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Influence of the Ground on the Calibration and Use of VHF Field-Intensity Meters

By Frank M. Greene

One type of error known to be present in VHF field-intensity meters (30 to 300 Mc) is caused by the influence of the ground on the value of the antenna voltage-transfer ratio. This is a result of fluctuation of the receiving-antenna input impedance with height and changing ground conditions. An approximate method is presented for calculating the input impedance of horizontal dipole antennas over earth having finite values of dielectric constant and conductivity. The effect of both changes in ground conditions and antenna terminating impedance on the above error is calculated as a function of the antenna height. Measured values are presented in support of the above method, and the results are discussed.

I. Introduction

As is known, VHF field-intensity measurements will be generally in error if made at antenna heights other than that for which the antenna constant was determined when the field-intensity meter was calibrated. An error will likewise exist if the ground constants at the site chosen to make measurements are appreciably different from those existing at the time or place of calibration.

At present most VHF field-intensity meters use a doublet receiving antenna, which is usually terminated at its center terminals in an impedance roughly equal in value to its free-space input impedance. The error referred to exists because of the change of the antenna-input impedance with height above ground or with changing ground conditions[1]. This results in a corresponding fluctuation in the *proportion* of the induced voltage that appears across the terminals at the center of the antenna. Consequently the value of the antenna constant determined at the time of the calibration is in general not the same if the height or ground conditions are altered.

An approximate expression for the input impedance at various heights above a finitely conducting ground may be easily obtained for the case of a horizontal antenna. The ground is assumed to be plane, homogeneous, and with finite values of the relative dielectric constant ϵ_r, and conductivity σ. Once the antenna-input impedance is known, the effect of the earth on the antenna constant may be determined.

Although the solution attempted here is not rigorous, it can be shown to yield the limiting value of the input impedance of a horizontal antenna if its height above ground is increased sufficiently. The results, however, are useful in obtaining approximate values of the input impedance corresponding to antenna heights of a fraction of a wavelength.

Theoretical values of the measurement error are reasonably well supported by measurement at one particular site for antenna heights down to one-tenth wavelength at 100 Mc. The effect both of changes in ground conditions and of the value of the antenna terminating impedance upon this error are determined. Practical rationalized mks units are used throughout.

[1] It is assumed here that the field-intensity meter is calibrated and used at such locations that the distances to the nearest reflecting objects such as trees or buildings are very much greater than the heights of the receiving antenna above the ground.

II. Theory

In formulating the following solution, the usual system will be considered, comprising a transmitting and receiving antenna at heights h_1 and h_2, respectively, above ground. The ground is assumed to be plane, homogeneous, and of infinite extent, having finite values of relative dielectric constant ϵ_r and conductivity σ. Although the method is applicable to horizontal antennas of any length, the results will be evaluated only for the case of parallel horizontal half-wave dipoles. Their locations and the geometry involved are shown in figure 1.

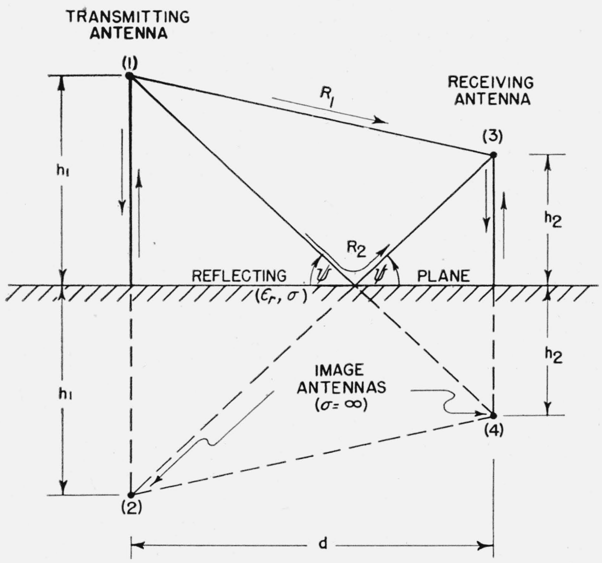

FIGURE 1. *Ray-path diagram showing: direct ray along R_1; ground-reflected ray along R_2; rays from both horizontal transmitting and receiving antennas reflected at normal incidence from the ground back to the antenna.*

Heights of the transmitting and receiving antennas are h_1 and h_2 respectively, and d is the horizontal distance of separation.

In addition to the direct and ground-reflected rays along R_1 and R_2, respectively, a ray will be considered that leaves each antenna and is reflected at normal incidence from the ground back to the antenna.

