FETI DDM methodologies for the simulation of High Gain Ka-Band Transmit arrays(single and dual band)

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***Abstract*—This paper is presenting Finite Element Tearing and Interconnecting (FETI) simulation results of large scale single and dual Ka-band lens transmit-arrays obtained on massively parallel clusters. The computation times observed with the FETI method allow us to consider using it in the optimization phase of such transmit-arrays. (*Abstract*)**

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The full wave simulation of these Fresnel lenses requires considerable computation effort. Indeed, the dimensions of the lens of 30 dBi gain are approximately 20 λ x 15 λ at 30 GHz and the electromagnetic problem to be solved is non-periodic.

The single band lens is composed of 4524 phase-shifting cells chosen from 63 different constitutive unit cells. These unit cells are composed by five metallized layers of concentric squared patches on four substrate layers of Rogers Duroid 5880 (ε_r=2.2 and tan δ = 0.0009).The in-plane width of the unit cell is P= 2.5 mm. The periodic simulation methods are therefore unusable here, whereas conventional full wave simulators require very important computing times as well as RAM memory.

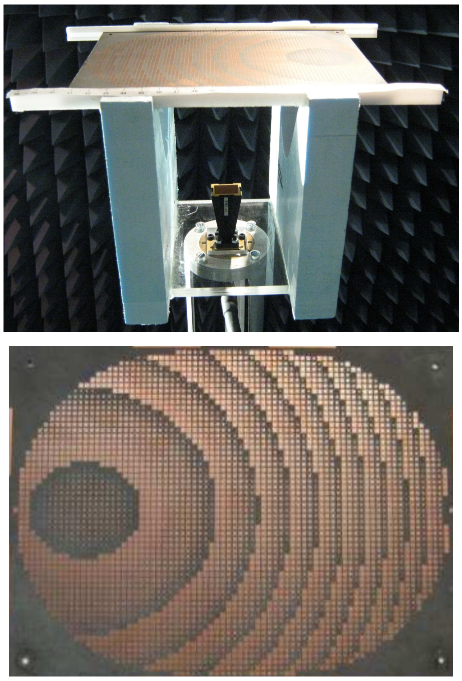
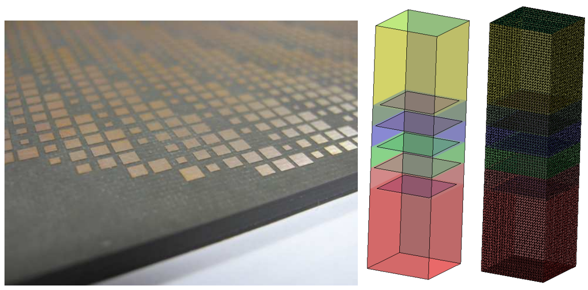


Fig. 1. Single band 30 dBi lens antenna (DOI: 10.1109/TAP.2015.2484419)



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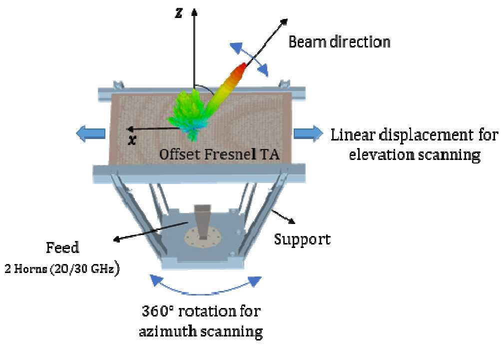
The objective of this presentation is to evaluate the potentialities of the domain decomposition method FETI-2LM implemented in the FACTOPO tool for the simulation of large transmit arrays on massively parallel clusters using MPI programming. For this purpose, recent results obtained in the context of RCS reduction, using the FETI-2LM technique ([3],[4]) have been completed for antenna gain simulations. They rely on finite element resolutions of the local problems of each of the phase-shifting cells and an iterative connection of the subdomains with the implementation of Robin type transmission conditions on the interfaces ([4]).



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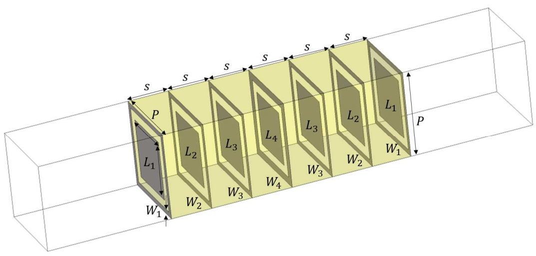

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A. HPC cluster used for benchmarking

The simulations are implemented on the Bull high-performance parallel machine "Occigen" of the "Centre Informatique National de l'Enseignement Superieur" (CINES). This machine has a total of 2,106 computing nodes with two Intel Xeon processors Haswell E5-2690v3 clocked at 2.6 GHz and each equipped with 12 cores. Each computing node has 24 cores with 5 GB memory each.

