A SIMPLIFIED TECHNIQUE FOR THE ANALYSIS OF SINGLE AND COUPLED MICROSTRIP RADIATORS

Martin Gimersky and Jens Bornemann

Laboratory for Lightwave Electronics, Microwaves and Communications
(LLiMiC)
Department of Electrical and Computer Engineering
University of Victoria, B.C. Canada

ABSTRACT

Radiation patterns of single and coupled microstrip radiators are analyzed using a standard method of moments algorithm. Symmetry properties of both the configuration and, after suitable modification, the impedance matrix are taken into account. The resulting CPU-time savings compared to a full-element analysis make the software operational on modern workstations. Computed radiation patterns are presented in comparison with measured data for a single patch. The influence of mutual coupling effects on the radiation pattern is demonstrated at the examples of 2x3 and 2x2 patch arrays.

I. INTRODUCTION

Microstrip radiators in standard and monolithic microwave integrated circuitry are well known for their excellent performance in low-cost array architectures [1, 2] where their physical characteristics such as low profile, light weight, ruggedness and conformability are highly desirable. While mobile satellite communication (MSAT), earth remote sensing and deep-space exploration are typical applications, printed-circuit radiators increasingly find their way into all types of personal commmunication devices and systems. The preferred frequency bands range from several hundred MHz to the lower portion of the millimeter-wave spectrum. The dimensions of typical rectangular structures, like those investigated in this contribution, are in the order of half a wavelength. However, since this parameter largely depends on the substrate material used, dimensions can be significantly reduced by selecting an appropriate relative dielectric constant, i.e., $\lambda_g \propto (\varepsilon_{\mathrm{reff}})^{-1/2}$.

Since the characteristics of a single patch radiator are insufficient for many applications, array architectures have to be employed for beam focussing and efficiency purposes. In these configurations, the mutual interactions between the individual elements of an array play an important role in the analysis and successful design of microstrip arrays. Most of the theoretical models presently available to predict the antenna performance [3], however, either neglect mutual coupling influences in the array design or require substantial computer resources to handle and reliably solve the large matrix systems involved. Although mutual coupling effects have been incorporated in the calculation of input impedances of coupled patches, e.g. [3], it is of crucial importance that these effects also be taken into account for the pattern analysis.

Therefore, this paper focuses on a simplified technique to reduce storage and CPU-time requirements in the pattern analysis of rectangular patch antenna configurations. Symmetry properties in both the structure and the resulting matrix equation system are efficiently utilized to analyze the characteristics of single and multiple patches including mutual coupling effects.

II. ANALYSIS TECHNIQUE

Microstrip radiators with their small-volume and low-weight architectures are almost an exclusive type of receiving antennas in modern mobile communication systems. As symmetric radiation patterns (non-directional, omnidirectional, etc.) are usually required, some sort of symmetrical radiating structure must be used. In a symmetrical patch antenna array (e.g., see Fig. 1 where a 3x1 microstrip-fed rectangular-patch array is depicted) symmetry properties of the structure result in a symmetrical surface current distribution.

If the standard method-of-moments algorithm [4] is used for the analysis, it is sufficient to model only the current distribution of the upper half of the array configuration, while the lower half is incorporated by copying the appropriate column of the admittance matrix $[\underline{Y}]$.

$$[\underline{Z}][I] = [\underline{Y}]^{-1}[I] = [V] \qquad (1)$$

Furthermore, if the array is divided into elements with potential functions approximations [4]

$$\psi(m,n) \approx \frac{e^{-jk_g r_{mn}}}{4\pi r_{mn}} \qquad (m \neq n) \qquad (2)$$

$$\psi(n,n) \approx \frac{1}{4\pi\,\Delta\ell_n} \int_{n^-}^{n^+} \left[\frac{1}{r_m} - \frac{k_g^2}{2} r_m \right] \mathrm{dy} - \frac{jk_g}{4\pi} \qquad (3)$$

and ordered in a suitable way, e.g., as shown in Fig. 2, the impedance matrix $[\underline{Z}]$ has Toeplitz symmetry; hence, only the upper half of the already reduce-sized square impedance matrix has to be evaluated. Consequently, the resulting matrix is non-square and, therefore, a singular value decomposition (SVD) technique, e.g. [5], is required to perform the matrix inversion. The radiation pattern of the complete structure is finally calculated by duplicating the related columns of the inverted matrix $[\underline{Y}]=[\underline{Z}]^{-1}$ to account for the Toeplitz symmetry of the matrix as well as the general symmetry of the structure.

