The Design of Wideband Arrays of Closely-Spaced Wire and Slot Elements

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INTRODUCTION

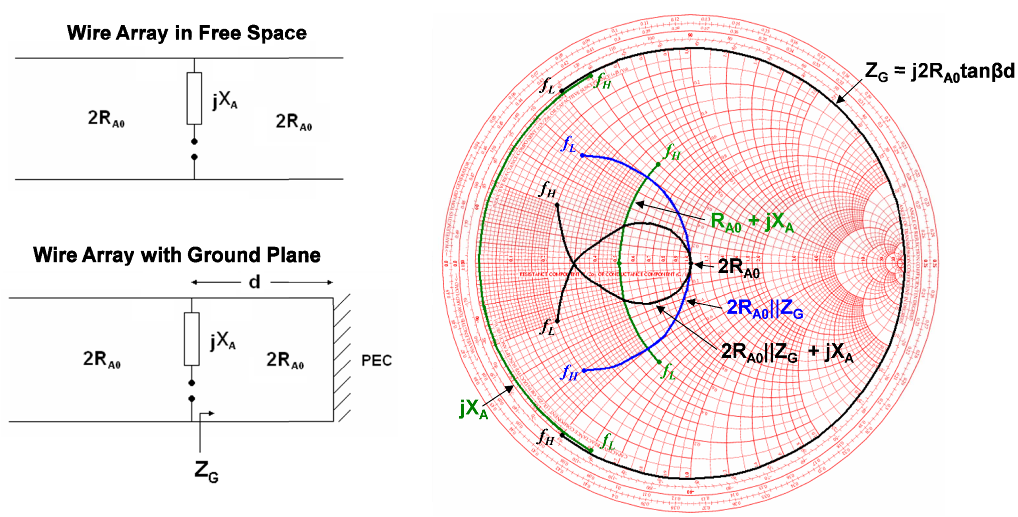
The quest for wide band operation of antenna arrays, for example reaching 10 to 1 or more, has led to the consideration of many different types of elements. Spirals and other wide band elements have been tried as one alternative, but this leads to large elements with wide interelement spacing that results in grating lobes at high frequencies. Munk [1, 2] has shown that simple dipoles and slots can be effectively used to achieve wide band widths without grating lobes by the effective use and control of element to element coupling and wide band matching techniques. This paper outlines the logic of this array design procedure. Many impedance calculations used in planar wideband array design are made using the Periodic Moment Method code [3]. The theory behind PMM is based on a plane wave expansion technique [4], and yields the analysis of infinite, periodic, and planar arrays of scattering elements (wires or slots). Semi-infinite calculations are made using a code referred to as SPLAT [5, 6].

GENERAL ARRAY CONSIDERATIONS

The general design philosophy of wide band arrays is to pick a size of dipole or slot that allows for element spacing small enough to avoid grating lobes at the desired frequencies and scan angles. The size must also be such that the resonance can be effectively manipulated by the coupling between elements with added capacitance or inductance to achieve the desired effect. The design process is started with the elements in thin layers of dielectric (underwear), which helps reduce the element size and spacing, but otherwise in free space. Next, a ground plane is added and the resulting size and spacing retuned. The next step is to add dielectric scan compensation layers to ensure stability of the impendence over the range of scan angles. Final wide band matching along with an appropriate balun is used to bring the design to the desired operational impedance. In this entire design process Smith charts are used to lead the designer to the proper parameters without the need for extensive computer search techniques.

WIRE ARRAYS

Antenna arrays based on simple dipoles yield an effective means of providing very wide band operation. This is largely because of the ability to use the impedance of the elements in conjunction with the enhancing effect of ground plane to achieve improved impedance properties over the band. The effect of the ground plane is best understood with the use of equivalent circuits and impedance curves on the Smith chart. Assuming that higher-order Floquet modes decay sufficiently such as to have negligible interaction with the ground plane, a wire array can be analyzed with equivalent circuits [4]. Equivalent circuits are shown in Figure 1(a) for a wire array, both in free space and with a ground plane. The X_A term shown is a reactance resulting largely from the evanescent modes of the array, and the R_{A0} term comes entirely from the real component of the propagating mode. A typical impedance curve for a wire array in free space is represented as the green curve in the center of the Smith chart in Figure 1(b). This curve is capacitive at lower frequencies and inductive at higher frequencies. The addition of a ground plane creates a short on one side of the equivalent circuit. This impedance is represented by the black curve on the rim of the Smith chart in Figure 1(b). The total combined impedance of a wire array backed by a ground plane is represented by the black curve in the center of the Smith chart in Figure 1(b). Note how the addition of a ground plane can tighten the impedance curve of the array, thus increasing the bandwidth if designed properly. The bandwidth can further be enhanced with the addition of an outer dielectric layer and impedance matching, as described in [1].

