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High Frequency Resistance and Capacitance Measurement for Archaeological Surveying

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SUMMARY

There are many different ways to map underground archaeological features. The open-ended coaxial probe, described in this paper, is another new prospective method. The principle of this method is to measure the microwave reflection co-efficient at particular points on the surface to map out subsurface features. Apart from non-destructive and low cost, a major advantage of this method is the ease of implementation and the additional data provided. In this paper, the principle of open-ended coaxial probing is discussed, and some experimental results

Introduction

Various methods, such as ground penetrating radar (GPR), resistivity and magnetometry have been used for mapping underground archeological features. The GPR is used to record the time duration from an electromagnetic wave reflected from a feature or a layer within the ground to map subsurface features. This method can be used over a hard surface, and has a comparatively high resolution. The resistivity method relies on the detection of the electrical resistance of the soil. An electric current is introduced into ground through a pair of electrodes. The current intensity between these electrodes depends on the conductivity of the ground. This method is highly dependent on the moisture content of the soil (Abingdon archaeological geophysics, 2005). Radar methods are not good for detecting features that are close to the surface, whereas the resistivity method can map features that are close to the surface very well. The method described here has the advantage of mapping features that are close to the surface as well providing information on the high frequency resistance and permittivity (capacitance) of the subsurface structure. This new geophysical method is based on open-ended coaxial probe. By placing the probe on the ground and measuring the reflection coefficient of a signal, the average resistance and capacitance generated by the material below the probe can be deduced. Further computation can be performed to extract the average permittivity and resistivity if necessary.

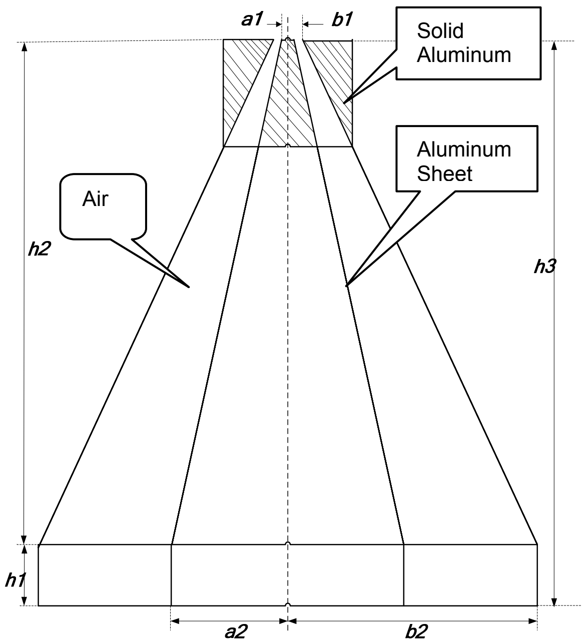

Figure 1. Longitudinal Cross Section of the Open-ended Coaxial Probe

Electrical Data	
Characteristic Impedance	50 Ohms
Materials	
Conductor	Aluminum
Insulator	Air
Dimensions	
Top Part	$a1$ = 2.5mm, $b1$= 5.75mm.
Bottom Part	$a2$=280mm, $b2$=650mm
Bottom Part Height	$h1$=200mm
Transition Height	$h2$= 1430mm
Total Height	$h3$= 1630mm

Table 1 Summary of the properties of the coaxial probe

The open-ended coaxial probe is shown in Figure 1. It is basically a coaxial cable tapered from a narrow top (to fit a standard coaxial cable) to a wide bottom. There are three main parts, which are the bottom non-tapered part, the middle tapered part and the top tapered part, in the measurement system. A 50 Ω characteristic impedance is maintained throughout the whole length. The bottom part is a cylinder, which has an outer and inner radius of $b2$=650mm and $a2$=280mm, respectively. The middle part is two hollow cones. Both the bottom and the middle parts are constructed with Aluminium sheets. Medium Density Fibreboard (MDF) is employed to fix the position of the outer and inner conductor. The top part (shown as hatched in Figure 1) is manufactured from a solid Aluminium cylinder. The properties of our coaxial probe are summarized in Table 1.

