COMMON MISCONCEPTIONS ABOUT CAPACITIVELY-COUPLED RESISTIVITY (CCR)
WHAT IT IS AND HOW IT WORKS

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Abstract

Capacitively-coupled resistivity imaging systems have been available as commercial geophysical instruments for over eight years and have seen increased acceptance in near-surface engineering applications (Ball 2006), (Garman et. al. 2004). In order for a geophysicist to determine whether a capacitively-coupled resistivity meter would be appropriate for a particular application requires a fundamental understanding of the technique and its relative capabilities and limitations in relation to other near-surface imaging tools. The underlying principles of the technique are outlined in the existing literature (Kuras et. al. 2006), (Timofeev et. al. 1994). This paper is intended to point out and discuss some of the most common misconceptions about capacitively-coupled resistivity (CCR) and to review practical considerations in basic survey fundaments compared to other resistivity measuring techniques. The Geometrics OhmMapper TRN is a commonly used CCR instrument, using a dipole-dipole configuration, and will be the base of reference for this paper (Figure 1).

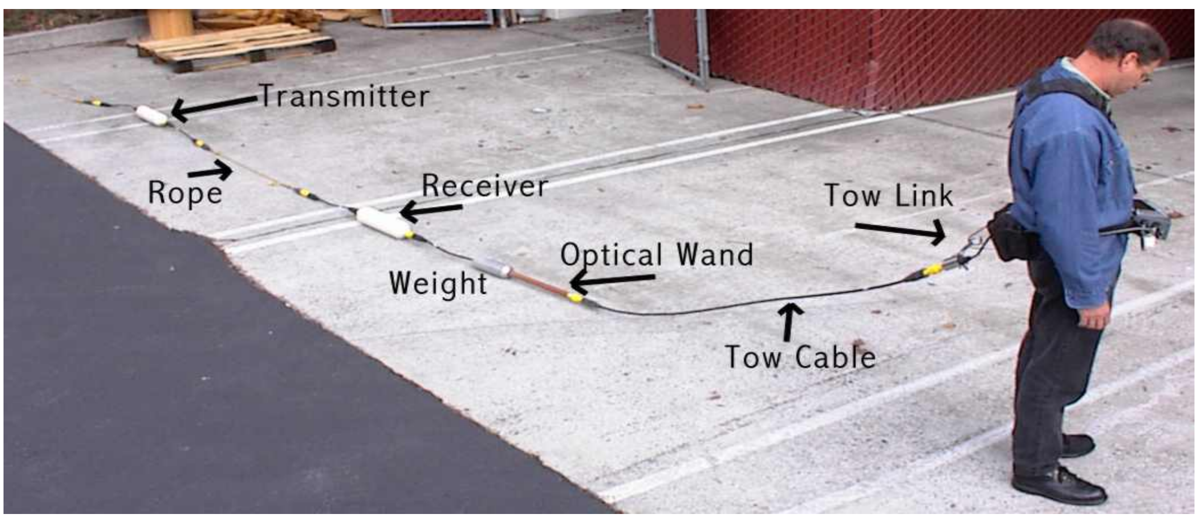


Figure 1: Towed capacitively-coupled, dipole-dipole array (photo courtesy of Geometrics, Inc.)

Theory of Operation

The fundamental principle of capacitive coupling is that AC current will pass through a capacitor. In a CCR instrument a cable (or metal plate) acts as one half of a capacitor, while the earth functions as the other half. This cable-earth capacitor (Figure 2) has a variable capacitance depending on the earth conditions, but an AC current generated by the transmitter will pass from the cable into the ground. At the receiver the transmitter-generated ground current will generate an AC voltage that is coupled into the CCR receiver and measured. The CCR receiver is conceptually equivalent to an AC

Volt meter. In the OhmMapper the dipole cables are a shielded twisted-pair. The transmitter drives a 16.5 kHz signal onto the cable shield and that signal is “lost” to the ground through the capacitance of the cable.

