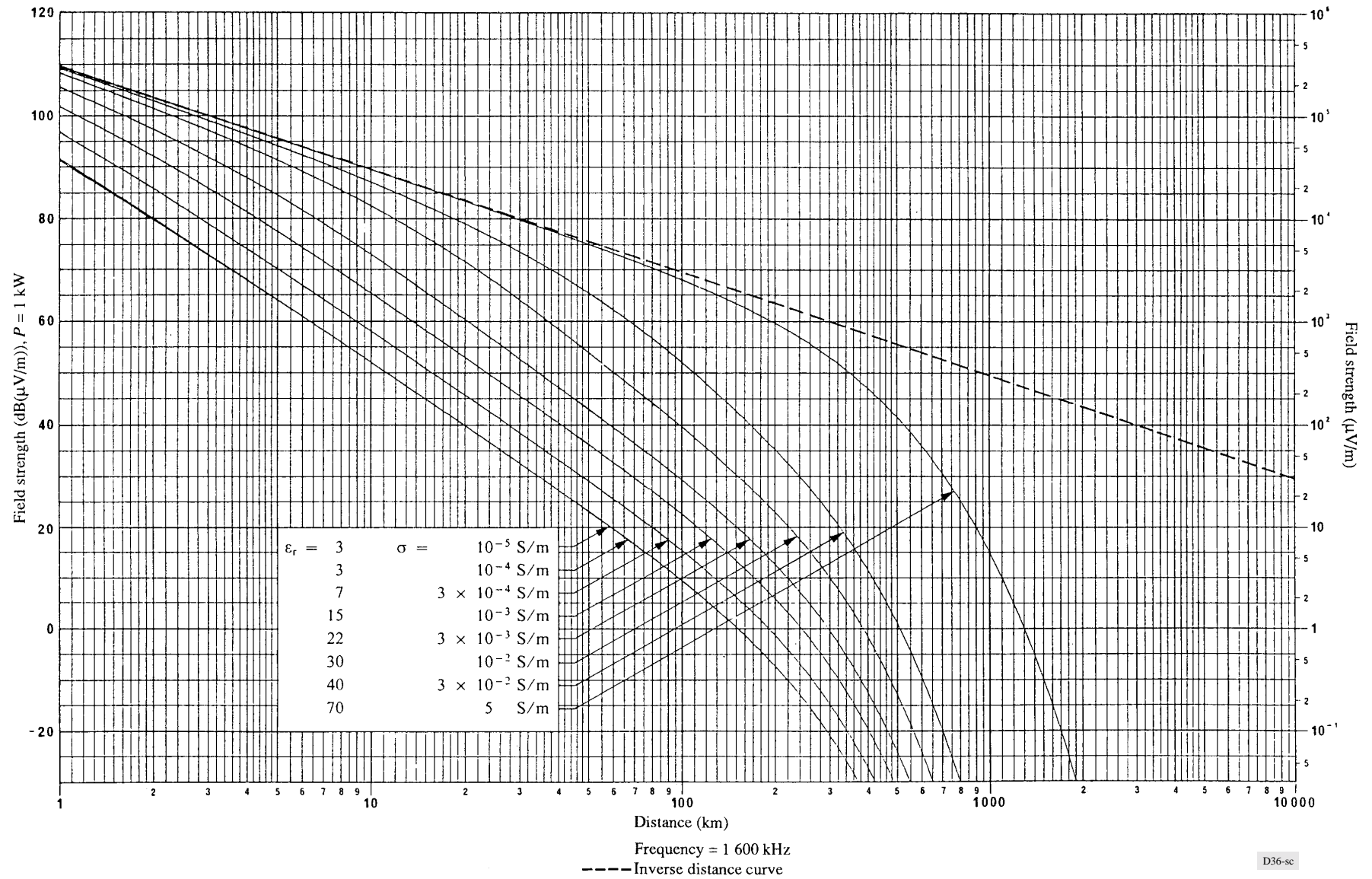
Ground-wave propagation for different values of σ and ϵ_r



D35-sc

FIGURE 36

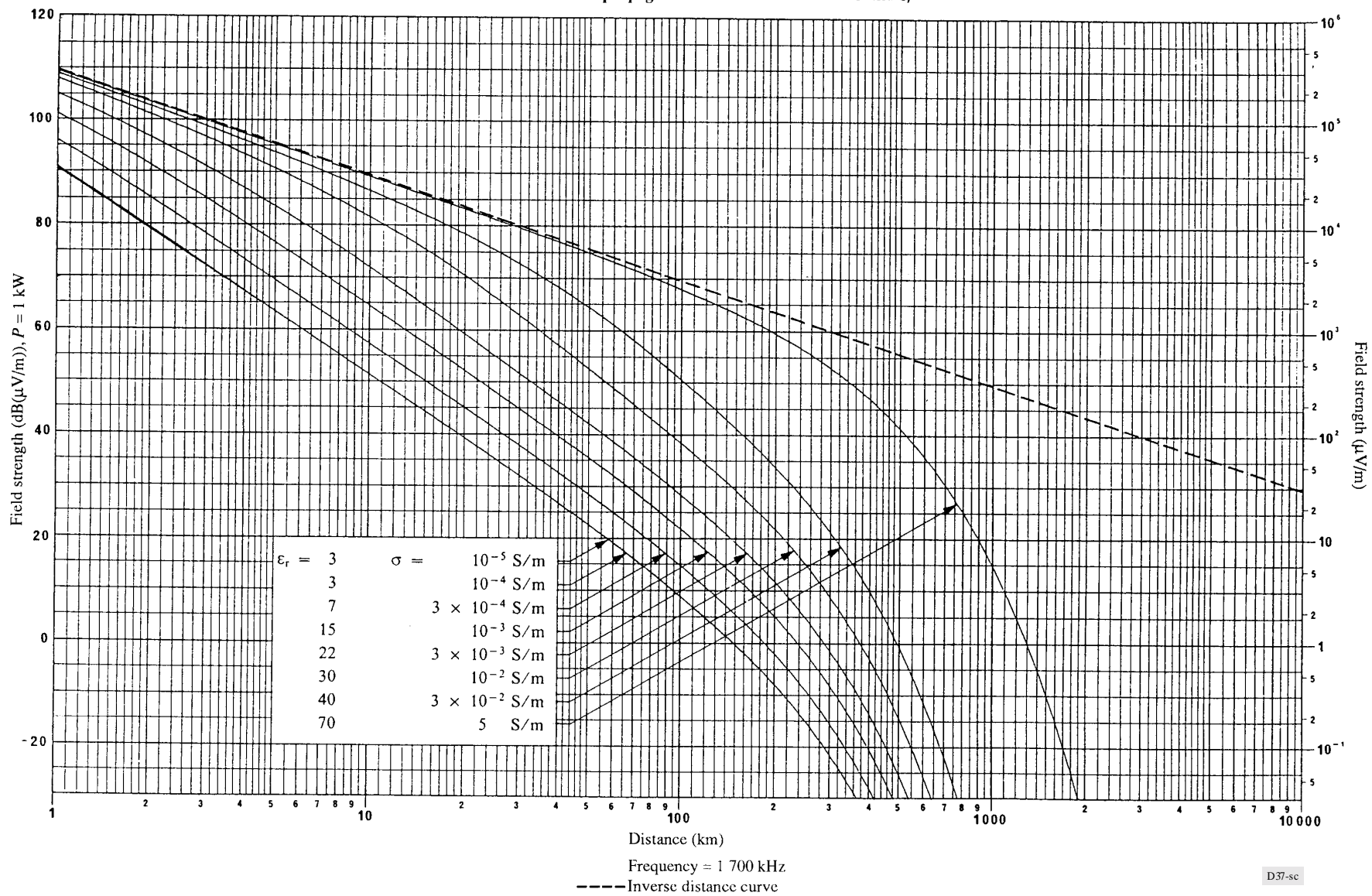
Ground-wave propagation for different values of σ and ϵ_r



