Measurement of Soil Parameters

Construction of a probe and practical experience in measuring conductivity and permittivity

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Abstract

Soil parameters near an antenna can show a pronounced effect on the antenna characteristics, especially for HF. Usually, soil is characterized by its conductivity ÿ in S/m and the relative permittivity ÿ versus vacuum (also known as dielectric constant). Antenna software like EZNEC and MMANA also needs these parameters for simulation.

Unfortunately, most hams don’t know those parameters for their antenna position and scarcely available maps don’t offer enough detail. Frequently, the ground type “Average” is chosen for simulations and users trust that errors are kept at bay. But the characteristics of low hanging and vertical antennas highly depend on the soil under them and so do simulation results for these types of antennas. Many efforts to come up with precise simulations are foiled by choosing the wrong ground type.

This needs not be the case since there are amateur methods available to measure these soil parameters. Understandably, these DIY methods do not offer outstanding precision, but are sufficient to choose a suitable ground type for modelling purposes.

This document deals with measuring the soil characteristics and describes building a soil probe, which comes especially easy if 3D printed parts are accessible. Measuring requires a vector antenna analyzer (or VNA). Two methods for calculating the soil parameters are presented, tested and discussed. Although both methods agree most of the time, the method according to DL1GLH offers superior stability under certain conditions.

Finally, this document shows and discusses results derived from real measurements. It became clear, that a probe length between 25 and 35 cm is best.

This work deals with the frequency span from 1 to 30 MHz, but the methods themselves are not confined to this range.

Summary

The properties of the soil at the antenna installation site can have a significant influence on the radiation properties of the antenna have. They are usually described by the conductivity ÿ in S/m and the relative permittivity (ie dielectric constant) ÿ of the earth as a dimensionless number. Also antenna simulation programs such as EZNEC or MMANA need these parameters for a calculation.

Unfortunately, very few radio amateurs know these values for their specific antenna installation location. Card material with these values is rare and often too imprecise. So usually all that's left is to set the value for "average ground" and hope that the error isn't too big. However, with low-hanging antennas and especially vertical radiators, this can have a significant impact on the simulation results and others This counteracts efforts to estimate the antenna properties as well as possible.

But that doesn't have to be the case, because with little effort and amateur means it is quite possible to measure the soil properties using the specific QTH. Even if you shouldn't expect high precision from these measurements, they provide more than a starting point for your own simulations.

This document provides an introduction to the problem and describes the structure of a measuring probe. Their production is very easy, especially if you have access to a 3D printer. A vector antenna analyzer (or

Network analyzer) required. Two methods for converting the measured impedance to ÿ and ÿ are described and evaluated. Although both usually lead to similar results, the DL1GLH method has proven to be more reliable under certain conditions.

Finally, practically carried out ground measurements are discussed. A length of the soil probe between 25 and 35 cm has proven to be optimal.

This work deals with the frequency range from 1 to 30 MHz. However, the fundamental usability of the methods used is not limited to these frequencies.

1.) Motivation

In the near field of an antenna up to a distance of around 4 ÿ from the radiator, the ground properties have a significant influence on its radiation characteristics. Antenna simulation programs also take this into account by allowing ground parameters to be set. Figure 1 shows an example of this selection in EZNEC1 . Here are the electrical conductivity ÿ in S/m and the relative permittivity (or dielectric constant) ÿ for some typical soil conditions including salt water.