1. Perfectly Conducting Ground

Perfectly conducting ground will be considered first. Its effect may be simulated in the usual manner by postulating the image antennas (2) and (4), each located at a distance below the perfect reflecting plane equal to the height of the actual antenna. The two antennas and their images may be treated as four coupled antennas. The resulting voltage-current relationship will have exactly the same form as would exist in a linear four-mesh network. For this case [2] the resulting four equations reduce to the following two:

$$\left.\begin{aligned} V&=I_1(Z_{11}-Z_{12})+I_3(Z_{13}-Z_{14}),\\ O&=I_1(Z_{31}-Z_{32})+I_3(Z_{33}-Z_{34}),\end{aligned}\right\} \quad (1)$$

where V is the impressed emf at the center of the transmitting antenna, and I_1, and I_3, are the respective currents at the centers of the transmitting and receiving antennas. The terms Z_{11} and Z_{33} are the free-space self impedances, respectively, of the transmitting and receiving antennas referred to the center terminals. Also

$$Z_{mn}=Z_{nm}=-\frac{V_{mn}}{I_n}, \quad (2)$$

where Z_{mn} is the mutual impedance between antennas m and n, and V_{mn} is the emf induced in antenna m (referred to the center terminals) by the current, I_n, at the center of antenna n.

2. Finitely Conducting Ground

In considering the case involving a finite earth, the equations for meshes (2) and (4) of the previous system become meaningless. However, by benefit of analogy with eq 1 and with the aid of experimental evidence, one may write a similar set of equations involving antennas (1) and (3) and the ground, which under certain conditions, describe this transmission system to a first approximation at least. The equations are:

$$\left.\begin{aligned} V&=I_1(Z_{11}+\Gamma_1 Z_{12})+I_3(Z_{13}+\Gamma_2 Z_{14}),\\ O&=I_1(Z_{31}+\Gamma_2 Z_{32})+I_3(Z_{33}+\Gamma_1 Z_{34}),\end{aligned}\right\} \quad (3)$$

where $\Gamma_1 \equiv \rho_1 e^{-j\theta_1}$=complex plane-wave reflection coefficient for vertical incidence; $\Gamma_2 \equiv \rho_2 e^{-j\theta_2}$= complex plane-wave reflection coefficient (horizontal polarization) for the angle $\psi=\tan^{-1}(h_1+h_2)/d$ made with the earth by the principal ground-reflected ray (along R_2).

The reflection coefficient, Γ_2, may be expressed in terms of the angle ψ and a complex dielectric constant ϵ_0 as follows [3] (for horizontal polarization):

$$\Gamma_2=\frac{\sin\psi-\sqrt{\epsilon_0-\cos^2\psi}}{\sin\psi+\sqrt{\epsilon_0-\cos^2\psi}} \quad (4)$$

where $\epsilon_0=\epsilon_r\left(1-j\frac{\sigma}{\epsilon\omega}\right)$,

$$=\epsilon_r-j\,60\,\lambda\sigma,$$

[2] P. R. Karr, The influence of the ground upon the voltage induced in a receiving antenna, Report OD-2-348R (NBS) (July 23, 1947).

[3] J. A. Stratton, Electromagnetic theory, p. 493 (McGraw-Hill Book Co., Inc., New York, N. Y., 1941).

ϵ_r=relative dielectric constant of the ground (referred to free-space as unity),

$\epsilon=\epsilon_v\epsilon_r$, where ϵ_v is the permittivity of evaluated free-space,

$\epsilon_v \cong \frac{1}{36\pi}\times 10^{-9}$ farads/meter,

σ=ground conductivity is mhos/meter,

$\omega=2\pi f$,

λ=wave length in meters,

$j=\sqrt{-1}$.

Equations 3 will reduce to eq 1 if the ground conductivity σ is allowed to increase without limit, since in this case $\Gamma_1=\Gamma_2=-1$ for all angles of incidence, as can be seen from eq 4.

