Resonance shift due to edge effects in finite-by-infinite monopole arrays

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Abstract

This paper describes the resonance shift that occurs in finite-by-infinite monopole arrays for large scan angles. The antenna elements are placed on a corrugated ground plane with WAIM layers to improve matching. It is shown that the $5\lambda/2$ distance rule for approximating finite arrays as infinite in not valid here.

Keywords : Antennas Arrays Mutual coupling Monopole

1. Introduction

The resonance shift characteristics of monopole elements close to an edge in a large phased array are presented in this paper. The array antenna is designed to be scanned in a single plane for large scan angles out to almost end-fire. The projected area of the antenna is small for these angles, which restricts the possible antenna gain. However, there are applications where the need for a minimal exposed projected area motivates that array antennas are used for near end-fire radiation. An element that is suitable for such cases is the monopole element. The element is capable of radiating in the plane of an infinite ground plane.

Monopoles are not a common antenna element in phased arrays, but they have been used for satellite antennas were it is important that the array does not radiate in the normal direction [1], and they have also been used as a close to end-fire radiator in radar applications [2].

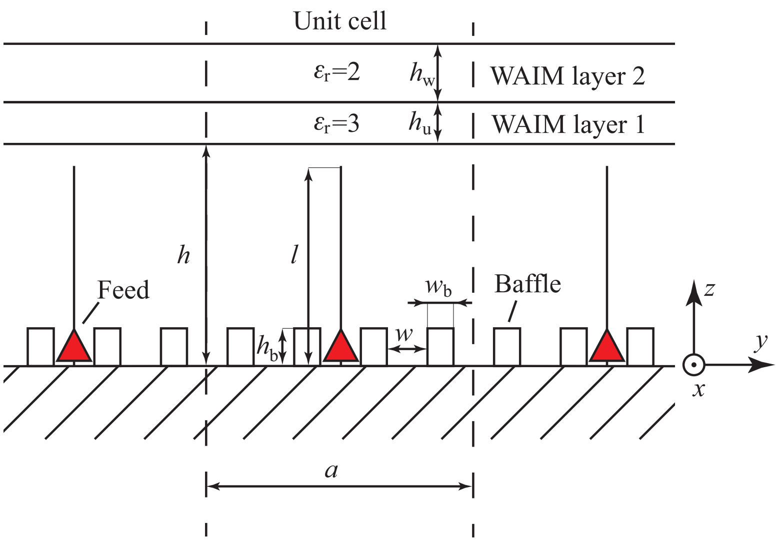

Figure 1. The monopole element. a=50.0 mm, l=31.3 mm, h=32.5 mm, h_w=7.5 mm, h_u=5.0 mm, h_b=6.3 mm, w_b=5.0 mm, w=7.5 mm

2. The antenna element

The antenna elements in this paper are monopoles placed in a rectangular lattice. They are fed by discrete feeds, each with a generator impedance of 25 Ω connected in between the element and the ground plane, see Fig. 1. Furthermore, the antenna elements in the array are positioned on a corrugated ground plane in between two metal baffles. The metal baffles are used in the design to achieve the desired input impedance. On top of the array there are two dielectric layers that acts as wide impedance matching layers (WAIM). Their primary function is to match the antenna when the array is scanned towards directions that are near grazing angle [3], *i.e.* near end-fire. Furthermore, the array antenna is assumed to be very large and the antenna elements within the array are approximated to behave similarly to the elements in an array of infinite size. This simplification is used to design the antenna elements. By approximating the array as infinite in size it is possible to use a unit cell with quasi periodic boundary conditions to design the element. This reduces the computational domain to a single element which is efficient to analyse.

The array is indented to be scanned in one plane, the *yz*-plane that is orthogonal to the metal baffles. To avoid grating lobes the element spacing, *a,* along the *y*-axis is 50 mm or ~0.42 λ_0, where λ_0 is the wavelength at the resonance frequency f_0=2.5 GHz. The element spacing along the *x*-axis, *b*=60 mm*,* is made larger to reduce the number of elements in the antenna. However, the increased spacing leads to limited scan performance in the *zx*-plane due to the early onset of grating lobes.

Numerical computations have shown that this element is capable of scanning a sector of 50º -80º in the scan plane with $|\Gamma|$<-10dB for a bandwidth of 6%, where Γ is the active reflection coefficient. It is possible to scan the array even closer to end-fire but then the bandwidth becomes even smaller. The limited bandwidth makes this design sensitive to coupling effects such as malfunctioning elements and edge effects. A good illustration of a coupling effect is the resonance frequency shifts for the elements close to an edge. A common measure for when an element is close to an edge is when the distance to the closest edge is smaller than $5\lambda/2$, where λ is the wavelength. This rule of thumb works well when the array is steered towards broadside [4]. However, for other scan directions, especially direction close to end-fire, elements further away than $5\lambda/2$ from the closest edge will behave differently from the centre elements, due to strong coupling.

