International Telecommunication Union

ITU-R
Radiocommunication Sector of ITU

Recommendation ITU-R P.368-10
(08/2022)

Ground-wave propagation prediction method for frequencies between 10 kHz and 30 MHz

P Series
Radiowave propagation

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Foreword

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P	**Radiowave propagation**
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SA	Space applications and meteorology
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SM	Spectrum management
SNG	Satellite news gathering
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V	Vocabulary and related subjects

Note: *This ITU-R Recommendation was approved in English under the procedure detailed in Resolution ITU-R 1.*

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RECOMMENDATION ITU-R P.368-10

Ground-wave propagation prediction method for frequencies between 10 kHz and 30 MHz

(1951-1959-1963-1970-1974-1978-1982-1986-1990-1992-2005-2007-2022)

Scope

This Recommendation provides information on the field strength and its dependence on ground characteristics due to ground-wave propagation at frequencies less than 30 MHz.

Keywords

Ground-wave propagation, Low Frequency, High Frequency

Related ITU-R Recommendations and Handbook

Recommendation ITU-R P.341

Recommendation ITU-R P.525

Recommendation ITU-R P.526

Recommendation ITU-R P.527

Recommendation ITU-R P.684

Recommendation ITU-R P.1321

Handbook on Radiometeorology (Edition 2013)

NOTE – The latest revision/edition of the Recommendation/Handbook should be used.

List of symbols in Annexes 1 and 2

ε_r	Relative permittivity
λ	Wavelength
σ	Conductivity
L_b, A_i	Basic transmission loss
E	Field strength
k	Wavenumber
S_i	i^{th} Section
d_i	length of the i^{th} section
σ_i	Conductivity of the i^{th} section
ε_i	Permittivity of the i^{th} section
E_R	Field strength calculated from receiver
E_T	Field strength calculated from transmitter
E_X	Field strength on mixed path

The ITU Radiocommunication Assembly,

considering

that, in view of the complexity of calculating ground-wave field strength, it is useful to have a ground-wave prediction method applicable to the frequency range from 10 kHz to 30 MHz and arbitrary ground characteristics,

recommends

1 that the integral software implementation of the prediction method in Annex 1, applicable to 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 methods should be used to determine the field strength only when it is known that the amplitude of ionospheric reflections are negligible;

3 that these methods should not be used where the receiving antenna is located well above the surface of the Earth;

NOTE 1 – When $\varepsilon_r \ll 60\lambda\sigma$ this prediction method 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 prediction methods may also be used to determine the field strength over mixed paths as indicated in Annex 2.

Annex 1

Ground-wave field strength at frequencies between 10 kHz and 30 MHz

The prediction method in this Recommendation are applicable to the following conditions:

- a smooth homogeneous spherical Earth;
- frequency between 10 kHz and 30 MHz;
- in the troposphere, assuming the refractive index decreases linearly with height;
- the transmitting and the receiving antennas are on or near the surface of the Earth;
- the radiating element is a short vertical monopole on the surface of a perfectly conducting plane Earth that radiates 1 kW, and the field strength at a distance of 1 km is 300 mV/m, corresponding to a cymomotive force of 300 V (see Recommendation ITU-R P.525); (refer to Table 1 of Recommendation ITU-R P.341 to refer the field strength to other reference antennas);
- the distance between the transmitter and the receiver is the great circle distance;
- the prediction methods provide the vertical field-strength component of the radiation field, which would be measured in the far-field region of the antenna.

The software implementation of this prediction method is an integral part of this Recommendation and is provided in the zip file R-REC-P.368-10-202208-I!!ZIP-E.zip.

NOTE 1 – 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(μV/m)) by using the following equation:

$$L_b = A_i = 142.0 + 20\log_{10} f_{\text{MHz}} - E \qquad \text{dB}$$

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

NOTE 2 – Even in cases where the distance between locations is much smaller than the distance to the transmitter, the real electrical characteristics of the ground and the condition of reception will not be identical. In many cases the difference in levels of a signal at nearby locations follows a log-normal distribution with a standard deviation within the limits of 3-4 dB; averaging approximately 3.5 dB.

Ground-wave field strength can also vary with seasonal temperature. The average annual difference between winter and summer monthly median field strengths, for 500-1 000 kHz, ranges between 5 dB (where the average northern hemisphere January temperature is +4 °) and 15 dB (where the average northern hemisphere January temperature is −16 °). Seasonal changes have also been observed on frequencies between 150 and 280 kHz in continental Europe. These changes at frequencies between 150 and 280 kHz increase monotonically with frequency, and distance; and can reach 10-20 dB at distances of 1 000-2 000 km (see also Recommendation ITU-R P.1321).