3. Evaluating the Self and Mutual Impedances

Before practical use can be made of eq 3, the various self and mutual impedances must be evaluated. Schelkunoff [4] has determined the free-space input impedance of cylindrical antennas in general. Values may be obtained graphically from figs. 11.21 and 11.22 of this reference for antennas of several length-to-diameter ratios. A value of $73.2+j\,42.5$ (ohms) may be used if desired, corresponding to a thin $\lambda/2$ dipole in free-space, without substantially affecting the resulting value of the measurement error. Carter [5] has evaluated the mutual impedance between antennas of various configurations. For the case of parallel half-wave dipoles in free-space the mutual impedance in ohms is:

$$Z=30\{2\mathrm{Ei}(-jkR)-\mathrm{Ei}[-jk(\sqrt{R^2+l^2}+l)] -\mathrm{Ei}[-jk(\sqrt{R^2+l^2}-l)]\}, \tag{5}$$

where l=antenna length in meters,

R=distance between antennas in meters,

$\mathrm{Ei}(-jx)\equiv \mathrm{Ci}(x)-j\mathrm{Si}(x)$,

$$\mathrm{Ci}(x)\equiv -\int_x^\infty \frac{\cos t}{t}\,dt,$$

$$\mathrm{Si}(x)\equiv \int_0^x \frac{\sin t}{t}\,dt,$$

$k\equiv 2\pi/\lambda$.

[4] S. A. Schelkunoff, Electromagnetic waves, pp. 441 to 479 (D. Van Nostrand Co., New York, N. Y., 1943).

[5] P. S. Carter, Circuit relations in radiating systems and applications to antenna problems, Proc. IRE **20**, pp. 1004 to 1041 (June 1932).

Values of eq 5 are shown plotted in figures 11 and 12 of the reference given in footnote 5 for spacings from 0 to 7.5 wavelengths.

It is possible to derive a more simple expression than eq 5, valid for distances of separation in excess of about 2λ. At this distance from an antenna, only the radiation component of the electric field-intensity usually need be considered. For a half-wave transmitting dipole in free-space, oriented normal to a line from its center to the point of observation, the field intensity is (in volts/meter)

$$E\cong -j\,\frac{60I}{R}\,e^{\frac{-j2\pi R}{\lambda}}, \tag{6}$$

where R=distance in meters,

I=current in amperes at the center of the antenna.

The voltage (referred to the center terminals) induced in a half-wave dipole placed in the field given by eq 6 and oriented parallel to the transmitting antenna is (in volts)

$$V\cong El_H\cong -j\,\frac{60\lambda I}{\pi R}\,e^{\frac{-j2\pi R}{\lambda}}, \tag{7}$$

where l_H=effective length of the dipole in meters,

$l_H=\lambda/\pi$ meters for a half-wave dipole assuming sinusoidal current distribution.

From eq 7 and 2 the mutual impedance between the two parallel half-wave dipole antennas is (in ohms)

$$Z=-\frac{V}{I}\cong j\,\frac{60\lambda}{\pi R}\,e^{\frac{-j2\pi R}{\lambda}}. \tag{8}$$

It can be shown that eq 8 is the limiting value of eq 5 for sufficiently large values of the distance of separation, R. In fact, for separations in excess of about 2 λ, the value of mutual impedance given by eq 8 is sufficiently accurate for many purposes [6] and will cause less than 0.1-percent error in the final results in which we are interested here. For smaller values of separations between the antennas than 2 λ, eq 5, or figures 11 and 12 of the reference given in footnote 5 must be used to evaluate the mutual impedance.

[6] Kosmo J. Affanasiev, Simplifications in the consideration of mutual effects between half wave dipoles, Proc. IRE **34**, pp. 635 to 638 (Sept. 1946).

III. Relations Existing in the Receiving Antenna

1. Antenna Current

Equations 3 may now be solved for the current I_3 at the center of the receiving antenna. The problem will be simplified if it is assumed that the distance between transmitting and receiving antennas is sufficiently large that the presence of the receiving antenna does not measurably affect the current flowing in the transmitting antenna. This is usually the case in practice, and the assumption is certainly justified if the spacing is at least several wavelengths. In this case the current in the receiving antenna terminated at its center in a load impedance Z_L is, from eq 3:

$$I_3 = -\frac{(Z_{31}+\Gamma_2 Z_{32}) I_1}{Z_L+Z_{33}+\Gamma_1 Z_{34}}. \tag{9}$$

2. Input Impedance

The numerator of eq 9 is the induced emf in the receiving antenna, and the denominator is the input impedance (in the presence of the ground) plus the terminating impedance Z_L connected at the center, the input impedance being

$$Z_i \equiv Z_{33}+\Gamma_1 Z_{34}. \tag{10}$$

The effect of the ground in the immediate vicinity of the receiving antenna is accounted for by the second term on the right of eq 10, $\Gamma_1 Z_{34}$. Z_{34} is the mutual impedance that would exist between the receiving antenna and its image if the ground were perfectly conducting, and is given by eq 5 or eq. 8 upon substituting $R=2h_2$. Γ_1 is of course the actual reflection coefficient of the ground for normal incidence obtained from eq. 4 by placing $\psi=\pi/2$, which gives

$$\Gamma_1 = \frac{1-\sqrt{\epsilon_r\left(1-j\frac{\sigma}{\epsilon\omega}\right)}}{1+\sqrt{\epsilon_r\left(1-j\frac{\sigma}{\epsilon\omega}\right)}} \tag{11}$$

