Chapter 1

The electrical properties of soils with their applications to agriculture, geophysics, and engineering

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Abstract

The electric properties of the soils are very important for several science like telecommunications, electrical engineering, geophysics and agriculture. There are semi-empirical dielectric models for soils, which represents the real and imaginary part of the dielectric permittivity as the function of the frequency. The measurement methods to obtain the dielectric properties of soils are described for different band of frequencies from some kHz to several GigaHertz. The parallel plate capacitors are widely used to measure dielectric properties. The transmission lines method of a coaxial transmission line can be used in frequency domain and time domain. The time domain technique with transmission lines is usually called time domain reflectometry (TDR), because are based in the voltage measurement as a function of time of pulses. The frequency domain technique with transmission lines are based of the reflection coefficient measurement of the transmission line. The transmission lines method are described with short load and open circuit load because are useful to obtain the characteristic impedance, and the electric permittivitty of the media inside.

Keywords: keywords: Soil, Dielectric properties, Permittivity, Models, Measurement method.

1. Introduction

The knowledge of Electrical Properties of Soils in Physics and Electrical Engineering are important for many applications. The long-distance electromagnetic telegraph systems from 1820 used, with two or more wires to carry the signal and the return currents. It was discovered, that the earth could be used as a return path to complete the circuit, making the return wire unnecessary [1]. However during dry weather, the earth connection often developed a high resistance, requiring water on the earth electrode to enable the telegraph to ring [1].

An important Radiopropagation and Engineering problem has been solved in 1909 by A. Sommerfeld. He was solved the general problem of the effect of the finite conductivity of the ground on the radiation from a short vertical antenna at the surface of a plane earth. The surface wave propagation produced over real ground for the Medium Frequency AM radio service, where the attenuation of the electric field depends on the dielectric properties of the soil, mainly of the dielectric losses [2]. Considering that the word 'Soil' means the uppermost layer of the earth's crust, which contains the organic as well as mineral matter. From 1936 up to 1941, Norton, Van der Pol and Bremmer made the computation of the field strengths at distant points on the flat and spherical Earths surface [3] and [4].

In agriculture applications the Electrical resistivity methods have been introduced by Conrad Schlumberger in France and Frank Wenner in the United States, for the evaluation of ground electrical resistivity. In saline soils the electric conductivity measured is high, and the effects of salinity are manifested in loss of stand, reduced rates of plant growth, reduced yields, and in severe cases, total crop failure [5].

The applications like the protection of electrical generating plant, is necessary to provide earth connections with low electrical resistance. The radio transmitting and receiving stations for broadcasting, is generally covered by radiation transmitted directly along the ground [6]. In electrical engineering, 'ground' is the reference point in an electrical circuit from which voltages are measured.

For archeology, geophysics, engineering and millitar applications the so-called ground propagating radar (GPR), is a technique widely used. The radar signal is an electromagnetic wave that propagates through the earth and its signal is reflected when an object appears or there is a change in the properties of the earth. In order to determine the depth of an object under the ground, it is necessary know the electrical properties of the soil [7].

2. Fundamental Concepts

The equations that relate the electric field (E) and magnetic field (H), are based on the Electromagnetic Theory formulated by James Clerk Maxwell in 1864, whose validity has allowed great advances in diverse areas, such as Telecommunications, electricity, electronics and materials [8].

Regarding the behavior of the materials under the action of an electric field, in the conductive materials, the charges can move freely, meaning that the electrons are not associated with an atomic nucleus. In the case of dielectric materials, the charges are associated with an atom or specific molecule [9]. There are two main mechanisms where the electric field distorts the distribution of charge in a dielectric, stretching and rotation. The relationship between the electric dipole moment inducted under the action of an applied electric field, is called atomic electric polarizability $\overrightarrow{p}$, and can be written as:

$$\overrightarrow{p} = \alpha \overrightarrow{E} \tag{1}$$

In a material with an applied electric field, a convenient definition is to consider the contributions of the dipole moment per unit volume, this parameter is called Polarization, which is a macroscopic definition instead of a molecular or atomic definition, [9] and [10]:

$$\overrightarrow{P} = \frac{\Delta\overrightarrow{p}}{\Delta v} \tag{2}$$

It is evident that the contributions of the electric dipole moment in a volume element Δv, are given by the sum of the microscopic contributions $\overrightarrow{p_m}$, therefore you can write:

$$\Delta\overrightarrow{p} = \sum_m \overrightarrow{p_m} \tag{3}$$

And the polarization:

$$\overrightarrow{P} = \frac{\sum_m \overrightarrow{p_m}}{\Delta v} \tag{4}$$

In Fig. 1 can be observed the external electric field applied to a dielectric material and the resulting polarization.

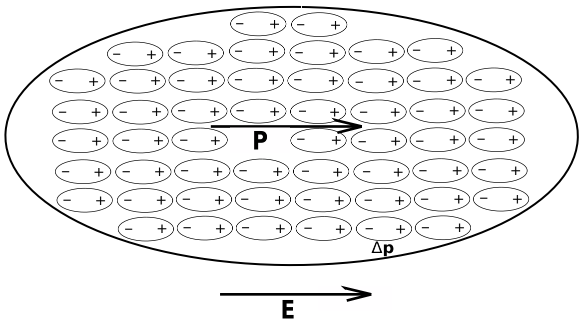

Figure 1.
Polarization applying external electric field E, to a dielectric material.