Although there are many parameters that can be extracted from this measurement system, the reflection coefficient (Γ) is the only parameter that will be directly measured. To illustrate the refection coefficient concept, the transmission theory will be briefly presented. Figure 2(a) shows the equivalent circuit for the measurement system in a form of a transmission line model. In Figure 2(a), Part 1, Part 2, and Part 3 represent a signal source, the open-ended coaxial probe and the ground, respectively. When carrying out measurement, the load impedance Z_l will vary as the condition of the ground changes. The measured parameter is the reflection coefficient which is given by

$$\Gamma = \frac{Z_l - Z_o}{Z_l + Z_o} \qquad (1)$$

where Γ is measured at the receiver end of the transmission line (z=0). Z_o is the characteristic impedance of the coaxial probe. Rearrange equation (1), gives:

$$Z_l = Z_o \frac{1+\Gamma}{1-\Gamma} \qquad (2)$$

Equation (1) shows that the reflection coefficient (Γ) changes when the load impedance (Z_l) is changed. So by placing the probe at different location on the ground, a different reflection coefficient (Γ) can be measured. By measuring an area of the ground, a contour map of reflection coefficient (Γ) can be built up. The subsurface feature can then be deduced from the contour map.

To extract the resistance and the capacitance associated with the ground, the load impedance can be modeled using a simple parallel RC circuit as shown in Figure 2(b). In this model, the load impedance will take the form,

$$Z_l = R + \frac{1}{j\omega C} \qquad (3)$$

where ω= 2π f and f is the operating frequency. From the measured reflection coefficient data, the load impedance Z_l can be calculated using equation (2). Then the resistance and capacitance can be extracted using equation (3). Contour maps can be plotted for the resistance and capacitance.

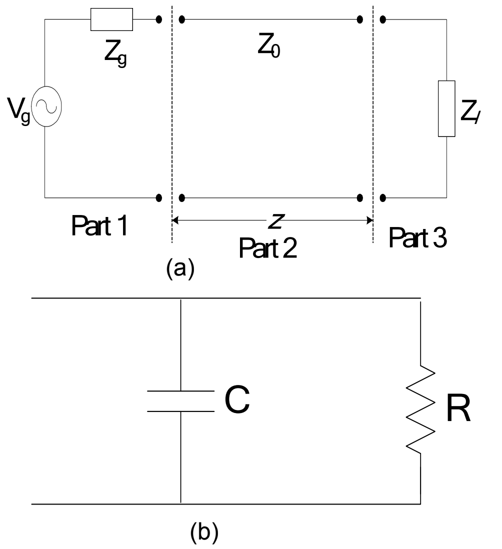

Figure 2: Equivalent circuit of a) the open-ended Coaxial measure system b) the Ground

Figure 3: The Practical Open-ended Coaxial Probe Measure system

Surface Measurement

An experiment has been carried out to determine whether the coaxial probe can measure surface variations. An area of 4.5 x 4.0 m^2 with distinct different in surface properties has been chosen. Figure 4(a) shows the map of the area. The reflection coefficients were measured at every 0.5m steps in a grid on the ground surface. Figure 4(a) also shows the distribution of these 9×8 measurement points and the location of the open-ended coaxial probe at points (1, 1), (1, 9) (8, 1), respectively. The green area represents a grass surface, while the white area represents a concrete footpath. Two metal manhole covers on the footpath are shown in charcoal grey. A contour map at f = 60MHz for this experiment is shown in Figure 4(b).From the contour map, there is a good distinction between the grass and the concrete, with clear separation between the two. The two metal lids of the manhole cover on the concrete also show up on the contour map, i.e. the two reddest areas in the contour map.

Based on the model shown in Figure 2(b), the equivalent resistance and capacitance of the ground have been extracted. Figure 4(c) is the contour map of the resistance. Figure 4(d) shows the capacitance (in Pico Farads) of the ground.

