Thermal and Dynamic Assessment for 3D-Plus MCM-V Module

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1. INTRODUCTION

This report outlines the results of thermal and random vibration analyses performed on the surface mount 3D-Plus MCM-V Cube. The 3D-Plus MCM-V Cube is an plastic-encapsulated 3-D stack multichip module manufactured by 3D Plus Electronics Company in France. A general view of the structure of the device is shown in Figs. 1-3. Two major analyses have been performed to assess the reliability of the module, namely, thermal analysis for assessing its conductive thermal performance as well as random vibration analysis for assessing the integrity of surface mount solder attachments.

2. THERMAL ANALYSIS

Thermal conductive analysis was performed under the normal operating conditions to examine the temperature distribution throughout the body of the 3D module. Generally speaking, plastic encapsulated electronic devices are not effective in heat conduction largely because of the low conductivity of the encapsulation material. Thus, a detailed assessment of thermal conduction is of great importance for spaceflight applications.

2.1 FEA Model

A 3-D FEA model was built for the thermal analysis (Fig. 4). Due to geometric symmetry, the model represents ¼ of the module. A total of 19404 8-node solid elements is used for this model.

2.2 Power Dissipation and Material Properties

Because of the multichip structure, total power dissipation is from several semiconductor chips and passive elements simultaneously during normal operation. Although the module can be biased at several different levels resulting in different values in total power dissipation, the analysis was performed based on a nominal voltage bias, i.e., the total power dissipation was 2.968 W. Table 1 summarizes the voltage and power dissipation from different heat-generating elements.

Table 1

ELEMENTS	POWER (mW)
Resistors	121
Constraint Chip	427
Thermal Chip	1920
TSOP DRAM	500

Material properties used for the analysis are listed in Table 2.

Table 2

MATERIAL	Si	Fe/Ni Alloy	Solder	FR-4	Hysol-4450
CONDUCTIVITY (W/mK)	148	129	50.6	0.2	0.6
YOUNG'S MODULUS (GPa)	110	145	14.9	17	12.5
POISSON'S RATIO	0.28	0.3	0.29	0.3	0.31
DENSITY (kg/m^3)	2330	8110	8470	1938	1770

2.3 Thermal Boundary Conditions

In the analysis, the surface of the PCB to which the module is attached was used as a heat sink, and the temperature rise in the module was based on the heat sink reference temperature.

2.4 Temperature Results

Fig. 5 shows the steady-state temperature distribution under the power dissipation conditions listed in Table 1. It is revealed that the maximum temperature rise (ΔT_{max}) is 50.1 C. Thus, in order to keep the device operating in a safe region, the PCB surface temperature should not be exceeding 65 C.

3. DYNAMIC RANDOM VIBRATION ANALYSIS

Random vibration and dynamic response analyses were also performed for this 3D module. In the dynamic analysis, the device was surface mounted onto a PCB simulating anticipated GSFC lab testing. The PCB (FR-4) is square in shape, with 4.5" length on each side. The thickness of the PCB is 0.062". Fig. 6 shows the PCB and surface mount layout.

The main purpose of the dynamic analysis is to extract the assembly's resonant frequencies and obtain root-mean-square (RMS) dynamic stresses over the random frequency range on the 63:37 solder attachments. In the GSFC test plan, two 3D MCM-V modules were planned to be mounted for random vibration experiment (see Fig. 6), however, our SUN Ultra-10 workstation has only 256 MB RAM and it was unable to perform such a large dynamic FEA simulation. Thus, the simulation had to be performed by removing one of the modules off the PCB. In Fig. 6, only the module mounted on the left side was included in this dynamic simulation.

In order to accurately simulate the stress concentration in the solder attachments during random vibration, finer mesh must be used for the solder joints and leads. This is the main reason why this FEA model is very big. Fig. 7 shows the details of the finer FEA mesh in one of the corners of the module.

The input acceleration spectral density (ASD) provided by the manufacturer in France was used in the analysis. The acceleration level of this ASD is unusually high, compared to what NASA's random vibration requirements call for the testing of spaceborne sub-assemblies. This ASD is shown in Table 3.