Values of the magnitude of eq. 11, ρ_1, are shown plotted vs ϵ_r in figure 2 for low-loss dielectrics, $(\sigma/\epsilon\omega<<1)$. Many types of ground may be treated as low-loss dielectrics over a large portion of the VHF band as far as their reflecting properties are concerned. This is particularly true at the higher frequencies above 50 or 75 Mc. Under these conditions the phase shift on reflection, ϕ, is very nearly 180°, so that $\Gamma_1 \cong -\rho_1$.

3. Voltage Relations

The terminal voltage of the receiving antenna terminated in an impedance Z_L is, from eq. 9

$$V_L = -\frac{(Z_{31}+\Gamma_2 Z_{32}) Z_L I_1}{(Z_L+Z_{33}+\Gamma_1 Z_{34})}, \tag{12}$$

and the open-circuit voltage is, letting $Z_L \rightarrow \infty$,

$$V_{oc} = -(Z_{31}+\Gamma_2 Z_{32}) I_1. \tag{13}$$

If the receiving antenna is sufficiently high above the ground, Z_{34} may be considered negligible compared to (Z_L+Z_{33}), in which case the terminal voltage will be, from eq 12,

$$V_L = -\frac{(Z_{31}+\Gamma_2 Z_{32}) Z_L I_1}{Z_L+Z_{33}}. \tag{14}$$

The true value of the electric component of field intensity at any antenna height, h_2, above the ground is, from eq 7 and 13:

$$E_t = \frac{V_{oc}}{l_H} = -\frac{(Z_{31}+\Gamma_2 Z_{32}) I_1}{l_H}. \tag{15}$$

The value of field intensity that would be indicated by a field-intensity meter previously calibrated in the presence of the ground is, from eq 12:

$$E_i = KV_L = -\frac{K(Z_{31}+\Gamma_2 Z_{32}) Z_L I_1}{(Z_L+Z_{33}+\Gamma_1 Z_{34})}. \tag{16}$$

K may be defined as the antenna constant and may be evaluated at any desired height of the receiving antenna. If a height h_2 is chosen such that $Z_{34} \ll (Z_L+Z_{33})$, K might then be termed the free-space antenna constant and in such a case its value would be

$$K \cong \frac{1}{l_H}\left(\frac{Z_L+Z_{33}}{Z_L}\right), \tag{17}$$

since $E_t \cong E_i$ at this height. The antenna constant is seen to be the reciprocal of the product of the effective length, l_H, and the voltage-transfer ratio, $V_L/V_{oc}=Z_L/(Z_L+Z_{33})$.

The assumption is made here that the *relative* current distribution and hence the effective length of the half-wave receiving dipole is not (to a first approximation) a function of either the terminating impedance, Z_L, or the height of the antenna above ground. Although a complete solution to the general problem of the receiving antenna has unfortunately not yet been achieved, this assumption is supported by a number of our measurements.[7]

IV. Evaluation of the Measurement Error

The difference between the true value of field intensity existing at some antenna height h_2, and that indicated by a field-intensity meter with a previously determined antenna constant is (in percent)

$$\delta=\left(\left|\frac{E_i}{E_t}\right|-1\right)\times 100. \tag{18}$$

For the case in which the antenna constant, K, was determined at a sufficient antenna height that it may be considered to have a free-space value, the above difference, or measurement error, may be obtained by substituting eq 15, 16, and 17 in eq 18, giving (in percent)

$$\delta=\left(\left|\frac{Z_L+Z_{33}}{Z_L+Z_{33}+\Gamma_1 Z_{34}}\right|-1\right)\times 100. \tag{19}$$

Z_L=load impedance connected to the center terminals of the receiving antenna.

Z_{33}=input impedance (in free space) of the receiving antenna. Z_{33} may be evaluated from figures 11.21 and 11.22 of the reference given in footnote 4 or if desired may be taken as $73.2+j42.5$ (ohms) corresponding to a thin $\lambda/2$ dipole in free-space, without substantially affecting the resulting value of the measurement error.

