Short guide for electromagnetic conductivity mapping
Address of the manufacturer:

GF Instruments, s.r.o.
Jecna 29a
62100 Brno

tel: +420 541 634 285
fax: +420 549 522 915
e-mail: info@gfinstruments.cz
Chapter 1
General features, depth range and resolution

The most important advantage of electromagnetic conductivity meters is fast mapping of apparent conductivity and inphase with rough possibility of EM inversion (section) if several layers are measured together. While talking about true conductivity meters it is necessary to take care especially of their three crucial properties:

- short & long term stability of readings (negligible temperature drift, no need of frequent recalibration)
- correct absolute calibration of apparent conductivity
- defined depth range.

The stability of reading is determined by design quality of electronic and mechanic parts of device. The correct calibration depends on the quality (homogeneity, volume) and proper conductivity levels of calibrating standards. The depth range is determined by the distance of magnetic dipoles (transmitter to receiver center distance with the respect to antenna EM field diagrams).
Keeping the above mentioned features we can obtain quick and useful results that match very well with DC resistivity methods (mapping and imaging). The other advantage of EM method could be easy measurement on dry or frozen ground as the method is contact less.

On the pictures below normalized sensitivity function for all four CMD instruments is shown. (The depth means depth under the probe.) For instance CMD 4 in high depth range is the most sensitive for object 1.3 m under the probe. Effective depth (where 75% of cumulative sensitivity is reached) is 6 m.
Depth range and resolution are closely depending. The increasing depth range decreases resolution and vice versa. There are two ways how to influence the depth range – to have proper probe with certain dipole distance or to change the orientation of dipoles (from vertical to horizontal direction). The first one is more correct and convenient especially if EM inversion is calculated. The second one (leading approximately to half depth range) is auxiliary but useful for fast judgment of locality when one probe is available.

Wish and reality regarding use of different frequencies

It would be really great to obtain correct conductivity maps from many different depths using broad band antenna and various frequencies of EM field. Unfortunately, physics does not support such a possibility. For correct conductivity measurement we have to remain at low induction numbers. Thus we can change the frequency relatively slightly (approx. to several tens of kHz) which does not influence the EM wave depth penetration very much. Finally we will find two basic features of multifrequency attempts:

- The frequency is changing in the frame of approx. kHz or 10 kHz orders. We will find the depth range determined mostly by the distance of magnetic dipoles.
- The frequency change is bigger (e.g. hundreds of kHz or higher). The device is crossing the transient zone of induction numbers with instable response which is really coming from different depths but this depth is ambiguous being strongly influenced by conductivity. Those results cannot be correctly calibrated in conductivity units and effectively used for comparison with other measuring methods and for EM inversion.

Following pictures from the same area illustrate how the conductivity map changes when we change the frequency and when we change the dipole distance. The accompanying DC resistivity section shows real situation on the same place.
Apparent resistivity maps measured with various frequencies and 2 m dipole distance

All maps show approximately the same results without obvious relation to the real depth structure.
Apparent resistivity maps measured with CMD-1, CMD-2 and CMD-4 probes

The map from CMD-1 shows generally lower conductivity being influenced mostly by upper resistive layer (see DC section). The maps from CMD-2 and CMD-4 show proportionally higher conductivities due to the more and more significant contribution of the clayey layer at approx. 5 m depth.
The section shows structure with bottom clayey layer (conductive) covered with quaternary sediments (sand and gravel). The upper resistive layer is regularly pinching from position 0 to approximately position 60.

Iteration 3 RMS error = 4.2 %
Choice of the probe

Four standard probes (at 10 kHz) are offered covering all typical tasks of shallow EM survey,

CMD-1 (formerly CM-138) with 1.5 m full depth range and typical use in archaeology and agriculture. This probe is carried mostly near the ground surface which allows the highest resolution of buried objects (vertically orientated zones, e.g. basement of walls, rock outcrops) and conductivity assessment of upper thin layers (soil quality).

CMD-2 (formerly CM-032) with 3 m full depth range and typical use in engineering survey can serve for cable and pipe localization as well as for general assessment of construction site (e.g. detailed investigation of basement positions – clayey, sandy, rocky parts).

CMD-4 (formerly CM-031) with 6 m full depth range and typical use in geological and environmental survey can be used for many connected tasks like mapping of raw material deposits, watered zones, localization of waste dumps, buried tanks and other hidden objects.

