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THE RESPONSE OF A TERMINATED TWO-WIRE LINE SUSPENDED IN AIR ABOVE A SEMI-INFINITE DISSIPATIVE MEDIUM AND EXCITED BY A PLANE-WAVE RF FIELD GENERATED IN FREE SPACE

by

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SUMMARY

The analysis previously made to determine the response of a two-wire transmission line buried at constant depth near the earth-air interface when excited by a plane wave electromagnetic field generated in free space is extended to include the case of the line suspended in air at a uniform distance above the earth's surface. The exciting field is the vector sum of the incident and reflected fields at the point midway between the line conductors. The polarization of the electric field is taken to be parallel to the wires, so that there is no pick up by the terminations. The objective of the study is to determine the current in specified load impedances in terms of the amplitude of the incident electric field evaluated at the surface of the earth.

INTRODUCTION

The present note is a sequel to an earlier investigation relating to the response of a terminated two-wire line buried in the earth and excited by a plane-wave RF field generated in free space.[1] The problem now under consideration is similar in many respects: the line is suspended at a uniform height in air above the semi-infinite dispersive medium. Reference to numbered equations in the previous paper is made by prefixing 1 to the appropriate equation number. For convenience, some obvious minor notational changes are made, so that there is not necessarily a one-to-one correspondence in symbolism.

THEORETICAL CONSIDERATIONS

The total electric field at a height d above the earth-air interface is the vector sum of the incident and reflected fields at that point. Thus,

$$E_t(x) = E^i(x) + E^r(x) = E^i(o)e^{-jk_o x} + E^r(o)e^{jk_o x} \tag{1}$$

where use has been made of (1-36) and (1-37).

One now eliminates $E^t(o)$ between (1-39) and (1-40). This leads to the result

$$E^r(o) = E^i(o) \left[\frac{k_o - k_1}{k_o + k_1}\right] \quad . \tag{2}$$

Substituting this result in (1),

$$E_t(x) = \frac{2E^i(o)}{k_o+k_1}\left[k_o \cos k_o x - j\, k_1 \sin k_o x\right] \tag{3}$$

so that at a height d above the imperfectly conducting earth,

$$E_t(d) = \frac{2E^i(o)}{k_o+k_1}\left[k_o \cos k_o d - j\, k_1 \sin k_o d\right] \quad . \tag{4}$$

For simplicity assume that the transmission line suspended in air is dissipationless, which is an excellent approximation. Also, let $k_o b \ll 1$.

Then (1-62) and (1-63) are directly applicable. Thus,

$$I_t(h) = -j\, E_t(d)\, b \left(\frac{\sin 2 k_o h}{Z_h \cos 2 k_o h + j Z_c \sin 2 k_o h} \right) \tag{5}$$

and

$$Z_{-h} = 0$$

$$I_t(h) = E_t(d)\, b \left(\frac{1 - \cos 2 k_o h}{Z_c \cos 2 k_o h + j Z_h \sin 2 k_o h} \right) \tag{6}$$

$$Z_{-h} = \infty$$

where $E_t(d)$ is given by (4).

The change in Z_c caused by line imaging in an imperfectly conducting earth is negligible provided $d > 5b$. It follows that the characteristic impedance of an isolated lossless transmission line may be used in (5) and (6). It is

$$Z_c = 120 \ln \left(\frac{b}{a} \right) \quad . \tag{7}$$

NUMERICAL RESULTS

The response of a two wire transmission line suspended in air parallel to the surface of the earth and oriented for maximum pickup was investigated using a high speed digital computer. The properties of the line used follow: $2h = 100$ m., $a = 0.5$ mm., $b = 2.5$ mm., $\sigma_c = \infty$, $Z_{-h} = 0$ or ∞, $Z_h = 1$ or 5 ohms.

In the study the incident field strength was assumed to be 1 volt/m. polarized parallel to the axes of the line conductors and the earth conditions considered were dry earth ($\epsilon_r = 7$, $\sigma = 10^{-3}$ mhos/m); damp earth ($\epsilon_r = 15$, $\sigma = 12 \times 10^{-3}$ mhos/m), and wet earth ($\epsilon_r = 30$, $\sigma = 30 \times 10^{-3}$).

It was discovered, after making a few computer runs, that the height of the mid-point of the transmission line above the surface of the earth for maximum pickup is always $k_o d \simeq \pi/2$ for the range of electrical properties of the earth considered. In other words, the current in the terminating impedance Z_h is essentially independent of earth properties provided $7 \leq \epsilon_r \leq 30$, $10^{-3} \leq \sigma \leq 30 \times 10^{-3}$ mhos/m. and $k_o d \simeq \pi/2$. However, the load current is sensitive to the value of Z_h. In Figures 1 and 2, $I_t(h)$ in μ A is given over the frequency range $10^3 \leq f \leq 10^9$ Hz for $Z_h = 1$ and 5 ohms, respectively. Observe that when $Z_{-h} = 0$ and $f = 10^3$ Hz the current in $Z_h = 1$ ohm exceeds by a factor of about 5 the current in $Z_h = 5$ ohms. For $Z_h = 1$ and 5 ohms and $10^4 \leq f \leq 10^9$ Hz the results are entirely comparable. When $Z_{-h} = \infty$, the curves showing $I_t(h)$ against f for $Z_h = 1$ and 5 ohms are essentially the same.