III. RESULTS

Computed and measured radiation patterns of a single patch and the patch geometry are shown in Fig.3. Good agreement between the simplified model and the measured data can be observed within angles up to 70 degrees. For higher angular values, measured and calculated patterns diverge due to the simplicity of this model, which necessarily leads to an E-plane null at 90 degrees.

Figs. 4 present calculated E- and H-plane far-field radiation patterns of a 3x2 array for the two following cases: first, mutual coupling between the individual patches of the array is neglected and second, mutual coupling effects are included using the technique described in section II. The distance between the feeding points of the patches is 3 cm in both directions. As mutual coupling effects are introduced (solid lines), it is clearly observed that the beamwidth decreases and sidelobe levels increase; both these phenomena are well known consequences of electromagnetic coupling within antenna arrays. Of particular importance is the difference of 32 dB in calculated E-plane sidelobe levels.

To demonstrate the advantage of this method with respect to CPU-time reduction, assume that the 3x2 array of Fig. 4 is first analyzed without symmetry conditions. While the incorporation of the structural symmetry reduces the number of matrix elements by a factor of four, the utilization of the Toeplitz form adds another factor of two (but requires SVD techniques for non-square matrix inversion). This size-reduction factor of eight makes the software operational on modern workstations. If, for example, the entire array is divided into 250 elements, an overall time-reduction factor of 27.4 is achieved.

Fig. 5 demonstrates the validity of the symmetry assumptions at the example of a 2x2 array. The solid line shows the resulting E-plane pattern if the entire array is analyzed, i.e., mutual coupling effects between all four elements are taken into account. The dashed line is calculated by considering mutual coupling only between the two upper patches (highlighted in the inset of Fig.5) and using the symmetry properties outlined in section II. Excellent agreement is obtained thus verifying the simplified approach presented in this paper.

IV. CONCLUSIONS

A simplified moment method technique for the radiation pattern calculation of mutually coupled microstrip radiators is presented. The utilization of symmetry properties in the surface current distribution and Toeplitz symmetry of the impedance matrix of mutually coupled microstrip antennas reduces storage and CPU-time requirements for the analysis of array radiation characteristics. A typical value of the CPU-time reduction factor is 30. Due to the symmetry properties considered, the software is operational also on non-virtual-memory computers. As expected, the electromagnetic coupling within the array can severely increase sidelobe levels and reduce the beamwidth and the first-null position.

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REFERENCES

[1] Huang, J., "Microstrip antenna developments at JPL", IEEE Antennas & Propagation Magazine, vol. 33, pp. 33-41, June 1991.
[2] Lalezari, F., T.C. Boone and J.M. Rogers, "Planar millimeter-wave arrays", Microwave Journal, vol. 34, pp. 85-92, Apr. 1991.
[3] Gupta, K.C. and A. Benalla (ed.), *Microstrip Antenna Design* , Artech House , Norwood, 1988.
[4] Harrington, R.F., *Field Computation by Moment Methods* , The Macmillan Company, New York, 1968, ch. 4.

[5] W.H. Press, B.P. Flannery, S.A. Teukolsky, and W.T. Vetterling, *Numerical Recipes - The Art of Scientific Computing (Fortran Version).* Cambridge University Press, New York, 1989.