From the macroscopic point of view in most of the dielectric material, when the electric field is canceled, the polarization in the material will be nullified. In addition, the polarization of the material will vary as the electric field varies, ie $\overrightarrow{P(E)} = \chi(E)\overrightarrow{E}$. The variable $\chi(E)$ is called electrical susceptibility of the material, and when the electric field applied to the dielectric is not high power, the relationship between the polarization and the electric field will be linear, as is the case of a soil [10]:

$$\overrightarrow{P} = \chi\overrightarrow{E} \tag{5}$$

It is convenient to define the electric displacement, because it allows to relate by means of the Gaussian law with the free charges, therefore:

$$\overrightarrow{D} = \epsilon_0 E + \overrightarrow{P} \tag{6}$$

Then:

$$\overrightarrow{D} = \epsilon_0 E + \chi \overrightarrow{E} \tag{7}$$

The electrical permittivity is defined as the relationship between the electric displacement vector $\overrightarrow{D}$ and the Electric field vector $\overrightarrow{E}$, thus:

$$\overrightarrow{D} = \epsilon \overrightarrow{E} \tag{8}$$

Result:

$$\epsilon = \epsilon_0 + \chi \tag{9}$$

It is convenient define [11]:

$$\chi = \epsilon_0 \chi_r \tag{10}$$

Result:

$$\epsilon = \epsilon_0 (1 + \chi_r) \tag{11}$$

The electric properties of the material are completely defined by mean of ϵ or χ [10].

In problems with electromagnetic fields four vectors are defined: E and B, D and H. These vectors are assumed to be finite throughout the entire field, and at all ordinary points to be continuous functions of position and time, with continuous derivatives [12].The constitutive relations link the vectors of the fields $\overrightarrow{B}$ with $\overrightarrow{H}$, and $\overrightarrow{D}$ with $\overrightarrow{E}$, usually dependent on the frequency [8]:

$$\begin{aligned} \overrightarrow{B} &= \mu(\omega)\overrightarrow{H} \\ \overrightarrow{D} &= \epsilon(\omega)\overrightarrow{E} \\ \overrightarrow{J} &= \sigma(\omega)\overrightarrow{E} \end{aligned} \tag{12}$$

For the electromagnetic propagation in soils, the parameters μ, ϵ and σ must be determined. The soils are usually non-magnetic media, therefore the magnetic permeability will be that of the vacuum $\mu = \mu_0$, and the variables to be determined will be the electric permittivity ϵ and the electric conductivity σ.

The electrical resistivity obtained by soil mapping exhibits a large range of values from $1\Omega/m$ for saline soil to several $10^5\Omega/m$ for dry soil overlaying crystalline rocks [13]. In Fig. 2 can be observed the resistivity of of different soils. The electrical conductivity is related to the particle size by the electrical charge density at the surface of the solid constituents, like in clay soil, the electrical charges located at the surface of the clay particles lead to greater electrical conductivity than in coarse-textured soils[13].

There are evidence that for compacted soils of clay, it exhibits an anisotropic behavior in the resistivity measured in the horizontal and vertical directions [14].

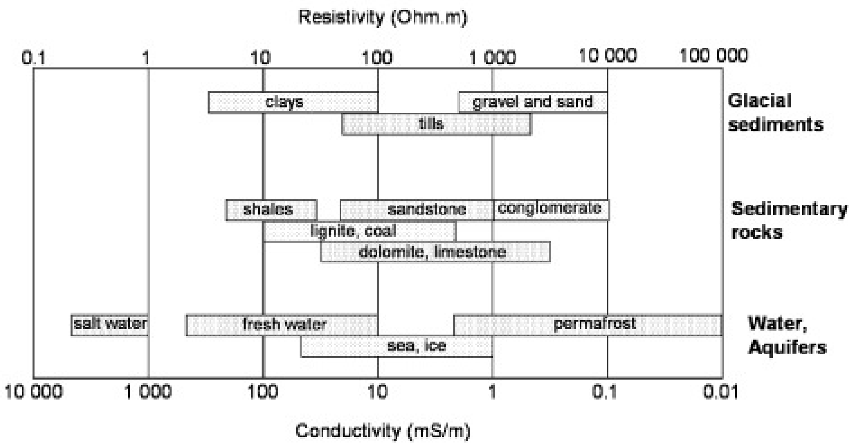

Figure 2.
Table of electric resistivity $[\Omega/m]$ *and electric conductivity* $[\sigma/m]$ *of soils, ref Samoulian [13]*

The literature contains the meassurement of the dielectric properties of soils at different frequencies with slotted lines and time domain reflectometry methods (TDR) [15].

The Measured variations of the electric permittivity of soils with fractions of sand, silt, and clay, and with volumetric moisture content have been studied for frequency of 440MHz used by the radar observations [16].

The coaxial probe technique terminated in the material under test, has been used to measure the dielectric properties of the vegetation. The dielectric data reported are based on measurements of the amplitude and phase of the reflection coefficient of a coaxial probe [17] and [18].

3. Transmission Line Fundamentals

The Transmission Lines method has been used to measure the dielectric properties [19] and [20]. These transmission lines are: Coaxial, quasi-coaxial and Two wires transmission lines. Consider a transmission line with a homogenous dielectric material inside, and the propagation is Transverse Electromagnetic Mode (TEM), where the electric and magnetic field are perpendicular to the propagation direction, this can be observed in Fig. 3 and 4.