Table 3

FREQUENCY (Hz)	ACCELERATION (G^2/Hz)
50 – 100	+6 db/oct
100 – 1000	0.8
1000 – 2000	-6 db/oct
Overall G (RMS)	33.8

Boundary conditions used for the dynamic analysis was to simulate GSFC test setup, namely, 5 screws will be used to attach the PCB assembly to the fixture of the vibration test equipment. Four screws are used at the four corners, and the fifth screw will be located at the geometric center of the PCB assembly. These screws will completely restrain the degree-of-freedom in Dx, Dy, and Dz at their mounting locations.

In the random vibration analysis, this ASD was applied to the direction perpendicular to the PCB plane (z-direction). In the first step of the analysis, four eigenmodes were extracted for this PCB assembly. The first four resonant frequencies are:

F1 = 1052 Hz

F2 = 1520 Hz

F3 = 1685 Hz

F4 = 1874 Hz

The modal displacements corresponding to these four eigenmodes are given in Figs. 8 – 11.

As in any vibrational environment, the highest dynamic stresses in the solder attachments occur in the first resonant mode, i.e., at 1052 Hz. Fig. 12 shows the RMS σ_{zz} distribution in the solder joints at 1052 Hz. It is obvious that the highest stress (10.6 MPa) occurs in the corner on the right-hand side, which is consistent with the eigenmodal displacement shown in Fig. 8. This highest stress is enlarged for better view in Fig. 13. Using the same procedures, we can obtain RMS stress distributions for all the components of the stress tensor. Finally, we can obtain the 3σ RMS von Mises stress at that corner solder location with the highest stress concentration:

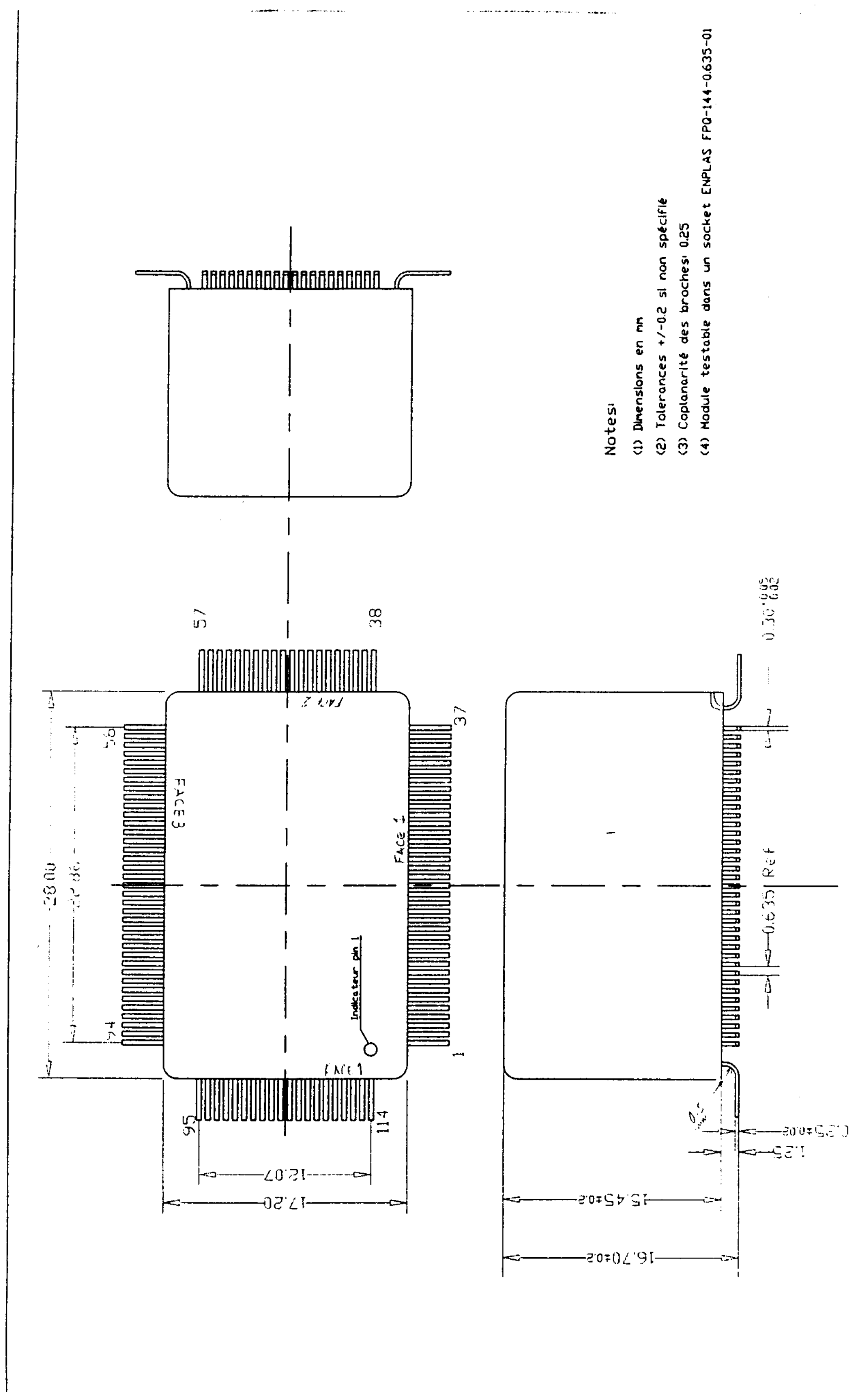
$$\sigma_{\text{von Mises}}\ (3\sigma\ \text{RMS}) = 34.68\ \text{MPa}$$

