ANTENNA SIMULATIONS ON SHIPS FOR AMRFS APPLICATIONS

Eighth Quarterly Report

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PROJECT INFORMATION

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CHRONOLOGY of Events (Updated Every Quarter)

• October 1998	Proposal Submission
• December 1998	Oral Presentation to ONR
• August 1999	Began Contract Negotiations
• 26 August. 1999	Kickoff meeting at Sanders (attended by Sanders, UM , ONR)
• 13 October 1999	Contract Signed between U-M and Sanders
• 18 October 1999	MR_TETRA Code and the manual delivery
• 15 December 1999	Submission of First Quarterly Report
• 19 January 2000	AMRFS Review Meeting I (Lockheed Sanders - Nashua)
• 19 January 2000	ARRAY_TETRA Code delivery
• 1 April 2000	Submission of Second Quarterly Report
• 15 June 2000	Submission of Third Quarterly Report
• 27 July 2000	AMRFS Review Meeting II (Lockheed Sanders – Nashua)
• 15 September 2000	Submission of Fourth Quarterly Report
• 15 December 2000	Submission of Fifth Quarterly Report
• 24 January 2001	AMRFS Review Meeting III (BAE Systems – Nashua)
• 15 March 2001	Submission of Sixth Quarterly Report
• 15 June 2001	Submission of Seventh Quarterly Report
• 26 July 2001	AMRFS Review Meeting IV(BAE Systems – Nashua)
• 15 September 2001	Submission of Eighth Quarterly Report

Quarterly Progress

Task	1st	2nd	3rd	4th
Implementation of the Periodic Boundary Conditions in MR_TETRA	→			
Fast Spectral Domain Algorithm Applied to MR_TETRA (AIM delivered at this time)		→	→	→
Finite Arrays / MR_TETRA_F Implementation and Formulation	→	→	→	
F77 to F90 code inversion for MR_TETRA_F And Code Optimization		→	→	→
Coupling Studies between Elements and Array groups		→	→	→
FMM_FSS_CURVE code initiation				→

Task	5th	6th	7th	8th
ARRAY_TETRA **delivery**				
Implementation of the Periodic Boundary Conditions in FSS-CURVE –(3rd year)	→			
Implementation of Multilevel FMM in FSS-CURVE	→	→	→	
Coupling Implementation Elements and Array groups	→	→	→	
Code Optimization and Testing	→	→	→	→
FSS_CURVE delivery				

DETAILED SCHEDULE (October 1999-December 2000)

No.	Description	Due Date
1	FSS_PRISM updated with Tetrahedral FEM(***MR_TETRA***) Accelerated with Adaptive Integral Method Code and the Manual	**DELIVERED (1st)**
2	a) Periodic Boundary Conditions Implementation and validation	**COMPLETE**
	b) ***ARRAY_TETRA*** Code	**DELIVERED (2nd)**
	c) Finite element approximation	**COMPLETE**
	d) Convert F77 to F90 (final modifications)	ONGOING
	e) Array coupling formulation	COMPLETE
	Added Task:	
	f) Validations for patch and slot arrays IDEAS/PATRAN/GID interface	**COMPLETE**
3	a) FSS-Curve updated with MLFMM BI and hexahedral FEM	**COMPLETE**
	b) External field coupling (plane wave)	**COMPLETE**

	f) LTSA mesh driver e) LTSA and ETSA validations	**COMPLETE** **COMPLETE**
4	a)Demonstrate fully documented ARRAY_TETRA Version 2 (all tasks except coupling to be completed in this version of the code) b) Update FSS-Curve for tetrahedral elements –removed task c) Implement Periodic boundary conditions in FSS_CURVE (added task)-3rd year	September. 2000 **DELIVERED** (see manual for the code information)
5	a) Coupling studies and realistic array analysis for FSS_CURVE (AMFIA) (edge diffraction effects, element grouping etc) b) Demonstrate fully documented FSS-CURVE First Release	December. 2000 ONGOING **DELIVERED**

DETAILED SCHEDULE (December 2000-December 2001)

No.	Description	Due Date
1	**Remaining ARRAY TETRA modifications**	
	1) BCs and Feeds in Patran	COMPLETED
	2) FSDA	ONGOING (July 2001)
	3) Arbitrary external excitations	ONGOING (July 2001)
	4) Pins and Loads	ONGOING (July 2001)
	4) F90 version	ONGOING (December 2001)
	ARRAY -TETRA final release (F90)	December 2001
	AMFIA Modifications	
	1) I/O modifications	COMPLETED
	2) Initial User's Manual	COMPLETED
	3) MLFMM implementation	COMPLETED
	AMFIA first release (f77)	**DELIVERED**
	5) Coupling in a finite array environment	December 2001

Executive Summary and Project Status

We continue to be on schedule with all activities and code development tasks. In the forth project review at Sanders (in July 2001), we presented results for finite arrays (patch, slot and TSAs (Tapered Slot Arrays)) using our AMFIA code. We also presented coupling results between antenna array elements and subarray-subarray. We also demonstrated some primary results using our newly developed, highly robust and exact AMFIA code. New code also upgraded from F77 to F90.

Besides the coupling studies we demonstrated in the last review, this quarter we also focused on enriching the solver capabilities in AMFIA. A new solver BICGS(L) (Biconjugate gradient solver with respect to parameter L) has been shown to give better convergence characteristics compared to CGS, QMR and BICG for TSAs. An example of microstrip fed TSA antenna is given to demonstrate the performance of different solvers.

Unother update in this quarter was the addition of a term to FE-BI formulation which is used when loads and shorting pins presents. A microstrip patch antenna has been choosen [1] to validate the results.

During this quarter no changes were made to ARRAY_TETRA. The final f77 version of ARRAY_TETRA will be delivered to BAE December 20th after remaining modifications (outlined in the last report—Executive Summary and Project Status) are completed. F90 version of ARRAY_TETRA will also be available by that time.

In the last report, we also gave some coupling results using our newly developed AMFIA code.

To summarize, the tasks carried out this quarter are;

- Formulation and Implementation (Shorting pins and Loads for AMFIA)
- Implementation of a new solver BICG(L) and comparison with the existing solvers for TSA
- Coupling between array groups
- Large finite arrays

For the next quarter our goals are;

- Formulation details and implementation outlines of Super Cell
- FSDA for ARRAY_TETRA with validations
- F90 version of ARRAY_TETRA

AMFIA UPGRADES

Several upgrades have been carried out for AMFIA this quarter. We first modified the existing formulation to treat loads and shorting pins in the geometry. Below we provide a microstrip patch antenna example for validation of this implementation. Another modification was the inclusion of a new solver. We show here that the new solver has increased the convergence substantially. To demonstrate the solver, we analyzed a microstrip-fed LTSA and compared convergence with the other solvers

EXAMPLE-Microstrip Patch Antenna

As an example for the validation of the loads and shorting pins, we consider the microstrip patch antenna displayed in Fig.1. Input impedance characteristics of this antenna were computed from 1-4GHz. Figure 2 shows the input impedance for the antenna when a 50 Ω resistor is placed at (x=-2,2 cm, y=-1.5cm). As seen our calculations compare well with measurements [1].

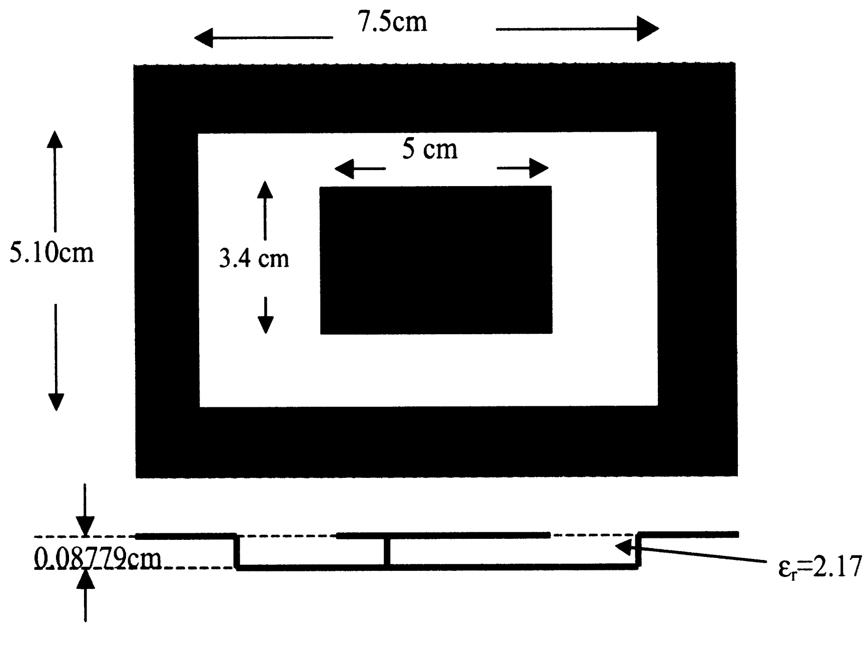


Figure 1. Microstrip Patch Antenna Geometry

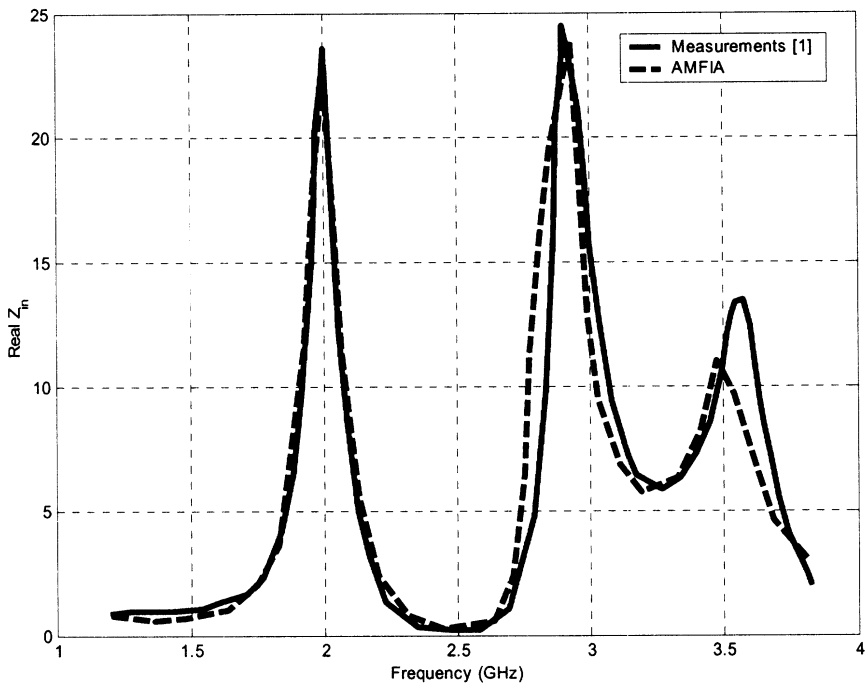


Figure 2. Input Impedance Validation (Real Part)