Z_{34} may be evaluated from eq 5, or from figures 11 and 12 of the reference given in footnote 5. For heights of the receiving antenna $h_2 \geqq \lambda$, Z_{34} may be evaluated from eq 8, placing $R=2h_2$. This gives (in ohms)

$$Z_{34}=j\frac{30\lambda}{\pi h_2}e^{-j\frac{4\pi h_2}{\lambda}}. \tag{20}$$

Γ_1=plane-wave reflection coefficient for normal incidence. Γ_1 may be evaluated from eq 11, or in the case of low-loss dielectrics, from figure 2, since $\Gamma_1 \simeq -\rho_1$.

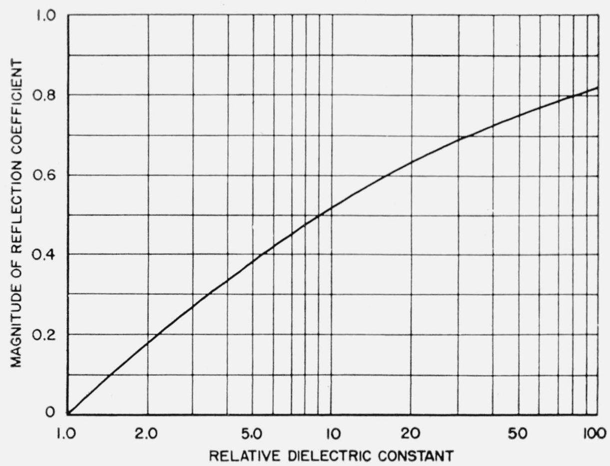

FIGURE 2. *Magnitude of the plane-wave reflection coefficient, ρ_1 (at normal incidence) vs the relative dielectric constant, ϵ_r.*

Low-loss dielectrics are assumed ($\sigma/\epsilon\omega << 1$). $\Gamma_1=-\rho_1$.

V. Discussion of Results

The measurement error to be discussed is that existing in a field-intensity meter whose antenna constant was determined under free-space conditions. This error or difference (as calculated) is given by eq 19 and is shown in figures 3 and 4 vs h_2/λ for various values of the parameters Γ_1 and Z_L. Measured values of the error determined at one particular site as well as the corresponding calculated values (f=100.0 Mc) are shown in figure 5.

Figure 3 shows the effect of changes in the ground constants on the measurement error calculated for an antenna terminated in an impedance $Z_L=73+j0$ ohms. The self-impedance of the antenna was assumed to be $73.2+j\,42.5$ ohms. Curves are shown for (A) $\sigma=\infty$, (B) $\epsilon_r=30$. (C) $\epsilon_r=15$, and (D) $\epsilon_r=9$. Low-loss dielectrics were assumed in the last three cases.

The high and low values of the relative dielectric constant chosen represent the approximate extremes measured at one particular site (f=100.0 Mc) during the summer of 1948 (see footnote 7). The value, $\epsilon_r=15$, is usually assigned to average ground, along with a value of conductivity $\sigma=5\text{x}10^{-3}$ mhos/meter. Values of conductivity of this order of magnitude can be ignored, at least for frequencies above 50 Mc as far as the

[7] Further details are contained in a forthcoming Bureau paper entitled "Development of VHF field-intensity standards", by F. M. Greene and M. Solow.

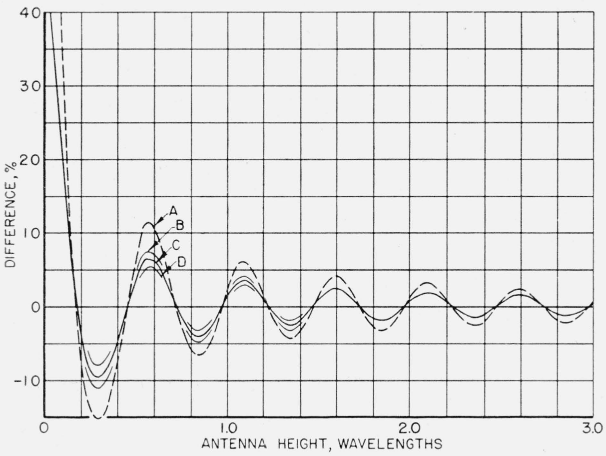

FIGURE 3.—*Calculated percentage difference* $(|E_i/E_t|-1)\times$ *100 vs receiving antenna height,* h_2/λ, *in wavelengths.*

E_t is the true value of field intensity, and E_i is the value indicated by a field-intensity meter with a previously determined free space value of antenna constant (horizontal polarization). Curves are shown for four values of ground constants: (A) $\sigma=\infty$; (B) $\epsilon_r=30$; (C) $\epsilon_r=15$; and (D) $\epsilon_r=9$ (for low-loss dielectrics $\sigma/\epsilon\omega<<1$). Antenna length $l=\lambda/2$. The free-space antenna input impedance is taken as $Z_{33}=73.2+j42.5$, and the terminating impedance $Z_L=73+j\,0$ ohms.

effect on the reflection coefficient $(\psi=\pi/2)$ is concerned.