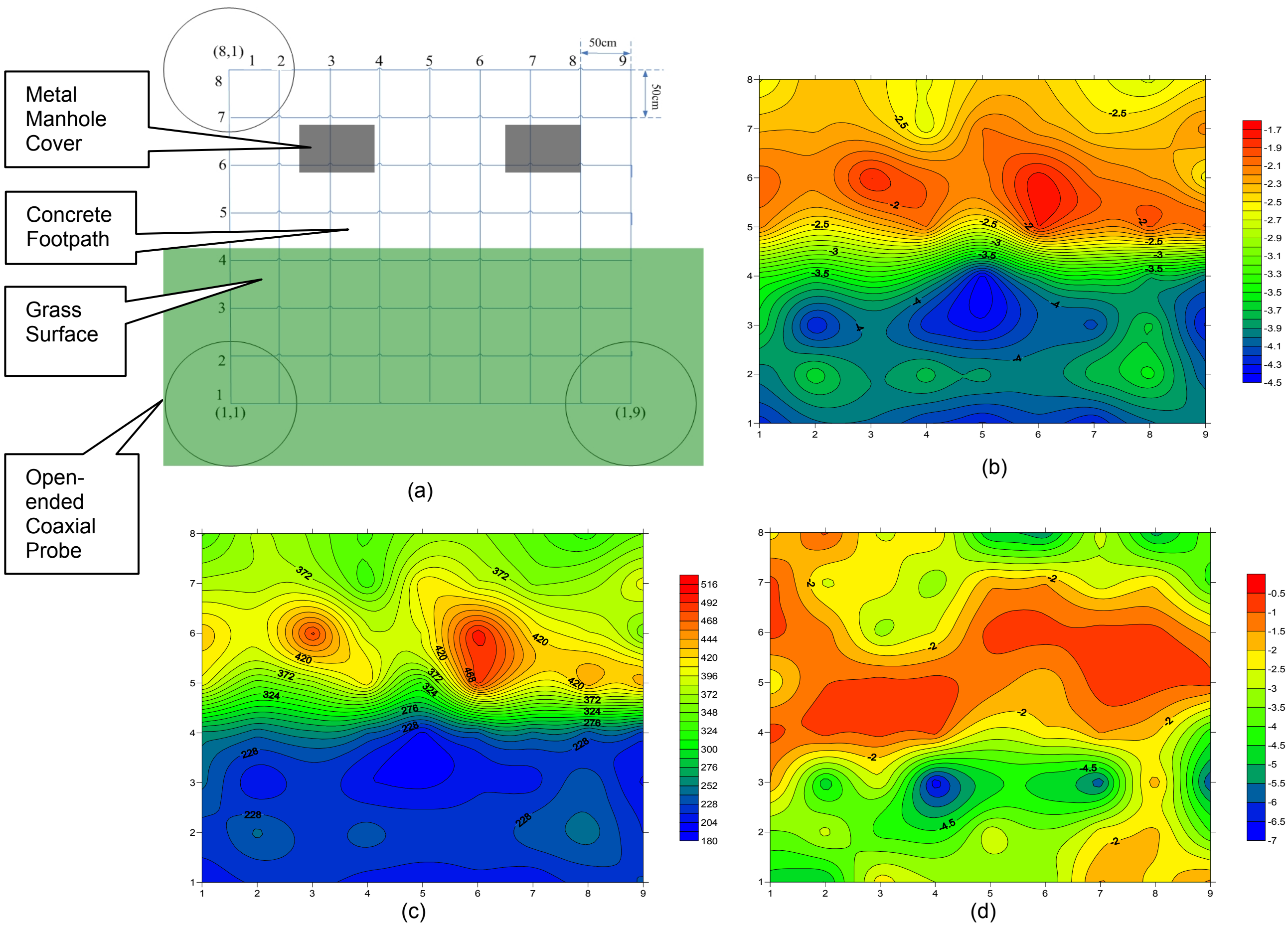

Figure 4:a) The Geographic map of the surface measurement; b) Contour map of the amplitude of the reflection coefficient, the *x* axis and *y* axis are positions which have the same meaning as axes in Figure 4(a) and the color bar shows scale of the amplitude of the reflection coefficient in decibels(dB); c) . Contour map of R (Unit: Ohms). The color bar represents the value of R. This map is generated basing on the measured reflection coefficient and the model in Figure 2(b); d) Contour map of C (Unit: Pico Farads). The color bar represents the value of C. This map is generated basing on the measured reflection coefficient and the model in Figure 2(b)

In this particular case the resistance map is more useful in determining the structures. However, more work is required in order to determine the usefulness of the method for subsurface surveying under different conditions.

Survey at Wroxeter

The open-ended coaxial probe is further tested at the Roman City of Wroxeter. Many techniques include aerial photography (AP), geophysical prospecting, and topographical methods have been used to survey on this area [1]. Therefore, a good map of the Wroxeter Roman City is available. This will allow a comparison between the measured data acquired by open-ended coaxial probe and the map acquired by other methods.

Figure 5(a) shows part of the map of this site. The highlight rectangle is the area where a coaxial probing has been performed. The graph in Figure 5(b) shows the amplitude of the reflection coefficient over the measured highlight rectangle area shown in Figure 5(a). Figure 5(c) and 5(d) are the contour line maps of the extracted resistance R and capacitance C maps, respectively. The survey is inconclusive at present and no identifiable features are present on the maps. In order to proceed further a larger area may be appropriate and/or an area with shallower features.

