

VECTOR OR SCALAR MAGNETOMETER ARRAYS?

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Abstract. We determined the information content in magnetometer arrays with different orientations and array densities from five potential current sources of biomagnetic fields. Using the inverse condition number of the modified Lead Field Matrix (mLFM), we found that tangential or full vector component recordings provide more information about underlying sources of current in all but the simplest current distributions. This condition number method facilitates magnetometer designs that provide optimal accuracy of inverse solutions.

Introduction. In the design of magnetometer arrays for detecting biological electrical activity, a key question is the optimal arrangement, positioning and orientation of detectors. Multichannel Superconducting QUantum Interference Device (SQUID) magnetometers currently in use are frequently designed with specific recording criteria as in the case of magnetoencephalography (MEG) systems with detectors arranged in a helmet-shaped dewar, or the flat-bottomed dewars that allow recording of cardiac and gastrointestinal magnetic fields. Most often, these detectors are oriented to record the magnetic field component normal to the body surface. Conventional wisdom has led many to think that optimum information content is achieved by increasing the number of channels and/or the channel density. One issue that has been largely overlooked is the idea of recording the magnetic field components tangential to the body surface.

Methods. In the present work, we compared the information content provided by different simulated magnetometer arrays and detector configurations recording five different current source distributions. Detector configurations were specified by the number of detectors. For a given detector configuration, we allowed a hexagonal pattern of either N normal component (x , y , or z) detectors, $N/2$ tangential component (x and y) detectors, or $N/3$ vector detectors (x , y , and z). Configurations

1-6 used $N=18, 36, 72, 144, 288,$ and $576,$ respectively. We examined the information content from a single dipole, two randomly oriented dipoles, three mutually orthogonal co-located dipoles, a 2-D 23-dipole distribution and a 3-D 26-dipole distribution. We evaluated the inverse condition number of the modified lead field matrix (mLFM) describing the source-measurement relationship. The mLFMs that were best-conditioned (least sensitive to errors on inversion) had the highest inverse condition numbers. Normalization of the inverse condition numbers to the number of detectors allows us to determine the optimum recording arrangement.

Results. For all sources except the 2-D dipole distribution, recordings of the tangential magnetic field components or the full vector magnetic field exhibited the highest information content. In the case of the 2-D distribution, the normal (z) component recording was slightly better than the tangential components. For the simpler sources (1-3 dipoles), a smaller number of detectors provides optimal information content, while the more complicated 2-D and 3-D distributions required the number of detectors present in configuration 4 (288 z -detectors, 144 xy -detectors, 72 xyz -detectors) to optimally record the sources.

Conclusion. For all but the simplest or most trivial sources of biological magnetic fields, recording of the tangential components or the full magnetic field vector optimizes the information content. Small array densities are suitable for a small number of current sources. For current densities confined to a 2-D plane, the magnetic field component normal to the plane has optimal information content. Optimizing the information content in the biomagnetic recordings increases the likelihood of correct inverse solutions.

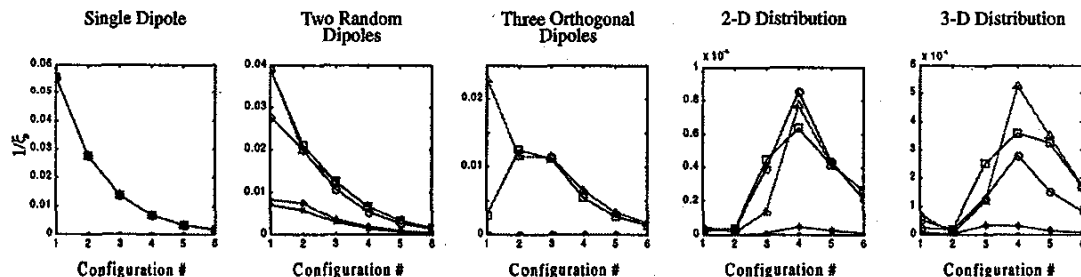


FIGURE 1. Inverse condition numbers ($1/\xi$) normalized to the number of detectors show that tangential arrays (Δ) or full vector arrays (\square) reveal more source information than increased-density recording of any single component (x - \times , y - $*$, or z - \circ).