NOTE 3 – The method gives the total field strength 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:

$$10\log_{10}\left\{1 - \frac{1}{(k\,r)^2} + \frac{1}{(k\,r)^4}\right\}$$

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 4 – 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 and 2 are example outputs of field-strength curves as a function of distance with frequency as an input parameter.

FIGURE 1

LFMF Ground-wave propagation curves; sea water, low salinity, σ = 1 S/m, ε_r = 80

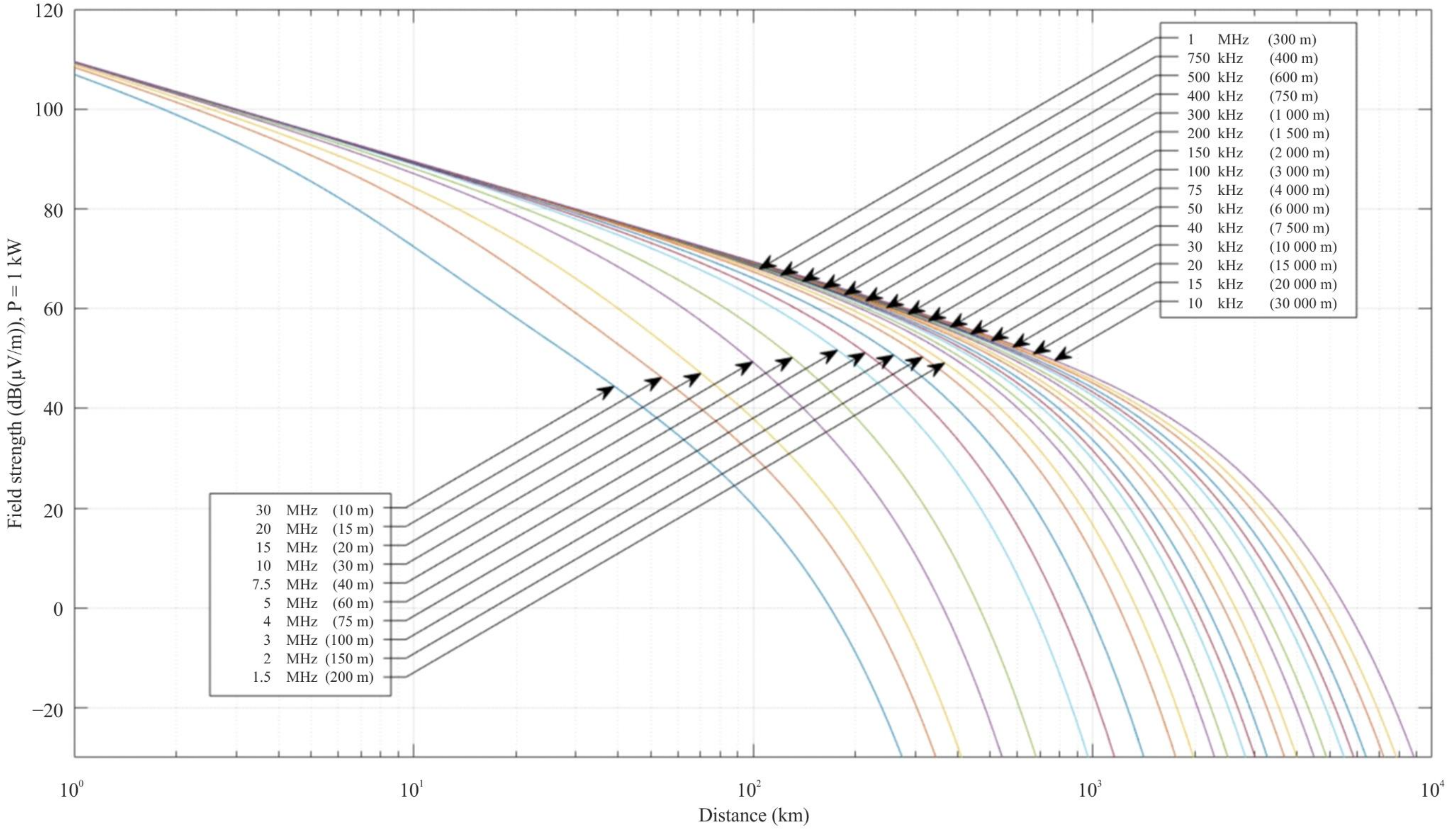

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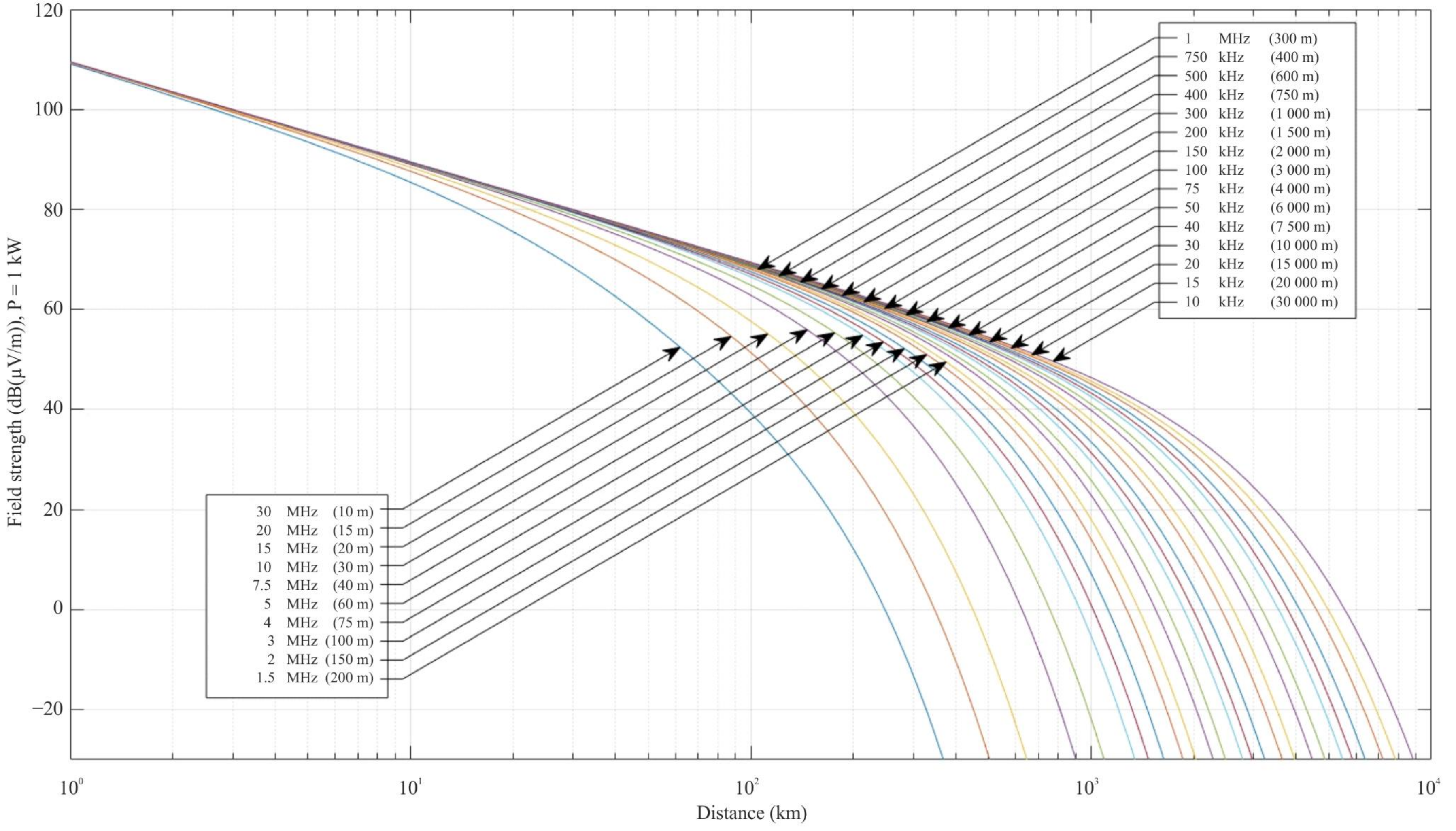
FIGURE 2

LFMF Ground-wave propagation curves; sea water, average salinity, σ = 5 S/m, ε_r = 70



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Annex 2

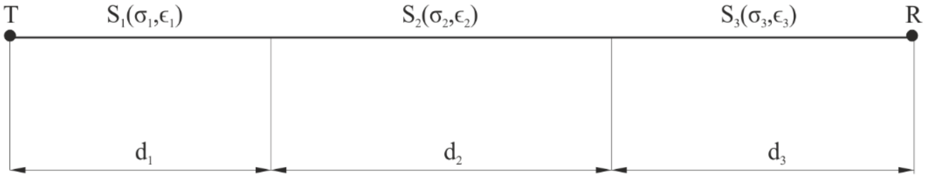
Application to mixed paths (inhomogeneous paths)

1 The method in this Annex may be used to determine the 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 σ_1, ε_1; σ_2, ε_2; σ_3, ε_3, etc., as shown in Fig. 3.

FIGURE 3

Example of mixed paths



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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 values for field strength, E, are available for the different types of terrain in sections S_1, S_2, S_3, etc., assumed to be individually homogeneous, for the 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 value of the field strength $E_1(d_1)$ in dB(μV/m) at the distance d_1 is calculated for section S_1. Similarly, the field strengths $E_2(d_1)$ and $E_2(d_1 + d_2)$ are calculated for section S_2; and the field strengths $E_3(d_1 + d_2)$ and $E_3(d_1 + d_2 + d_3)$ are calculated for section S_3.