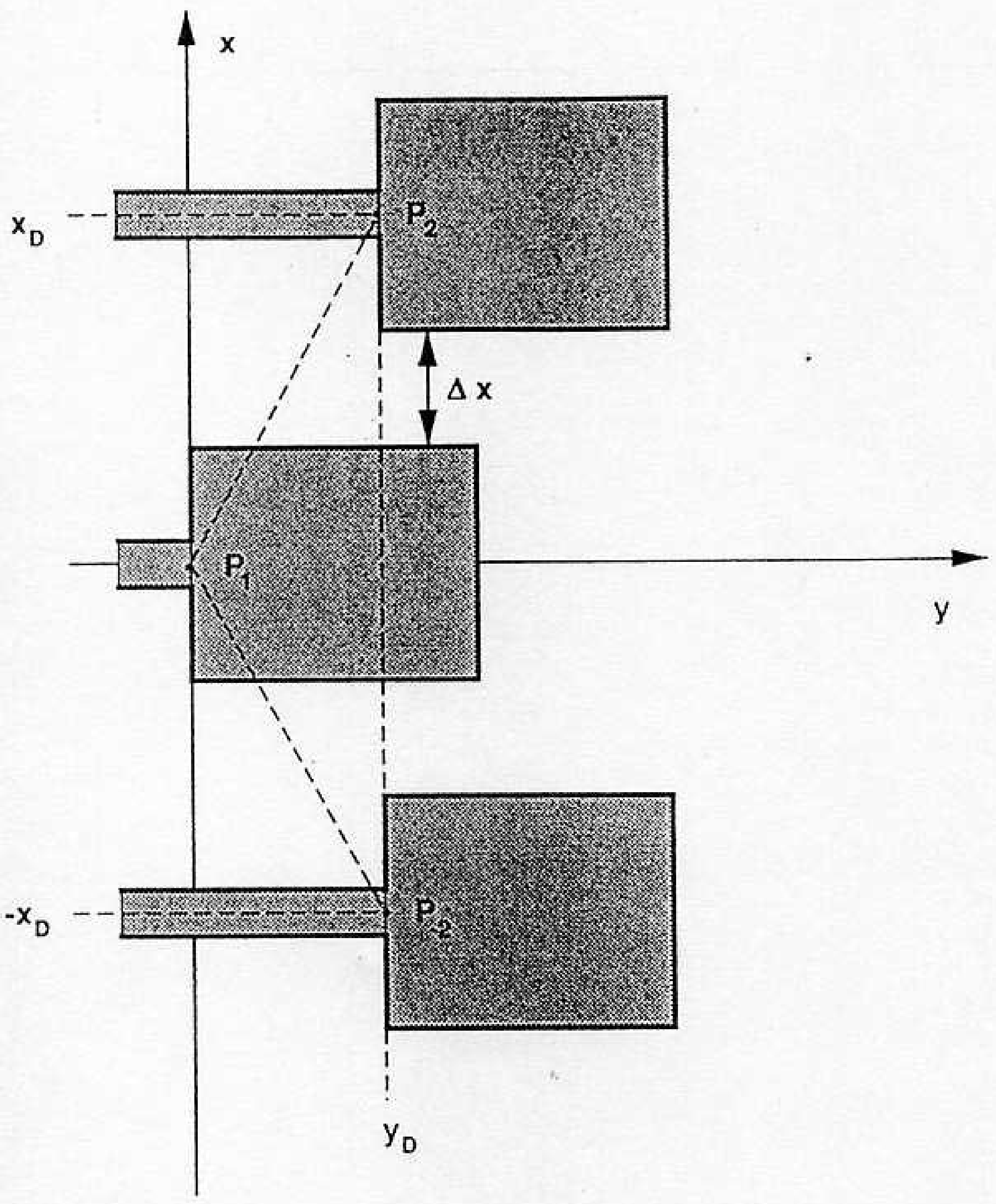


Fig. 1 Symmetrical arrangement of three coupled microstrip radiators.