Apparently the usual changes in the ground constants experienced (due to changing moisture content) have but little effect upon the measurement error as presented here. The total variation from average ground conditions $(\epsilon_r=15)$ does not exceed 1.5 percent, except for values of h_2/λ <0.15.

As shown by figure 3, a field-intensity meter

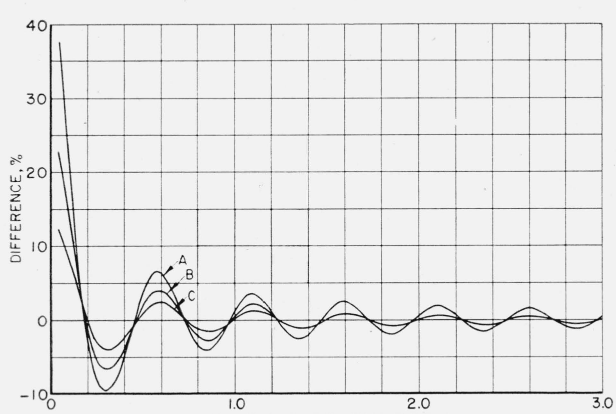

FIGURE 4. *Calculated percentage difference in field intensity (horizontal polarization)* $(|E_i/E_t|-1)\times100$ *vs receiving antenna height,* h_2/λ, *in wavelengths for three values of antenna terminating impedance.*

(A) $Z_L=73$; (B) 150, and (C) 300 ohms, over average ground $\epsilon_r=15$, $\sigma/\epsilon\omega<<1$. $l=\lambda/2$, $Z_{33}=73.2+j42.5$

$(Z_L=73\Omega)$ calibrated under free-space conditions may indicate values of field intensity that are in error by as much as 10 percent for values of h_2/λ near 0.3, and 7.5 percent for values of h_2/λ near 0.6. If this error is to be held to values less than 5 percent, antenna heights greater than about 0.65 wavelength should be used for field-intensity measurements under these conditions.

It is somewhat doubtful at the present state of the art just what maximum values of measurement error of this type should be permitted. One method of reducing the error, obviously, is to increase the value of the antenna terminating impedance, Z_L.

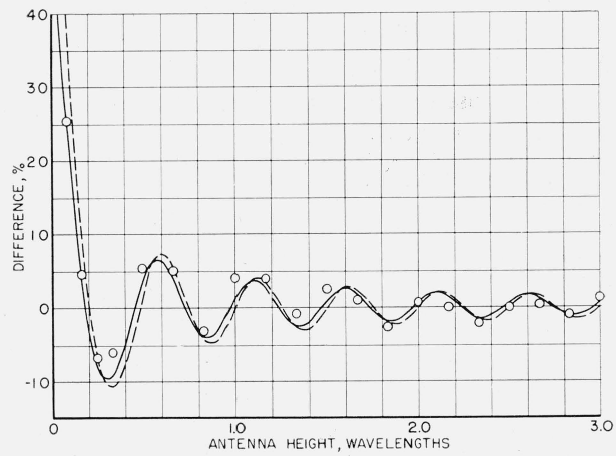

FIGURE 5.—*Calculated percentage difference in field intensity (horizontal polarization)* $(|E_i/E_t|-1)\times100$ *vs receiving antenna height,* h_2/λ, *in wavelengths over average ground,* $\epsilon_r=15$, $\sigma/\epsilon\omega<<1$, *for both a half-wavelength dipole and a self-resonant dipole* $(l\cong\lambda/2)$.

The measured points were determined at 100.0 Mc and were obtained from the data presented in figure 7. --------, self-resonant dipole; ________, $\lambda/2$ dipole; ○, observed for self-resonant dipole.

Figure 4 shows the calculated measurement error vs h_2/λ for values of $Z_L=73$, 150, and 300 ohms for average ground, $\epsilon_r=15$, $(\sigma=0)$. For the case of $Z_L=73$ ohms, the error does not exceed 10 percent for heights of the receiving antenna in excess of 0.15 wavelength. If Z_L is increased to 150, and 300 ohms, this error is reduced to 7 and 4 percent, respectively, and approaches zero as Z_L approaches infinity.