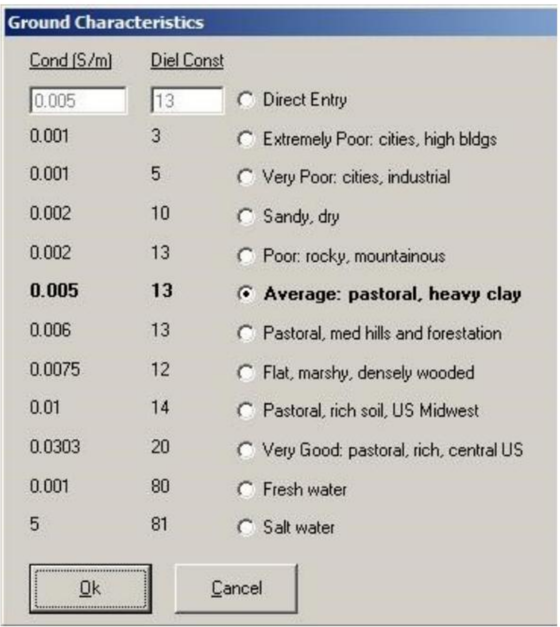

Image 1: Predefined soil parameters in EZNEC

A look at Figure 1 shows that the conductivity of the specified values for various soil qualities increases by a factor of up to 30 and the permittivity up to a factor of 7
differentiate.

In EZNEC it is also possible to enter your own values directly. This means that the self-determined ground parameters of your own antenna installation location can be taken into account in simulation calculations. Without further knowledge, the radio amateur often only has to use the value "Average: pastoral, heavy clay" (highlighted in bold for a reason) when modeling. Figure 2 shows that this selection can have a significant influence on the simulation result. It shows simulated elevation diagrams of a vertical antenna (5.5m fishpole with extension coil for the 40m band) made from EZNEC over different earth qualities.

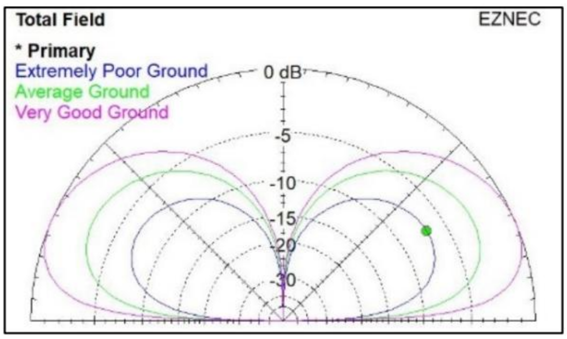

Figure 2: Radiation characteristics of a 40m vertical antenna over different ground qualities, simulated with EZNEC

Not only does the radiated power differ by 6.85dB with an ideal increase, the ideal radiation angle also drops from 32° in poor soil to 23° in very good soil. The total radiated power even varies by 7.1dB.

Mind you, all with the same power input!

Such differences are of course greatest for antenna shapes that interact strongly with the ground, such as vertical antennas or low-hanging dipoles. High-hanging antennas (in terms of wavelength) are less sensitive to different ground conditions.

Of course, the ground properties around the antenna may be different in different directions and distances from the radiator.
Distances of up to around 4ÿ, i.e. the area in the antenna's near field, play a role. Most simulation programs only allow limited granularity in the soil description, so in extreme cases you have to be satisfied with an average value.

Some allow a certain flexibility, such as:
EZNEC, where a second soil with different properties can at least be taken into account for the far field calculation.
Unfortunately, EZNEC does not see any frequency dependent ones Soil parameters, while in practice such a dependency is clearly present, as we will see below.

The fact that the depth of penetration of electromagnetic waves into the ground can be relatively large, depending from on the frequency and the nature of the ground, also remains problematic. Figure 3 shows that the penetration depth decreases with increasing frequency and soil conductivity.

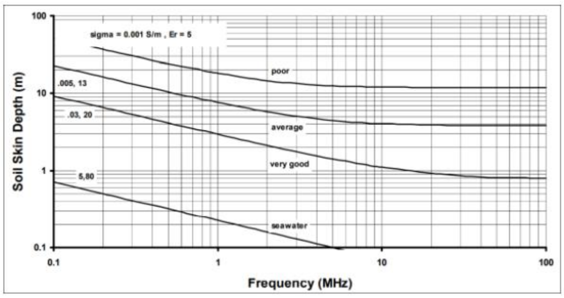

Figure 3: Penetration depth of electromagnetic waves into the ground2

Especially in poor soil qualities, the waves can penetrate several meters into the ground and can therefore also be influenced by the properties of deeper layers. Simple amateur probes, such as the one described here, measure the parameters of a

at best a few decimeters deep surface layer of the earth. In principle, it would be possible to obtain a complete picture down to greater depths through excavation and successive measurements, but the question arises as to whether the effort justifies the gain in knowledge.
In many cases one will therefore have to be content with surface measurements and an estimate for deeper layers. However, for good soil and from the 40m band, these probes already cover a good part of the relevant soil.