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FIGURE 37

Ground-wave propagation for different values of σ and ϵ_r



D37-sc

FIGURE 38

Ground-wave propagation for different values of σ and ϵ_r

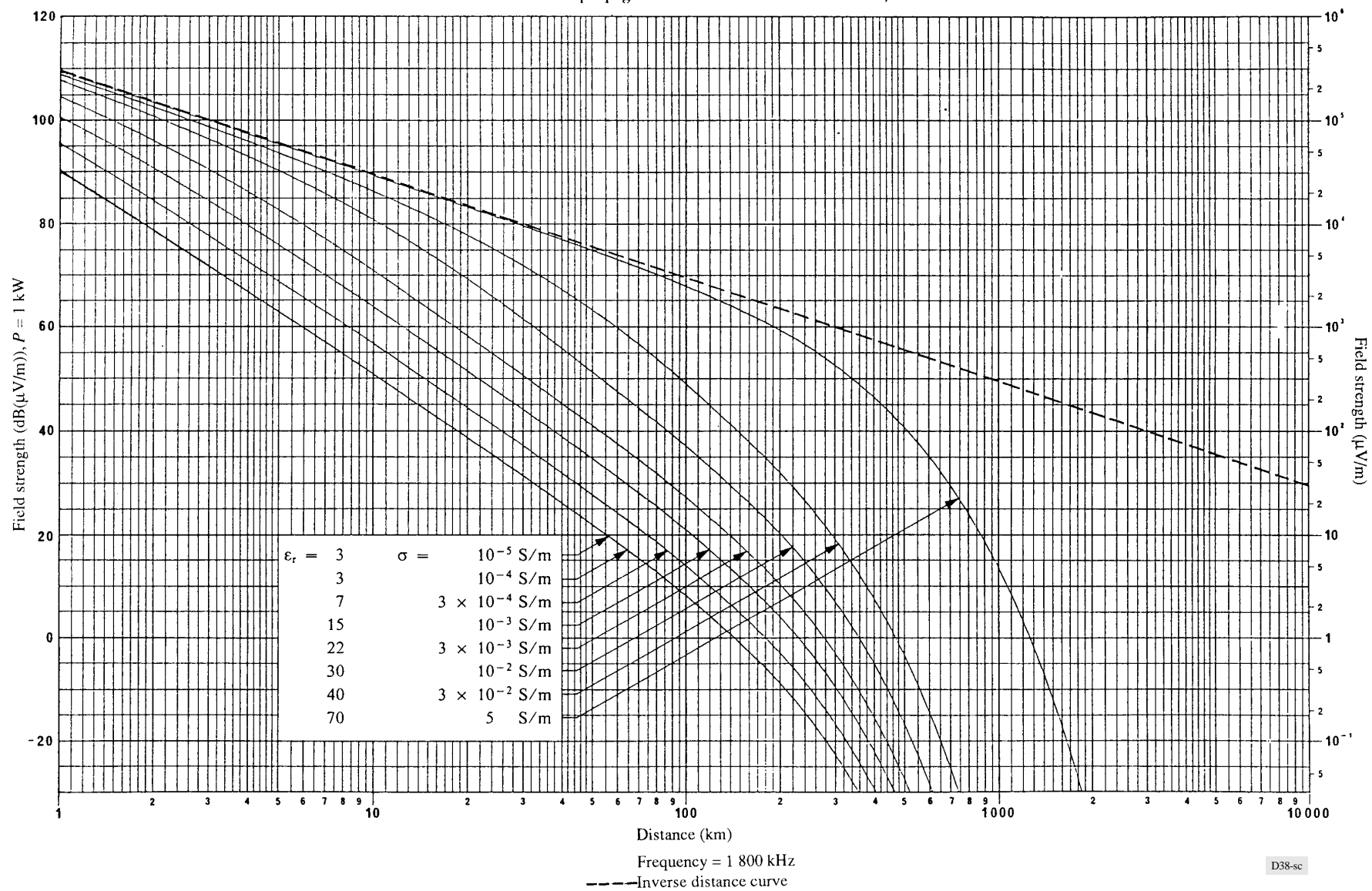


FIGURE 39

Ground-wave propagation for different values of σ and ϵ_r

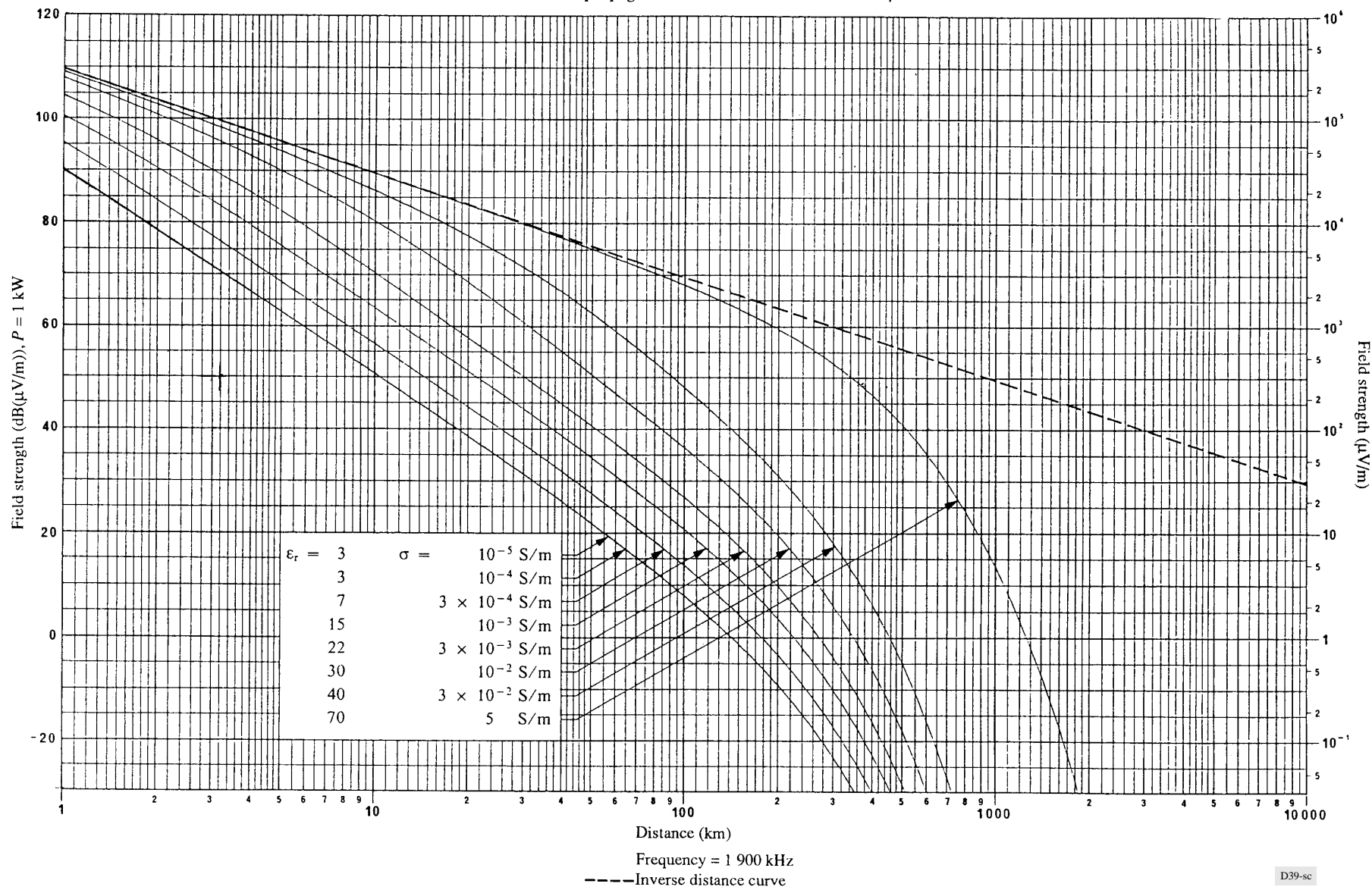
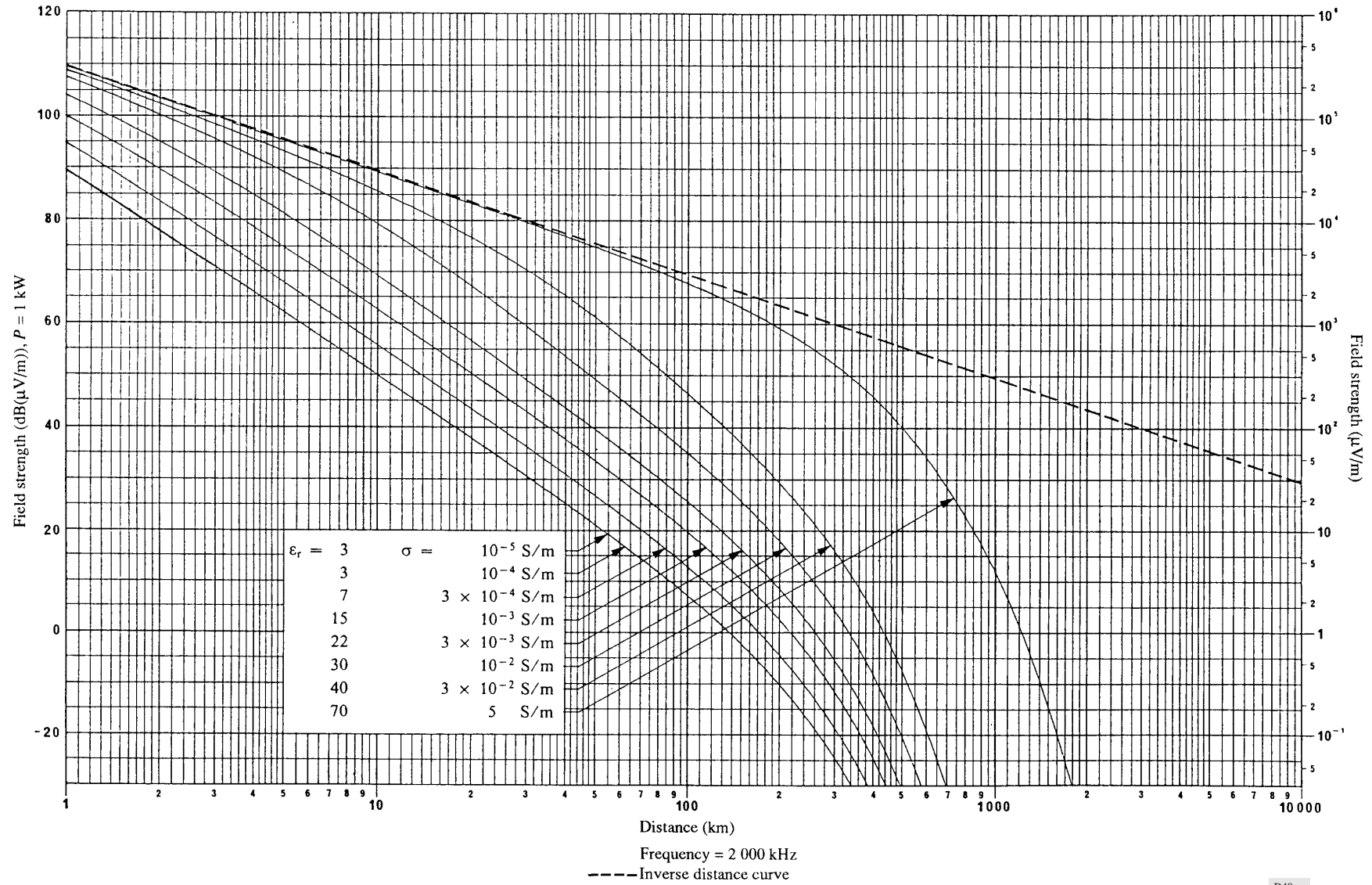