The separation between the conductive cylinders that form the coax transmission line should be much lower than the wavelength of the signal that propagates, so the transmission line will not be affected by the propagation modes of high orders, such as the TE_{11}[19].

The use of coaxial transmission lines is widely used for the transmission of radiofrequency signals, and its application in radiocommunications and for broadcasting [21]. The transmission lines allow the connection between a generator or emitter and a load or antenna. The Air coaxial transmission line consists of two cylindrical conductors, with air between both conductors. These metallic conductors are those that impose the boarder conditions that must comply the electric and magnetic fields of the electromagnetic wave that travel inside the line. The coaxial transmission lines are used to measure the electrical

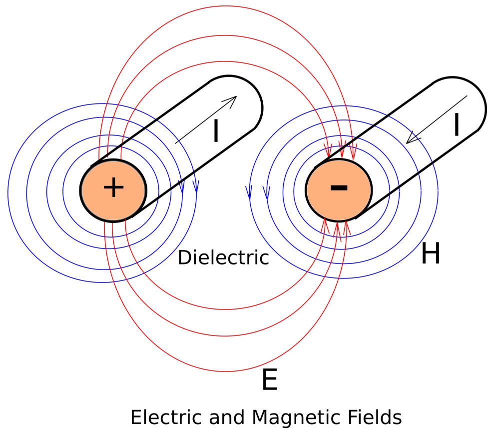

Figure 3.
Section of the two wires transmission line with the electric and magnetic fields.

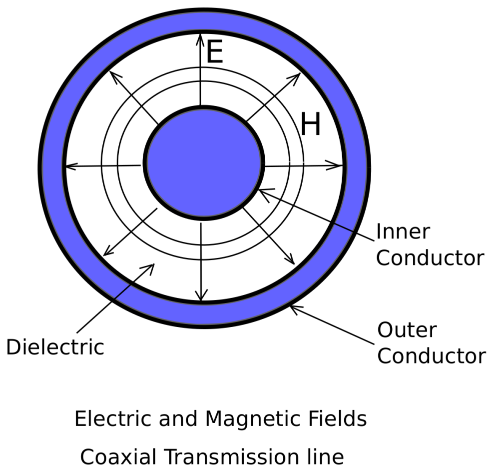

Figure 4.
Section of coaxial transmission lines and the electric and magnetic fields.

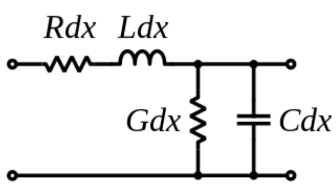

Figure 5.
Distributed Parameters of the Transmission Line.

properties of a dielectric material located inside the coaxial transmission line, as shown in Figure 4.

By analyzing the circuit model of a transmission line, the currents and voltages that propagate along it can be determined, using the circuit theory [22]. The equivalent circuit model of a transmission line can be seen in Fig. 5. According to the equivalent circuit model of a transmission line, the characteristic impedance Z_0 and the propagation constant γ can be expressed thus [21]:

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \tag{13}$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)} \tag{14}$$

where:
R: is the series resistance per unit length [Ω/m].
L: is the series inductance per unit length [H/m].
C: is the parallel capacity per unit length [F/m].
G: is the parallel conductance per unit length [S/m].

If the transmission line has no losses, it means that R = 0 and G = 0, then the characteristic impedance can be reduced as follows:

$$Z_0 = \sqrt{\frac{L}{C}} \tag{15}$$

$$\gamma = j\omega\sqrt{LC} \tag{16}$$

The input impedance of a transmission line, with a material inside considering the material with dielectric losses, can be expressed thus [23]:

$$Z_i = Z_0 \frac{Z_L + Z_0 tanh(\gamma l)}{Z_0 + Z_L tanh(\gamma l)} \tag{17}$$

where:
γ: is the propagation constant [$1/m$].
Z_L : is the load impedance [Ω].
l: is the length of the transmission line from the load [m].
Z_0 : is the characteristic impedance of the transmission line [Ω].

4. Time domain measurement method of dielectric permittivity and conductivity of soils (TDR)

The Time domain reflectometry (TDR) is a well known technique used to find the interruption point of the transmission lines in a CATV installation, and is also useful to determine the dielectric permittivity, see Fig. 6.

The time domain reflectometry use a step generator and an oscilloscope, a fast edge is launched into the transmission line under investigation, where the incident and reflected voltage waves on the transmission line are monitored by the oscilloscope. This method shows the losses and the characteristic impedance of the line: resistive, inductive, or capacitive [25]. The TDR method is based on the velocity of the electromagnetic wave that propagates through