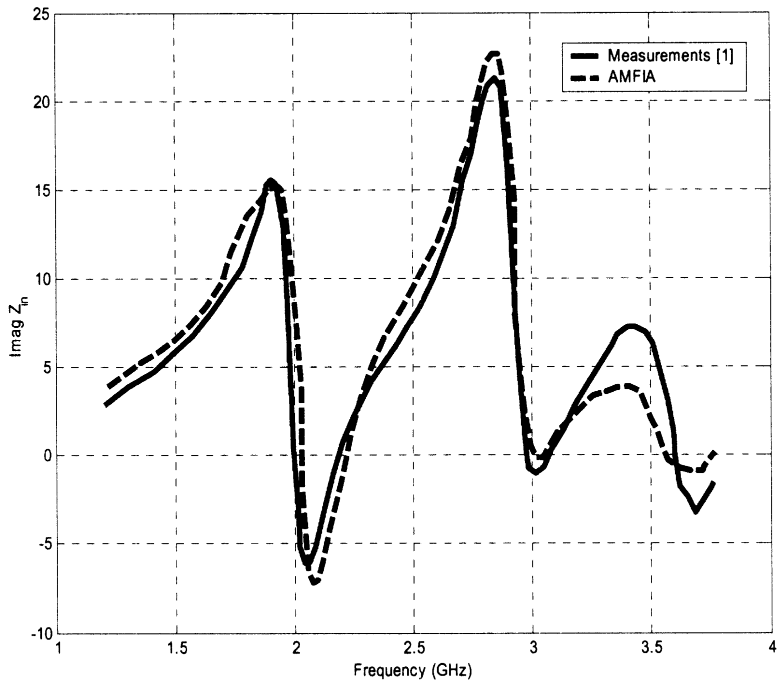


Figure 3. Input Impedance Validation (Imaginary Part)

SOLVERS AND PRECONDITIONERS

This quarter we also investigated the convergence behavior of different solvers and preconditioners for TSAs. For this purpose 4 solvers and 2 preconditioners were analyzed.

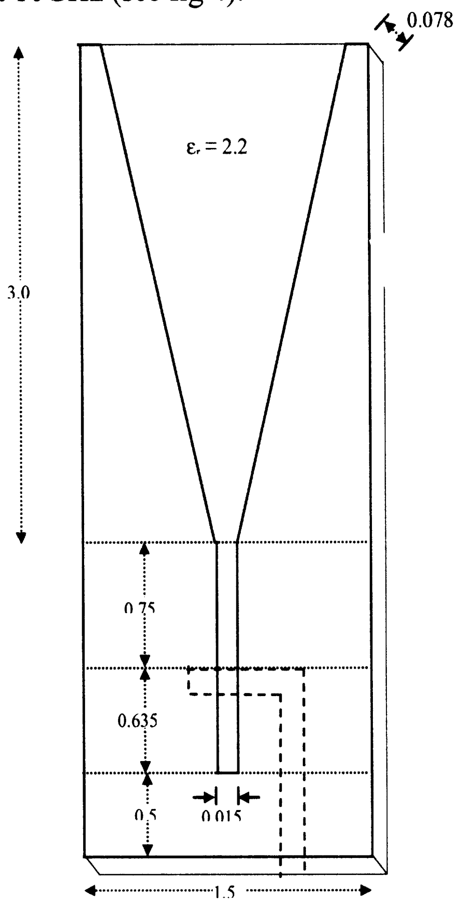
Solvers:

- QMR (Quasi-Minimal Residual)
- CGS (Conjugate Gradient Squared)
- BICG (Bi-conjugate Gradient)
- BICGS (L) (Bi-conjugate stabilized with respect to L)

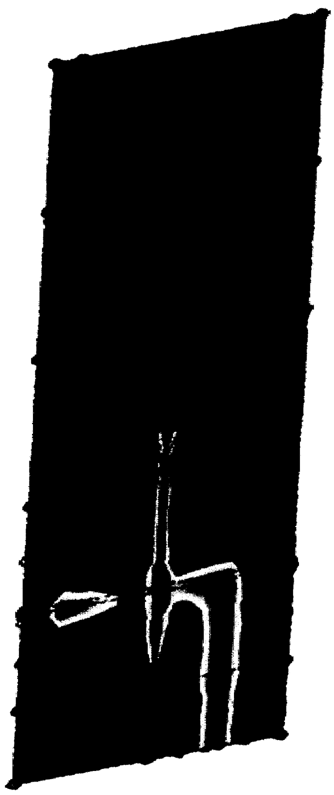
Preconditioners:

- Diagonal
- ILU (Incomplete LU)

We are not going to go into details of these methods here. References can be found in the literature. (QMR,CGS,BICG and Preconditioners [2],[3], BICGS(L) [4]). To see the performance of those solvers and preconditioners, we consider a microstrip fed LTSA antenna operating at 10GHz (see fig 4).



a)



b)

Figure 4. a) Microstrip-fed antenna geometry **b)** Field Distribution

Figs. 5&6 show the field patterns for E&H plane cuts from 8-12 GHz. As seen the data are not symmetric due to non-symmetric feeding (see fig.4a).

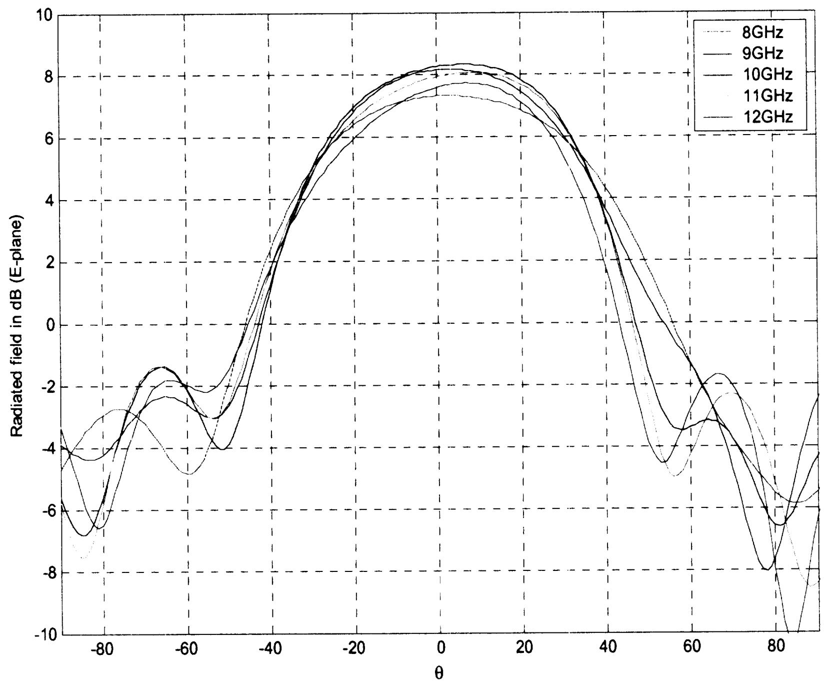


Figure 5. Radiated Field versus observation angle–(E-plane)

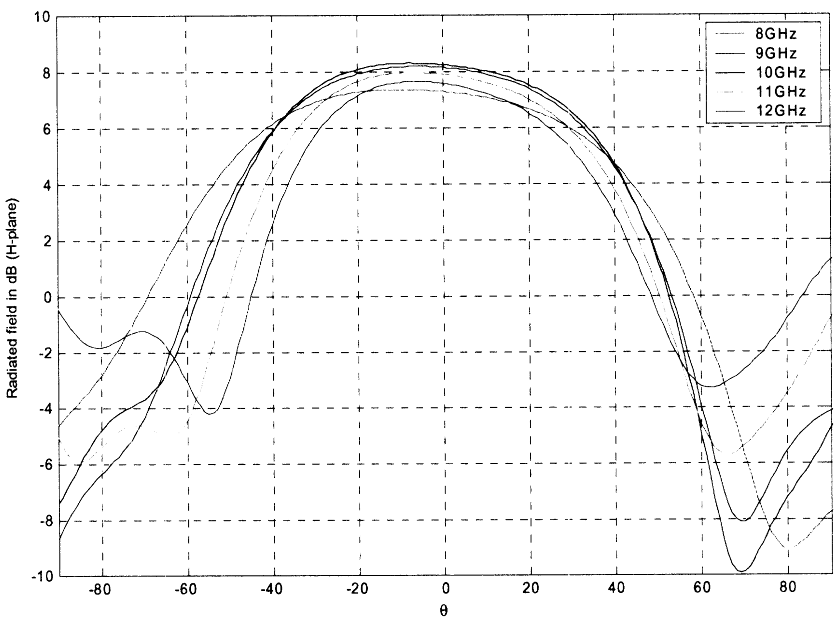


Figure 6. Radiated Field versus observation angle–(H-plane)

Figs. 7-9 show the convergence behavior of the solvers used in AMFIA for the microstrip fed LTSA antenna. In Fig. 7 no preconditioners are used. In Figs 8,9 diagonal and ILU preconditioners are used. As seen, BICGSTAB(L) has substantially better convergence behavior compared to the other solvers. It converges almost 10 times faster in all cases compared to the closest converged solver.