FIGURE 40

Ground-wave propagation for different values of σ and ϵ_r



D40-sc

FIGURE 41

Ground-wave propagation for different values of σ and ϵ_r

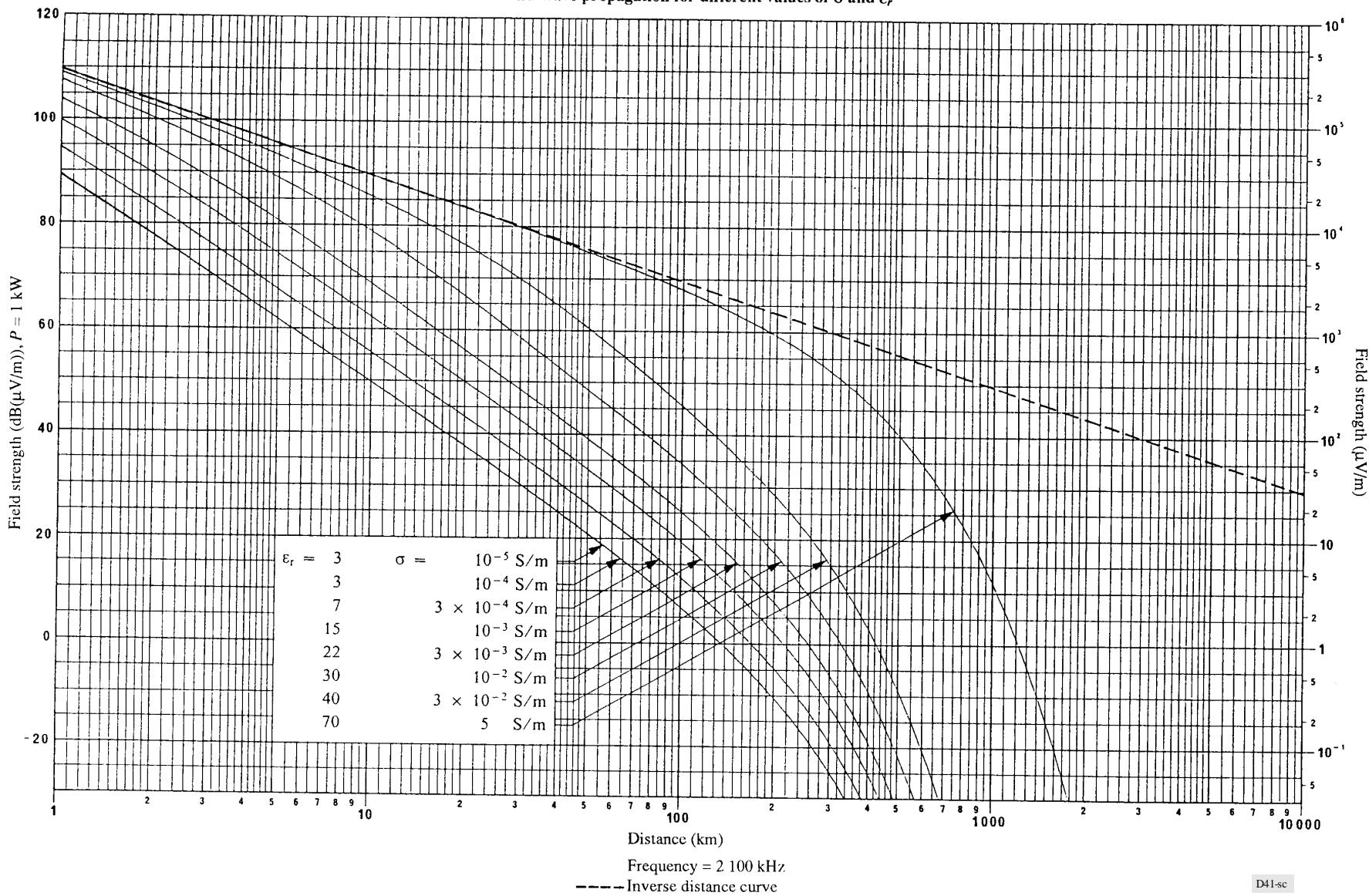


FIGURE 42