Figure 5 shows the computed measurement error for both a $\lambda/2$ dipole and a self-resonant dipole, as well as measured values for the latter case ($f=$ 100 Mc). In the case of the $\lambda/2$ dipole, $Z_{33}=73.2$ $+j\,42.5$ ohms, and $Z_L=73+j\,0$ ohms. For the

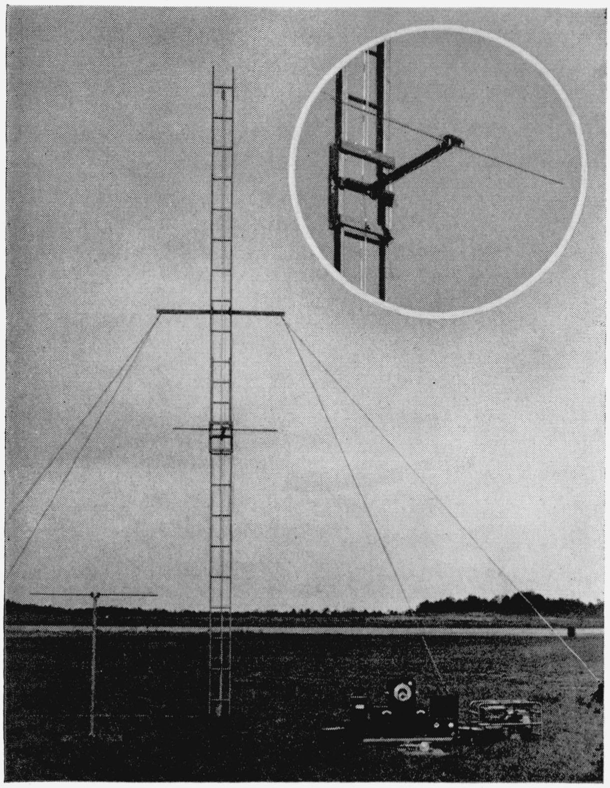

FIGURE 6. *View of the various pieces of transmitting and receiving equipment used in obtaining the measured data of figure 7.*

In the background is shown the ladder-mast and carriage for the receiving dipole. The location is the Beltsville, Md., airport.

self-resonant dipole, $Z_{33}=65+j\ 0$ ohms, and $Z_L=62+j\ 0$ ohms.

The latter values were chosen as representing the approximate impedances of the self-resonant antenna actually used for obtaining the measured points of figure 5. The terminating impedance, $Z_L=62+j\ 0$ ohms, was the closest value to 65 ohms available at the time the measurements were made. As might be expected, there is no substantial difference between the calculated values of the measurement error for the full $\lambda/2$ dipole and for the self-resonant dipole. The measured points support the theory reasonably well. The difference does not exceed 3 percent for antenna heights above 0.1 wavelength. Various pieces of the transmitting and receiving equipment used in making these measurements are shown in figure 6.

The measured values of figure 5 were obtained from the data presented in figure 7. In the latter, the receiving antenna terminal voltage (horizontal polarization) is shown vs height, h_2, in meters over ground having a measured relative dielectric constant $\epsilon_r \simeq 15$, $(\sigma/\epsilon\omega << 1)$ for: (A) antenna "open-circuited"; and (B) antenna terminated in $Z_L=62+j\ 0$ ohms. The measured percentage difference shown in the upper curve of figure 7 was determined from the data with the aid of eq 18 which, upon substituting eq 15 and 16, gives (in percent)

$$\delta=\left(Kl_H\left|\frac{V_L}{V_{oc}}\right|-1\right)\times 100. \tag{21}$$