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The single band lens operating at 30 GHz [1] is constituted by 4524 phase shifting cells belonging to a set of 63 elementary cells and the dual band lens is composed of 2352 cells. The problem is then definitively non periodic as illustrated by Fig. 2. In our domain decomposition strategy, only the meshes of the elementary cells are sent to a core processor and the total mesh of the lens is not generated for the simulation.

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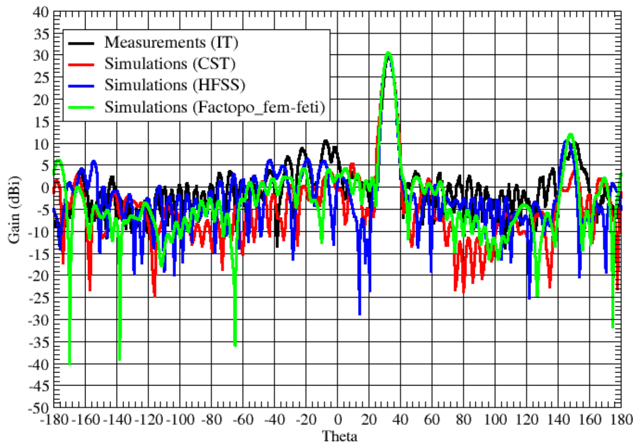
We illuminate the lens with a standard 14.5 dBi horn antenna oriented such that the E-field is parallel to the shortest dimension of the horn. The horn is positioned at the focal distance F=100 mm below the lens and the analysis is done at 30 GHz (Fig. 1).

The 30 dBi full lens problem including the horn source is requiring 3.12 billion volume unknowns, 631 million interface unknowns and is solved on 15,688 Intel E5-2690v3 cores in less than 10 minutes per beam. The memory per core processor consumed is 2.5 GB. The FETI gain diagrams are considered acceptable compared to measurements, CST TD time domain and HFSS FE-BI ([5]) frequency domain simulations results obtained on 28 Intel E5-2670v2 cores (Fig. 5,Fig. 6,TABLE I.). The computation times observed with the FETI method allow us to consider using it in the optimization phase of such transmit-arrays.



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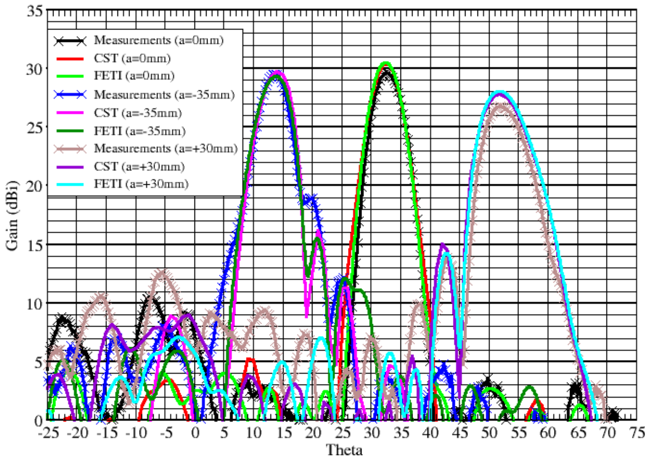

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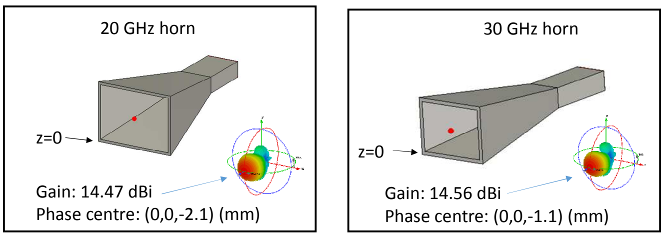
Two 15-dBi standard-gain rectangular horn antennas are used to illuminate the transmit array at each band (Fig. 7), with their phase centers positioned at 100 mm distance from the bottom face of the transmit array. For each lens position, one horn orientation should be simulated (y-pol) as shown in Fig. 7.