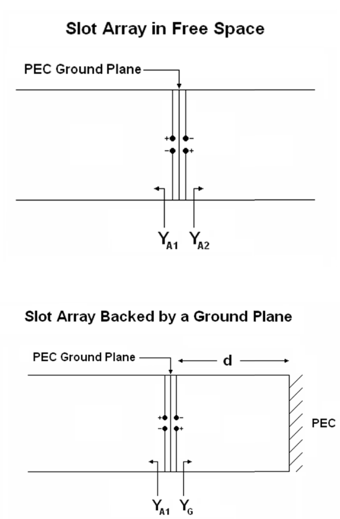


(a) **(b)**

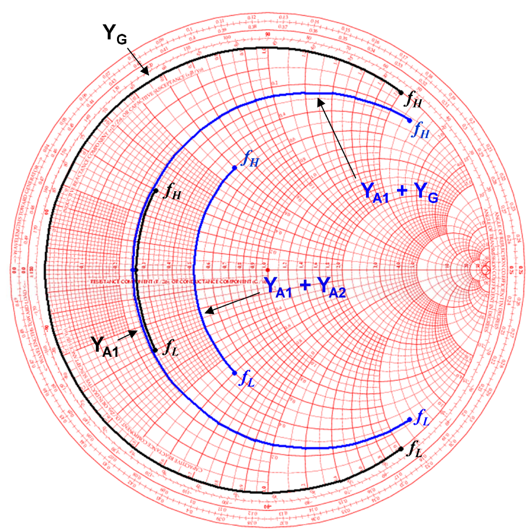
Figure 1: Equivalent circuits (a) of typical wire arrays in free space and with a ground plane and (b) Smith chart showing impedance transformation caused by the addition of a ground plane

SLOT ARRAYS

For some applications, slot antennas may be desirable due to their wide scan angle performance. The early stages of the design process of slot arrays are similar to that of wire arrays because they are complementary surfaces. Inductance between slot elements is used as opposed to capacitance between dipole elements to manipulate resonance, and admittance Smith charts are used instead of impedance Smith charts for analysis. However, the addition of a ground plane affects slot arrays differently than wire arrays. This difference is seen in the equivalent circuits of a typical slot array, shown in Figure 2(a). An array of slot elements can be represented by equivalent magnetic currents flowing in opposite directions on either side of a PEC ground plane. Therefore, the admittances looking left and right from the array are independent of one another. Each of these two components includes a reactance resulting from the evanescent modes of the array (comparable to the X_A term in the equivalent circuit for wire arrays) as well as a component resulting from the propagating mode [4]. For a slot array in free space, these admittances are equivalent due to symmetry. When a ground plane is added, spaced by a distance d, the admittance in one direction is replaced by a ground plane admittance, Y_G. The Smith chart in Figure 2(b) shows the effect of this addition of a ground plane. It is evident that the addition of a ground plane has almost the opposite effect on slot arrays as it does on wire arrays. The admittance curve spreads out with frequency, making the design of broadband slot arrays very challenging. However, it is still possible to achieve reasonably wide bandwidths without resorting to exotic materials. It is just a matter of carefully understanding how the impedances interact with one another.



(a)



(b)

Figure 4: Equivalent circuits (a) of typical slot arrays in free space and with a ground plane and (b) admittance Smith chart showing transformation caused by the addition of a ground plane

WIDEBAND MATCHING

Effective wide band matching is necessary to achieve useful operational impedance. Clever use of transmission line impedance changes between the elements and phase shifters provide a means of bringing the impedance at the element to the desired operating range [4]. Again, Smith charts are an effective guide this process.

FINITE ARRAYS

A computer code that utilizes standard MoM in one dimension and Floquet techniques in the other has been used to understand the effect of finite size on the array operation. Munk and Janning [7] have shown that in addition to the impedance of the end elements being modified by the edge effects, there is a surface wave that travels along the elements at a frequency at the lower end of the band.

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