2.) Measurement method

In principle, two types of methods are used to measure soil properties.
On the one hand, the direct measurement using ground probes and, on the other hand, the indirect measurement by measuring signal strength at different distances from a transmitter and comparing it with simulation results. The second method is often used by commercial radio stations, but is labor intensive. Direct measurement is therefore usually preferred for hobbyists, although a variation of the indirect measurement in the form of impedance measurement on a low-hanging dipole3 and comparison with NEC4 simulations has already been used successfully by amateurs.

Direct measurements are described in the literature using two forms of measuring probes. The original variant of a ground spike, which is measured against a larger ground surface placed on the ground ("monoprobe"), has proven to be problematic with regard to the mobility of the probe and, in particular, to be sensitive to the way in which the ground surface is in contact with the ground . More recent work on this topic therefore mostly refers to a measuring probe in the form of two parallel ground spikes between which the impedance is measured vectorially. In terms of HF technology, these ground spikes represent a two-wire line that is open on one side, which is why this method is also known as OWL (Open Wire Line). An OWL probe was also used in this work.

In his detailed document4 "Measurement Of Soil Electrical Parameters At HF" Rudy Severns, N6LF describes both methods.

3.) Building an OWL probe

Figure 4 shows an OWL probe. It consists of two brass rods with a diameter of 6 mm, which are parallel to each other at a distance (center-to-center) of 50 mm are arranged. For this purpose, they are screwed into a 3D printed part5 , to which a BNC socket is also mounted. The screw connection is done via M4 internal threads, which are cut into the brass rods and the connection to the BNC socket with brass sheet. The circular part in Figure 4 serves as a guide when inserting the probe into the ground and remains directly under the handle during measurement.

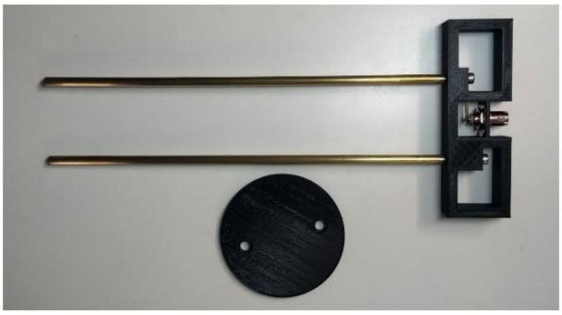

Figure 4: OWL probe for measuring soil properties

The brass rods are sharpened at the front to make it easier to drive the probe into the ground. Pulling it out after measuring is easy thanks to the handles in the 3D printed part.

Neither the diameter nor the distance or length of the conductors are particularly critical, but they define, among other things, the area of the floor that is included in the measurement. This is essentially a cylinder around the two rods, starting at the bottom slightly lower than the tips and extending to the surface. However, in practice it has been shown that a probe length of more than 30 to 40 cm can cause problems when piercing. This is the reason why the author also built a shortened second version that was around 25 cm long for a first version that was almost 50 cm long.

Figure 5 shows a detail of the sample handle with the 0.2 mm thick copper sheets for connecting the probe rods and BNC socket. Its jacket is screwed to the right sheet metal and the inner conductor is soldered to the left copper sheet.

Figure 5: Detail of the mounted handle of the OWL probe

A vector impedance measuring device (antenna analyzer or network analyzer) is connected directly to the BNC socket for measurement.
In the measurements described here, this was a NanoVNA6 which was previously calibrated so that the reference plane corresponds to the position of the BNC socket of the probe. The measurements themselves were carried out using the “NanoVNA Saver” software on a notebook and saved as S-parameter files.

4.) Evaluation of the measurement data

The ground parameters ÿ and ÿ must then be derived from the measured, complex impedance be calculated. The author has two for this Various methods are known, which are described and compared below.