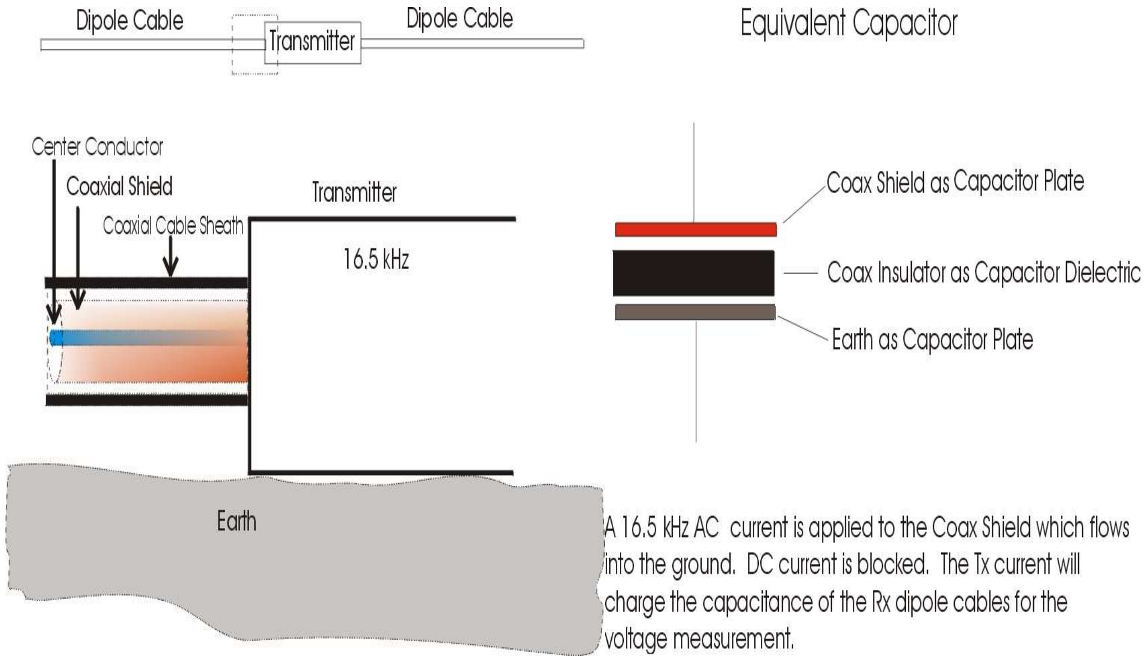


Figure 2: Equivalence of the cable-ground capacitor to a traditional capacitor.

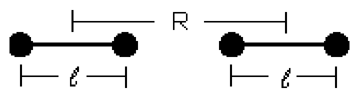
Is a CCR instrument an EM device?

Under normal operating conditions the CCR technique is not regarded as an EM device. For example, the OhmMapper is a resistivity meter measuring electric fields only. The magnetic field can be ignored as long as the transmitter-receiver separation is within a skin depth. It is not factored into the measurement in the OhmMapper. . This doesn’t mean that EM phenomena aren’t present and aren’t influencing the measurement. It simply means they can be safely ignored under the operating conditions of the OhmMapper. As long as the Tx-Rx separation is within one skin depth ($503^* \sqrt{\rho/f}$) any errors introduced by EM effects can be assumed to be less than 2%, which is less than instrument and environmental measurement variability. This 2% number is based on theoretical calculations (see Millet) and practical observations of comparative CCR and galvanic results. EM effects here are considered to be the contribution of the quadrature (imaginary) component of the field. Standard measurement is of the in-phase (real) component. The quadrature component’s affect on the calculated resistivity is negligible when the transmitter-receiver separation is less than one skin depth.