CMD-4/6 with 6/9 m depth range allow measuring with extended depth range in the frame of applications similar to CMD-4.
Inphase quantity

The second parameter which is measured simultaneously with apparent conductivity is inphase. It is defined as relative quantity in ppt (part per thousand) of primary magnetic field and is closely related to magnetic susceptibility of measured material. The inphase can especially serve for indication of artificial metal objects like cables, pipes, reinforced concrete, tanks etc. Thus the inphase map can help to distinguish artificial structures from natural geology seen in apparent conductivity map.

EM inversion

Although the EM inversion is never so detailed as DC resistivity section its useful contribution cannot be omitted for many cases of investigation (showing e.g. good models of 2-3 layered structure with realistic depths and conductivity values). Together with apparent conductivity maps from individual applied probes EM inversion brings quick and complex view on the studied structure.

For EM inversion a measurement with several probes is needed. It is usually better to use the same (rather vertical than horizontal) orientation of probes although the combined measurement (vertical with horizontal) can sometimes bring more detailed and realistic results as well.
EM conductivity section obtained from CMD-1, CMD-2 and CMD-4 measurements

The section shows two layered structure of sandy and clayey sediments. EM inversion is calculated by means of IX1D (Interpex).
Chapter 2
Examples of typical applications

Engineering survey, road and railway building
- judgment of bedrock
- detection of cellars, cables, pipes
- assessment of mechanical properties of rocks

Dams and dikes (flood protection)
- localization of watered zones and landslides
- mapping of impacts
- beaver holes detection

Water management
- water source survey and protection
- monitoring of waste water leakage

Geological mapping
- raw material prospecting
- geological survey
- cavities detection

Agriculture
- soil quality monitoring
- fertilizer and watering management

Archaeology
- detection of remains of walls, cellars, vaults
- detailed survey of historical sites (graves, settlements)
- localization of underground corridors
Environmental
- mapping of pollution plumes
- survey of illegal waste dumps
- monitoring of leakages from agricultural and industrial plants

Military and police
- pioneer work
- UXO survey
- detection of graves and hidden objects
Engineering geology survey for road reconstruction

Limestone cliff decay in marginal part of Moravian karst was endangering the road built over river sink and caves (falling blocks of walls and sediments were taken by sinking underground river). The road reconstruction based on new bridge over destroyed part was considered.

The map shows places with solid limestone blocks, depression filled with terra rossa and other unstable structures.

Measured with electromagnetic conductivity meter CM-031.

- **B** Risk zone
- **C** Limestone crags
- **E** Geodetically fixed caves
- **D1** Deformation parallel with slopes
- **D2** Direction of limestones
- **D3** Deformation parallel with tectonics

**Legend:**
- Depression of the limestone bedrock filled with loams and sandy loams
- Course of surface and groundwater

**Contour map:** Contour map of apparent resistivity
Mapping slope deformation

A road was fatally destroyed by active landslide as a consequence of heavy rain. Detailed monitoring of the slope was performed before road reconstruction to detect unstable zones.

The position of extremely risky watered zone is seen on the picture. Water accumulation below the road (damaged dewatering system) and consequent permanently watered sediments activate continuous landslide. The probable directions of outflow show the possibility of activation of the mass of old landslides.

Measured with electromagnetic conductivity meter CM-031.

- **W**: Wet sediments - zone of saturation
- **D**: Old dry landslide accumulation
- **Schematic path of water outflow**

[Map showing contour map of apparent resistivity with labeled zones and measurement units.]
Monitoring of road body

This survey shows the possibility of fast monitoring of road body quality accompanied with information about geological structure of bedrock.

Two maps were obtained using probes with different depth ranges. The first map (from CM-032) shows irregular structure of construction materials - sand and gravel (high resistive) with different width and thickness. The second map (CM-031) shows rather homogenous clayey bedrock.

![Contour maps of apparent resistivity](image)

---

- **Clay loam**
- **Sand and gravel**

Measured with electromagnetic conductivity meter CM-032.

Measured with electromagnetic conductivity meter CM-031.

[Contour maps of apparent resistivity]
Mapping road stability

Continuing road destruction was studied using two measurements with different depth ranges. Obtained maps show that the clayey zone (as the main reason of landslide) is situated rather in deeper part of road basement. Both maps show increased moisture below the damaged place. Its measure increases with the depth.

Area with increased moisture and caverns filled with clayey mud

Measured with electromagnetic conductivity meter CM-032.

Measured with electromagnetic conductivity meter CM-031.