The field strength E_R is then calculated as:

$$E_R = E_1(d_1) - E_2(d_1) + E_2(d_1 + d_2) - E_3(d_1 + d_2) + E_3(d_1 + d_2 + d_3) \tag{1}$$

and the field strength E_T is calculated as:

$$E_T = E_3(d_3) - E_2(d_3) + E_2(d_3 + d_2) - E_1(d_3 + d_2) + E_1(d_3 + d_2 + d_1) \tag{2}$$

The required field for the mixed path, E_X, is then:

$$E_X = \frac{E_R + E_T}{2} \tag{3}$$

Figures 4 and 5 are example outputs which contain field-strength curves as a function of distance with the electrical characteristics of the ground as an input parameter.

FIGURE 4

LFMF Ground-wave propagation for different values of σ and εr, *f* = 30 kHz

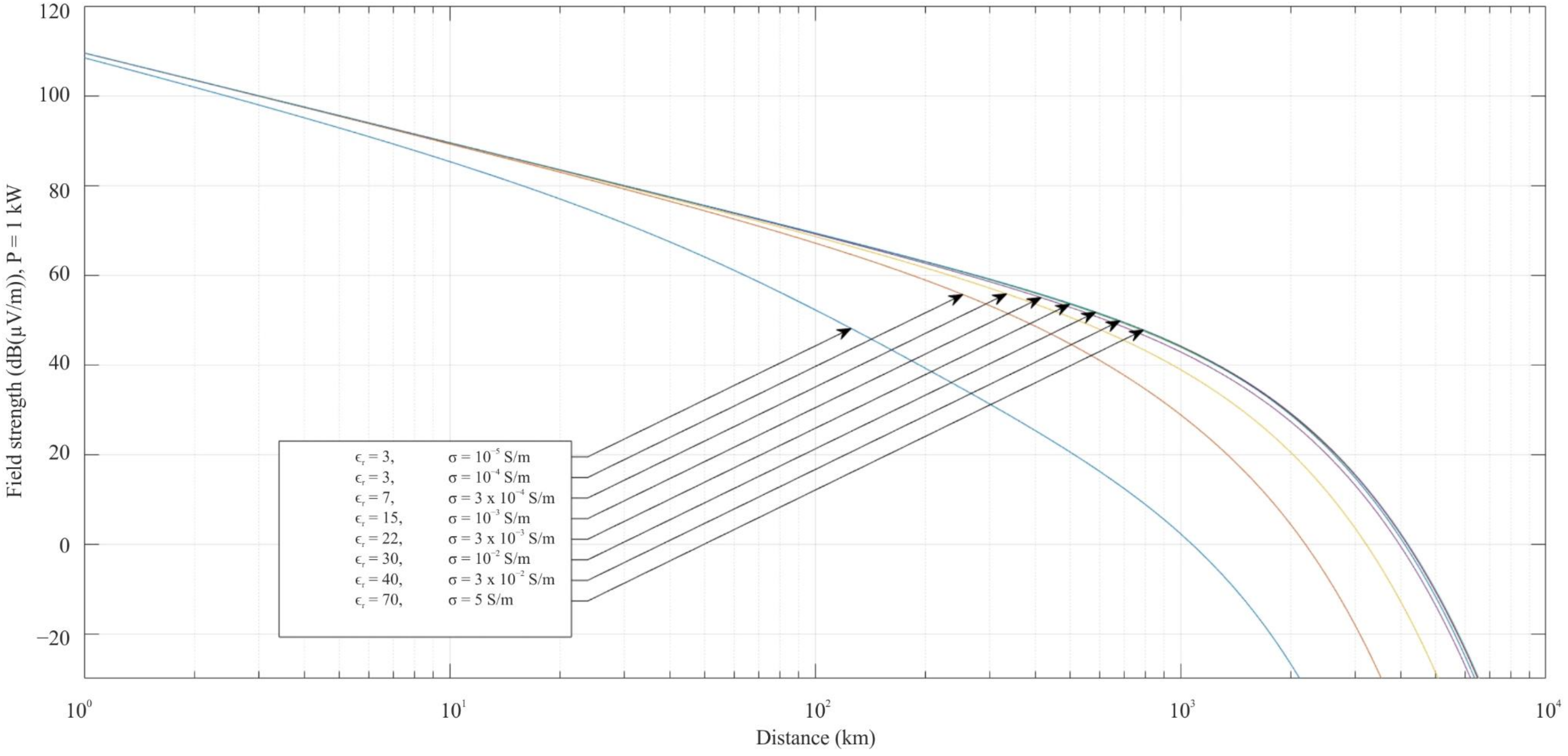

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FIGURE 5

LFMF Ground-wave propagation for different values of σ and εr , *f* = 60 kHz