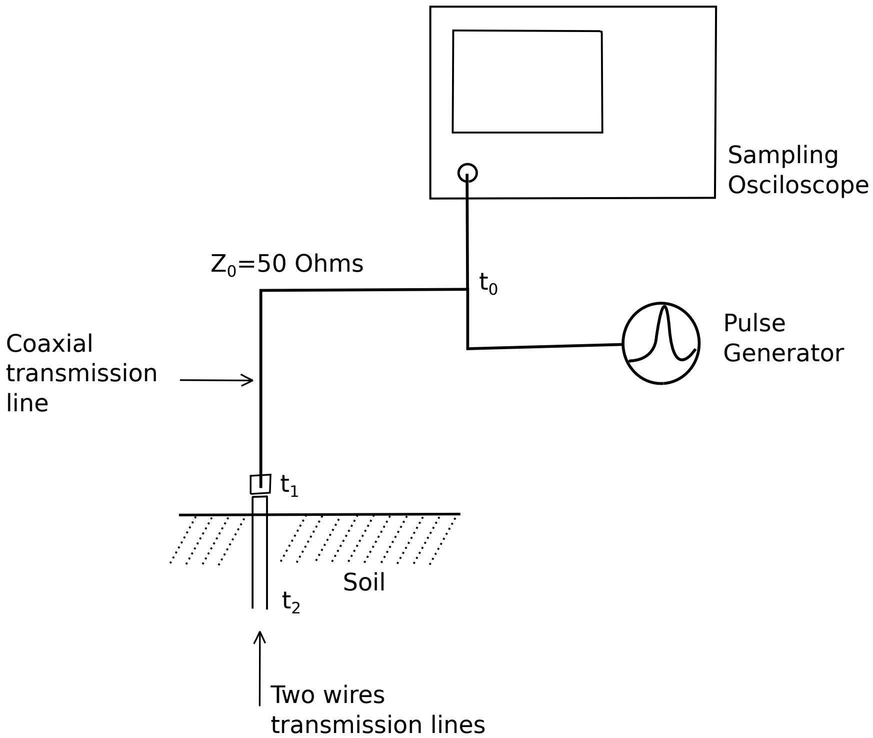

Figure 6.
Setup of the Dielectric measurement by the TDR method [24]

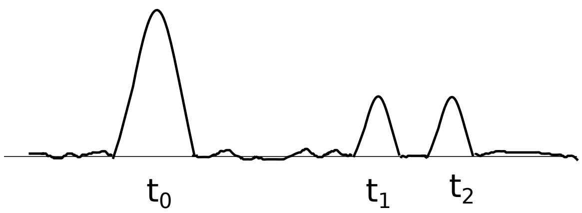

Figure 7.
Propagation of the pulses in the Time domain graphic with dielectric air [24]

the soil, and the velocity of the wave depends on the water content of the soil. If a pulse is applied to a no loss transmission line, the time domain graphic can be shown like in Fig. 7. Considering the soil like a non-magnetic media with low dielectric loss is [26], [27] :

$$v = \frac{c}{\sqrt{\epsilon}} \tag{18}$$

where:
$c[m/s]$: is the light velocity
ϵ: is the electric permittivity of the soil under test

The time interval Δt between the received pulse and incident pulse can be observed in Fig. 8, and the velocity can be expressed thus:

$$v = \frac{c}{\sqrt{\epsilon}} = \frac{2L}{\Delta t} \tag{19}$$

where: L is the probe length

Then:

$$\epsilon = \left(\frac{c\Delta t}{2L}\right)^2 \tag{20}$$

Usually the transmission lines probes has a minimum length of 15cm, because the incident electromagnetic wave takes a time of 1ns in air in order to return to the input of the line. This time is too short to be measured.

The conductivity of the soil can be determined computing the reflected pulses in the probe in the time domain graphic, see the Fig. 8 [26] and [28] Numerous methods have been proposed by researchers, one of these are the procedure of Dalton et. al. (1984).

$$\sigma_{dalton} = \left(\frac{\sqrt{\epsilon}}{120\pi L} ln\left(\frac{V_f}{V_e - V_f}\right)\right) \tag{21}$$

where:
V_0: the amplitude of the TDR pulse
V_s: the amplitude after reflection from the start of the probe
V_e: the amplitude after reflection from the end of the probe
V_f: the reflected signal after a very long time

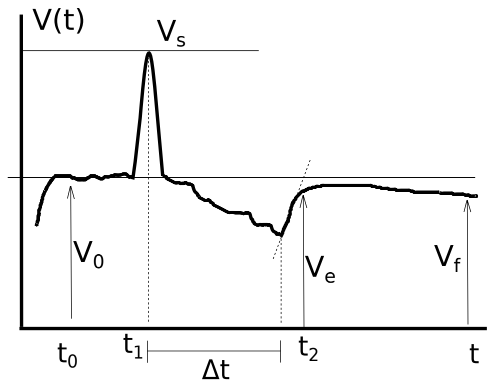

Figure 8.
Picture of the voltage as a function of time for the probe is in the soil. [26]

Also the conductivity can expressed thus [29]:

$$\sigma = \frac{K}{Z_0}\left(\frac{1-\rho}{1+\rho}\right) \tag{22}$$

where:
$\rho = \frac{V_f - V_0}{V_0}$
Z_0 is the characteristic impedance of the transmission line
K is a geometric constant of the probe, and it is experimentally determined by immersing the probe in solutions of known electrical conductivity Nt at Temperature
$K = EC \cdot RL \cdot ft^{-1}\ (m)^{-1}$
Temperature correction: $fT = 1 + KT(T - 25)$ KT depends on the used solution. $KT = 0.0191$ for a 0.01 M KCI solution

5. Measurement method of dielectric permittivity and conductivity of soils in frequency domain

This method is based on the measurement of the reflection coefficient by mean of the Vector Network Analizer (VNA) on the frequency domain of a coaxial transmission line in the soil, this can be observed in Fig. 9, [30] and [31] and [32].