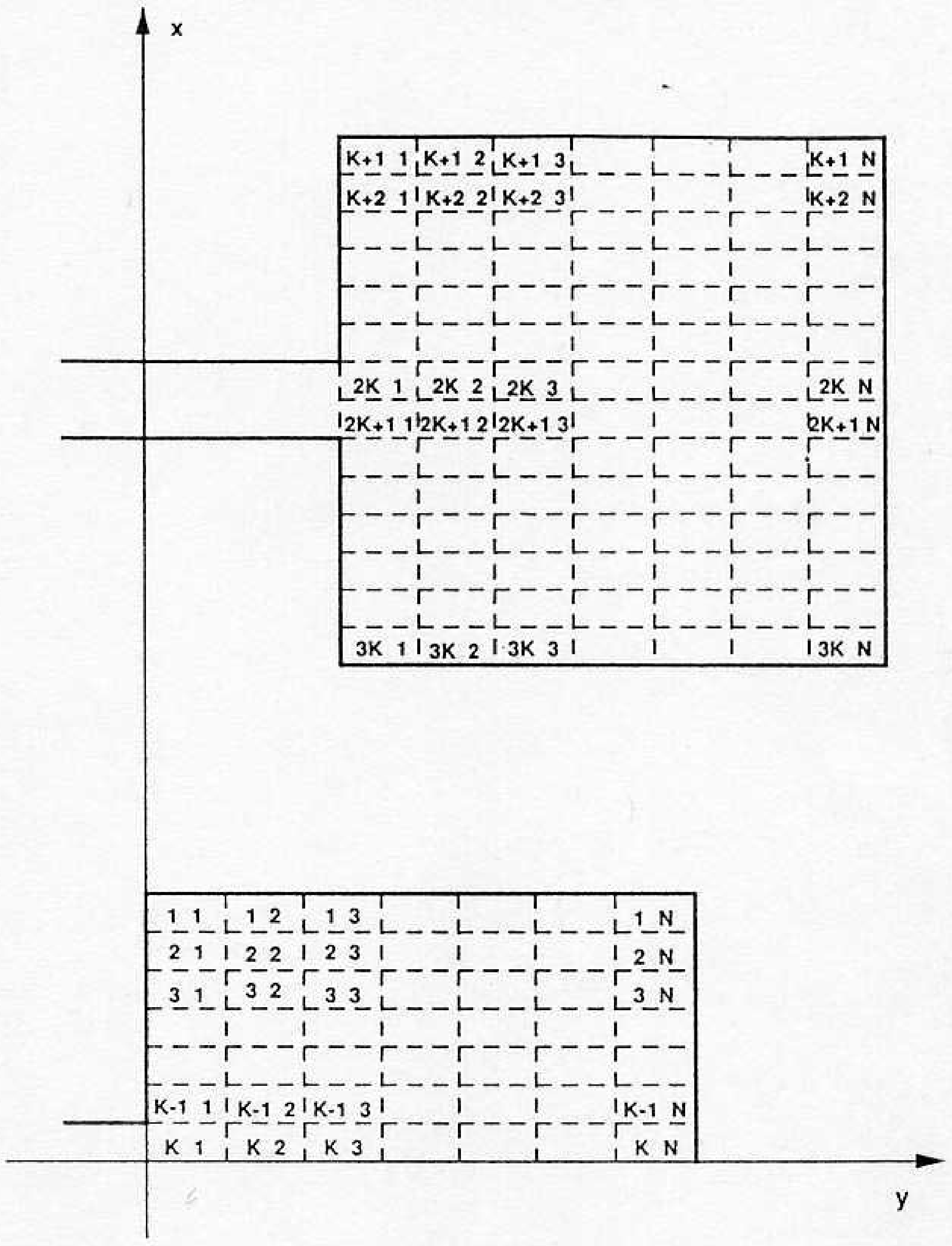


Fig. 2 Element notation for the upper half of the array.