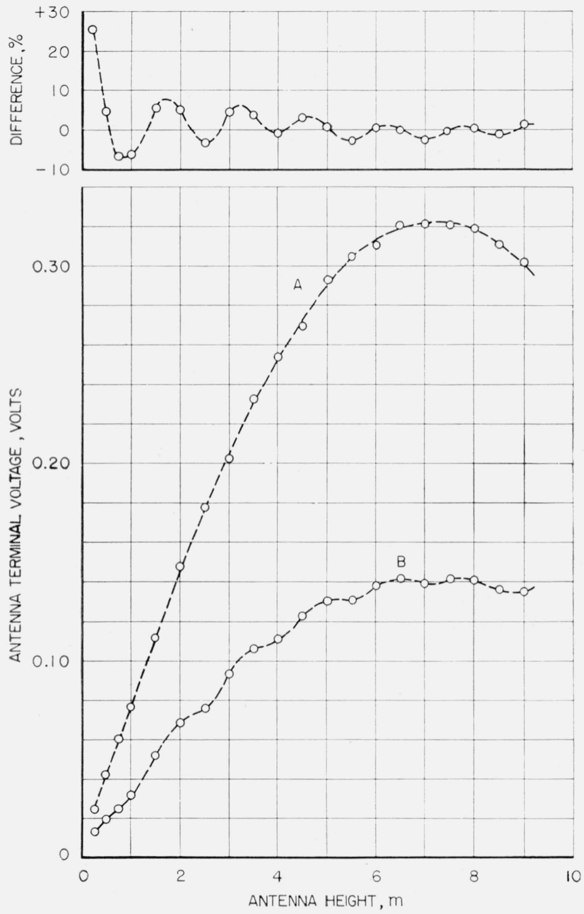

FIGURE 7.—*Measured values of receiving antenna terminal-voltage (horizontal polarization) vs height in meters over ground having a measured relative dielectric constant* $\epsilon_r=15$, $(\sigma/\epsilon\omega<<1)$ *for: (A) antenna "open-circuited"; and (B) antenna terminated in* $Z_L=62+j\ 0$ ohms.

The measured percentage difference was determined with the aid of eq 21, $\delta=(Kl_H V_L/V_{oc}-1)\times 100$. The free space value of the factor $Kl_H=(Z_L+Z_{33})/Z_L=V_{oc}/V_L$ (see eq 17) was estimated from the data, and is the reciprocal of the voltage-transfer ratio. f=100.0 Mc, d=30.5 m, h_1=3.05 m, I=0.100 amp.

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The free-space value of the factor, $Kl_H=(Z_L+Z_{33})/Z_L=V_{oc}/V_L$, used, was estimated from the data, and is the reciprocal of the voltage-transfer ratio previously mentioned.

For the open-circuited condition referred to above, the receiving antenna was actually terminated in a special balanced voltmeter of the silicon crystal-rectifier type. This crystal rectifier, together with the balanced RC network used to take off the direct-current output voltage, presented a resistance of approximately 4,000 ohms in shunt with 0.75 $\mu\mu$f across the gap at the center of the antenna. This accounts for the slight oscillation of the points around the averaging curve, but introduced an error of less than 1 percent in the final results, as the shunting was present during both the open-circuited and terminated runs.

VI. Conclusions

An approximate method has been presented for determining the effect of finitely conducting ground beneath a horizontal receiving dipole on the value of the antenna constant as used for measuring VHF field intensity. Three variables are mainly involved in this effect: (a) the antenna height, in wavelengths, h_2/λ, (b) the ground constants ϵ_r and σ; (c) the antenna terminating impedance Z_L.

Changes in antenna height probably have the greatest effect on the antenna constant, as can be seen from figure 3, and are of primary concern here. Normal variations in the ground constants encountered in practice apparently have only a minor effect. Under most conditions and to within the probable accuracy of this method, these variations can probably be neglected.

This error [8] in measurement caused by the ground may be reduced by increasing the value of Z_L. The error vs height is shown in figure 4 for three values of Z_L, viz, 73, 150, and 300 ohms. The error approaches zero as Z_L approaches infinity.

In figure 5, measured values of the error are compared with theoretical values calculated as previously described. The agreement is reasonably good for antenna heights above 0.1 wavelength.

In view of the approximations involved it is felt that the curves shown in figures 3, 4, and 5 probably should not be used for actually applying corrections to field-intensity measurements. Rather they might be used to estimate the maximum probable error (due to ground effect) existing in measurements made below a given antenna height.

Figure 3 shows the variations in the error with antenna height occurring over perfectly conducting ground.[9] The error is appreciably larger in this case than for finitely conducting ground. This would seem to indicate the inadvisability of using or calibrating a VHF field-intensity meter over a perfectly conducting plane unless the antenna heights were carefully chosen so as to result in a low value of error.

[8] The error, as previously defined, is the percentage-difference between the true value of field intensity existing at a given antenna height, in wavelengths, h_2/λ and that indicated by a field-intensity meter whose antenna constant was determined under free-space conditions.

[9] Perfectly conducting ground and a solid metallic ground plane would have essentially the same reflecting properties for the present purpose.

WASHINGTON, October 18, 1949.