Rudy Severns, N6LF describes a method that relies on the capacity of the measuring probe in air.
This must therefore initially be measured as accurately as possible, for which a reasonably accurate DMM (0.1pF resolution) or other capacitance measuring device is sufficient.
Important: The capacity of those parts of the probe that will later be in the ground must be measured! This is best done by subtracting the capacitance of the top of the probe from the total capacitance of the probe.

So first the capacitance of the entire probe is measured, in my case this was 7.1 pF for the long probe and 5.2 pF for the short version.
The brass rods are then replaced with shortened rods that only go to the underside of the round base part. This remainder CP therefore represents exactly the part of the probe that will later be outside the ground and in my case was

measured with a capacity of 2.3 pF. This means that the effective capacitance C0 of the long probe is 4.8 pF (= 7.1 - 2.3) and that of the short probe is 2.9 pF. When making these measurements, care must be taken to ensure that the capacity is not distorted by surrounding materials.

Rudy Severns does provide formulas in his work Calculation of soil parameters on, on another However, these can be found easily in place 7 modified form. These differ in particular by a subtractive term at the Calculation of the ÿ from the documentation at N6LF.
Our own measurements have clearly shown that the modified form is to be preferred, which is why it is also listed here:

$$= \frac{8{,}859}{_0} \cdot \frac{}{(2+2)} \qquad (1)$$

$$= \frac{106ÿ}{2\ ÿ\ 0ÿ(2+2)} - \frac{}{_0} \qquad (2)$$

with:

- Conductivity of the earth [S/m]
- Relative permittivity of the Earth, dimensionless
- 0 : Capacitance of the probe part in the ground [pF]
- Capacitance of the probe part above ground [pF]
- Frequency of measurement [MHz]
- Effective resistance, measured [ÿ]
- Reactance, measured [ÿ]

As soon as the capacities of your own probe have been determined, the measured impedance values in the ground can easily be converted into the ground parameters using a spreadsheet. I will refer to this method somewhat loosely as the capacity method.

Another type of calculation is described by Hardy Lau, DL1GLH on his website8 . He views the sample as a two-wire line, the open, lower end of which is transformed to the upper end depending on the ground conditions and measured there.
On his website, Hardy Lau gives the transformation equation as well as an approximation for taking into account the end effect of the open two-wire line. The determining parameters are length, distance and diameter as well as the material of the earth rods. From this and the measured impedance, he determines the impedance using an iterative process that is not described in detail

Soil parameters and also provides a corresponding program for download. This is also available in an online version on his website, which I used for this work. Figure 5 shows the input mask for this tool. The operation is self-explanatory, only the need to use a period instead of the comma as a decimal separator and to specify the frequency in MHz (megacycles, Mc) is noted.

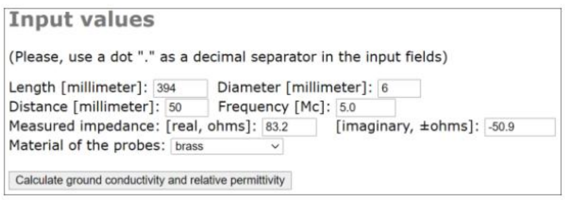

Figure 5: Input window for the DL1GLH online calculator

After pressing the calculation button, the program returns the calculated input impedance (not infinite due to end effects large), the necessary impedance of the transformation line to explain the measured impedance and the ground parameters calculated from this.

The disadvantage of this method, which I will now call the transformation method, of having to rely on the computer (online/onsite), is offset by the advantage of not having to carry out a measurement of the sample capacity compared to the capacity method. However, the sample dimensions must be known with millimeter precision.

5.) Evaluation of the procedures

At the outset, I would like to make it clear that no excessive expectations should be placed on the accuracy of these measurements of soil parameters. However, a high level of precision is not necessary and a deviation of, for example, 25% does not pose a problem in modeling, as Rudy Severns also states in the introduction to a publication. In addition, other effects, such as previous rainfall, cause greater fluctuations in the parameters. Nevertheless, these measurements using amateur means are sufficient to no longer have to make “blind” assumptions about the ground conditions in antenna simulations.

