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# Mapping Archaeological Features and/or Removing Disturbances

## Tricky Behaviors of Electromagnetic Multi-Frequency Signal in the Vicinity of Metallic Objects

François-Xavier SIMON<sup>a</sup>, Julien THIESSON<sup>b</sup>, Alexandre BEYLIER<sup>c</sup>, Carole FOSSURIER<sup>d</sup>  
and Alain TABBAGH<sup>b</sup>

### Highlights:

- *Effects of metallic bodies depend on the frequencies used in electromagnetic measurement.*
- *Archaeological features in the vicinity of metallic artefacts can be mapped.*
- *An electromagnetic system can be used to detect non-ferrous metallic features.*

**Keywords:** multi-frequency electromagnetic induction, metal artefacts, early Christian period, Iron Age.

### INTRODUCTION

Electromagnetic prospection has been used for many years to detect metallic artefacts, such as Bronze Age deposits (Tabbagh & Verron, 1983) and unexploded ordnance (UXO) (Huang *et al.*, 2007). If the EM method is well suited to the detection of metallic objects, the use of a multi-frequency device shows that the response to these kinds of objects and features strongly depends on the measurement frequency.

During recent geophysical studies carried out on different sites and in different geographical environments, the use of the low multi-frequency EM method has made it possible to highlight specific characteristics of metallic object responses. The use of this technique would allow, on the one hand, to identify all types of metallic objects, contrary to other tools which are limited by the physical

properties of the metal (for example lead, which is not detectable with magnetometry). On the other hand, it can also reduce the effects of surrounding metallic disturbances (stakes and fences) in order to detect the less contrasted archaeological features. This talk describes and interprets two case studies where measurements were carried out with a multi-frequency device.

### METHODS

The electromagnetic device used in this study is a GEM-2 from Geophex Ltd (Fig. 1). It allows measurements at five different frequencies distributed between 500 Hz and 90 kHz. It consists of one transmitting and two receiving coils, one of them acting as a bucking coil which both

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enhances instrumental stability and extends its depth of investigation (Hunkeler *et al.*, 2015; Simon *et al.*, 2015). At lower frequencies, the GEM-2 can measure simultaneously both electrical conductivity and magnetic susceptibility. The computation of these apparent properties is achieved under the Low Induction Number assumption, which implies a low frequency associated with a relatively low conductivity of the ground and a limited distance between coils. Thus, the in-phase part of the signal is related to magnetic susceptibility and the quadrature part is related to electrical conductivity. In some contexts, the dielectric permittivity and magnetic viscosity of the medium can also be determined (Simon *et al.*, 2019). When the device is in the vicinity of a metallic artefact, the assumptions used to estimate the above properties are not valid anymore and the response of the very high electrical conductivity/magnetic permeability of the objects dominates in both the in-phase and out-of-phase measurements.

## RESULTS

### Iron Age oppidum of Bessan (Hérault, France)

The first site studied is a multi-period site in southern France (prehistoric to medieval). The objective was to detect two ditches, one from the Neolithic period, about 4 m wide, and the other from the Iron Age, more than 10 m wide. This site has the particularity of being partly located in a vineyard with iron wires spaced every two meters and metal posts implanted in line every 4 m. The nature of the sought after features considerably limited the choice of geophysical technique: the clay level is too high for ground penetration radar with a strong signal attenuation, the soil is too cluttered and dry for the direct-current resistivity method, and the environment is too magnetic for the magnetic method. The use of the EM device was therefore motivated by the sensitivity of the device to features such as ditches through the measurement of magnetic susceptibility, but also the need to reduce the effect of the metallic stakes. The low sampling rate imposed by the vine rows is compensated here by the considerable size and orientation of the structures in question. The device was fixed on a non-magnetic cart, in HCP mode. A profile was performed every 2 m (Fig. 2).

### Early Christian necropolis of Saint-Pantaléon (Autun, Saône et Loire, France)

The second site studied is an early Christian necropolis near the ancient city of Augustodunum in central France,



Figure 1. A GEM-2 acquisition system mounted on a Sensys MXPDA cart.

excavated by Inrap in 2020. This large necropolis is composed of more than 300 graves, with some of them including stone sarcophagi and/or lead coffins. A magnetic survey was carried out before the excavation, but the physical characteristics of the lead (non-magnetic and conductive) as well as the non-magnetic characteristics of the pits did not allow their detection prior to the excavation. An EM survey was carried out after the soil had been stripped. Geophysics was used in order to visualize as quickly as possible the number of lead coffins which were for the most part not observed until excavation of the burial pits at a depth of 1 m and which required specific treatment. Measurements were made on profiles spaced 1 m apart, in HCP mode, using a handheld device.