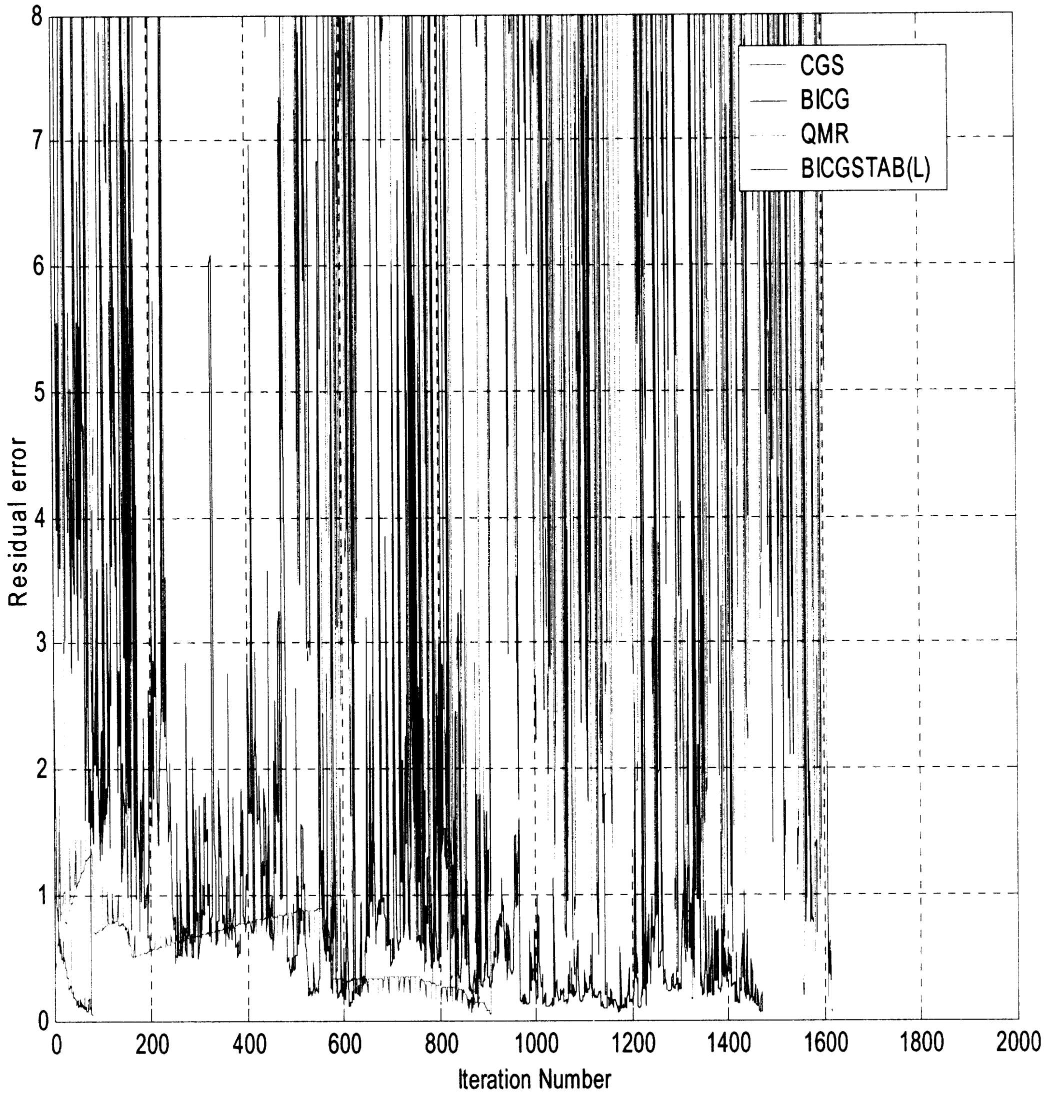


Figure 7. Solvers convergence behavior (no pc)

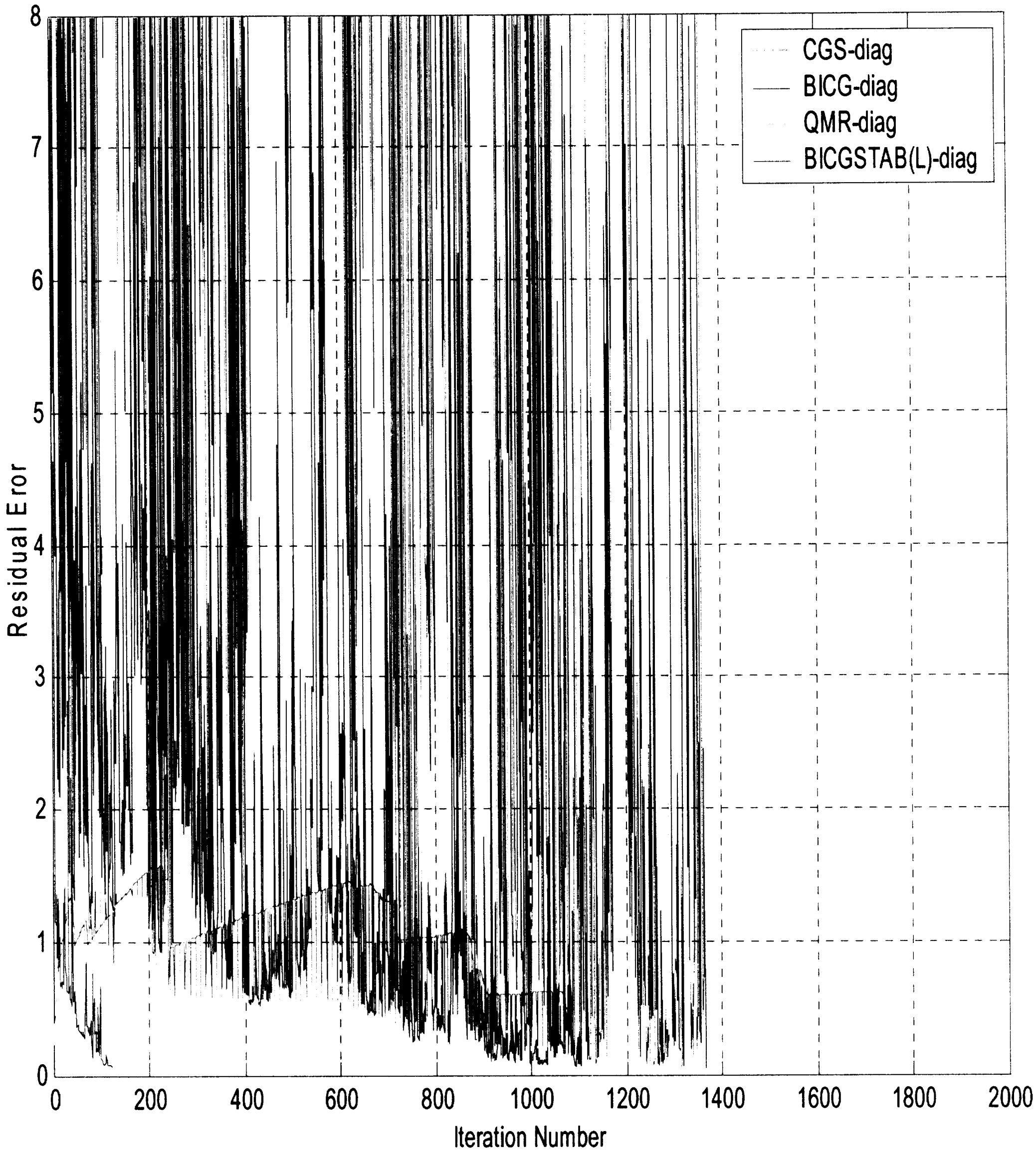


Figure 8. Solvers convergence behavior (Diagonal Preconditioner)

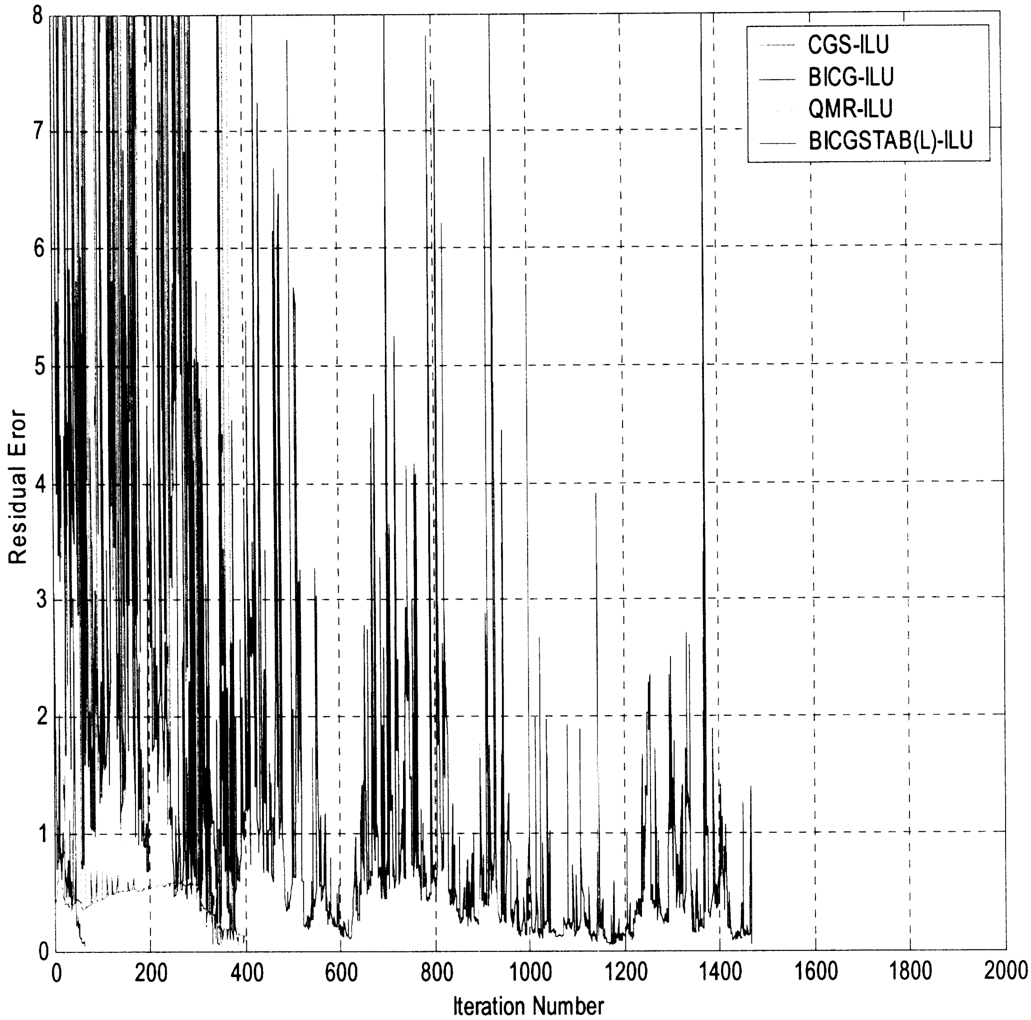


Figure 9. Solvers convergence behavior (ILU)

Figs. 10-12 show the effect of the "L" parameter for BICGSTAB(L) solver for various precinditioners. In all cases, iteration number decreases with increasing "L" value. However for values of "L" greater than "5" , decrease in the iteration number slows down.