For regular 63:37 eutectic solder, a nominal value of its yielding strength is 16.1 MPa. We see that the highest von Mises stress for that corner joint at 1052 Hz is more than twice the value beyond the yielding point. In our opinion, this solder joint will not be able to survive under such a harsh ASD level largely due to high-cycle solder fatigue.

4. SUMMARY

Thermal, eigenmodal, and random vibration analyses have been performed for the 3D Plus MCM-V Module as a part of the NASA technology evaluation process. Due to large bulk of encapsulation material used for this module, thermal conduction is not as effective comparing with other MCMs used by NASA where ceramic packages are used. Because of the 50 C temperature rise from PCB heat sink, this module should be used with great care when the PCB surface temperature is near 50-60 C.

Due to the center screw mounting for the PCB assembly, the first resonant frequency is more than 1000 Hz. The corresponding von Mises stress at the corner solder joint (near the PCB edge) is found to be more than twice the value of the eutectic solder's yield strength. Thus, we conclude that this ASD level is too harsh for this particular assembly and should not be used for the testing purposes. If the launch vehicle will indeed deliver such a high G_{rms}, we then need to redesign the module attachment in order to survive the launch process. If that is the case, we will need to perform a series of FEA simulations to find an optimal scheme for module attachment.



Doc. N°: 3300-0100-2

Fig 1

<u>CUBE CROSS-SECTION (SIMPLIFIED)</u> See Doc N°3300-0100 for more details.