In order to gain confidence in the measurements, especially for use in the shortwave range, and also to be able to compare the two calculation methods, test measurements were carried out. These were carried out in materials with known properties: air, fresh and salt water, with a 0.61 molar NaCl solution serving as a substitute for seawater for the latter. Figure 6 shows the measurement setup.

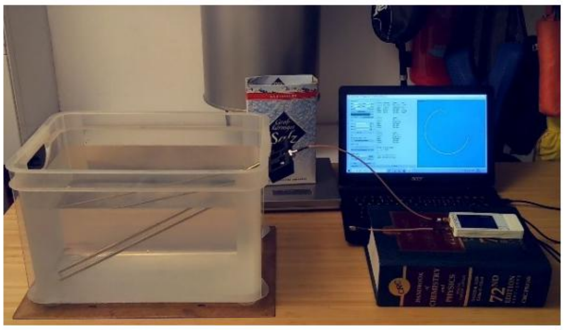

Figure 6: Setup for test measurements

As expected, both methods provided extremely low conductivity in air (<0.1 mS/m) over the entire frequency range from 1 to 30 MHz for both probes. The results were more differentiated and somewhat surprising

Dielectric constant for which a value of 1 was expected. While the capacity method delivered a value of around 1.4 for the long sample, this was around 0.7 for the short sample. The transformation method indicated a high value of slightly above 2 in all cases.

The measurements in tap water immediately showed an increase in the calculated conductivity and especially the permittivity. Both methods showed values of 0.015 to 0.04 S/m for both probes (increasing with increasing frequency). For the dielectric constant, values between 70 and 90 were determined using the transformation method, while the capacitance method provided values between 40 and 70. These measurements revealed a weakness of the capacitance method for the first time: in the vicinity of natural resonances, i.e. when the magnitude of the measured reactance becomes small, extreme values for both ÿ and ÿ sometimes occur. Here the transformation method proves to be significantly more robust.

The tests in salt water finally resulted in the calculated some surprises. The conductivities increased significantly compared to previous measurements and, with maximum values of 4 S/m using the transformation method, came close to the published values (5 S/m). However, these values fell rapidly with increasing frequency and were sometimes below 0.05 S/m at 30 MHz. The results of measurements using the capacity method were still lower in some the cases.

The calculated dielectric constants were even worse: at low frequencies they delivered completely implausible values of several hundred units; only from 25 MHz both methods achieved values between 70 and 90. Here, doubts remained about the admissibility of the measurement setup, especially its limited volume. However, due to the lack of access to sea water and considering the cold season, I left it at that.

Nevertheless, the test measurements were able to increase my confidence in the measurements, especially for the planned area of application in soil. The behavior of the calculated conductivity is plausible for both methods and is roughly the same (outside the resonance ranges, see above). The permittivity of air and fresh water is also at least in the expected range. Since real soil properties usually lie between these two media, probably even closer to fresh water, plausible values could be expected when using the probes.

6.) Measurements on ground

The first soil measurements took place in our own garden at various positions in well-maintained and fertilized lawns. Before these measurements it rained heavily and due to the winter weather the ground was completely soaked. In particular, a location at the foot of a slight embankment and close to the rainwater seepage led to the expectation that excellent conductivities would be found here.

Although the soil was well maintained overall, it quickly became apparent that the longer probe with a penetration depth of almost half a meter could not be completely inserted into the ground in several places due to stones, whereas the shorter probe could always be. Even without stones, pushing in and pulling out the long probe in the lowest part was very laborious due to the frictional forces and the resulting loads reached the limits of the material. Based on these experiences, when building a new probe for good soils, I would recommend a length of 35 to 40 cm. For medium soil quality, a probe length of 25 cm should be useful.

Already the first measurements at the foot of the embankment met expectations and indicated high soil conductivity. Both measurement methods were in reasonable agreement and the frequency curve was as described in the literature.
While the conductivity ÿ increased from 1 to 30 MHz with increasing frequency (Figure 7), the permittivity ÿ decreased (Figure 8).