Ground-wave propagation for different values of σ and ϵ_r

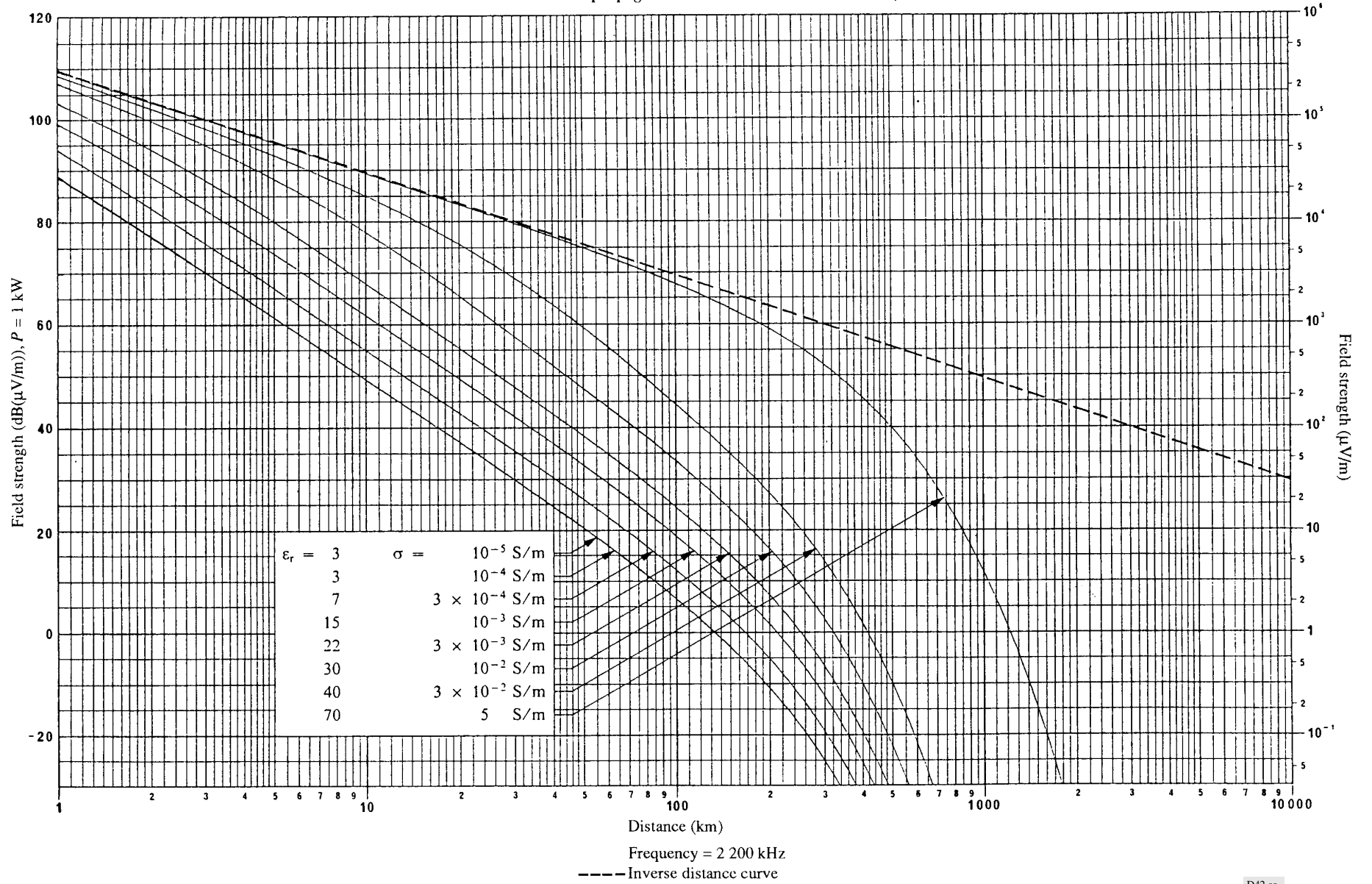


FIGURE 43

Ground-wave propagation for different values of σ and ϵ_r

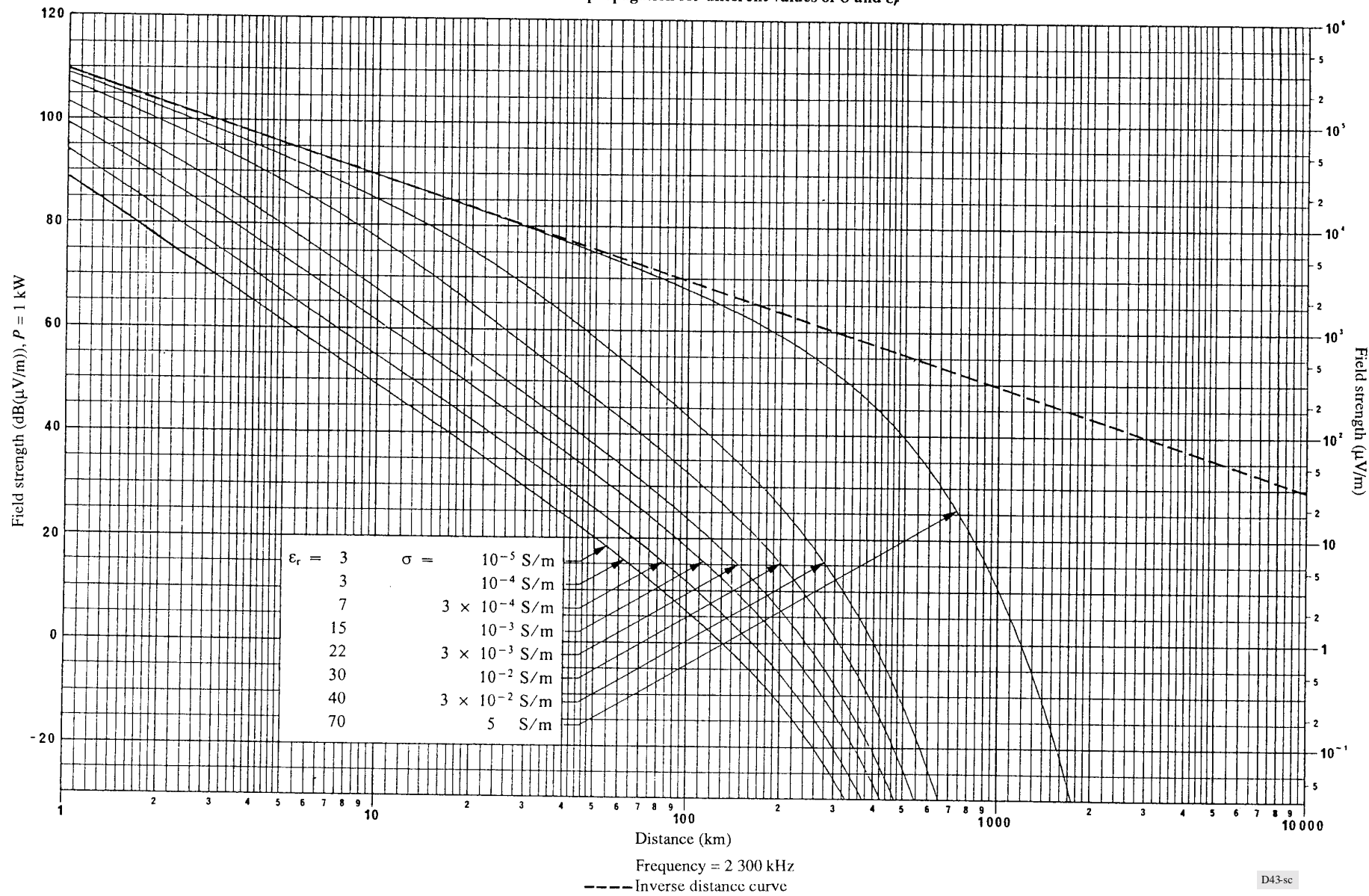
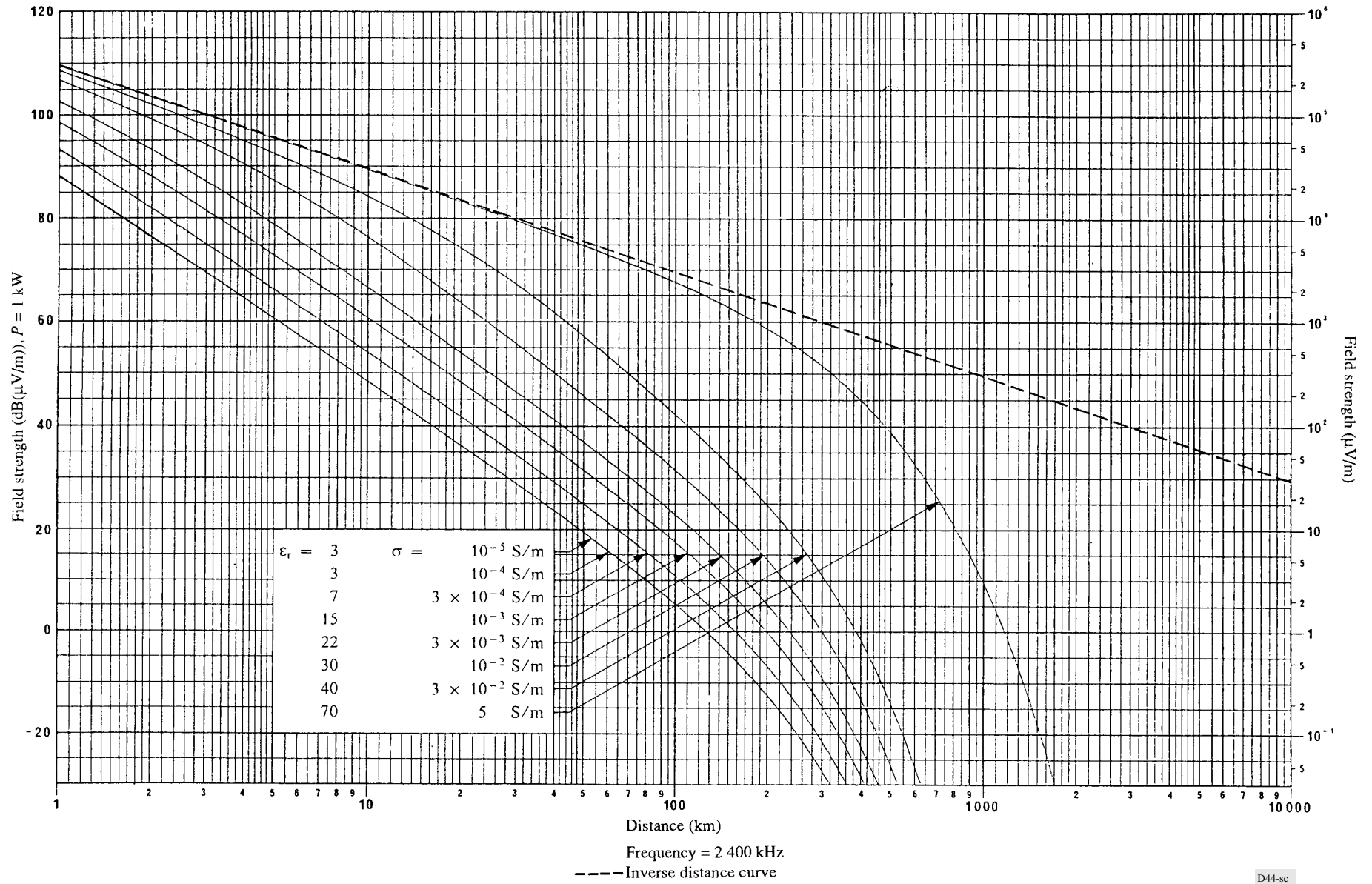