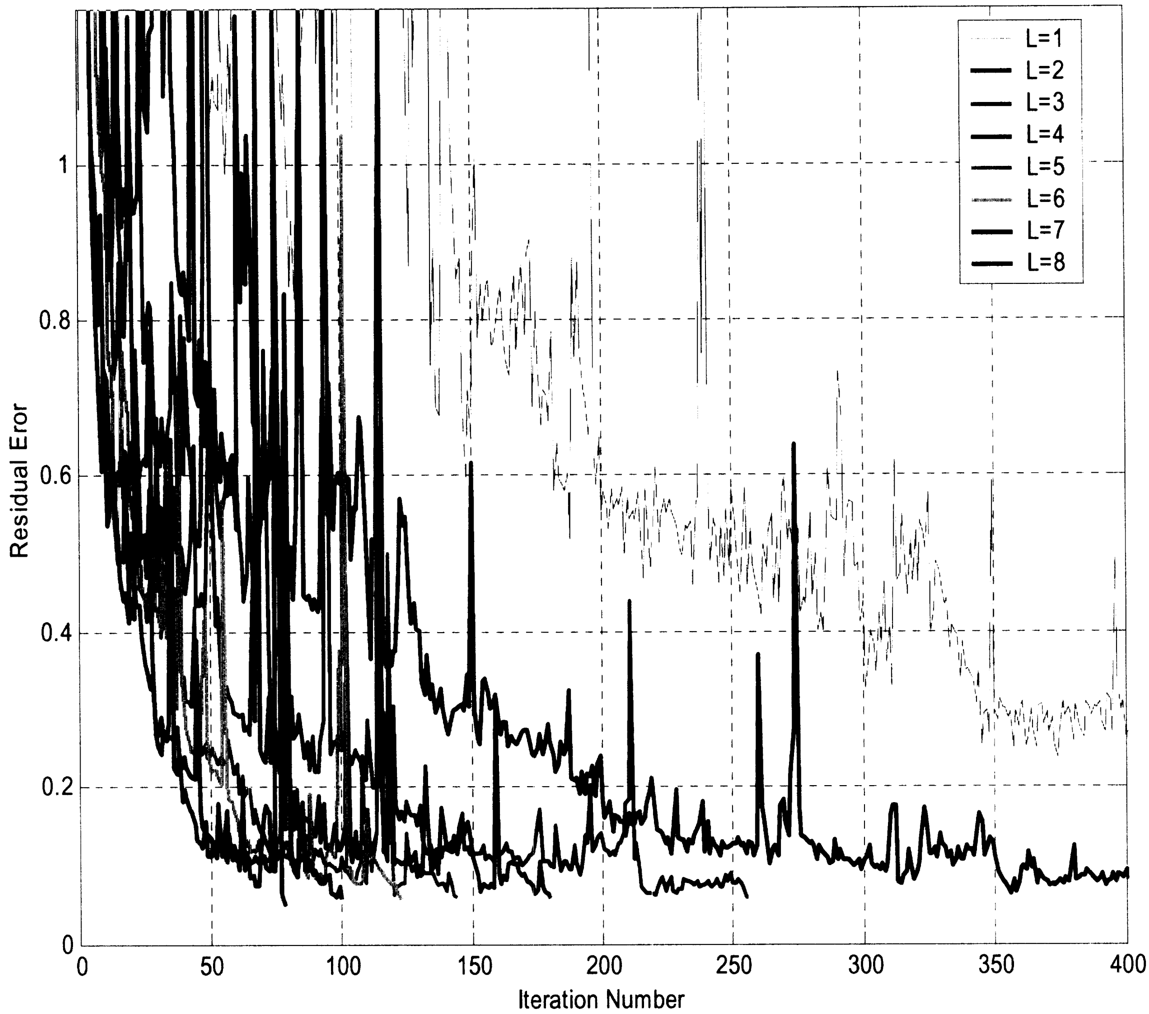


Figure 10. Effect of L parameter (nopc)

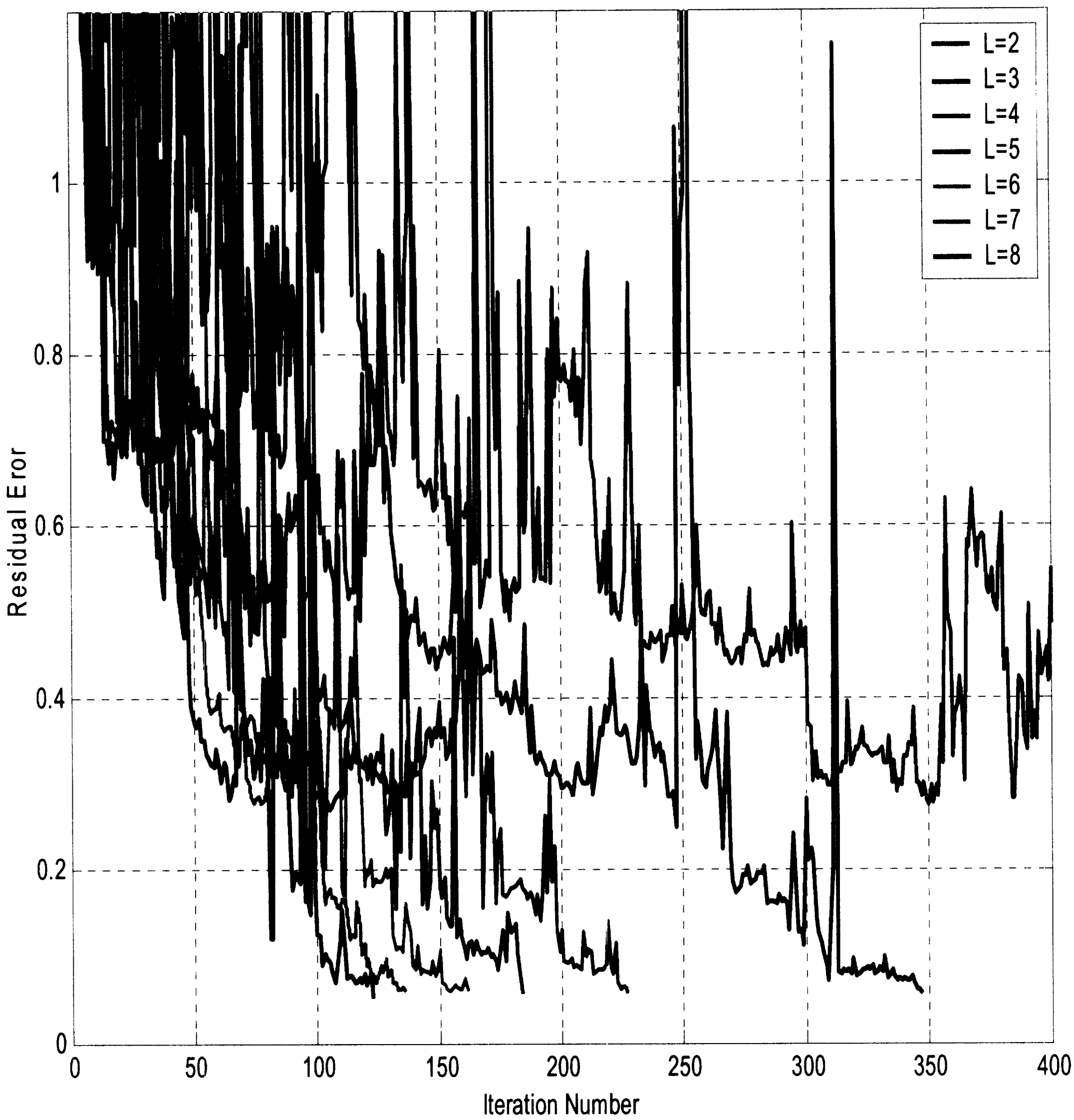


Figure 11. Effect of L parameter (Diagonal Preconditioner)