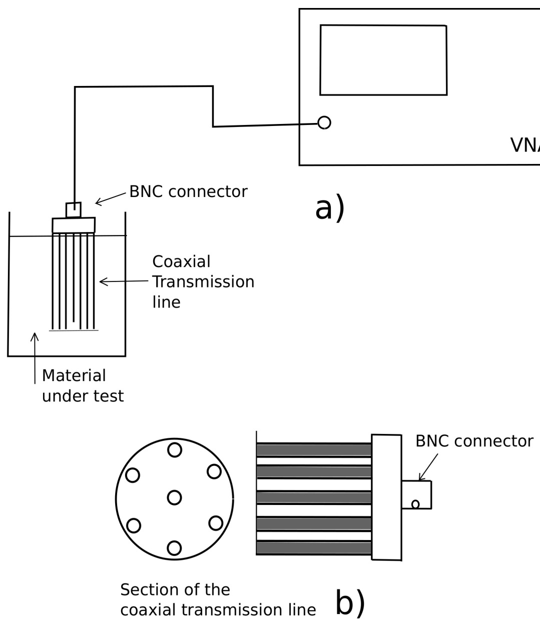

Figure 9.
Dielectric measurement by the coaxial transmission line method. a) setup of the measurement experiment b) Section of the transmission line and the material under test [33]

The Vector Network Analyzer can measure the scattering coefficient of a two port passive network where the reflection coefficient in voltage Γ is the S_{11} [34]. The probe impedance with the material inside is related with the reflected coefficient Γ [31]:

$$\frac{Z_p}{Z_0} = \frac{1 + \Gamma}{1 - \Gamma} \tag{23}$$

where:

Z_p impedance of the probe at the load
Z_0 characteristics impedance of the probe
The impedance of the probe can be calculated thus:

$$Z_p = \frac{2log\frac{B}{A}}{\sqrt{c\epsilon*}} cotangh \frac{\omega L\sqrt{\epsilon*}}{c} j \tag{24}$$

where:
L is the electric length of the probe
c is the speed of light
L coaxial probe of length,
A inner diameter
B outer diameter

Then the complex electric permittivity for frequencies lower than $50MHz$ can be approximated thus [31]:

$$\epsilon = \left(\frac{\frac{L}{2log\frac{B}{A}}}{\frac{1}{Z_T\omega j} - C_s} + \frac{\omega^2 L^2}{3c^2} \right)^{-1} \tag{25}$$

6. Dielectric Measurement by the Characteristic Impedance of a Transmission Line in frequency domain

Some references of these measurement method by mean of characteristic impedance have been [35] and [36].

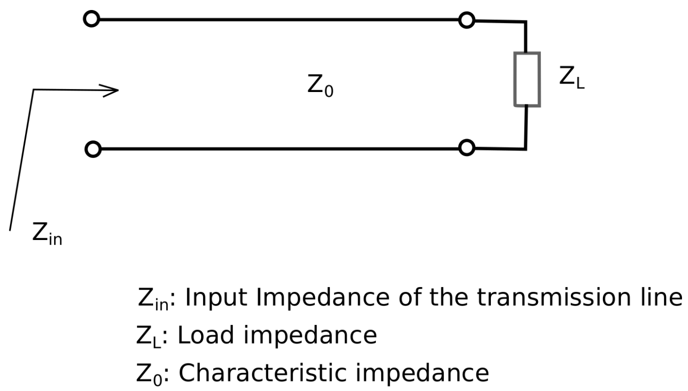

Figure 10.
input Impedance of the Transmission Line for $Z_L = 0$ and $Z_L \longrightarrow \infty$.

The input impedance can be computed by eqn. (17) for two different loads impedance:
a) Open circuit in the load $Z_L \longrightarrow \infty$

$$Z_i \mid_{Z_L=\infty} = \frac{Z_0}{tanh(\gamma l)} = Z_0 tanh^{-1}(\gamma l) \tag{26}$$

b) Short circuit in the load $Z_L = 0$

$$Z_i \mid_{Z_L=0} = Z_0 tanh(\gamma l) \tag{27}$$

where in general, the material inside the transmission line could be a losses dielectric, the propagation constant can be written thus:

$$\gamma = \alpha + j\beta \tag{28}$$

where: α: is the attenuation constant [Neper/m]. β: is the phase constant [rad/m].

Using eqns. (26) and (27):

$$\gamma \mid_{Z_L \longrightarrow \infty} = \frac{1}{l} atanh\left(\frac{Z_0}{Z_i}\right) \tag{29}$$

$$\gamma \mid_{Z_L=0} = \frac{1}{l} atanh\left(\frac{Z_i}{Z_0}\right) \tag{30}$$

Using the relation between $ln(x)$ and $th^{-1}(x)$:

$$\gamma \mid_{Z_L \longrightarrow \infty} = \frac{1}{2l} ln \frac{Z_0 + Z_i}{Z_0 - Z_i} \tag{31}$$

$$\gamma \mid_{Z_L=0} = \frac{1}{2l} ln \frac{Z_i + Z_0}{Z_i - Z_0} \tag{32}$$

The argument of the ln:

$$\gamma \mid_{Z_L \longrightarrow \infty} = \frac{1}{2l} ln(\rho_1 e^{\phi_1}) \tag{33}$$

$$\gamma \mid_{Z_L=0} = \frac{1}{2l} ln(\rho_2 e^{\phi_2}) \tag{34}$$

Replacing the Ln:

$$\gamma \mid_{Z_L \longrightarrow \infty} = \frac{1}{2l} ln(\rho_1 e^{\phi_1}) = \frac{1}{2l}[ln(\rho_1) + ln(e^{j\phi_1}) + j2k\pi] \quad k = 0, 1, 2, 3.... \tag{35}$$

$$\gamma \mid_{Z_L=0} = \frac{1}{2l} ln(\rho_2 e^{\phi_2}) = \frac{1}{2l}[ln(\rho_2) + ln(e^{j\phi_2}) + j2k\pi] \quad k = 0, 1, 2, 3.... \tag{36}$$