FIGURE 44

Ground-wave propagation for different values of σ and ϵ_r



D44-sc

FIGURE 45

Ground-wave propagation for different values of σ and ϵ_r

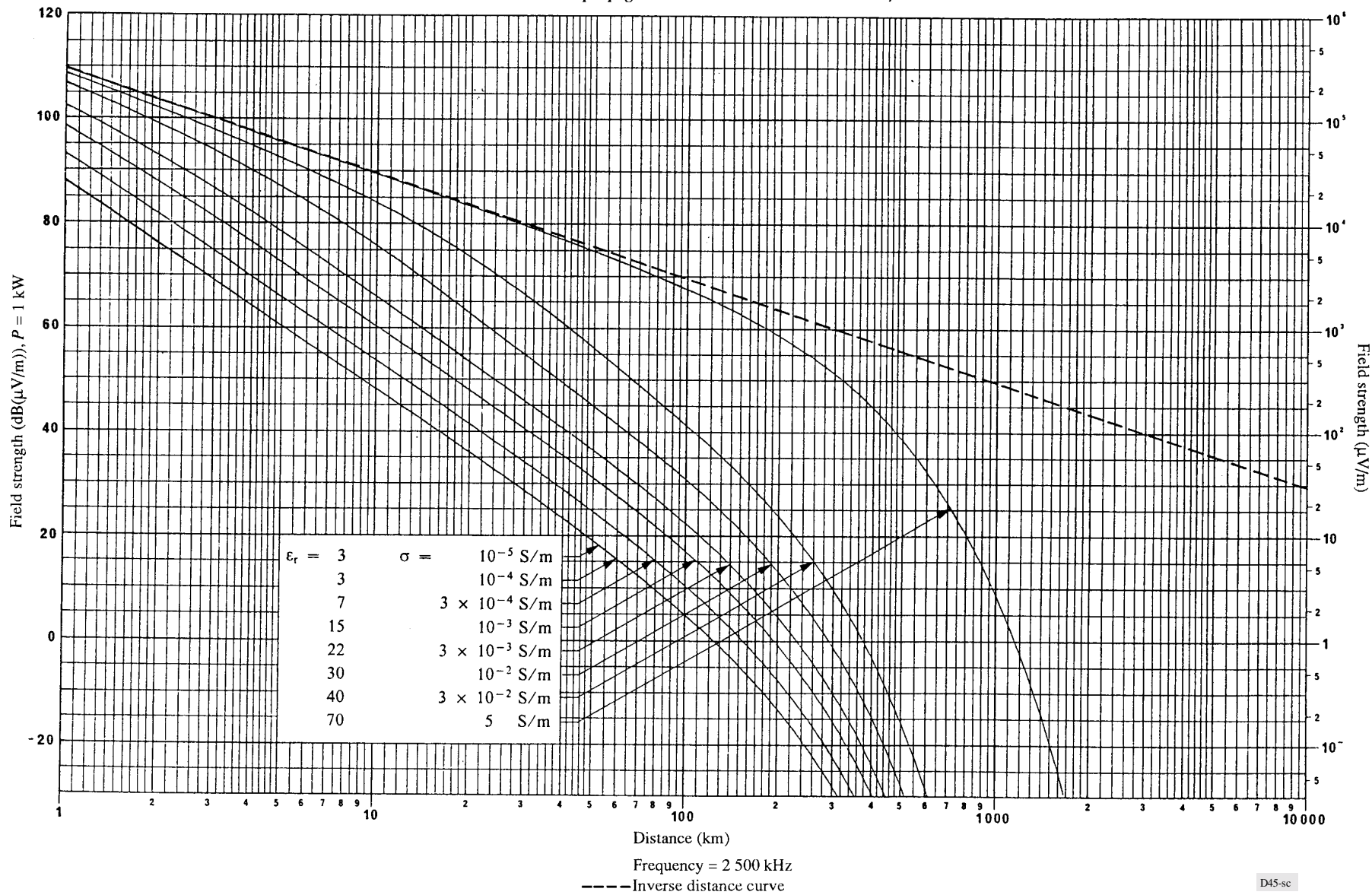
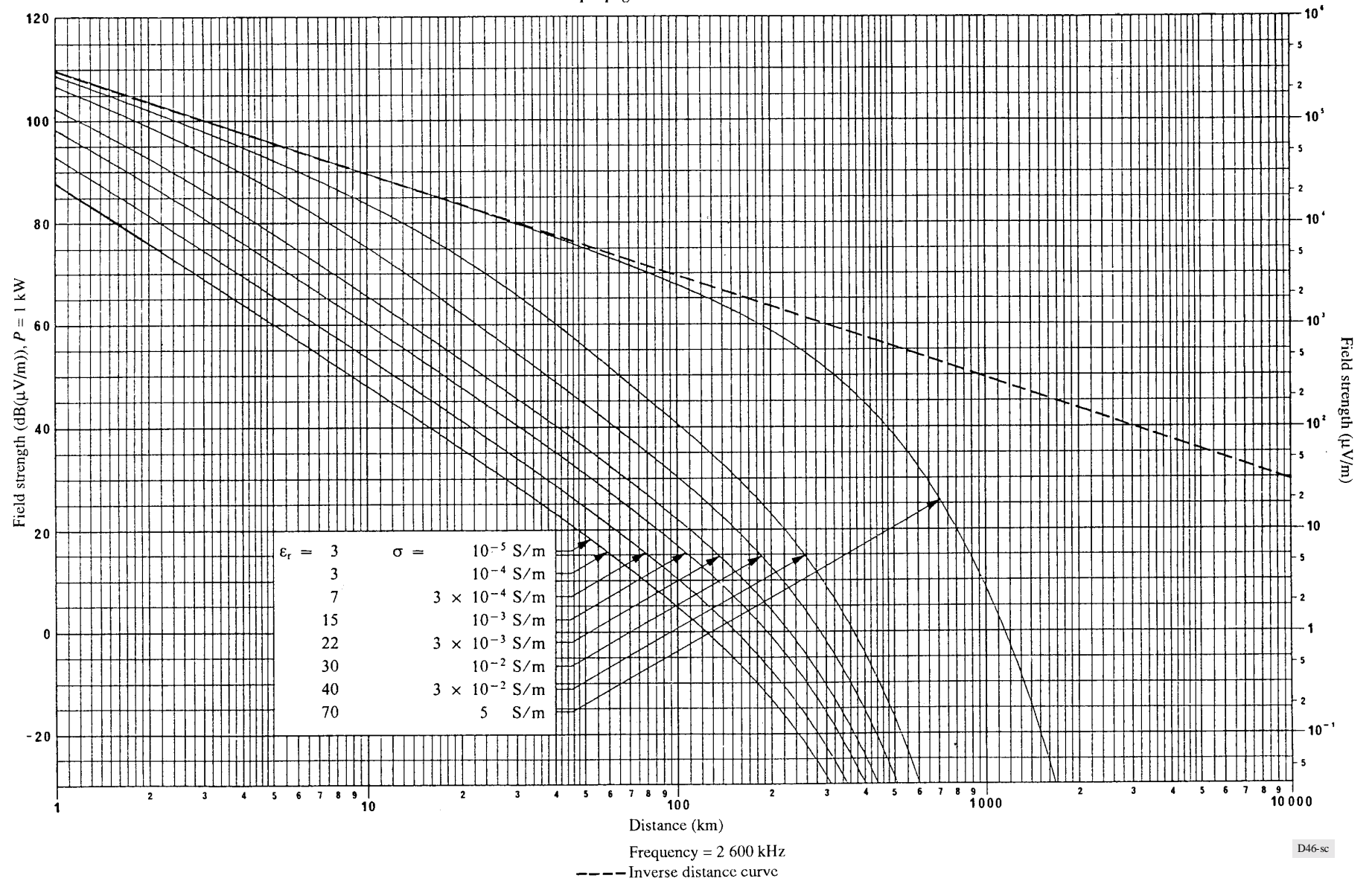