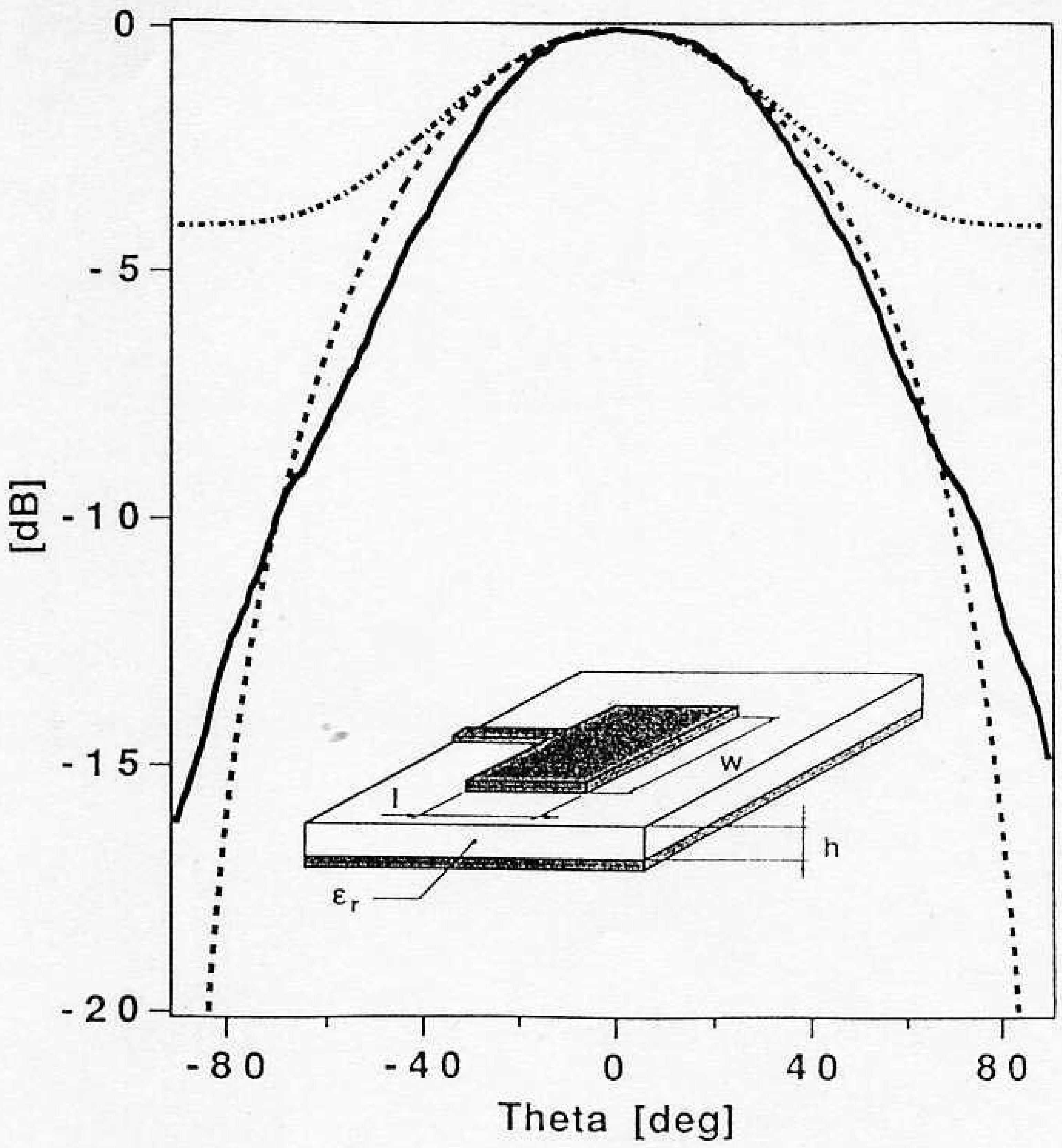