Contour maps of apparent resistivity
Buried metal pipeline detection

The metal pipeline was detected at about 1 m depth. Its position is indicated with very strong and narrow anomaly - increased values of inphase.

Measured with electromagnetic conductivity meter CMD 2.

Underground metal pipeline
Mapping underground objects

Area of former starch factory was investigated to determine positions of pipelines and other buried objects before projecting of new commercial centre.

The map shows inhomogeneous structure of backfill in former potato yard (random direct investigation discovered building waste material, concrete blocks and other waste material). The position of basement of industrial track and two pipelines are visible as well.

Measured with electromagnetic conductivity meter CM-032.

![Contour map of apparent resistivity](image)
Dike investigation

Searching for cavities in the fishpond dike. The fishpond dike was partially destroyed during the flood. The survey was performed to detect its weak places.

The low resistivity indicates larger destructed zones (voids) filled with water and mud.

Measured with electromagnetic conductivity meter CM-032.

- Cave filled with water
- Cave repaired with concrete grouting

Contour map of apparent resistivity
Determination of the penetration of sodium sulphate from a mud pit

The mud pit is filled during the mining technology process with the solution containing sodium sulphate. The conductivity measurement was done to monitor the tightness of the dam and the efficiency of the dewatering ditches along the dam. One part of the long area under the dam was chosen for the survey.

The measure of the contamination is obvious from the apparent conductivity map. The measure of underground water pollution with sodium sulphate decreases homogenously with the distance from the dewatering ditch.

The inphase map copies the conductivity map on the great part of the measured area showing that no buried metallic objects are present. The bottom part of the inphase map is influenced by the dewatering ditch and the concrete pavement reinforcement.

Measured with electromagnetic conductivity meter CM-031.
Geological mapping

Geological mapping before construction of new highway crossing was performed. The recent agriculture area (on former gravel deposit) was investigated before digging of the basement of the road overpass. The map shows precisely the position of exploited gravel deposit filled with inhomogeneous rubbish. This area is typical with low resistivity (remains of organic mass). Measured with electromagnetic conductivity meter CM-031.
Archaeology

Detailed mapping of foundations of abolished Sanctus Vitus chapel from 1263 had to verify roman vault situated on the former cemetery.

Two maps from various depths allow distinguishing individual parts and shape of the chapel. The CM-138 map shows rather detailed structure near surface while the position of the vault as well as shape of basements and position of peripheral walls are seen in CM-031 map.

Contour maps of apparent resistivity


A Presbiterium  B Metallic enclosure with metallic cross inside  V Old vault
C1,G2 Main foundation lines  D1,D2,D3 Cross foundation lines  E1,E2 Indications of the peripheral walls
Archaeology

Identification of hidden parts of fortification was performed to complete formerly discovered walls and underground objects of medieval castle.

The map with two high resistive stone objects corresponds with remains of a gate (or pillars). The left part of the picture shows the area of outer court.

Measured with electromagnetic conductivity meter CM-031.
Environmental protection

The studied area was inside a uranium mining field. During the mining process a technologic difficulty occurred and the sulphuric acid leaked out from a plastic pipe near to one of boreholes. The determination of the pollution plume was needed to allow sanitation works in the area.

The direction and the measure of the propagation of the acid flow are indicated with higher values of apparent conductivity. Measured with electromagnetic conductivity meter CM-031.

Contour map of apparent conductivity
Environmental protection

A complex monitoring in the frame of ground water protection in close vicinity of a pig farm was done. The goal was to detect leakage from a liquid manure tank.

The decreased resistivity indicates the zone with contamination. These extremely low values of resistivity are typical for the high contamination with organic substances.

Measured with electromagnetic conductivity meter CM-031.

![Contour map of apparent resistivity]

- **B** Backfill - sand and gravel
- **C** Zone of contamination with liquid manure
- **I** Influence of reinforced concrete centring

![Contour map of apparent resistivity]

**Liquid manure tank**
Mapping of buried waste dump

Higher values of conductivity indicate the area formed with homogenous clay sediments. High variability and low values of conductivity are typical for the inhomogeneous landfill (without organic material). The inphase map shows a lot of metallic objects in landfill (increased inphase).

Measured with electromagnetic conductivity meter CMD 4.
Detection of buried objects

Geophysical survey was performed to detect underground objects from World War II. Several objects were identified. There are two concrete bunkers connected with trenches serving for treatment of city inhabitants and workers from close factory. The central low resistive bended zone shows former watershed filled with conductive sediments. Measured with electromagnetic conductivity meter CM-031.