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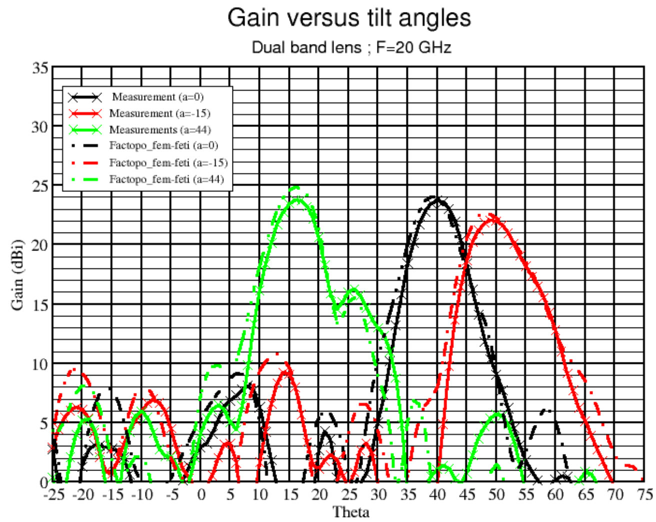

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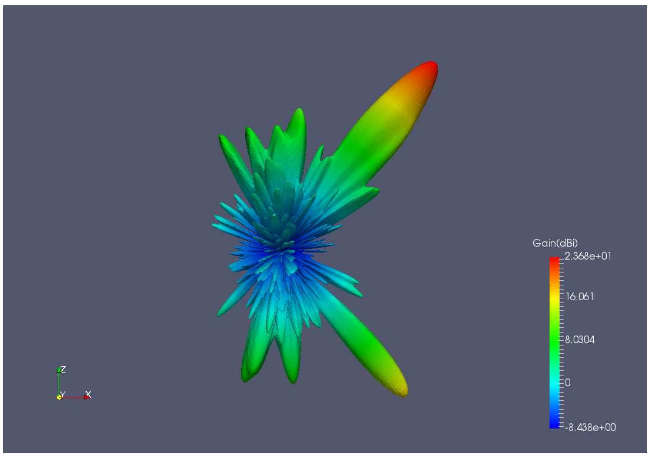

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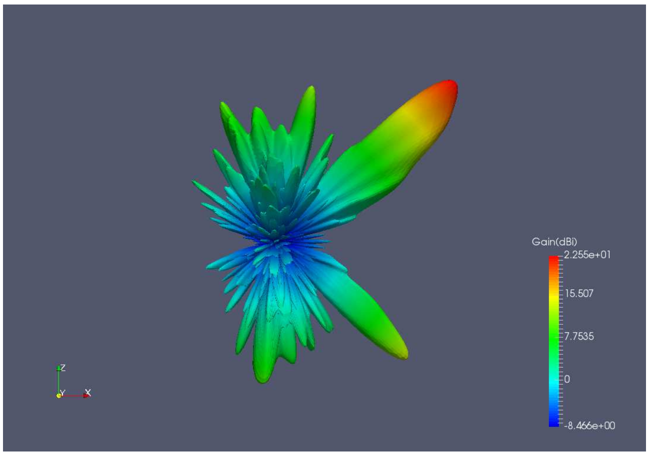

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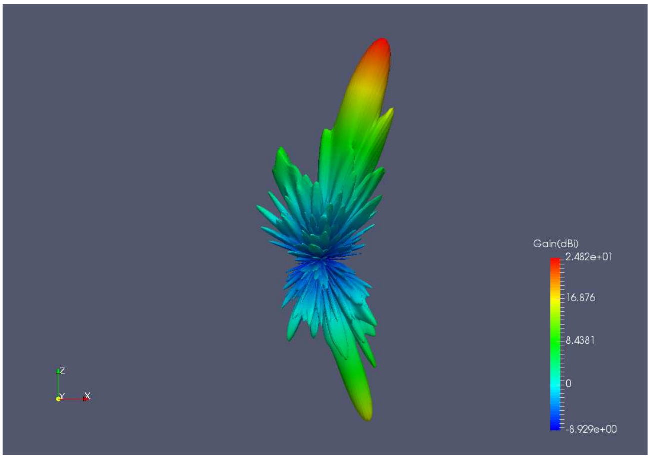