Then the propagation constant can be writting thus:

$$\begin{array}{l}\alpha\mid_{Z_L\longrightarrow\infty}=\frac{1}{2l}ln(\rho_1)\\ \beta\mid_{Z_L\longrightarrow\infty}=\frac{1}{2l}[\phi_1+2k\pi]\quad k=0,1,2,3....\\ \alpha\mid_{Z_L=0}=\frac{1}{2l}ln(\rho_2)\\ \beta\mid_{Z_L=0}=\frac{1}{2l}[\phi_2+2k\pi]\quad k=0,1,2,3....\end{array}\tag{37}$$

By these last eqns. the attenuation constant and the phase constant can be calculated with $Z_i\mid_{Z_L=0}$ or $Z_L\longrightarrow\infty$

6.1 Determining ϵ and σ from the propagation constant

The propagation constant γ can be written thus [11]:

$$\gamma=\sqrt{j\omega\mu(\sigma+j\omega\epsilon)}\tag{38}$$

From eqn. (38) and (28):

$$\gamma^2=j\omega\mu(\sigma+j\omega\epsilon^{'})=-\omega^2\mu\epsilon^{'}+j\omega\mu\sigma\tag{39}$$

$$\gamma^2=\alpha^2-\beta^2+2j\alpha\beta=(\alpha^2+\beta^2)e^{j2atan\left(\frac{\beta}{\alpha}\right)}\tag{40}$$

Equating real and imaginary parts of γ^2 of eqns.(39) and (40):

$$\begin{array}{l}-\omega^2\mu\epsilon^{'}=(\alpha^2+\beta^2)cos\left(2atan\left(\frac{\beta}{\alpha}\right)\right)\\ \omega\mu\sigma=(\alpha^2+\beta^2)sin\left(2atan\left(\frac{\beta}{\alpha}\right)\right)\end{array}\tag{41}$$

ϵ and σ can be obtained:

$$\begin{array}{l}\epsilon^{'}=\frac{(\alpha^2+\beta^2)cos\left(2atan\left(\frac{\beta}{\alpha}\right)\right)}{-\omega^2\mu}\\ \sigma=\frac{(\alpha^2+\beta^2)sin\left(2atan\left(\frac{\beta}{\alpha}\right)\right)}{\omega\mu}\end{array}\tag{42}$$

Another expresion of ϵ and σ is using eqns.(39) and (40):

$$\begin{array}{l}\gamma^2=j\omega\mu(\sigma+j\omega\epsilon^{'})\\ \gamma^2=\alpha^2-\beta^2+2j\alpha\beta\end{array}\tag{43}$$

Equating real and Imaginary part of (43):

$$\begin{array}{l}\omega\mu\sigma=2\alpha\beta\\ -\omega^2\mu\epsilon=\alpha^2-\beta^2\end{array}\tag{44}$$

Results:

$$\begin{aligned} \sigma &= \frac{2\alpha\beta}{\omega\mu} \\ \epsilon &= \frac{\beta^2-\alpha^2}{\omega^2\mu} \end{aligned} \tag{45}$$

The series resistance of the conductor of the Coaxial Transmission Line used is $R_{in} \cong 10^{-3}\Omega/m$ ($f = 100MHz$) $Z_L = 0$. This Resistance can be neglected, because it has no effect in the measured attenuation constant α.

6.2 Measurement Procedure of the ϵ and σ

1. The input impedances are measured for a load impedance at short circuit $Z_L = 0$ and open circuit $Z_L \longrightarrow \infty$, see eqns. (26) and (27).

2. The attenuation constants α and phase β are calculated with the equations found ad hoc, see eqn. (37).

3. The electric permittivity ϵ and the electrical conductivity σ are calculated using the equations found in Section 6.1.

In this way, a practical method of measurement is available to determine the parameters of dielectric materials, using coaxial transmission lines, in the frequency range from 1 MHz to 1000 MHz. A problem that appears when measuring dielectric materials is the connector that establishes the link between the coaxial transmission line and the vector impedance meter. A systematic error in the impedance measured are introduced.