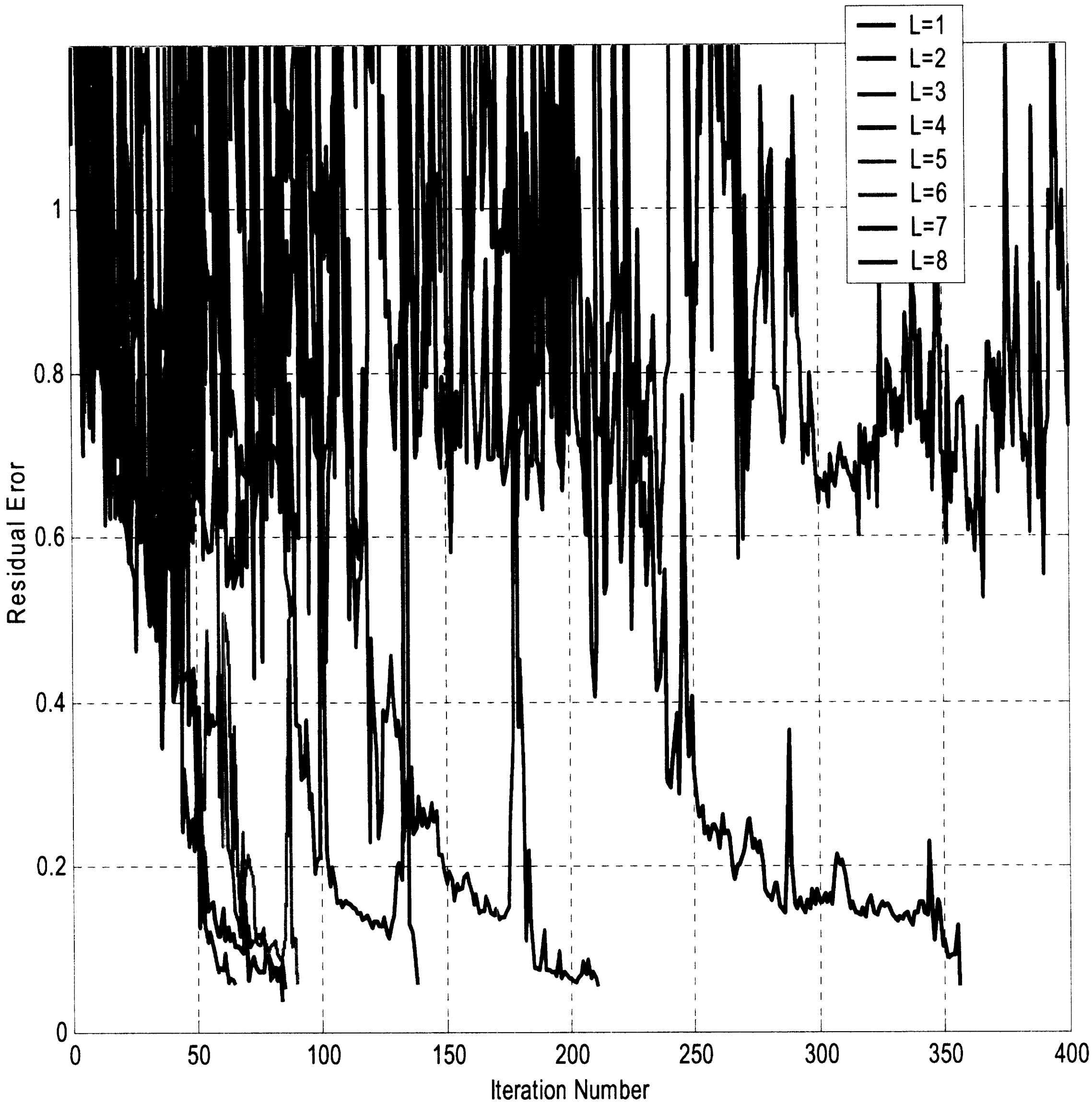


Figure 12. Effect of L parameter (ILU)

Large Finite LTSA arrays

a) 4x3 LTSA array

Consider the 4x3 LTSA shown in fig. 13b. All array elements are identical and the dimensions are given in Figure 13a. The slotline feed is designed to be 100 ohms at 10GHz and the feed point is positioned 0.635cm from the slotline short. The antenna is 4.885cm in length.

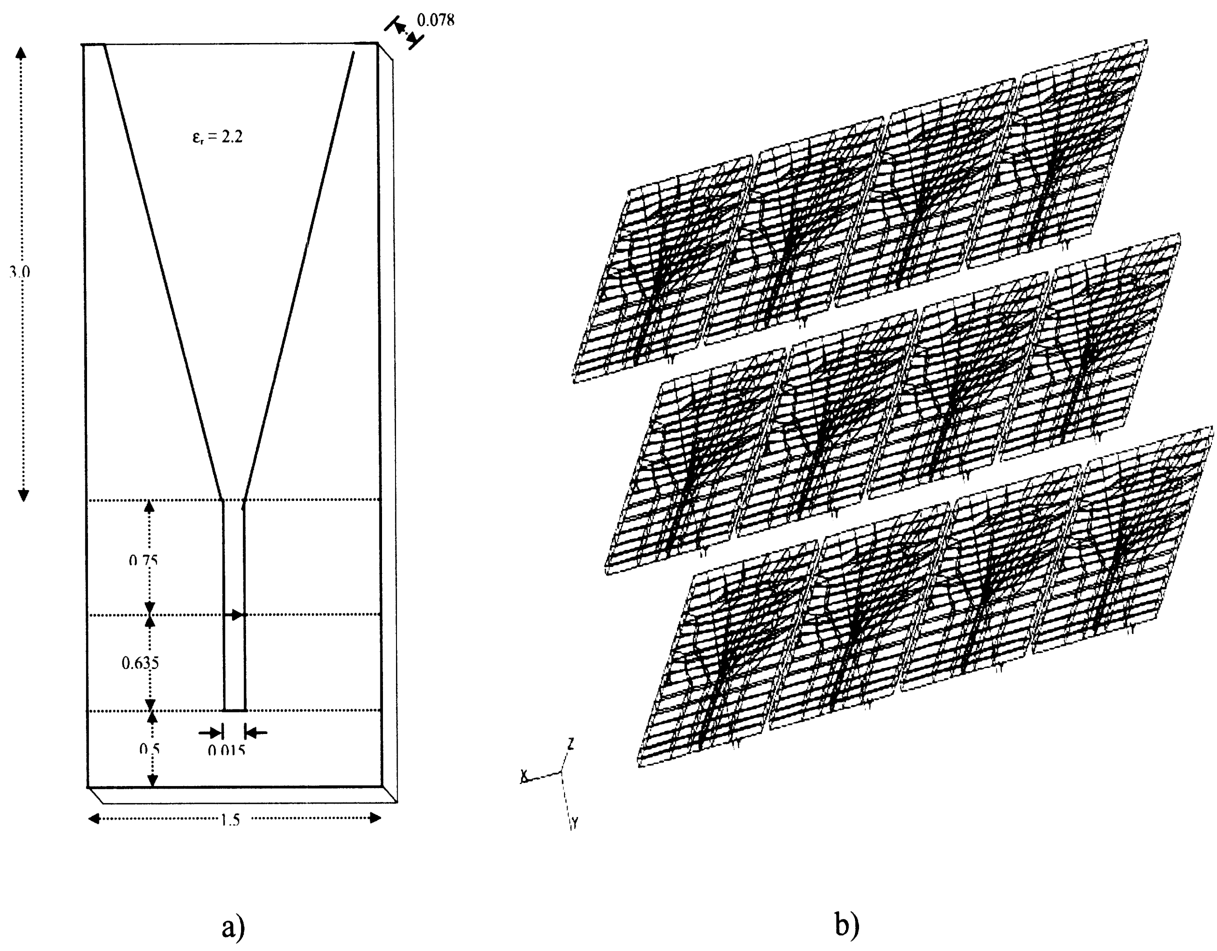


Figure 13 a) Element geometry b) 4x3 array

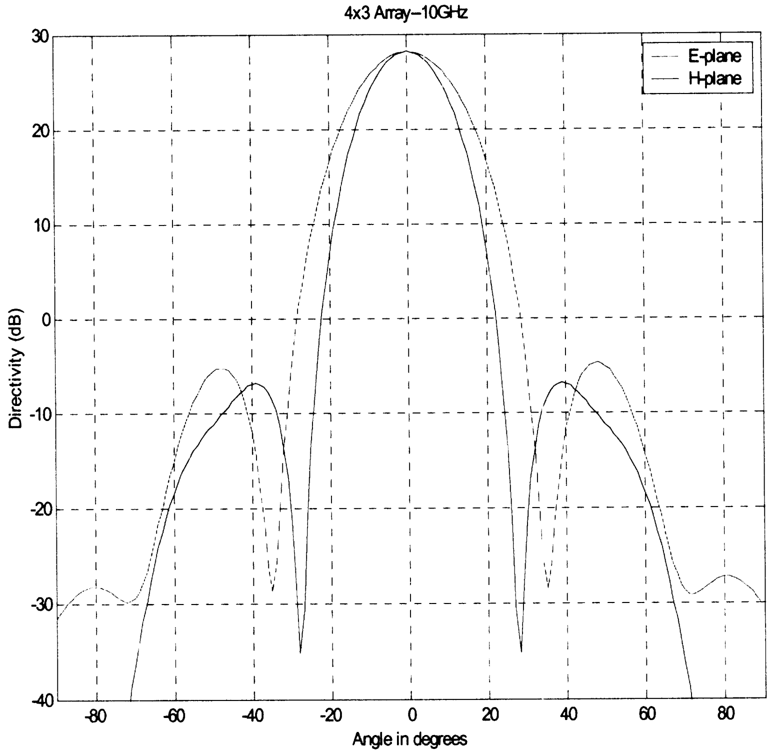


Figure 14. Directivity

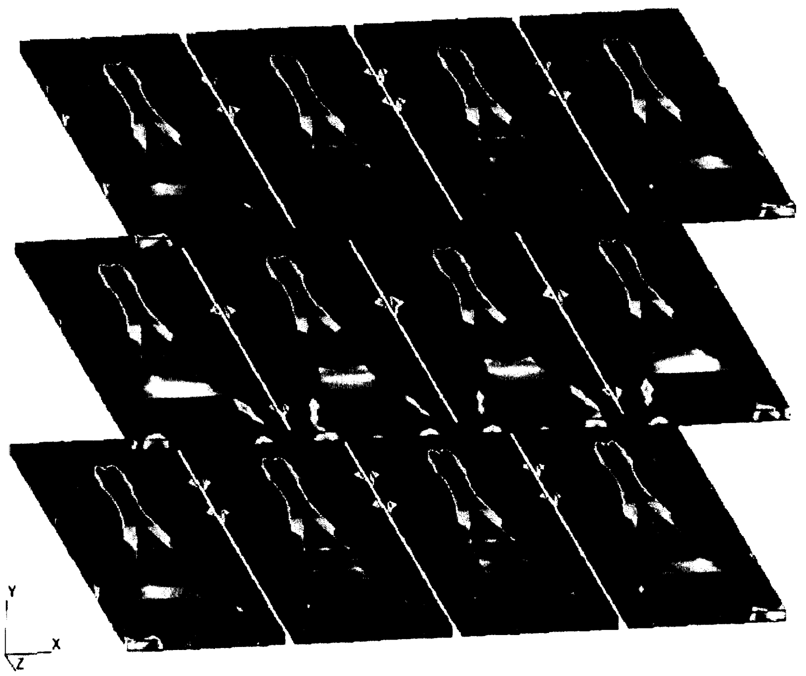


Figure 15. Field distribution on 4x3 array

b) 6x6 LTSA array

Consider the 6x6 LTSA array. All array elements are identical and the dimensions are given in Figure 13a. This prob;em was solved using 4 level FMM with **800 MB of memory. Without FMM 10 GB of memory is** required and thus a parallel machine is required to carry out the analysis.