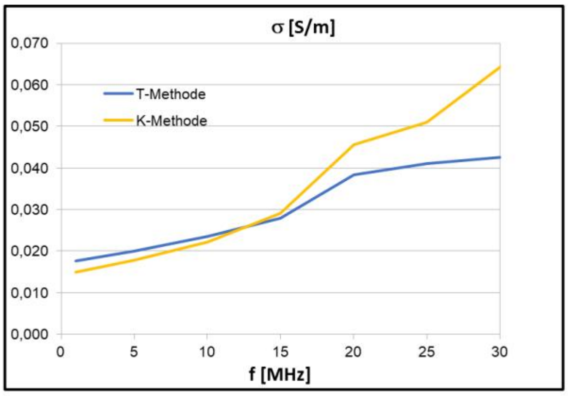

Figure 7: Soil conductivity in a very damp area, measured with the short probe

In the figure legends, "T-method" stands for the transformation method and "K-method" stands for the capacity method.

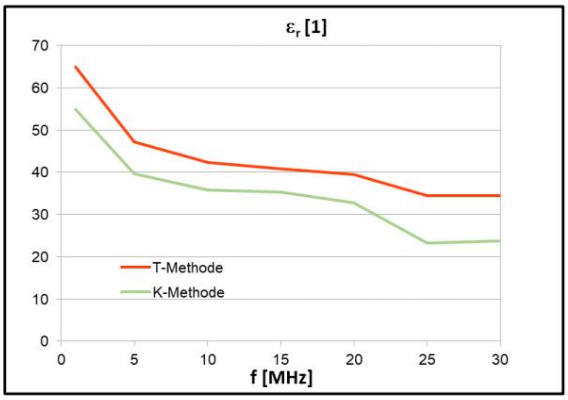

Figure 8: Relative permittivity, moist soil, short probe

The two methods agree well over long distances; only at high frequencies does the capacitance method calculate a significantly higher conductivity than the transformation method. Looking at the data in EZNEC in Figure 1, this soil can certainly be described as "Very Good". The fact that the permittivity is even above the EZNEC value can be easily explained by the extremely high level of moisture. However, it is also clear that an average value cannot really do justice to the frequency-dependent curve. The measured conductivity at 30 MHz is more than twice the value at 1 MHz.

The relative permittivity measured using the transformation method is constantly slightly higher than that using the capacity method. A behavior that was also evident when evaluating the processes on air and tap water. However, the difference remains manageable and so an average value can be entered into the simulation programs with a clear conscience.

In the next step I repeated the measurements at the same point but with the long probe. The
The conductivity values calculated from this are shown in Figure 9 in addition to those of the short probe.

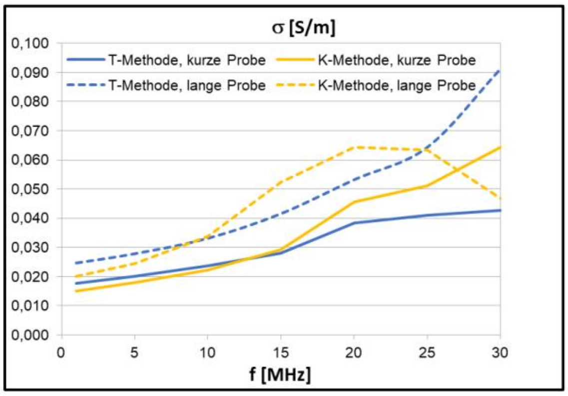

Figure 9: Comparison between measurements with different Sample lengths

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It is noticeable that both calculation methods typically result in a higher soil conductivity for the longer probe. This may indicate an increase in deeper layers (higher moisture content?). On the whole, the values are also confirmed by these measurements. An exception are the calculations after the capacitance period for the long sample (yellow dashed line in Figure 9) at frequencies above 20 MHz. However, a look at the measured impedance values (see the corresponding Smith chart in Figure 10) quickly clarifies: It is precisely at this frequency that resonance occurs and above that positive reactances occur. It has been shown time and time again that the capacity method has problems in these areas.