How is CCR similar to standard galvanic resistivity

There are notable similarities between a standard galvanic resistivity meter (stakes in the ground) and a capacitively-coupled resistivity meter. In both, the depth of investigation is determined by the geometry of the array, not the signal frequency or the timing of the measurement. In both galvanic and capacitive resistivity the apparent resistivity is calculated using a geometric ‘K’ factor. That is, resistance is normalized to resistivity by a factor for the array type. The geometric factor for a DC, galvanic, point-source measurement is considerably different from that of an AC, capacitive, line-source measurement, but both factors are derived from the same general principles. The standard galvanic dipole-dipole geometric factor is well known and can be found in many geophysical, electrical theory references (Telford et. al. 1990). The geometric factor for conversion of OhmMapper measurements to resistivity is given in Figure 3.

$$\rho = K \cdot \Delta V / I$$



$$\frac{1}{K} = \frac{\Delta V}{\rho_\omega I} = \frac{1}{\pi} \int_0^{l_1} \int_0^{l_2} \frac{I(L_1)}{I_{(L_1=0)}} \frac{I(L_2)}{I_{(L_2=0)}} \frac{dL_1 dL_2}{R^3}$$

$$K = \frac{l\pi}{\ln\left[\left(\frac{b^2}{b^2-1}\right)^{2b}\left(\frac{b^2+2b}{(b+1)^2}\right)^{(b+2)}\left(\frac{b^2-2b}{(b-1)^2}\right)^{(b-2)}\right]} \qquad \text{where} \qquad b = 2R/l$$

Figure 3: Capacitive, AC, line-source, dipole-dipole geometric factor

How is CCR different from a standard galvanic resistivity meter.

There are also some significant differences between CCR and galvanic resistivity that should be taken into account when making a decision on what type of instrument should be applied to any specific job.

1. Galvanic resistivity uses a nominal DC current generated at the transmitter and DC voltage measurement at the receiver. There is often a low switching frequency, of 30 Hz or less, used to prevent polarization of the measurement electrodes and avoid amplifier distortion, but for all intensive purposes the transmitter current can be considered to be a DC current when compared to the higher frequencies of greater than 16,000 Hertz of a CCR system. Although both CCR and galvanic systems use alternating current the difference is that a CCR system typically uses orders of magnitude higher frequencies. There are advantages and disadvantages of both DC and AC measurements. On the positive side, capacitive AC measurements are generally immune to power-line and natural telluric interference because these currents are relatively low frequency AC currents and are not easily coupled into the CCR dipole cables. The CCR receiver can also narrowly band limit the measurement to look only at the CCR transmitter frequency and avoid telluric, power-line, and other signal sources, thus increasing noise immunity from lower-frequency and higher-frequency noise sources. On the negative side the transmitter-receiver separation needs to be within a skin depth of the transmitter frequency in order to avoid unwanted EM affects on the measurement. The OhmMapper uses a transmitter frequency of approximately 16.5 kHz. This will limit depth of investigation, especially on conductive ground where skin depth is less than on more resistive ground. The inverse of this is true for a galvanic resistivity meter. Although, under certain conditions, the quality of the measurement can be compromised by power line and telluric currents, the DC (or near DC) transmitter means the skin depth effect can be ignored in essentially all ground conditions. The exception to this is for very powerful galvanic

resistivity/IP, long offset systems – they can be noticeably affected by EM effects caused by the low-frequency AC waveforms they rely on.

2. Galvanic resistivity measurements use point-source stakes for the dipoles whereas CCR uses line-source cables for dipoles. For galvanic measurements the current injection is at the point of the dipole stakes, and the measurement is at the point of the receiver stakes. CCR uses line-source cables for the dipoles, meaning that the current is coupled into the ground along the length of the transmitter dipole cables, and the voltage measurement is made along the length of the receiver cable. The total length of the CCR cable dipoles are treated as equivalent to the distance between the two stakes of a galvanic dipole. This equivalence is determined mathematically by the geometric factor used on the conversion of V/I to apparent resistivity.

Survey technique as compared to multi-electrode galvanic resistivity survey

The concepts of both a galvanic resistivity survey and a CCR survey are fundamentally the same. In both techniques the depth of investigation is determined by the total array length. Longer arrays provide greater depths of investigation. This is commonly translated into n-space where a dipole-dipole "n" of one is equivalent to a separation between the transmitter and receiver dipoles equal to the dipole length. For example, if the separation between the two transmitter stakes were 5 meters, and the distance from the end of the transmitter dipole to the beginning of the receiver dipole were 5 meters then the array is an "n = 1" array. An "n" of 2 would be a separation of twice the dipole length, an "n" of three is three times the dipole length, etc.. A galvanic, 2-D dipole-dipole resistivity survey is done by making successive measurements at n = 1, n = 2, etc. with each measurement representing an apparent resistivity at a different depth. This provides a 1-D sounding. The transmitter location is then moved and the process is repeated at the new sounding position. This procedure will generate multiple 1-D soundings at several locations along a profile line to create a 2-D data set.