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REFERENCES

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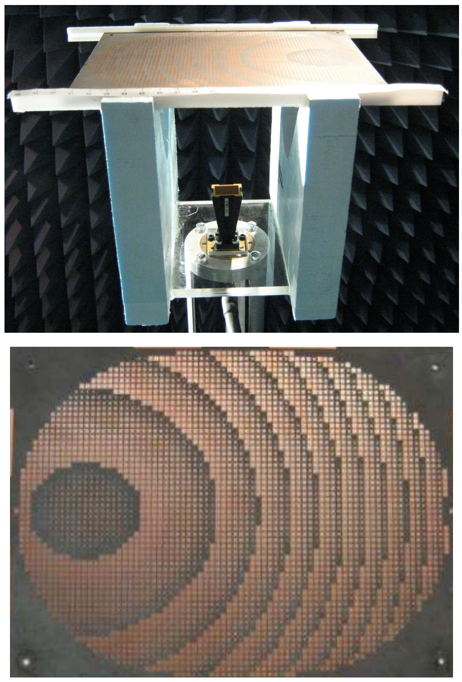

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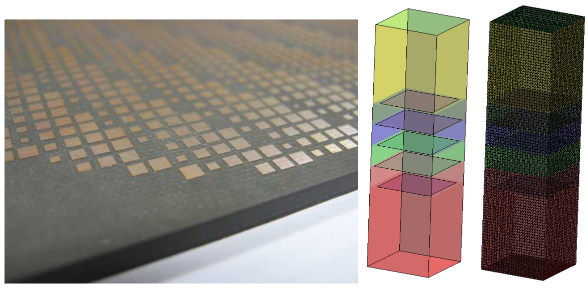

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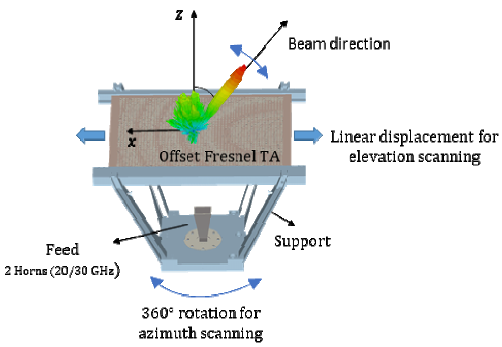

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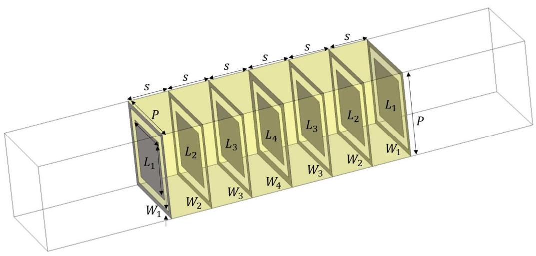

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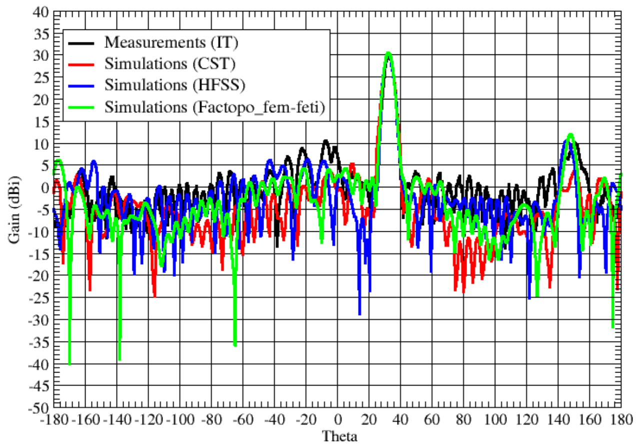

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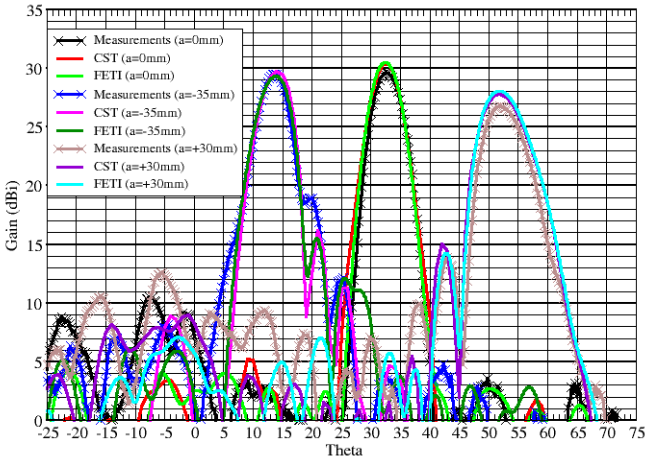