Therefore, the study and correction of the mentioned error in the section will be carried out

6.3 Transmission lines used

Three coaxial transmission lines of General Radio (GR) Type 874, with air dielectric, have been used with a length of $100mm$, $200mm$ and $300mm$. The main characteristics of the General Radio coaxial transmission lines, type 874, are the following:

Characteristic impedance $Z_0 = 50\Omega$

Input and output connector GR874

$r_1 = 12 \cdot 10^{-3}[m]$

$r_2 = 5.2 \cdot 10^{-3}[m]$

$\sigma \cong 5.810^7[S/m]$

6.4 Correction error produced by the connector of the transmission line

It is important perform the correction of the impedance introduced by the connector of the transmission line used. This connector is shown in Figure 11, and it is composed by a dielectric of very low dielectric losses, and has a length of $10mm$. The characteristic impedance of the connector is practically $Z_0 = 50\Omega$ with no losses [36]:

$$\gamma = \alpha + j\beta \cong j\beta \tag{46}$$

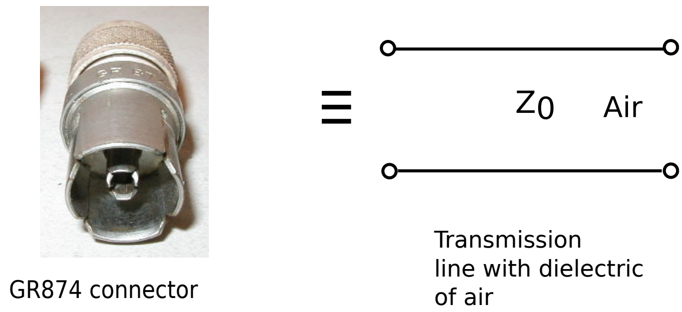

Figure 11.
N connector and it's equivalent of a transmission line with dielectric of air.

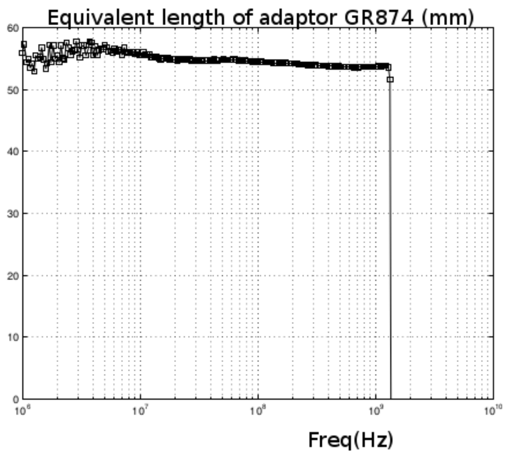

Figure 12.
Equivalent length of the transmission line of the connector GR874.

The input impedance to the connector can be written thus:

$$Z_i = Z_{0con} \frac{Z_L + jZ_{0con} tg(\beta x)}{Z_{0con} + jZ_L tg(\beta x)} \tag{47}$$

where: x: is the length of the transmission line [m].

The electric permittivity of the dielectric of the connector is unknown, then it is easy assume a transmission line with air equivalent of the connector with $\epsilon = \epsilon 0$, $\mu = \mu_0$, and $Z_{0con} = 50\Omega$.

Considering the connector with no losses:

$$\begin{aligned} \alpha &= 0 \\ \beta &= \omega_0 \sqrt{\mu_0 \epsilon_0} \end{aligned} \tag{48}$$

Then the input impedance of the connector with $Z_L = 0$ is:

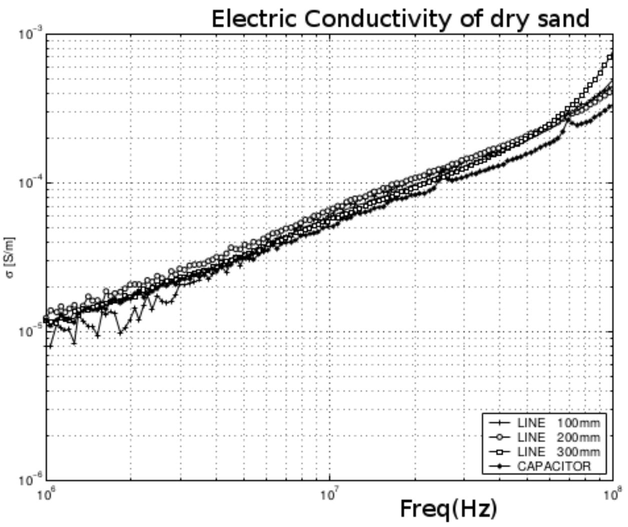

Figure 13.
Electric conductivity as a function of the frequency for dry sand samples, using a capacitive method and three transmission lines: 100mm, 200mm and 300mm.

$$Z_i \mid_{Z_L=0} = jZ_{0con} tg(\beta x) \tag{49}$$

where:x is the length of the connector of the equivalent transmission line.

The length x of this equivalent transmission line can be written thus:

$$x = \frac{1}{\beta} tg^{-1} \left(\frac{Z_{icon} \mid_{Z_L=0}}{jZ_{0con}} \right) \tag{50}$$

6.5 Results and Discussion

a) Method of measurement

The experimental results of the electric conductivity and the dielectric permitivitty measurement of the dry sand can be observed in the Figures 13, 14. In the Figure 13 the electric conductivity as a function of the frequency, by mean of the capacitive method and three types of transmision lines lengths have been measured, $L = 100mm$,$200mm$ and $300mm$, the convergence of all measurements are evident.

In the Figure 14 the relative electric permittivity as a function of the frequency, by mean of the capacitive method and three types of transmision lines lengths have been measured, $L = 100mm$,$200mm$ and $300mm$, there are a convergence of all measurements. It is important to note that the shorter transmission line has a wider bandwidth of measurement.The transmission line length of $L = 300mm$ shows the useful results up to 30MHz, with a T.L. length of $L = 200mm$ the useful results is up to 50MHz, and the a T.L. length of $L = 100mm$ the useful results are up to 300MHz.

