Near-field Beamforming with Electrically Small Antennas

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Beamforming techniques using electrically small antennas at low frequencies have been implemented by radio amateurs in far-field direction finding applications. Typically, nulls in a small loop antenna pattern are used to determine the direction of an emitter; however, the technique suffers an ambiguity due to the two diametrically opposed nulls. In that application, a second linear electric dipole element is introduced to form a unidirectional pattern and resolve the ambiguity. The condition to achieve the desired unidirectional pattern in the far field is easily derived from the field expressions and requires the loop and dipole electric currents to be appropriately adjusted in amplitude and that they be excited in phase quadrature. Using the $e^{i\omega t}$ time convention, the dipole current, I_D, in terms of the loop current, I_L, is given by:

$$I_D = \frac{-ikS}{L}\left[\frac{1+ikr}{1+ikr-\frac{i}{kr}}\right]I_L$$

The length of the electric dipole is L, the area of the loop is S, k is the wavenumber and r is the range. Here the expression in the brackets is referred to as the complex range factor. For large r, the relationship between I_D and I_L is independent of range, that is, the complex range factor approaches unity and the unidirectional beam forms at ranges slightly less than the far field distance, which for electrically small antennas is typically given as $r_{ff} > 1.6\ \lambda$. However, at ranges a fraction of this distance, a unity complex range factor results in patterns that are substantially degraded; that is, the front-to-back ratio may degrade from 25 – 30 dB down to a couple of dB.. To compensate for this, a non-quadrature component for the electric dipole current is required for small kr.

This paper will address the impact of the complex range factor upon formation of a unidirectional pattern at ranges a fraction of the far field distance. The measured results for the prototype antenna will be compared to numerical results and conclusions will be drawn. This technique may be applicable to low frequency, geophysical applications.