FIGURE 46

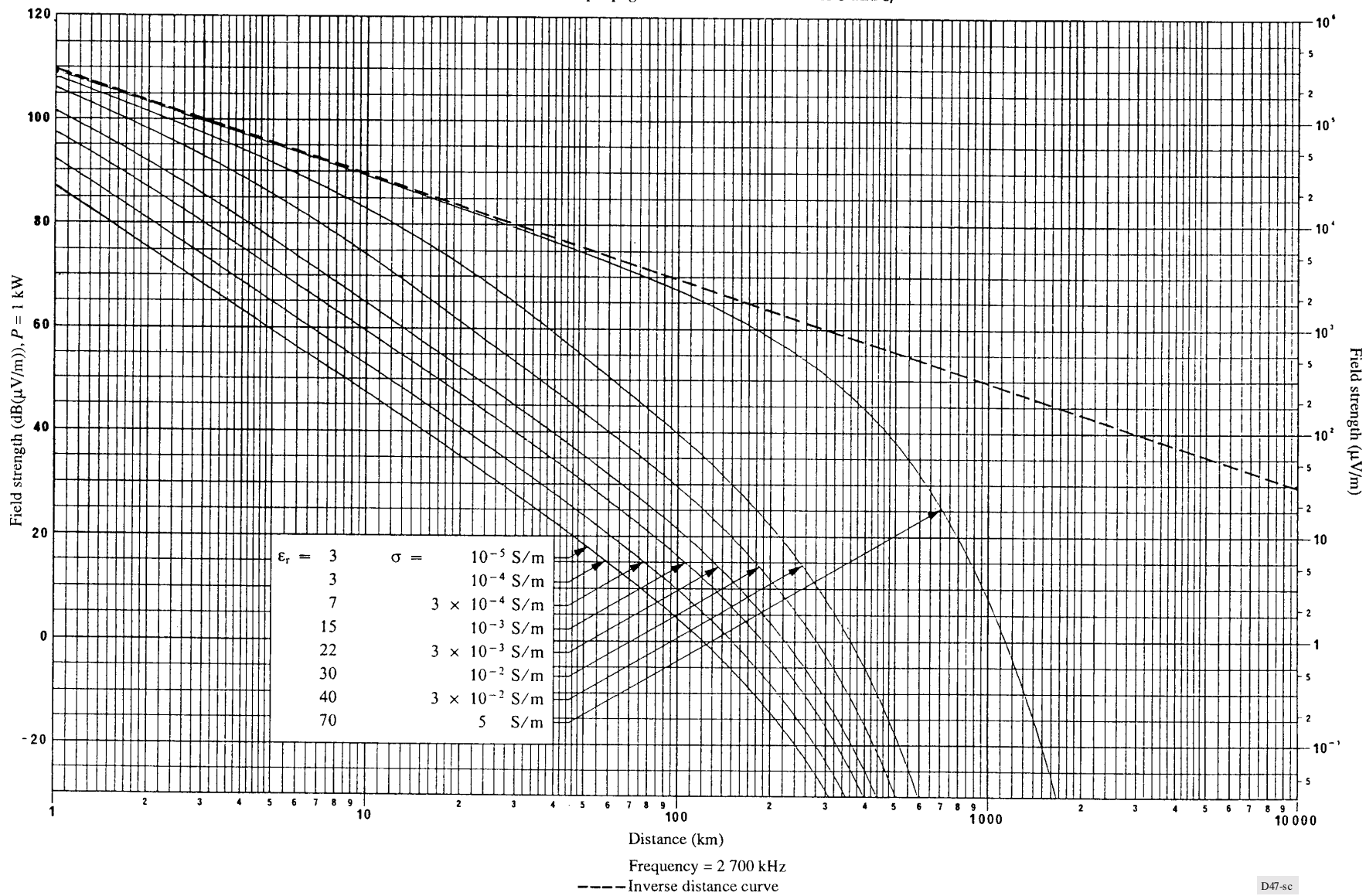
Ground-wave propagation for different values of σ and ϵ_r