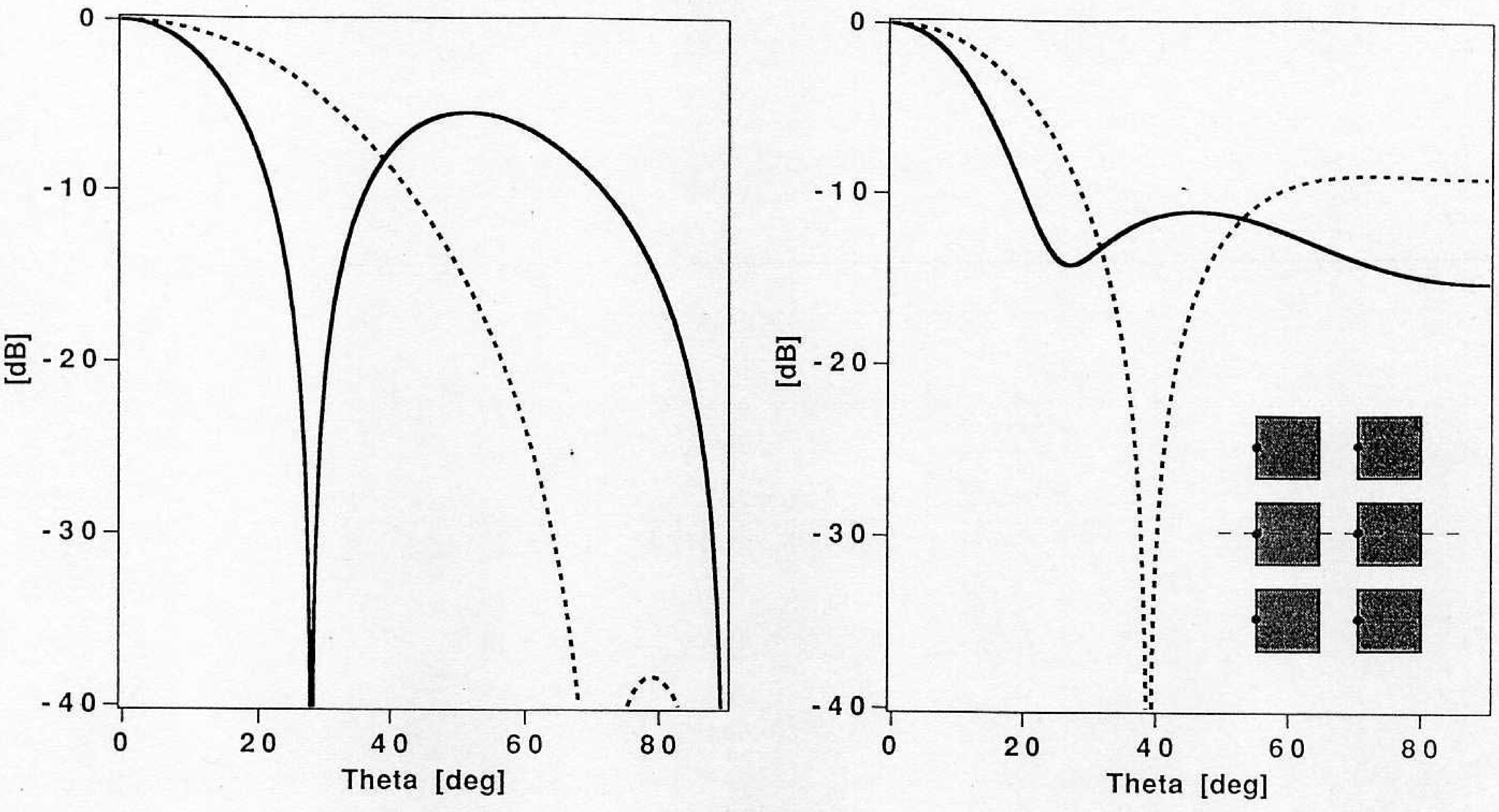


