The Electromagnetic Properties of Soil

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Introduction

Accurate electromagnetic ground constants are required for the modelling of ground wave communications, calculating clutter and reflections in radar applications, calculating the ground penetration (skin depth) of an electromagnetic wave and to model antennas above a real, imperfect earth [1]. They are also widely used in geological surveys and agricultural applications [2].

The International Telecommunications Union (ITU) published various graphs for relative permittivity, ε_r, and conductivity, σ, [3]. The validity and usefulness of these ITU publications are however questionable. The IEEE made the following statement regarding the published data [4]:

> *"The International Telecommunications Union (ITU) has published world surface conductivity maps for a number of frequency bands, although these are no longer being updated.* [A number of problems with the model are listed.] *Therefore, the ITU values for the HF band are inconsistent with the results of complex variable theory and are in error."*

This is an extraordinary statement relating to a professional ITU standard and illustrates the problem with conventional values for soils at radio frequencies.

Universal Soil Model

During the 1970's Longmire and Smith developed a universal soil impedance model valid from 1 Hz to 10 GHz for the Defence Nuclear Agency [5]. This research was conducted to quantify the effect of an electromagnetic pulse (EMP) generated by a high altitude nuclear explosion coupling into structures and underground cables through the soil. An EMP is a very fast nanosecond time-domain pulse with a frequency spectrum beyond 100 MHz.

Longmire modelled soil as a resistor-capacitor (RC)–transmission line with the variation of conductivity, σ, and dielectric constant, ε_r, with frequency as a function of water content. Thus if one knows the water content of the soil, one can predict with good accuracy what the values of σ and ε_r will be at a specific frequency. Longmire's contribution was thus to show how to use the frequency-dependent parameters to formulate a time-domain treatment of electromagnetic problems. The time-domain method solved Maxwell's equations in dispersive soils, based on the assumption that each volume element of the soil could be represented by an RC network.

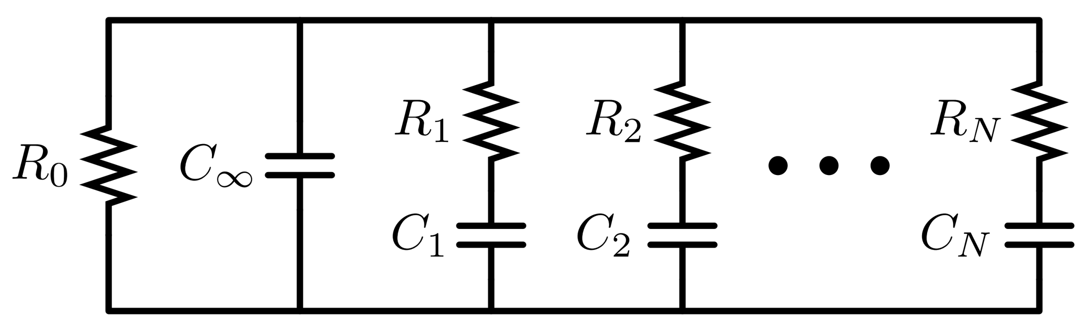

Figure 1. RC network model of the characteristics of the earth as a conductor.

Longmire and Longley's contribution also includes an indication on how the electrical parameters can be measured directly by pulse (RF) techniques.

Determining Soil Moisture Content

Time-domain reflectometry (TDR) uses a narrow pulse of electromagntetic (EM) energy at one end of a parallel transmission line located in a lossy material. The characteristics of the reflected waveform are influenced by the dielectric properties of the medium. In the 1980's, Topp used TDR to measure soil conductivity and dielectric constant and used these measurements to determine the moisture content [2]. Soil physicists have since extensively researched and documented TDR methods to obtain soil moisture content.

Commercial equipment employing the TDR technique to measure soil moisture content is now freely available and is used to measure the soil water content on golf courses and also in the agricultural sector.

Using the freely available low cost commercial soil moisture measurement equipment now makes it possible to easily and accurately determine the soil moisture content using RF techniques (TDR). The moisture percentage is then used in conjunction with Longmire's soil impedance model to determine the conductivity, σ, and dielectric constant, ε_r, for the frequency of interest as displayed in Figure 2.