A towed CCR survey, on the other hand will generate a series of readings at a uniform depth as the transmitter-receiver array is towed along the profile line with a fixed separation between the transmitter and receiver. A second traverse can then be done with a greater n space to allow for a series of readings along the profile line at a greater depth. As additional traverses are done at different n spaces a 2-D data set is created. This process can be greatly sped up by towing an array of several receivers, each at a different n space from the transmitter, thus generating several different profile depths on the same traverse. Typical one-receiver and multiple-receiver arrays are pictured in Figures 4a and b.

Figure 4a: Single-receiver manually-towed array

Figure 4b: Five-receiver vehicle-towed array

In both galvanic and CCR surveys the depth of investigation is determined by the total length of the array (Tx dipole length + Rx dipole length + Distance between dipoles)

|----------total array length = L----------|
|____Tx____| separation |____Rx____|

- For n >= 3 depth = total array length/5 (0.2L)
- For example if Tx=5m, separation = 30m, Rx=5m then depth=8m. (0.2 * 40m)
- For n=1 depth = array length/7.2 (0.14L)
- For n=2 depth = array length/5.7 (0.17L)

Practical considerations

As in any technique there are many issues to take into consideration when making a decision to use one geophysical technique or another. Noise sources, soil type and other site conditions, target size and depth, and many other factors all come into play when evaluation the most appropriate tool for the job.

Advantages and drawbacks of capacitively-couple resistivity (OhmMapper)

Noise sources play an important role in data quality. As mentioned earlier power lines and telluric currents tend to be noise sources in traditional galvanic resistivity but are not a major source of noise in a band-limited CCR system. Of course it is possible for a local transmitter to be in the frequency band of the transmitter (16.5 kHz in the case of the OhmMapper). If this occurs it would be a severe noise source, but if the receiver is narrowly band limited to only the transmitter frequency the odds of encountering an environmental noise source at the exact transmitter frequency is minimal. CCR is not affected by high contact-resistance problems since this is strictly a phenomenon resulting from poor contact between a point electrode and the ground. It is not a consideration in capacitive coupling. A different, but analogous, problem for CCR would be a dramatic reduction in the cable-to-ground capacitance such as would occur if the cable were to be lifted off the ground.

A common problem for both capacitive and galvanic resistivity would be the presence of a long-linear conductor along the profile line. For example a railroad track, metal gas pipeline, grounded metal fence, rebar, or other linear metal conductor parallel to the transmitter-receiver array would channel the transmitter current into the metal conductor such that the resistivity measurement would be unreliable. It is a simple Ohm's Law problem. Essentially all the current would flow in the metal and not the ground. The receiver is measuring voltage. Since V=IR and R is extremely low the resulting voltage is also extremely low to the point of being unmeasurable.

Since a CCR measurement is generally made while the array is being towed along the ground the speed of the tow vehicle is another consideration. The OhmMapper samples at 1 measurement per second. At a tow speed of 3.6 km/hour the ground is sampled every meter. Obviously, at 1.8 km/hour the measurement density is higher (every 50 centimeters), and at 7.2 km/hour it is coarser, at 2-meter sample intervals. Higher resolution and better target definition is provided by slower survey speeds. The recommended survey speed of the OhmMapper is less than 5 km/hour.

Conclusions

As is the case with all geophysical tools, there are appropriate and inappropriate uses of capacitively-coupled resistivity imaging systems. In order to best evaluate the utility of a CCR survey the investigator requires a fundamental understanding of the capabilities and limitations of the technique. This paper has attempted to highlight some of those parameters to be considered. A capacitively-coupled resistivity imaging system is a unique tool. It is not an EM device, yet EM considerations are taken into account in the design of the instrument. It is a resistivity meter, yet the survey techniques are unique to CCR surveys, and are significantly different from a traditional galvanic resistivity survey set up.

References

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