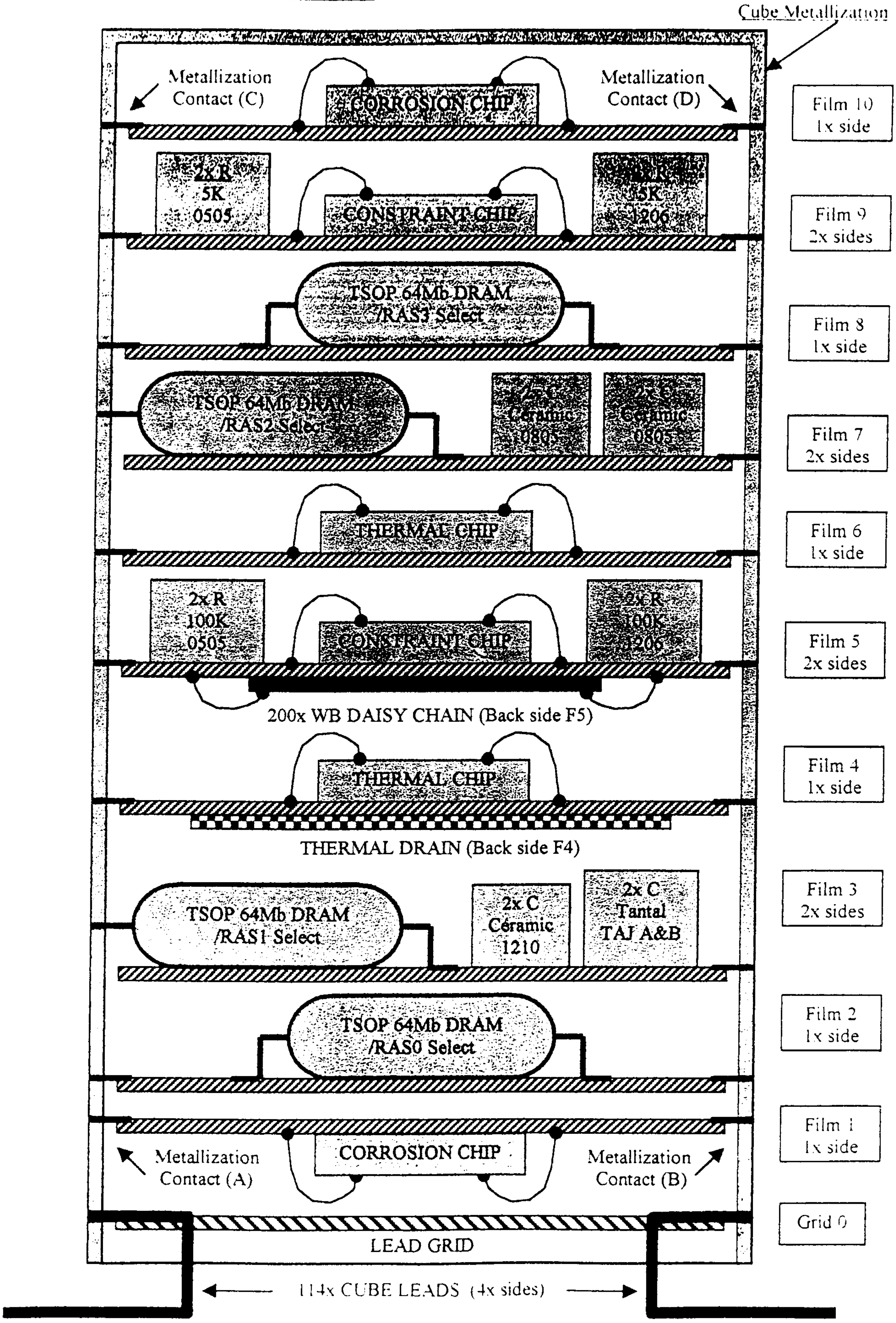


Fig. 2

Notes:

(1) Dimensions en mm

(2) Tolerances +/-0.2 si non spécifié

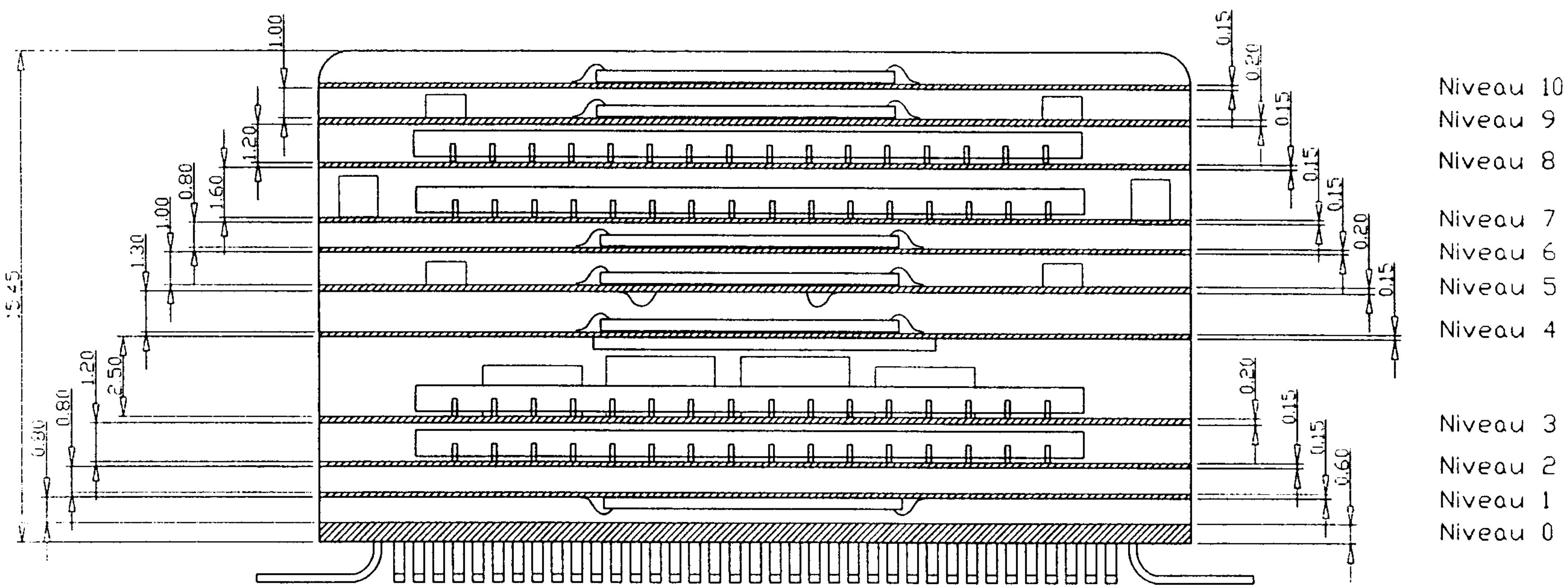