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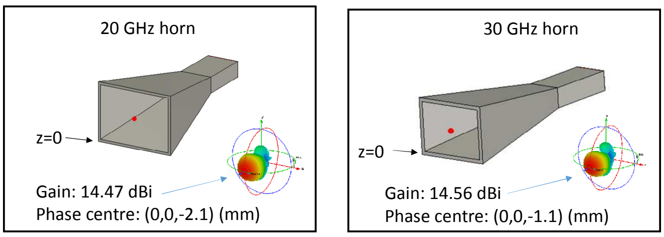

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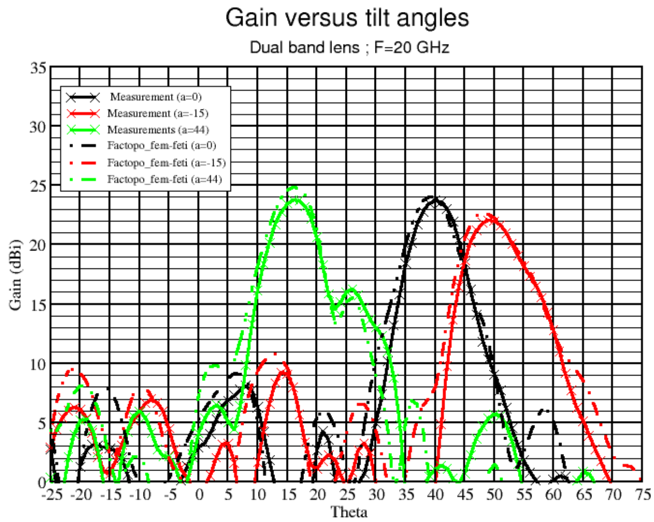

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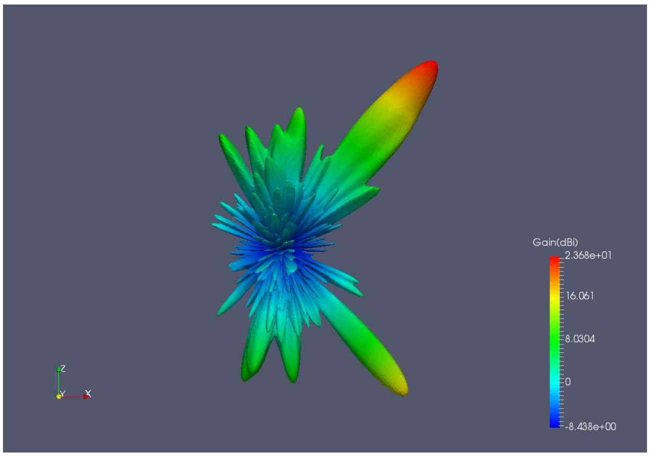

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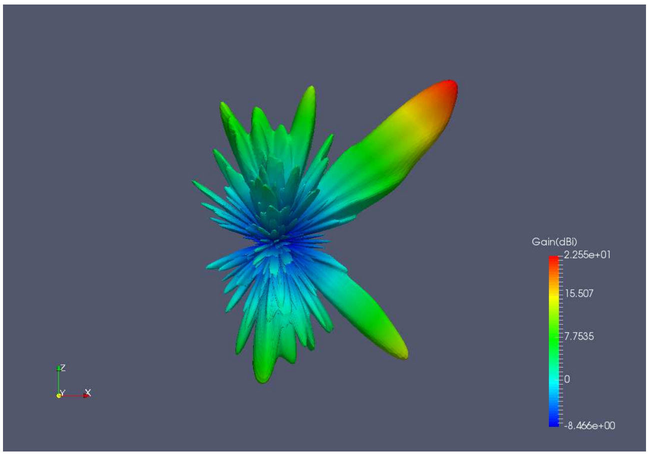

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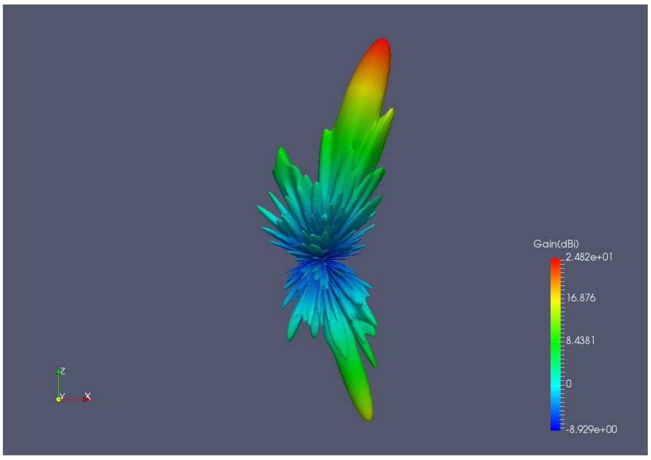

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