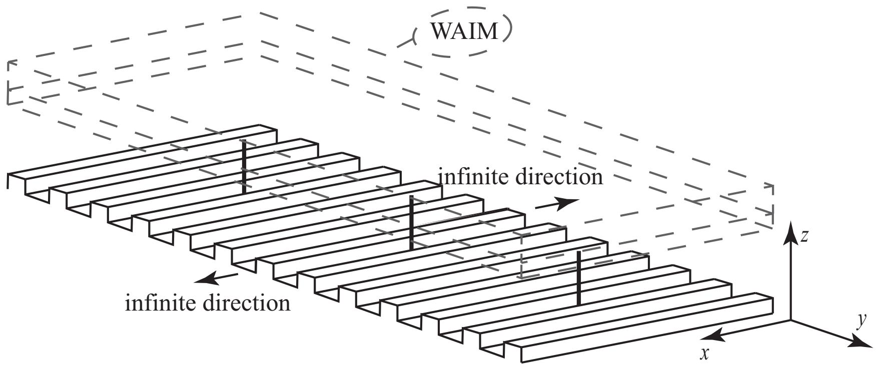

Figure 2. The illustration depicts a segment of a FIFA antenna with monopole elements.

3. Infinite-by-finite arrays

To isolate the effects of finite edges in a larger array, we can consider an array that is infinite in one direction and finite in the orthogonal direction, a so called finite-by-infinite array (FIFA). The FIFA approximation removes the effects of two of the antenna's edges which make it easier to determine the cause of perturbations in the active reflection coefficient caused by edge interaction. Furthermore, the antenna can be analysed by applying periodic boundaries in the infinite direction and thereby reducing the computational domain to a linear array, see Fig 2. The edge of the array will be parallel to the *x*-axis and there is no edge tapering, *i.e.* the array is created from blocks identical to the unit cell.

The S-parameters are computed for arrays with 19, 39, and 59 elements in the finite direction, and for comparison the S-parameters are also computed for the infinite array, with the methods described in [5-6]. To identify the elements they are numbered from edge to edge and the beam is steered towards element 1.

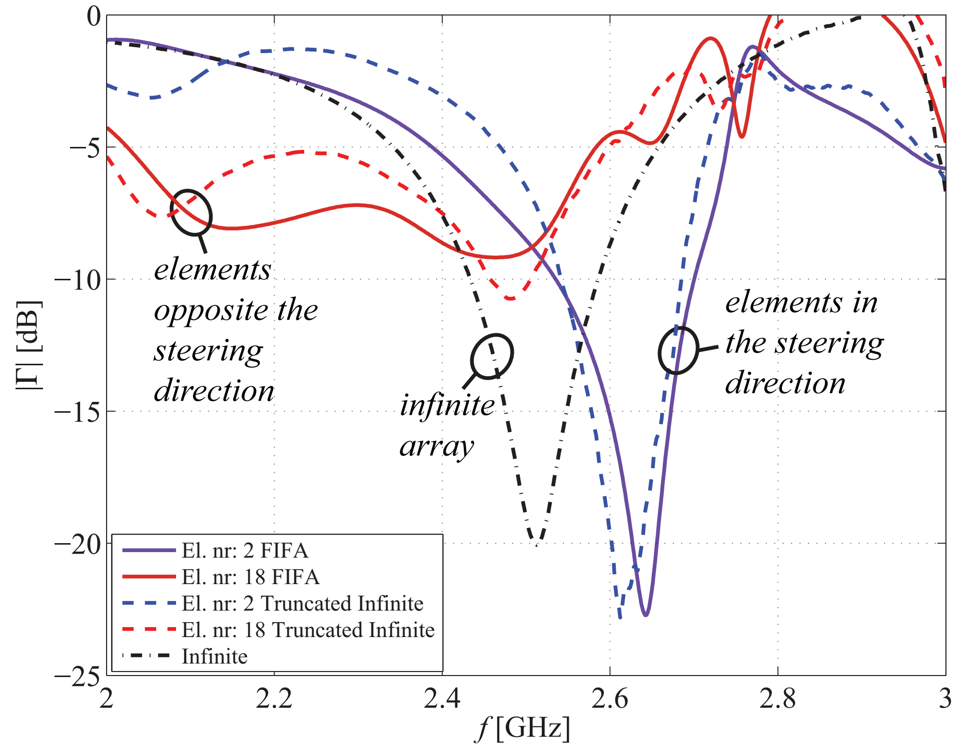

Figure 3. Active reflection coefficient for edge elements in a FIFA, an infinite array with truncated excitation, and an infinite array with uniform excitation. The scan angle is set to 77.2º from the *z*-axis.