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Fig 3

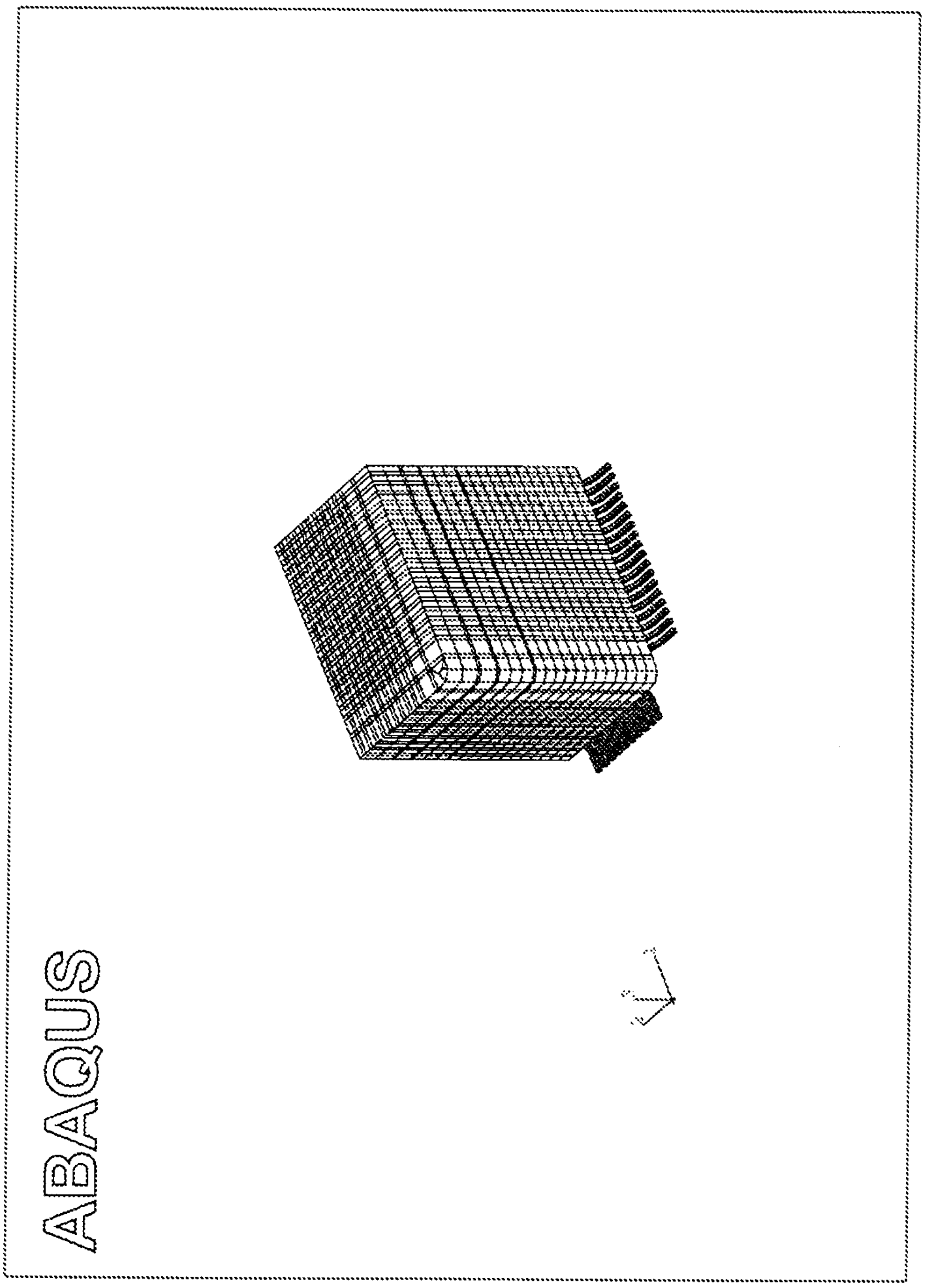

Fig. 4