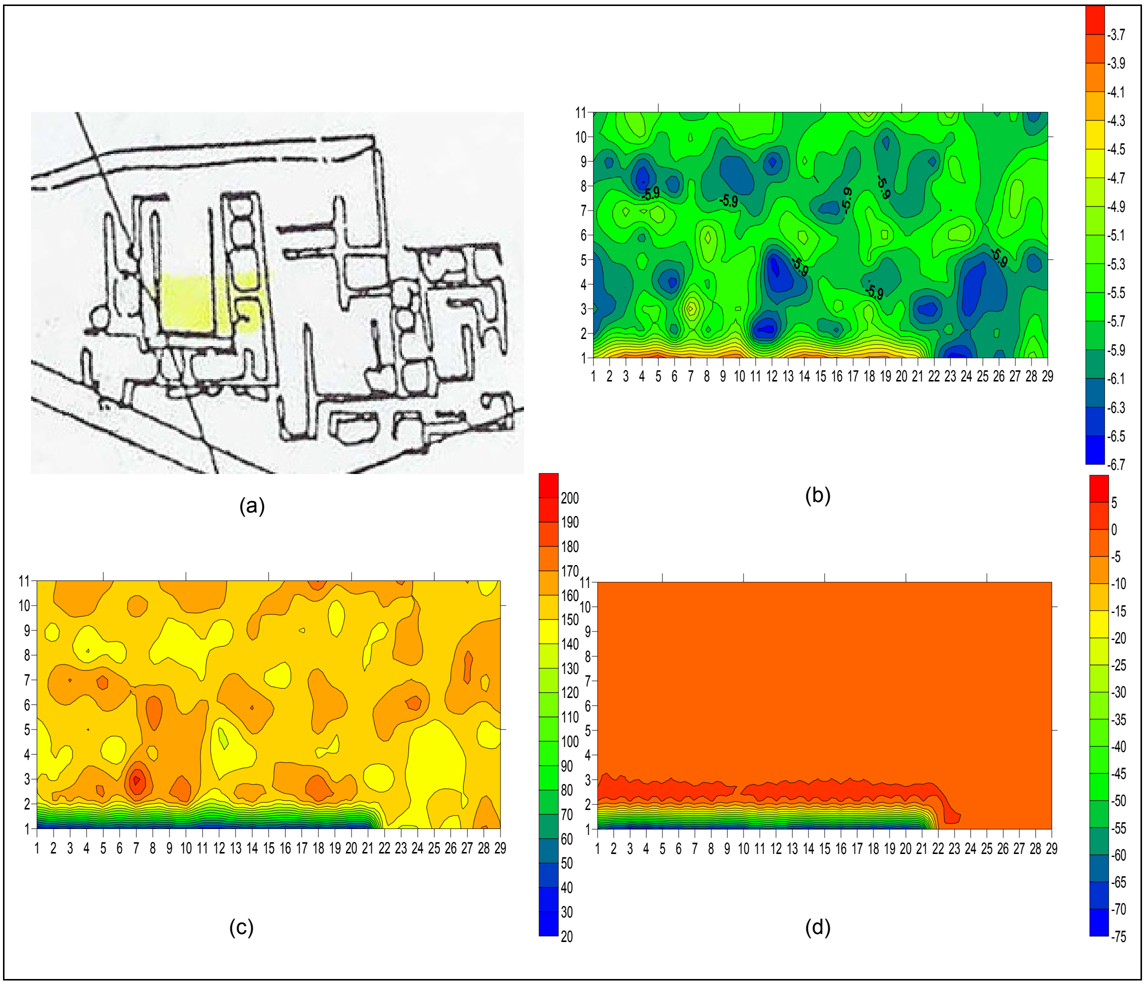

Figure 5: a) Part of the map of Wroxeter. The highlight part is a rectangle area we measured, which is 19.5m×7.8m; b) Contour map of the amplitude of Γ measured at Wroxeter. The color bar represents the amplitude of Γ in decibels (dB); c) Contour map of R acquired at Wroxeter (Unit: Ohms); d) Contour map of C acquired at Wroxeter (Unit: Pico Farads)

Conclusion:

We have shown that the open-ended coaxial probe measurement system is capable for geophysical measurement. However, further improvement in the system is required to improve the accuracy of measurement. The present probe is rather bulky and difficult to move around for measurement. Therefore, it is beneficial to improve the physical coaxial probe design with more ergonomic construction to reduce the measurement time. More work is needed on the usefulness of both the capacitance and resistance measurements, which are available over a wide frequency range. In addition, more survey work is required in order to determine the usefulness of the device. An area with shallower features would be an interesting start. In conclusion, the technique has promise, but more work is needed.

Reference:

http://www.iaa.bham.ac.uk/bufau/research/WH/tours/geophysics.html [Assessed in July, 2008]

Abingdon archaeological geophysics. 2005. *Archaeological geophysics: a Short Guide.*