4. Results and conclusions

The active reflection coefficient is shown in Fig. 3 for two edge elements. In this case we consider element 2 and 18 in an array of 19 elements when the array is scanned out to 77.2º from the *z*-axis. The results are shown for the FIFA, the infinite array with truncated excitation corresponding to excitation of the FIFA, and an infinite array with uniform excitation. The truncated excitation of the infinite array corresponds to that the non-excited elements acts as dummy element terminated with 25 Ω resistors. From Fig. 3 it is clear that the elements close to the edge that the antenna is steered towards will have a higher resonance frequency than the infinite array. This is the case both for the finite array and truncated infinite case. Furthermore, the resonance frequency for the elements on the opposite edge will be lower and the resonance minima have become less sharp; again this effect is visible both for the finite array and the truncated infinite array.

The resonance frequency shift occurs for element far from an edge in the array, *e.g* there is a clear shift in resonance frequency for the central element in an array of 39 elements, see Fig 4. This means that there are edge effects in this array for elements that is more than $7\lambda_0$ from the closest edge in the array. However, if we consider the centre element in an array of 59 elements the shift is almost gone. It is clear from these results that the $5\lambda/2$ thumb rule cannot be applied in this case. Since both finite arrays and truncated arrays display the same behaviour the reason must be missing fields from absent or non-excited elements. The active reflection coefficient changes rapidly as a function of phase shift when it is scanned near end-fire since it changes from a low value from when it the antenna is matched, to unity when the antenna is steered into invisible space. Since the active reflection coefficient is a truncated Fourier series, were the coefficients are the scattering parameters, a large number of elements are needed to recreate the large derivatives of the active reflection coefficient. However, the $5\lambda/2$ thumb rule is valid for broadside scan where the active reflection coefficient usually changes slowly as a function of phase shift and therefore usually requires fewer antenna elements to correctly represent the infinite array results.

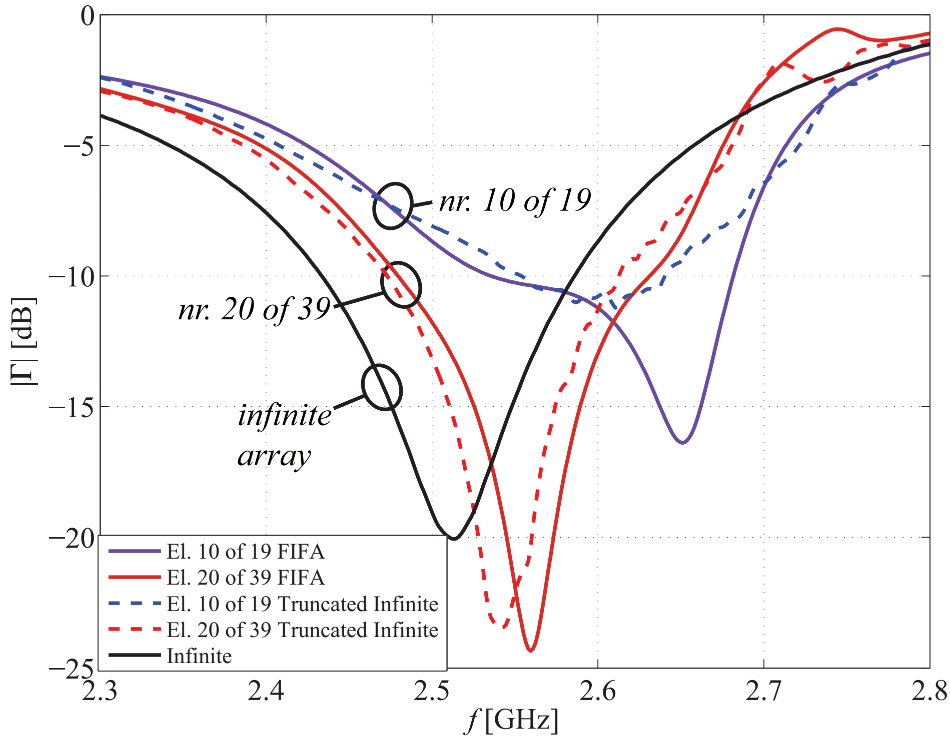

Figure 4. Active reflection coefficient for centre elements in a FIFA, an infinite array with truncated excitation, and an infinite array with uniform excitation. The scan angle is set to 77.2º from the *z*-axis.

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