## DISCUSSION

The effect of metallic objects on the electromagnetic data acquired at these two sites differs depending on the frequencies. The results show a very strong contribution of metallic objects to both the in-phase and out-of-phase signals at low frequency. When the frequency increases, the relative contribution of these objects is strongly attenuated or sometimes even disappears. This occurs at a very fast rate with the frequency on the quadrature maps, while on the in-phase maps it is slower so that they are no longer visible at higher frequencies. Thus, the behaviour at the two sites is different with the contribution of metallic objects on the Bessan site

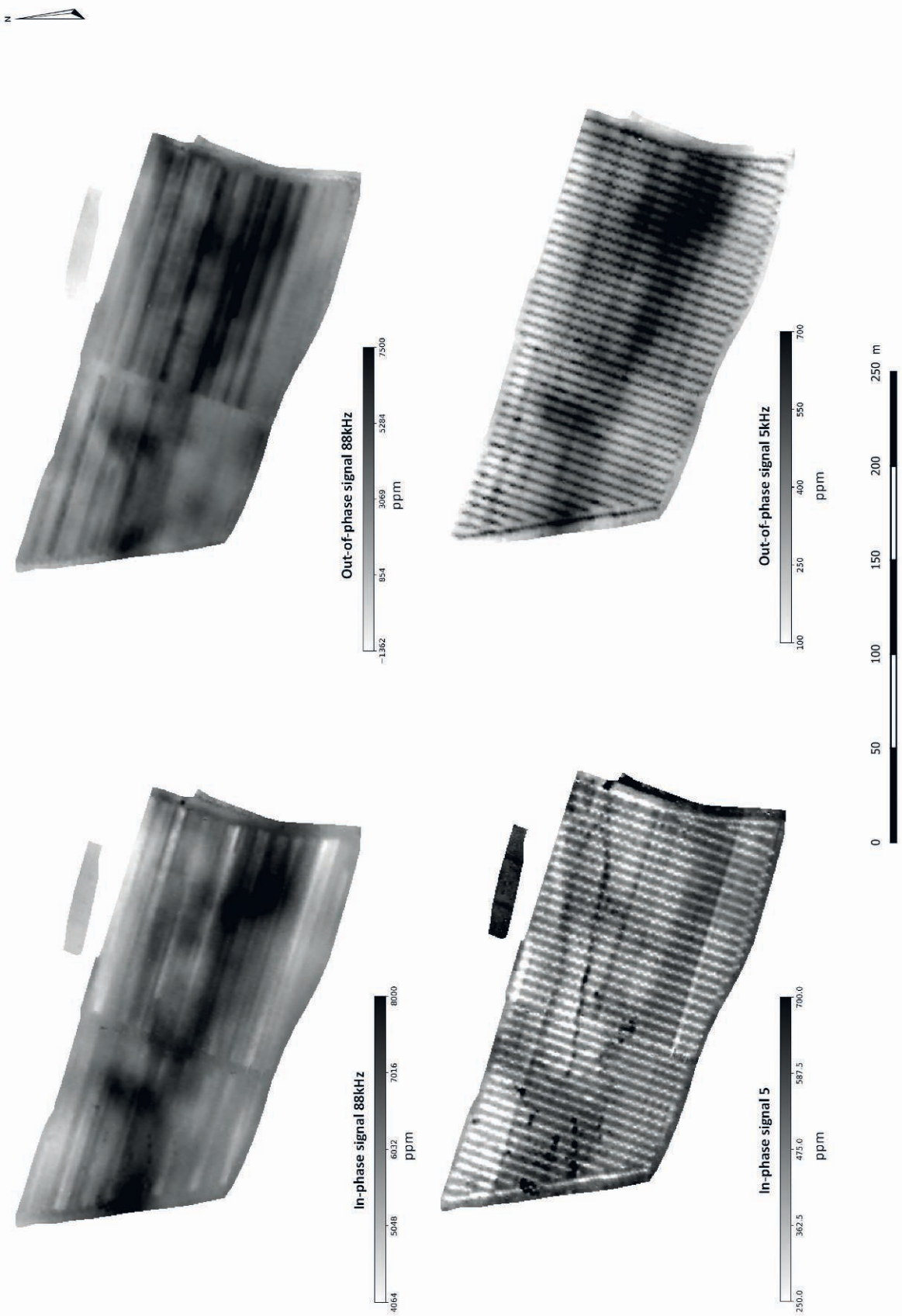


Figure 2. Map of the in-phase and out-of-phase electromagnetic signal at 5 and 88 kHz in HCP configuration on the Iron Age site of Bessan (34).



being zero on phase maps at high frequencies, while still visible at Autun. For the quadrature maps, both sites show data without metallic effects at the highest frequencies. At the Bessan site, given the high conductivity of the ground, strong induction effects exist on the in-phase signal at the highest frequencies. The influence of the susceptibility signal is therefore limited. The strong contribution of conductivity is difficult to assess because the estimation of magnetic susceptibility at the lower frequencies is impeded by the presence of metal.

## CONCLUSION

The use of a multi-frequency electromagnetic device offers unexpected opportunities. The observations made show that this method could be implemented in environments where metal artefacts are omnipresent and exclude the use of other methods, such as the magnetic method. This is especially the case when surveying post-hole/pit features or ditches. In addition, the use of different frequencies could allow the estimation of the location and shape of metallic bodies in the ground, nevertheless this requires modelling work which necessitates prior test trials of feature shape.

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