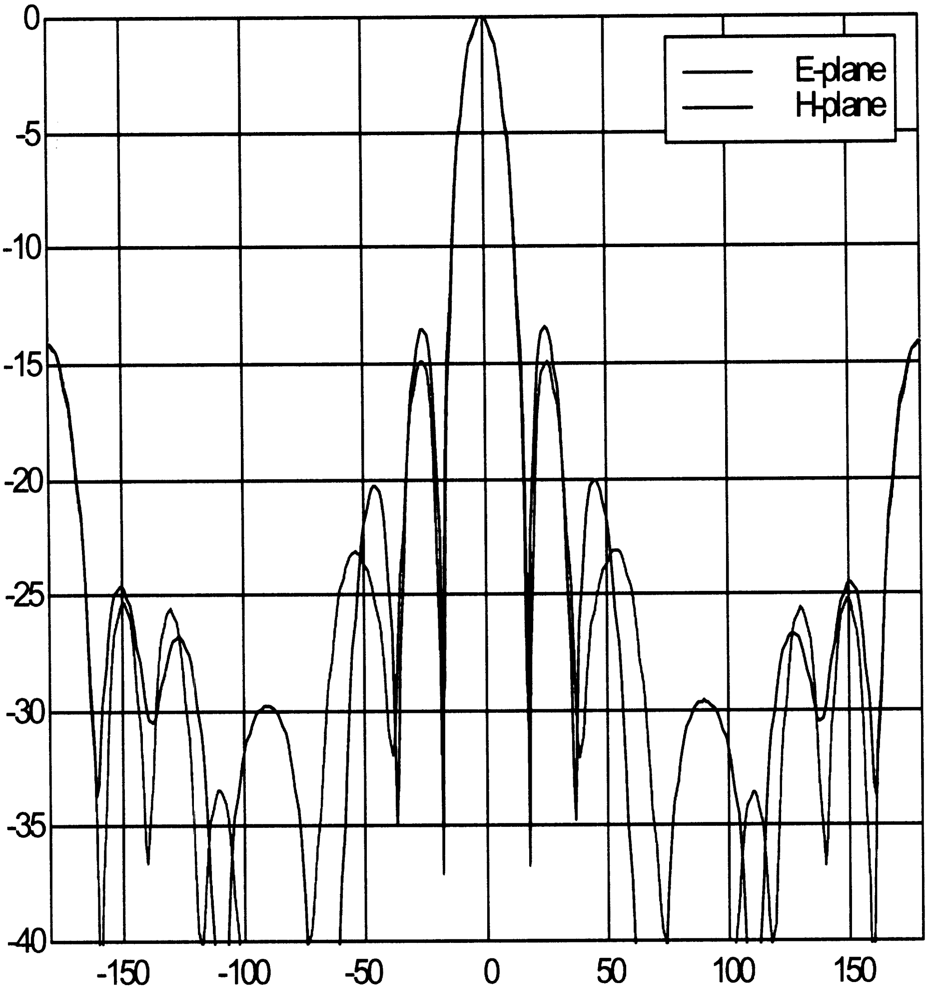


Figure 16. Radiated Fields as a function of observation angle

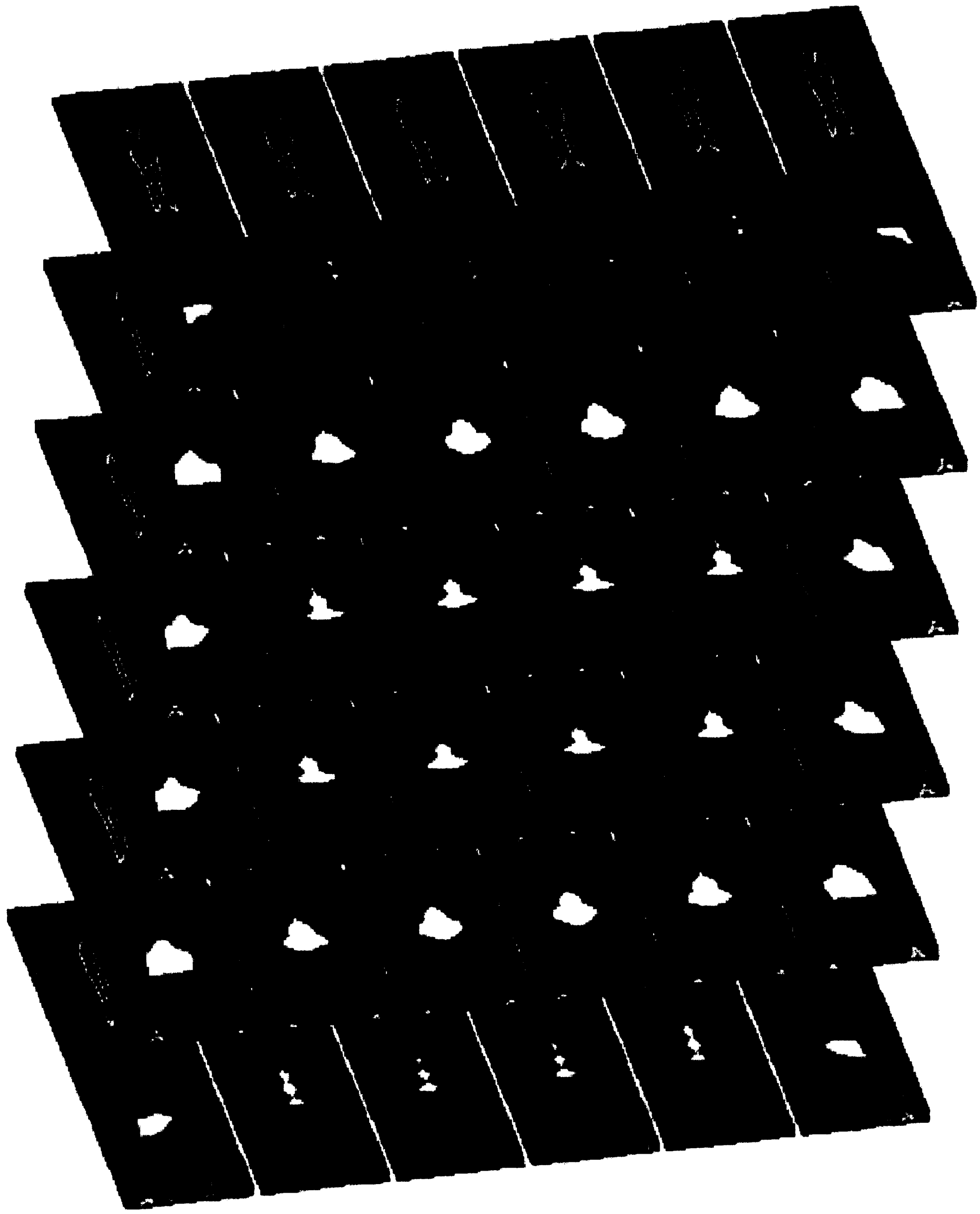
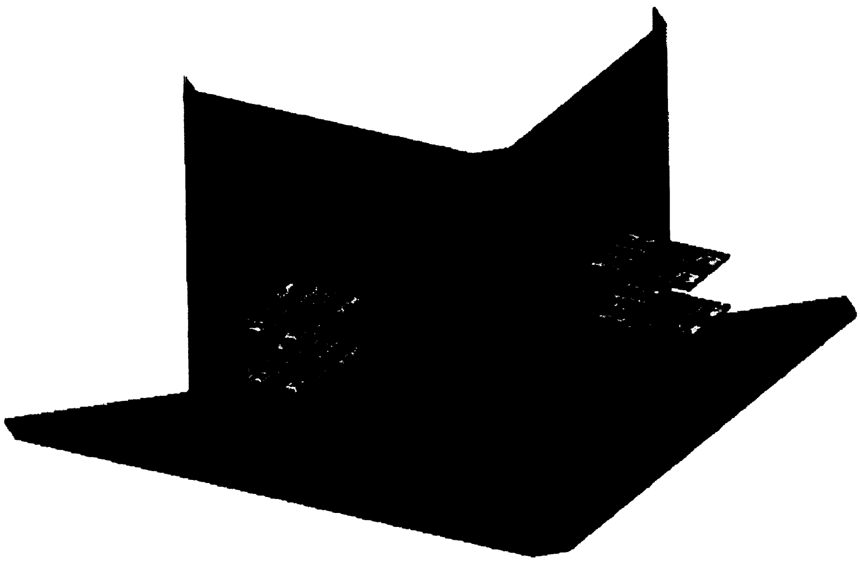


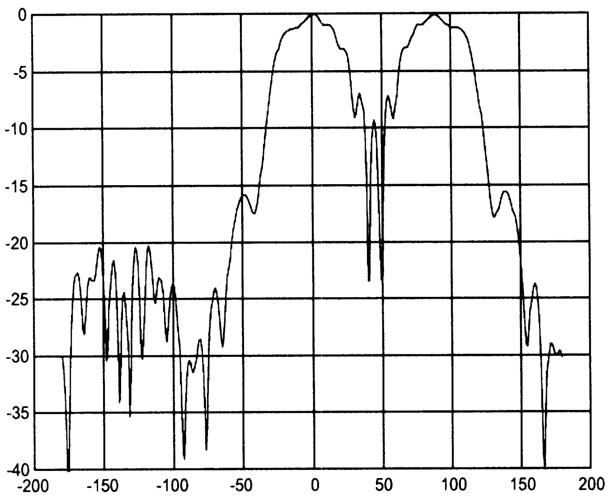
Figure 17. Field distribution

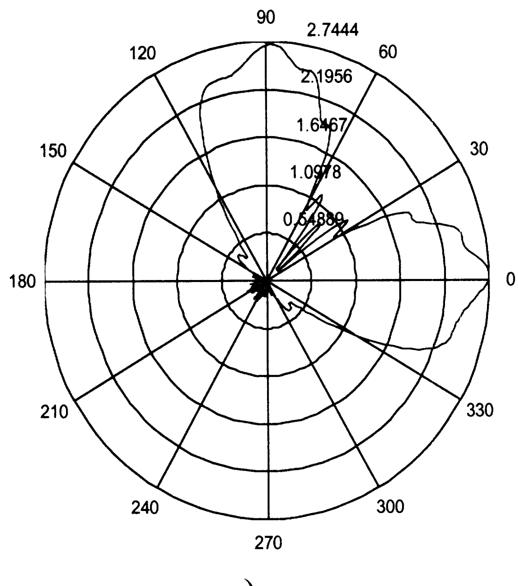
Ship Tower

To demonstrate the capabilities of AMFIA we consider the geometry in Fig. 18a. LTSAs are the same ones used in our previous example (see Fig 13a). This problem required only 187Mbytes of memory with 6 level FMM. Without FMM the required memory was 4.3 GB (i.e. 23 times larger).