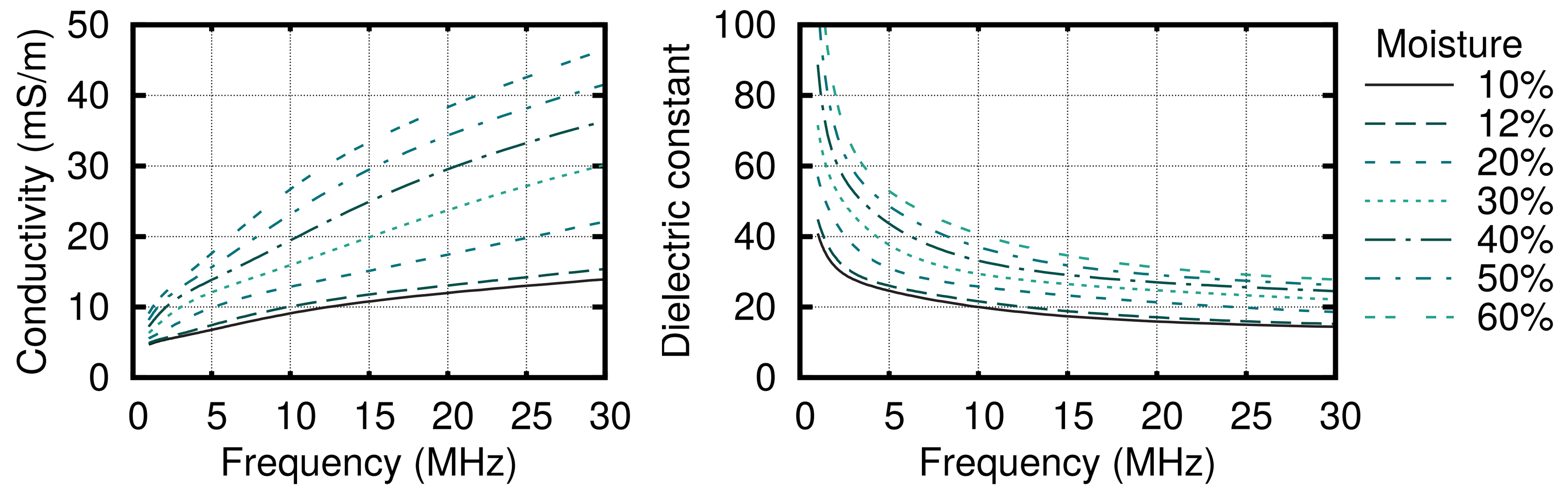

Figure 2. Calculated conductivity and dielectric constant curves for various soil moisture percentages.

Confirming the Electromagnetic Parameters

GRWAVE is the de-facto industry standard program for modelling ground propagation [6]. The received power level of a ground-wave, HF signal between Pretoria and the National Antenna Test Range (NATR) at Paardefontein, was measured and compared to the values calculated by the GRWAVE model using electromagnetic parameters determined by the soil moisture technique described above. The measured and calculated results correlated very well.

Conclusion

The universal soil impedance model/moisture percentage technique offers significant advantages in terms of simplicity, speed and cost in determining the electromagnetic properties of soil (σ and ε_r) at any frequency of interest when compared to current techniques [7].

With the correct electromagnetic ground constants for the applicable frequency, it is now possible to more accurately model ground-wave propagation, transmitter area coverage, ground penetration of an RF signal, radiation patterns and input impedances of HF antennas as well as ground reflections at reflective antenna test ranges such as at the NATR at Paardefontein.

References

[1] J. M. Goodman, "HF propoagation and channel characterization," in HF Communications Science and Technology. Van Nostrand Reinhold, 115 Fifth Avenue, New York, New York, 1992, ch.4, pp. 184, 192 and 196.

[2] G.C. Topp, J.L. Davis, A.P. Annan, "Electromagnetic determination of soil water content Measurements in coaxial transmission lines," *Water Resources Research*, vol. 16, no. 3, pp. 574-582, June 1980.

[3] ITU–R. Recommendation P. 527–3. "Electrical characteristics of the surface of the Earth," ITU–R Recommendations, P Series, Radiowave Propagation; 2000.

[4] IEEE Guide for Measurements of Electromagnetic Properties of Earth Media IEEE Std 356–2001. Published by The Institute of Electrical and Electronics Engineers, Inc. 3 Park Avenue, New York, NY 10016–5997, USA; 3 June 2002.

[5] G.L. Longmire, K.S. Smith, "A universal impedance for soils," Topical Report for period 1 July 1975 to 30 Sept. 1975. Report No. MRG-N-214. Mission Research Corporation. Santa Barbara, CA, October.

[6] ITU-R. rsg3-grwave. ITU. Geneva; 2009. Available from: http://www.itu.int/oth/R0A0400000F/en.

[7] P. J. Coetzee, "A technique to determine the electromagnetic properties of soil using moisture content," South African Journal of Science. 2014;110(5/6), Art. #2013-0225, 4 pages. http://dx.doi.org/10.1590/sajs.2014/20130225.

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