Fig. 3 Comparison of the pattern obtained by this method with measured results for a single patch; solid line: measured (E-plane), dashed line: this theory (E-plane), dash-dotted line: this theory (H-plane). Dimensions: w=l=1.712cm, h=1.575mm, ε_r=2.33, f=5.3GHz.



a

b

Fig.4 Computed radiation patterns of a 3x2 array; dimensions of individual patches as in Fig. 3a ; (a) E-plane, (b) H-plane; solid lines: mutual coupling included, dashed lines: mutual coupling neglected.

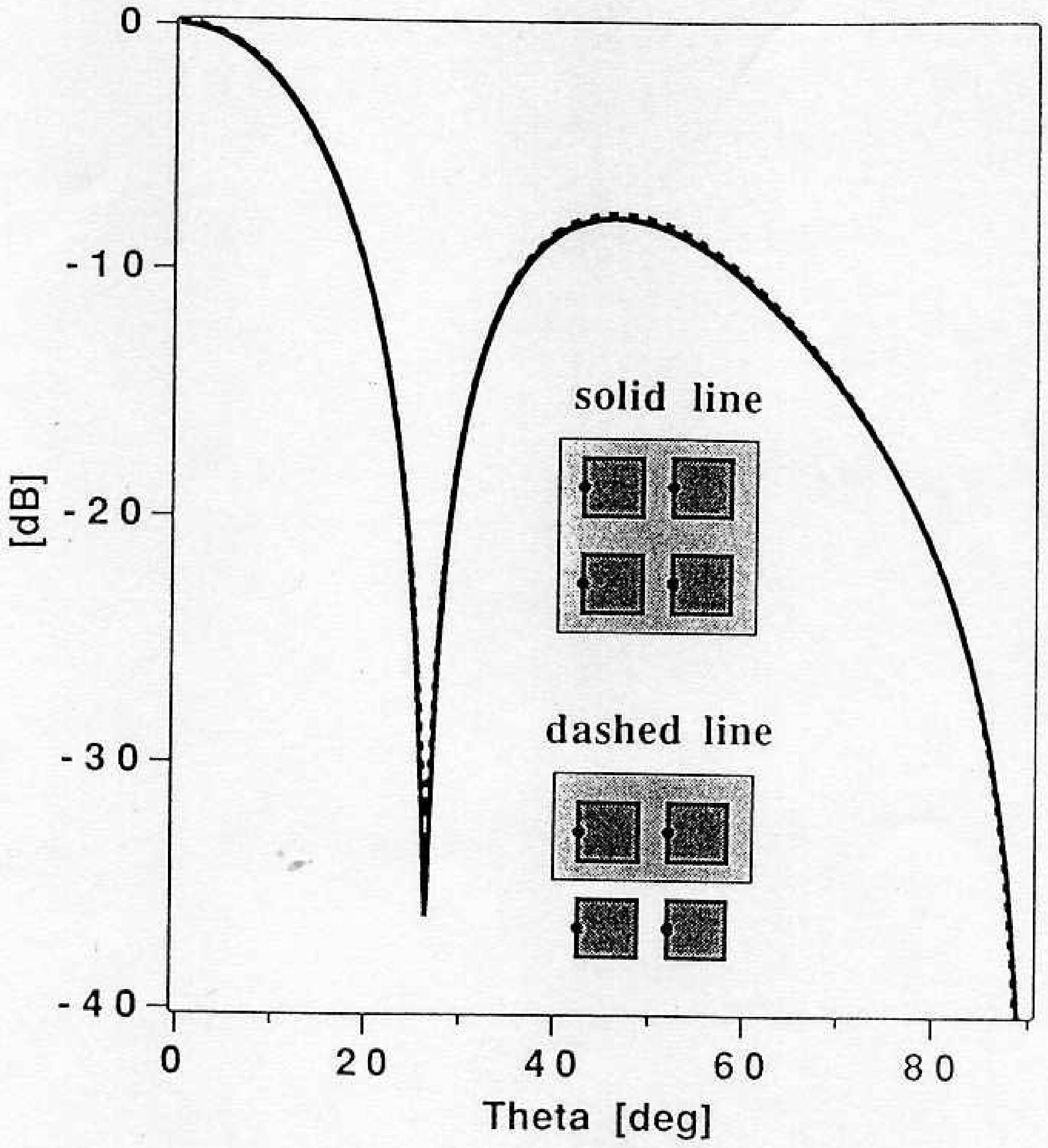


Fig.5 Comparison between calculated E-plane patterns of a 2x2 array; solid line: symmetry conditions neglected, dashed line: symmetry properties included. Dimensions (c.f.Fig. 3): w=l=6.8mm, h=0.8mm, spacing between patch centers = 19mm, ε_r=2.32, f=14GHz.