a)





b) c)

Figure 18. a) Field distribution **b)** Radiated Field versus observation angle **c)** Radiated Field versus observation angle (polar coordinates)

COUPLING STUDIES

In the previous reports we studied element to element coupling within the same array environment this quarter we are expanding our analysis to subarray/subarray coupling.
For demonstration we consider the slot to patch array coupling in Fig.19. Slot-Patch array system considered for this purpose(see fig.19). Slot array consists of 18 identical slots with 0.4λx0.1λ. The patch array to the right consists of 9 identical patches with dimensions 0.4λx0.2λ (inner rectangle) and 0.6λx0.4λ (outer rectangle). Solution of this problem **required 116 Mbytes of Memory without FMM** but **only 11Mbytes** with FMM. All slots are excited (active) . Our goal is to observe the coupling as a function of array separation between two array systems. Fig. 20-22 show the field distribution for different separation distances. As you can see that the coupling decreases as "d" increases.

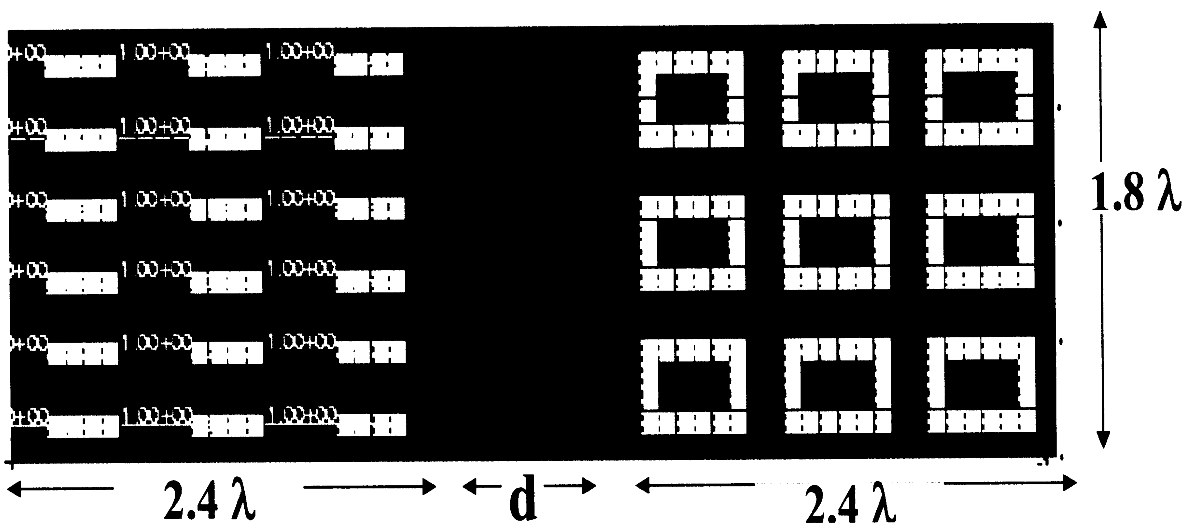


Figure 19. Geometry of the array system