CONCLUSIONS

The response of a terminated two-wire transmission line suspended in air above a semi-infinite dissipative medium and excited by a plane-wave RF field generated in free space has been studied. It is shown that for the usual range of electrical properties of the earth (dielectric constant and conductivity) the pickup of the line is very insensitive to their actual values. Maximum pickup occurs when $k_o d \simeq \pi/2$, ($d \simeq \lambda/4$). This implies that at every frequency considered in this investigation the height d of the line above the surface of the earth changes. At low frequencies the load current is sensitive to the value of the terminating impedance and changes considerably when the other end of the line is open-circuited and then short-circuited.

ACKNOWLEDGMENT

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REFERENCE

1. Charles W. Harrison, Jr., and Margaret L. Houston, "The Response of a Terminated Two-Wire Line Buried in the Earth and Excited by a Plane-Wave RF Field Generated in Free Space."

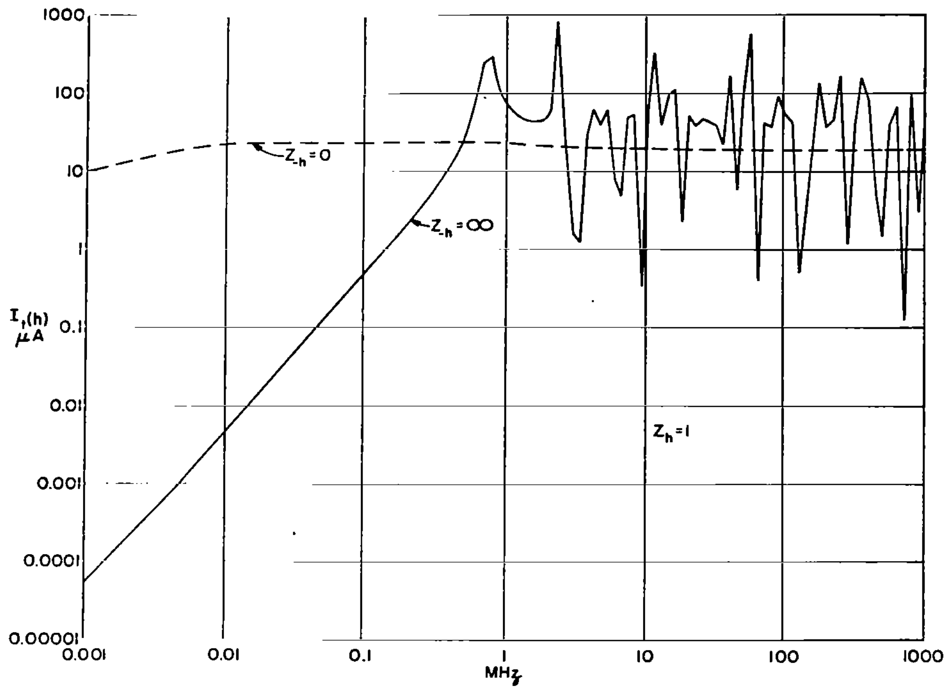

Figure 1. Load Current $I_t(h)$ in μA as a Function of Frequency in MHz for $Z_{-h} = 0$ and ∞, $k_od \simeq \pi/2$, $7 \leq \epsilon_r \leq 30$, $10^{-3} \leq \sigma \leq 30 \times 10^{-3}$ and $Z_h = 1$ ohm. The incident electric field is assumed to be 1 volt/m polarized parallel to the conductors.

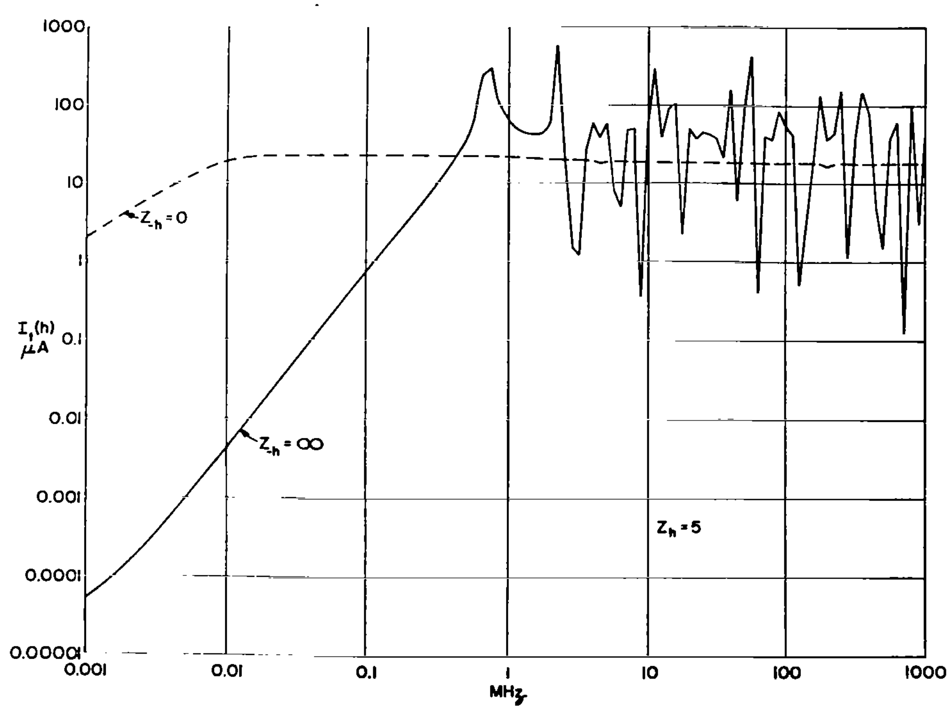

Figure 2. Same as Figure 1 Except $Z_h = 5$ Ohms