D46-sc

FIGURE 47

Ground-wave propagation for different values of σ and ϵ_r



D47-sc

FIGURE 48

Ground-wave propagation for different values of σ and ϵ_r

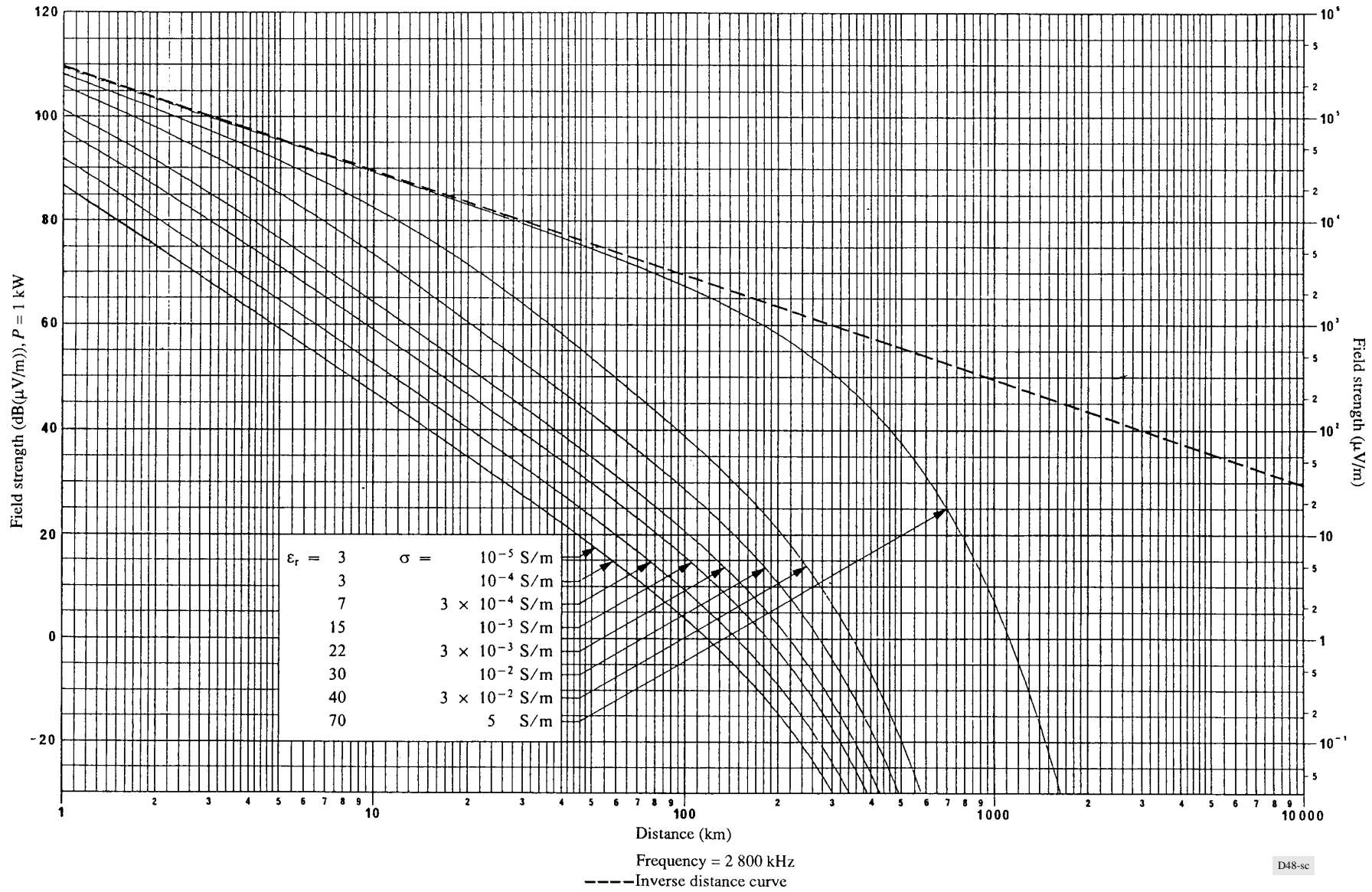


FIGURE 49

Ground-wave propagation for different values of σ and ϵ_r

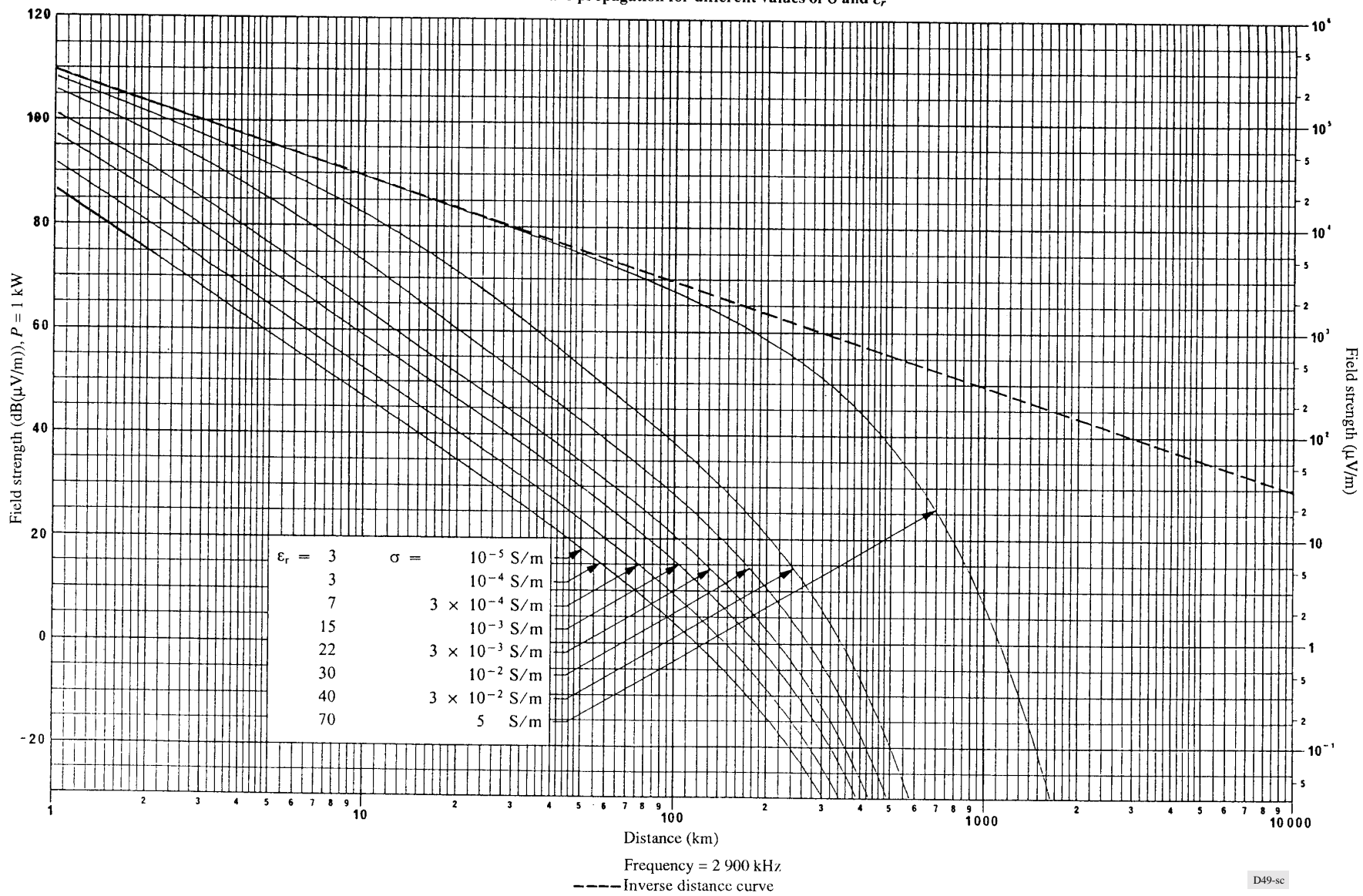
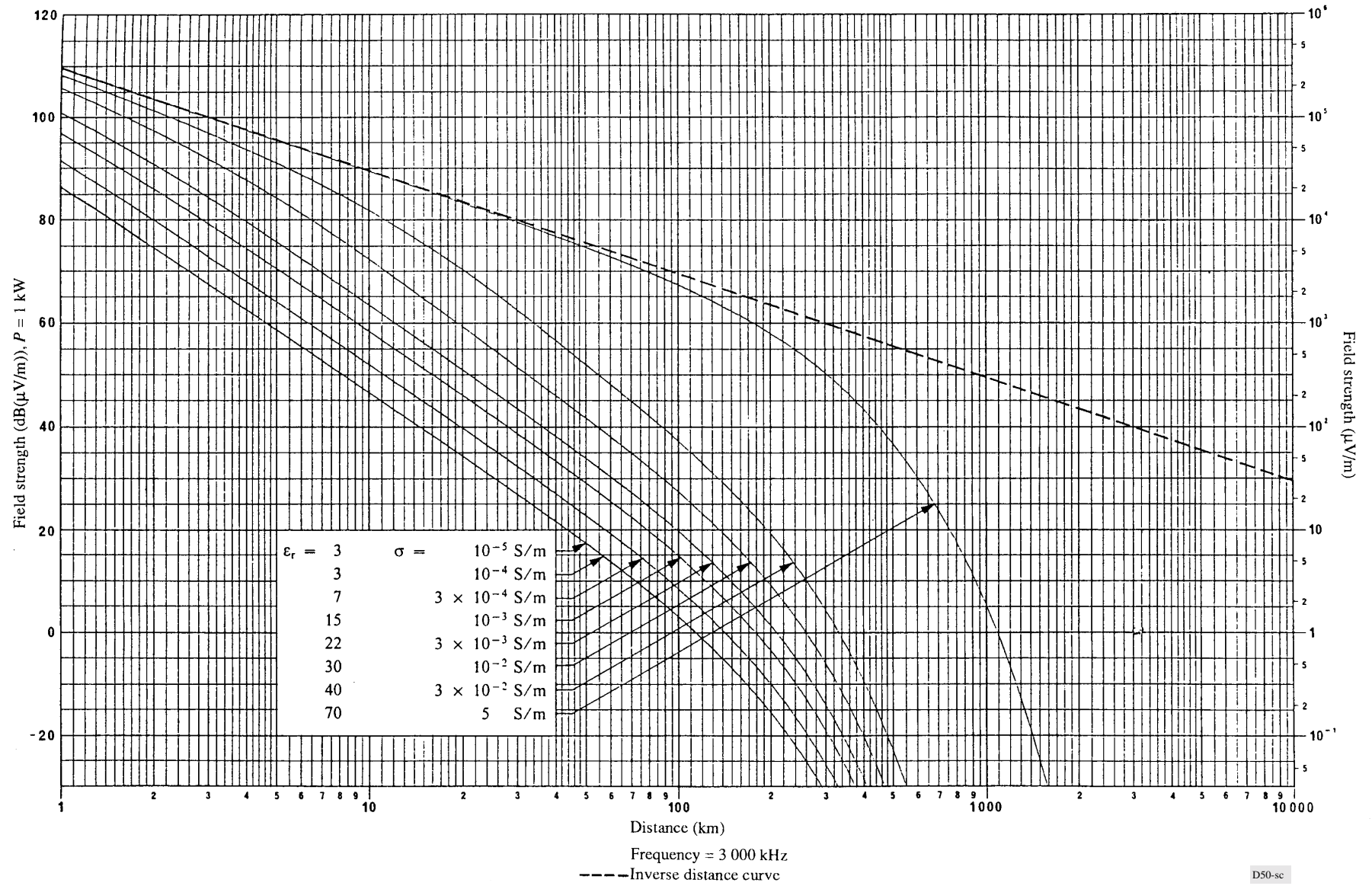


FIGURE 50

Ground-wave propagation for different values of σ and ϵ_r



ANNEX 3

Generation of propagation curves

The computer program GRWAVE has been used to generate the propagation curves in Annexes 1 and 2. GRWAVE performs the calculation of ground-wave field strength in an exponential atmosphere as a function of frequency, antenna heights and ground constants; approximate frequency range 10 kHz-10 GHz.

The program is available, with documentation, from that part of the ITU-R website dealing with Radiocommunication Study Group 3.