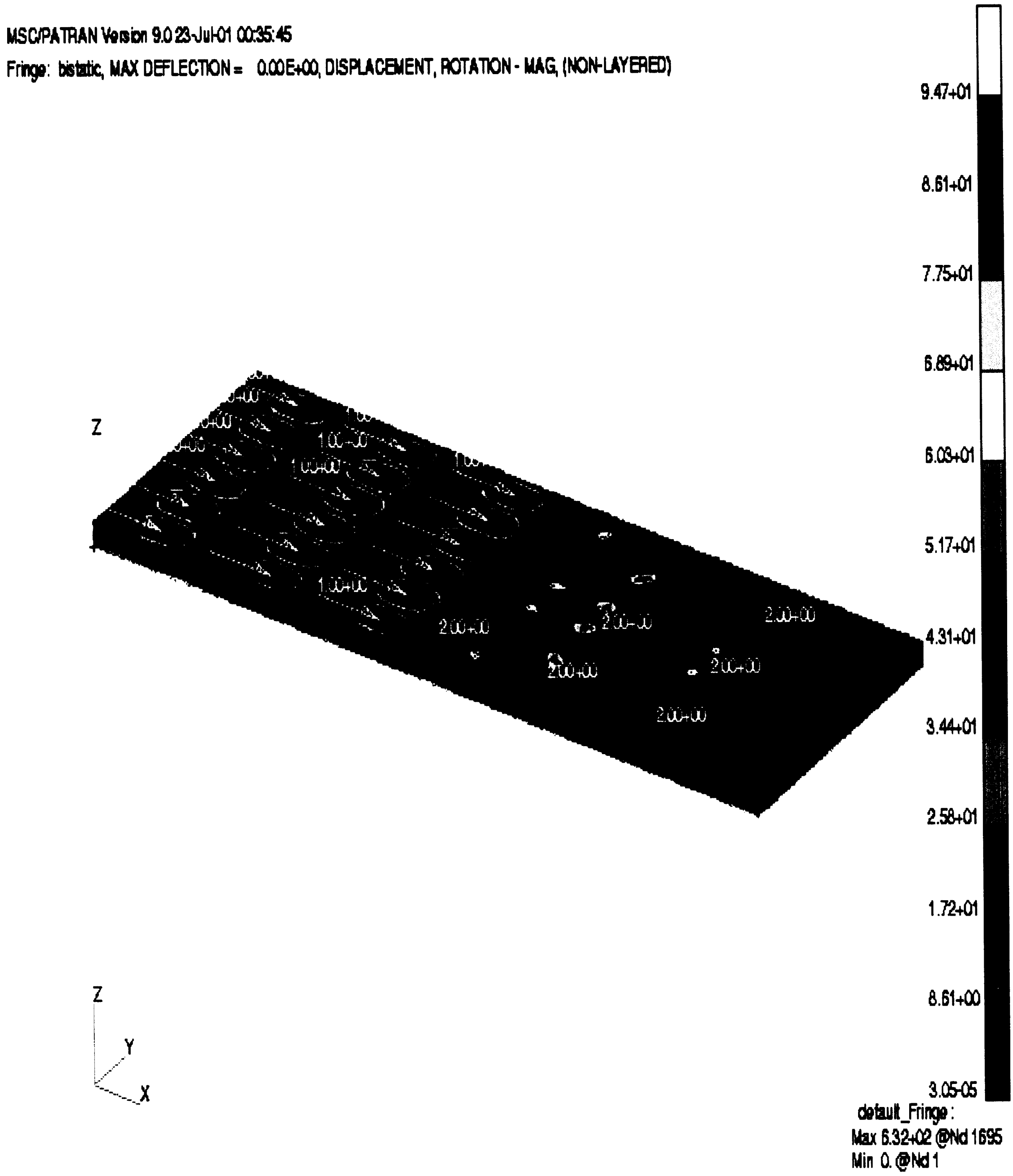


Figure 20. Field distribution d=0.1λ

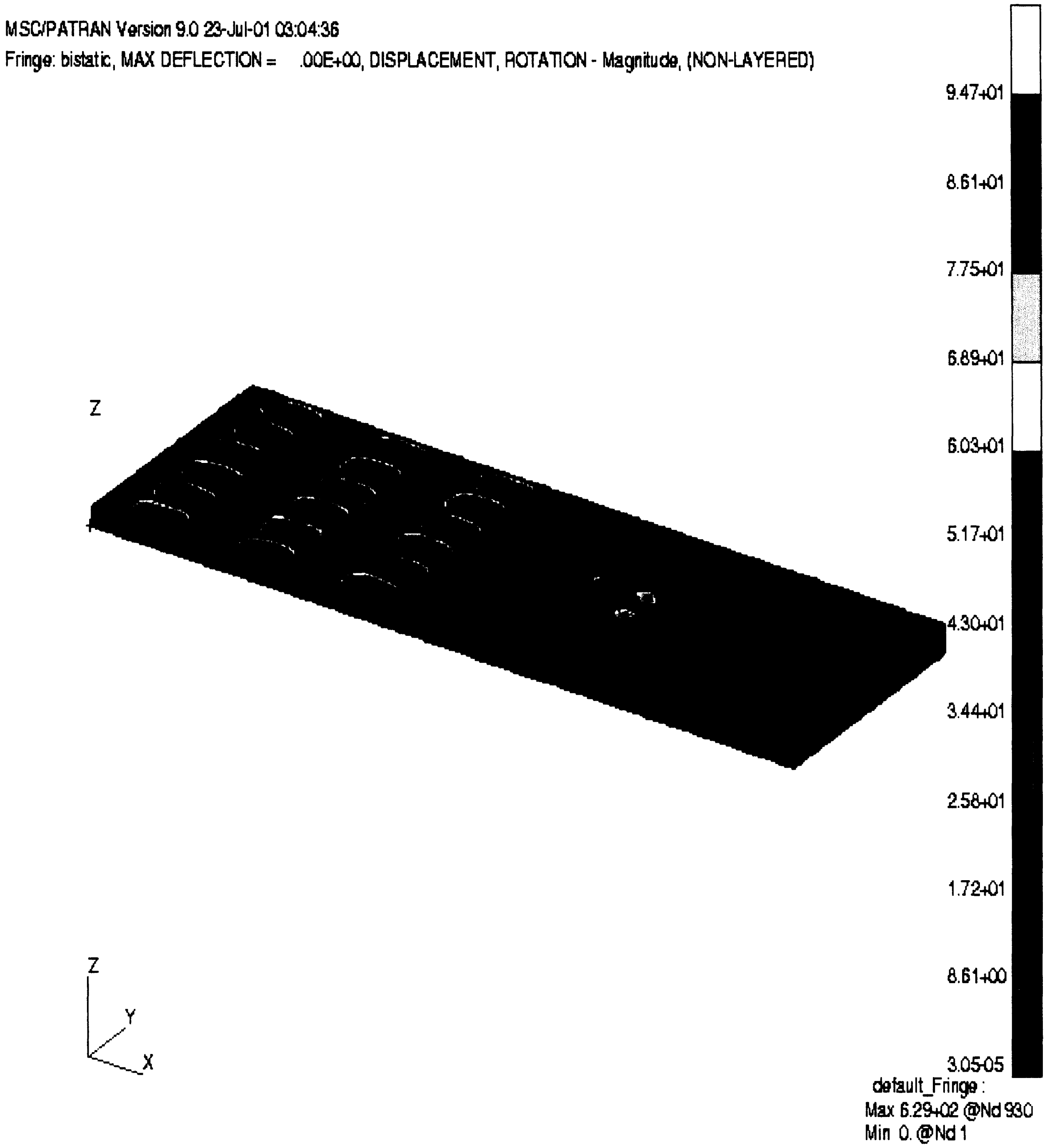


Figure 21. Field distribution d=0.5λ

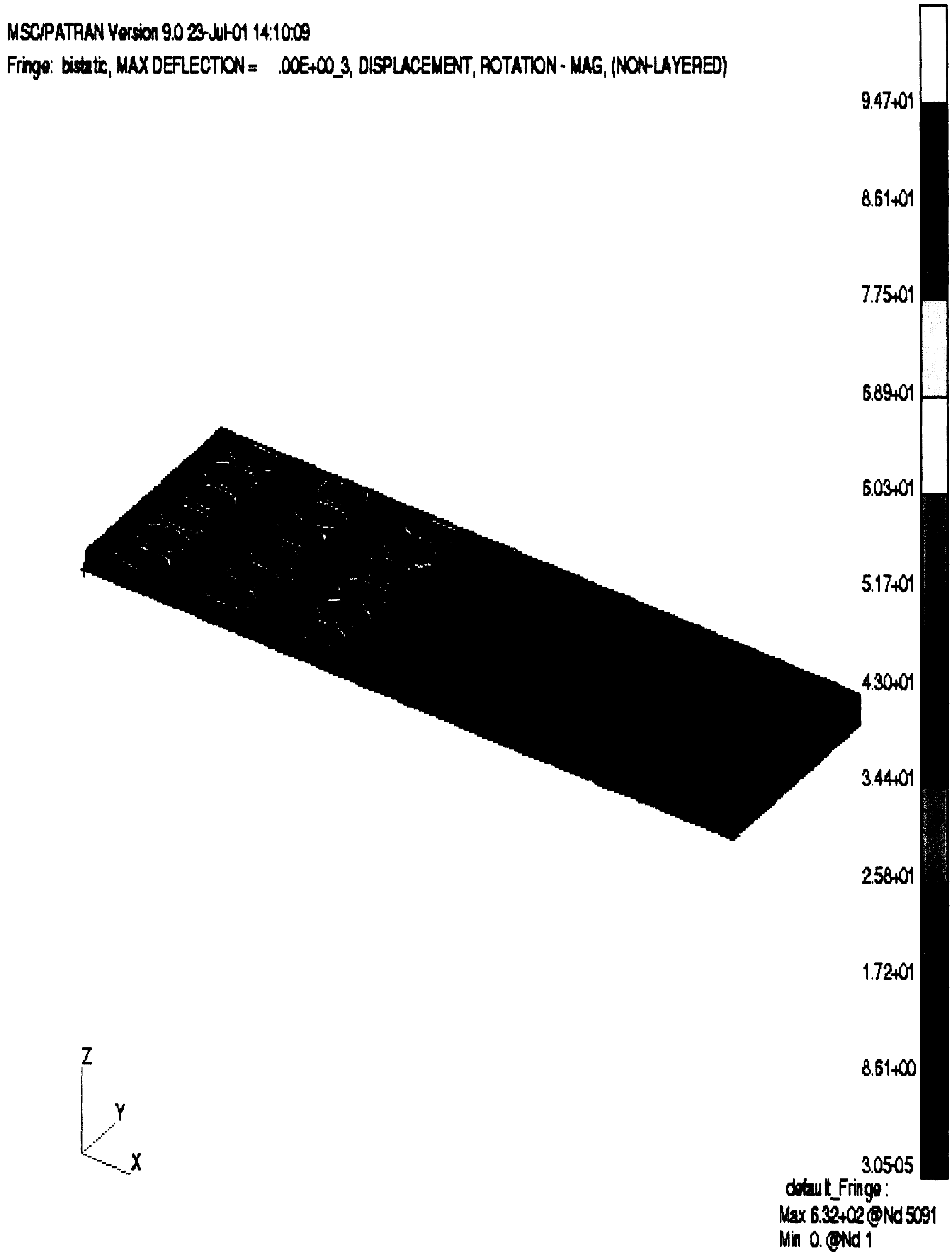


Figure 22. Field distribution d=1λ

Fig. 23-25 show the coupling from slot array to patch array elements. Element 1 is the upper left patch, element 2 is the middle left patch and 3 is the lower left patch.

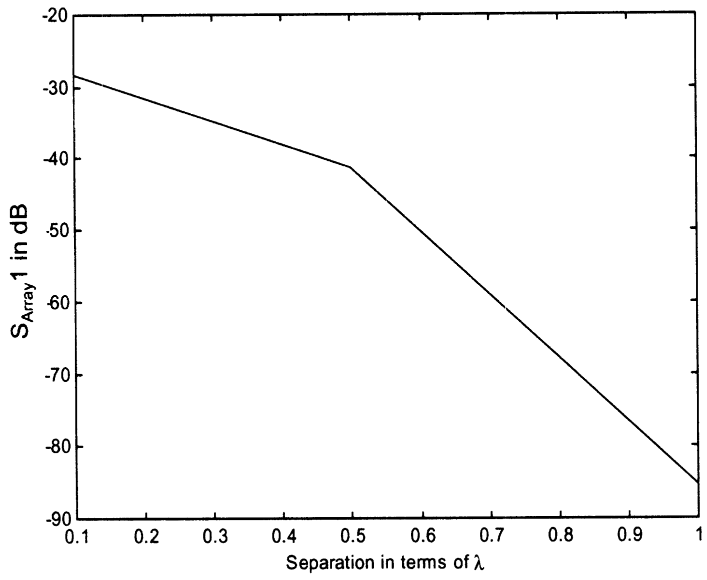


Figure 23. Coupling (array to element)

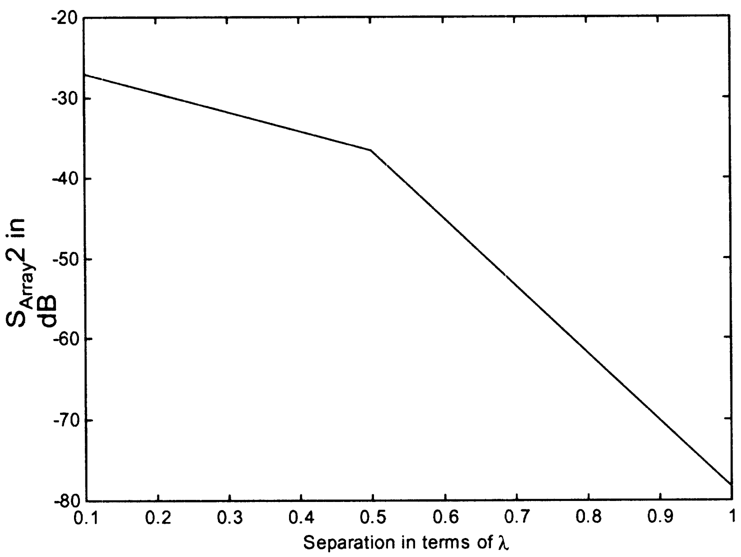


Figure 24. Coupling (array to element)

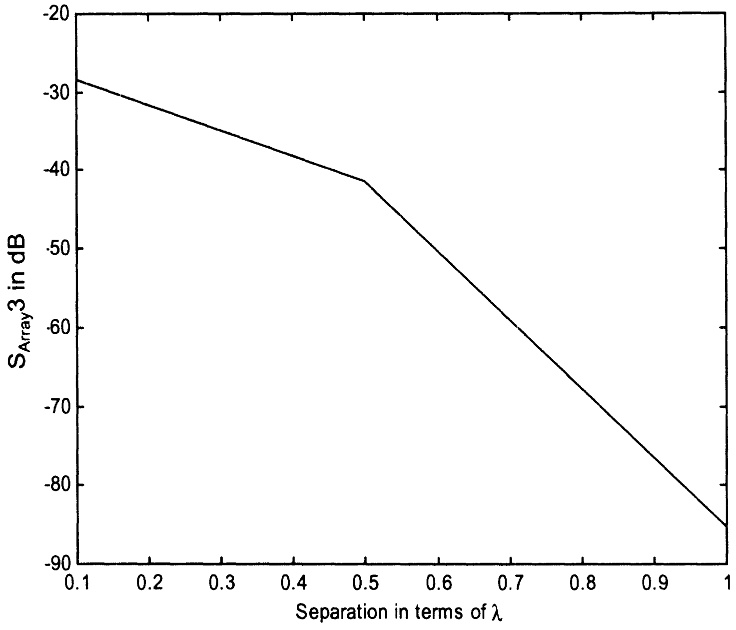


Figure 25. Coupling (array to element)

REFERENCES

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[2] **Yousef Saad,** "Iterative Methods for Sparse Linear Systems", **http://www-users.cs.umn.edu/~saad/books.html**

[3] **John Volakis, Arindam Chatterjee, Leo Kempel,** "Finite Element Method for Electromagnetics", IEE press, 1998

[4] **Gerard L.G.Sleijpen, Diederik R. Fokkema,** "BICGSTAB(L) for Linear Equations Involving Unsymmetric matrices with Complex Spectrum", Electronic Transactions on Numerical Analysis, vol.1, pp.11-32, Septmber 1993