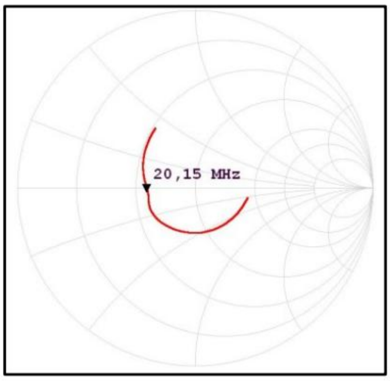

Figure 10: If the reactance is small or positive, as here from around 20 MHz, the capacitance method usually leads to implausible results

I have therefore made it a habit to always carry out the calculations using both methods and to also take a look at the measured impedances during the evaluation.
If I had to choose a method, I would probably choose the transformation method give preference because it has repeatedly proven to be more stable.

The values shown in Figures 11 and 12 were measured with the short sample in another, slightly less moist place.

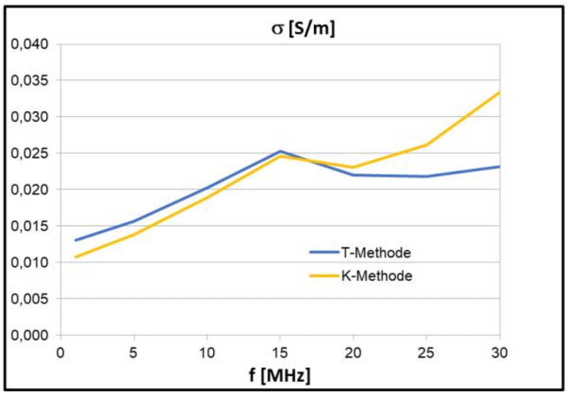

Figure 11: Soil conductivity in a slightly less moist place

It is obvious that the conductivity is significantly below that measured below the slope (see Figure 7). What is noticeable is the kink at 15 MHz, which is not due to the resonance problem described above. It also occurs not only with the capacity method, but also with the transformation method.

Together with the much more stable permittivity curve (Figure 12), this may therefore not be an artifact, but an actual property of the conductivity of this soil at higher frequencies.

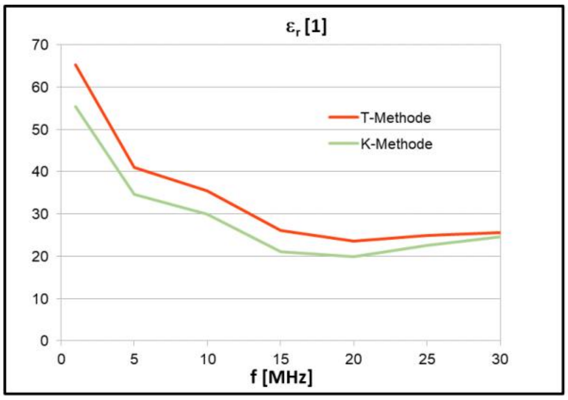

Figure 12: Relative permittivity of the less moist soil

When comparing the relative permittivities from Figures 8 and 12, it is noticeable that these are approximately the same for the very moist and moderately moist soil. A comparison with measurements on dry soils would be interesting here.

In summary, it has been shown that measuring soil properties with an OWL sample is also possible using amateur means and provides plausible results. The method is absolutely suitable for the field as long as a portable, vectorial measuring device is available. A sample length of around 35 to 40 cm will be practical for good soils, but only 25 cm for poorer soil qualities. Both calculation methods (capacitance and transformation method) lead to similar results over wide ranges, but the capacity method can be problematic near resonances and with positive reactances.

[1] *https:// www.eznec.com/*

[2] Quelle: „Skin Depth And Wavelength In Soil", Rudy Severns, N6LF

[3] "Determination of Soil Electrical Characteristics Using a Low Dipole", Rudy Severns, N6LF, erschienen in QEX Nov/Dec 2016

[4] *https:// www.antennasbyn6lf.com/ files/ ground_parameter_measurements_2.pdf*

[5] The part description is here: *https:// www.thingiverse.com/ thing:4750825*

[6] *https:// www.amazon.de/ dp/ B083BB82G5*

[7] See for example: Jürgen A. Weigl, OE5CWL, "Simple measuring probe for determining soil properties", Funkamateur magazine 6/09

[8] *https:// www.dl1glh.de/ groundconductivity.html*