The expected value of the dielectric permittivity measured of the dry sand by mean of a paralell plate capacitor and the 3 transmission lines used, are showed in Table 1. The standard deviation of the three meassurements

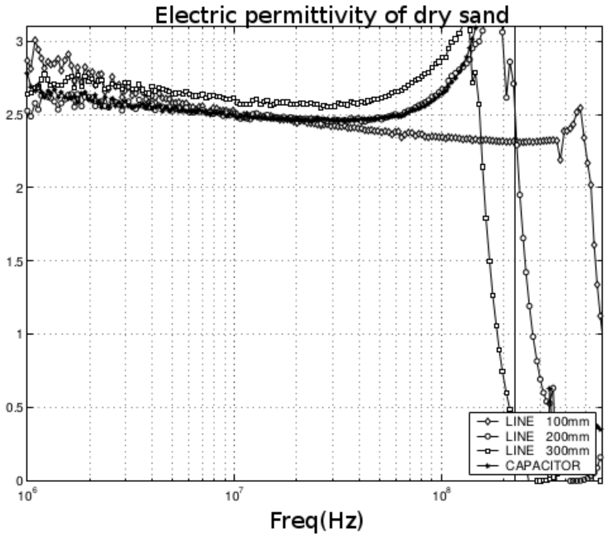

Figure 14.
The relative dielectric permittivity as a function of the frequency for dry sand samples have been measured, using a capacitive method and three transmission lines: 100*mm*, 200*mm and* 300*mm.*

Table 1.
Relative electric permittivity of dry sand

freq. (*MHz*)	**Capacitor**	**T.Line 100mm**	**T.Line 200mm**	**T.Line 300mm**	**Expected value**	**std dev**
1	2.80	2.86	2.65	2.65	2.74	0.034
2	2.60	2.76	2.62	2.75	2.68	0.021
3	2.60	2.70	2.60	2.70	2.65	0.010
5	2.50	2.61	2.57	2.65	2.58	0.012
7	2.50	2.54	2.55	2.62	2.55	0.0075
10	2.50	2.51	2.50	2.60	2.52	0.0073
20	2.40	2.45	2.47	2.57	2.47	0.0153
30	2.40	2.42	2.46	2.57	2.46	0.0173
50	2.40	2.40	2.46	-	2.41	0.0028
70	-	2.37	-	-	-	-
100	-	2.35	-	-	-	-

shows a good agreement up to the vecinity of the resonant frequency of each transmission line. In the Table 2, the electric conductivity of the dry sand can be observed. These curves are the same slope and shows a good convergence.

b) Applications

The values of the electrical conductivity and the electrical permittivity are very useful to evaluate the propagation of surface waves in real ground, where the attenuation depends mostly on the conductivity of the soil. Such is the case that AM transmitters include radials, which consist of metallic conductors, placed at the base of the monopole antenna to increase conductivity, and in this way the losses due to Joule effect on the earth's surface are reduced. If the conductivity of the soil is perfect, the electric field vector that propagates will be perpendicular to the earth's surface, however in real soils the electric field vector tilts and partly spreads into the earth, dissipating power, which dissipates power. Transforms into heat [2]. This constitutes losses on earth.

Table 2.
Electric conductivity of dry sand $\sigma[\frac{S}{m}10^{-5}]$

freq. (*MHz*)	**Capacitor**	**T.Line 100mm**	**T.Line 200mm**	**T.Line 300mm**	**Expected value**	**std dev**
1	1	1.1	1.3	1.2	1.15	0.13
2	1.6	2.0	1.7	1.7	1.75	0.17
3	2.1	2.6	2.3	2.2	2.30	0.22
5	3.2	3.1	3.3	3.1	3.20	0.096
7	4.4	5	4.3	4	4.40	0.42
10	6.0	6.5	5.5	5.1	5.80	0.6
20	10	11	9.4	8.4	9.70	1.08
30	14.4	14.6	12.7	11.1	13.20	1.60
50	21.9	21.5	20.8	16	20.00	2.7

Apparent soil electrical conductivity (ECa) to agriculture has its origin in the measurement of soil salinity, in arid-zone problem, are associated with irrigated agricultural land. ECa is a quick, reliable, easy-to-take soil measurement that often, relates to crop yield. For these reasons, the measurement of ECa is among the most frequently used tools in precision agriculture research for the spatio-temporal characterization of edaphic and anthropogenic properties that influence crop yield [37]. There are portable instruments for measuring the electrical conductivity of the soil by the method of electromagnetic induction, and by the method of the four conductors, which are installed in the agricultural machinery to obtain a map of the soil, before carrying out the work of tilling the earth.

For geophysics applications, the solar disturbances (flares,coronal mass ejections) create variations of the Earths magnetic field. These geomagnetic variations induce a geoelectric field at the Earths surface and interior. The geoelectric field in turn drives geomagnetically induced currents, also called telluric currents along electrically conductive technological networks, such as power transmission lines, railways and pipelines [38]. This geomagnetically induced currents create conditions where enhanced corrosion may occur. Earth conductivity can create geomagnetically induced currents variations, in particular where a pipeline crosses a highly resistive intrusive rock. It is important to make pipeline surveys once a year to measure the voltage at test posts to ensure that pipe-to-soil potential variations are within the safe range, impressed by cathodic protection systems [38].

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