TOP

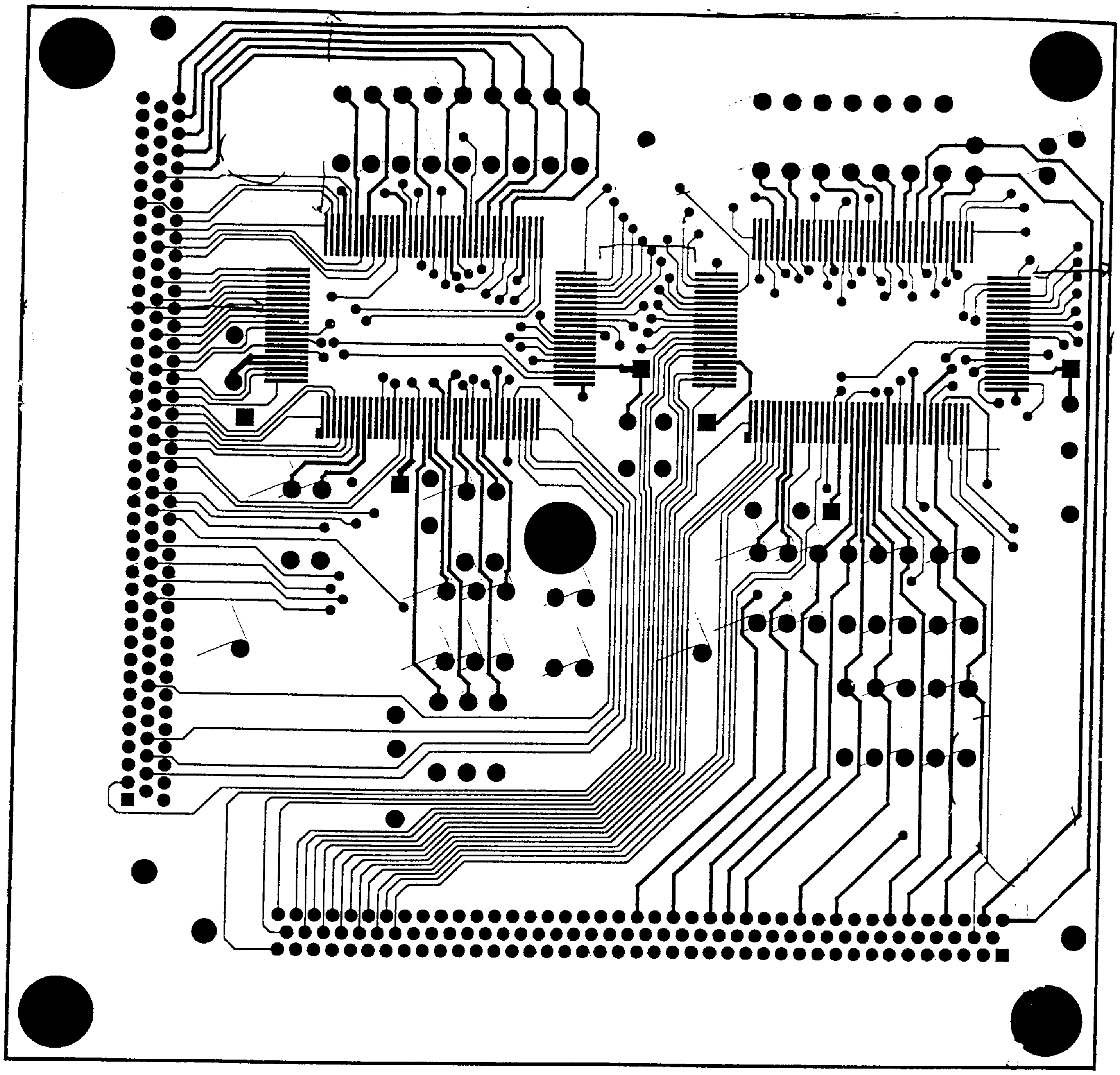

Fig. 6

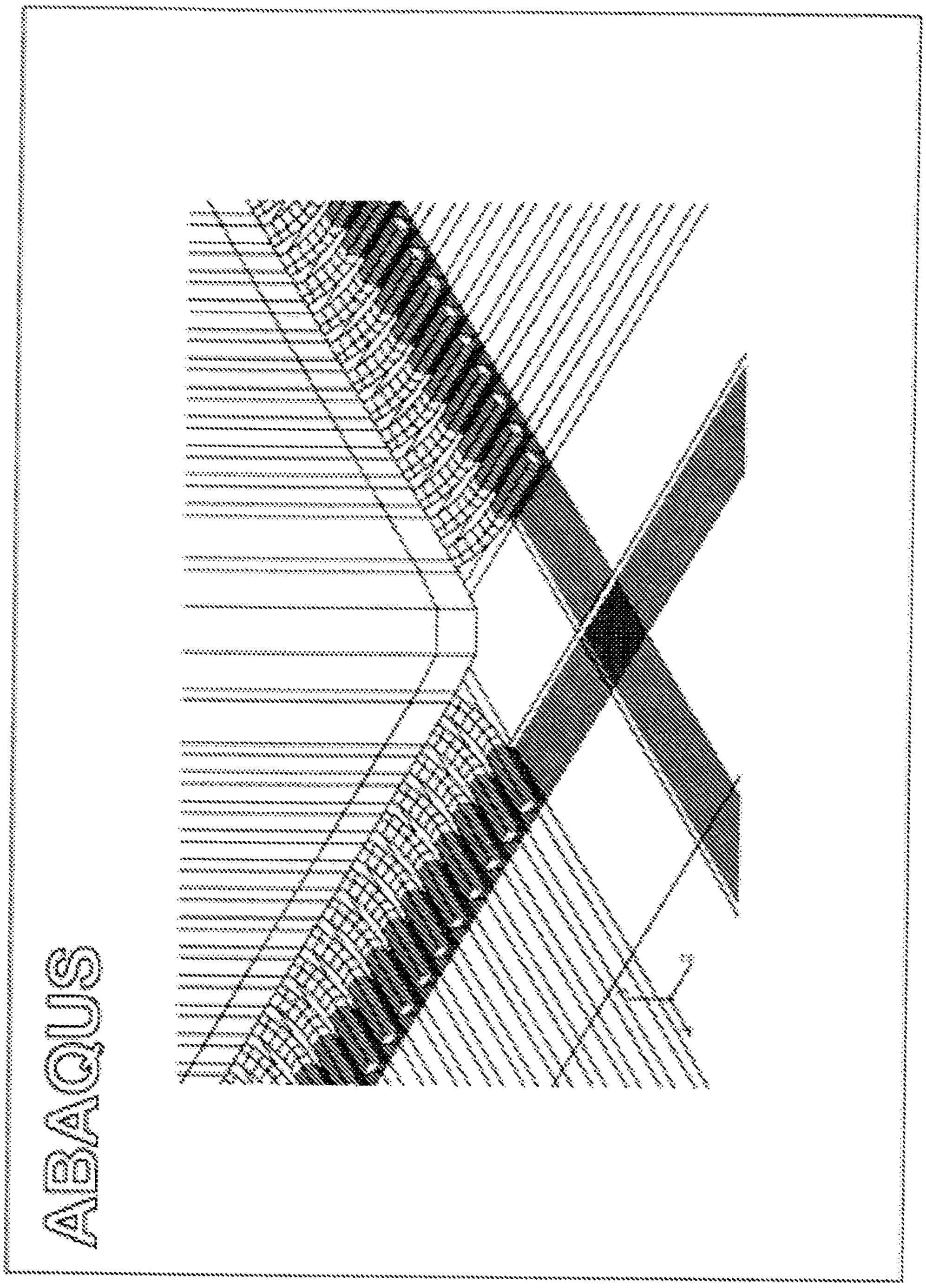

Fig 7

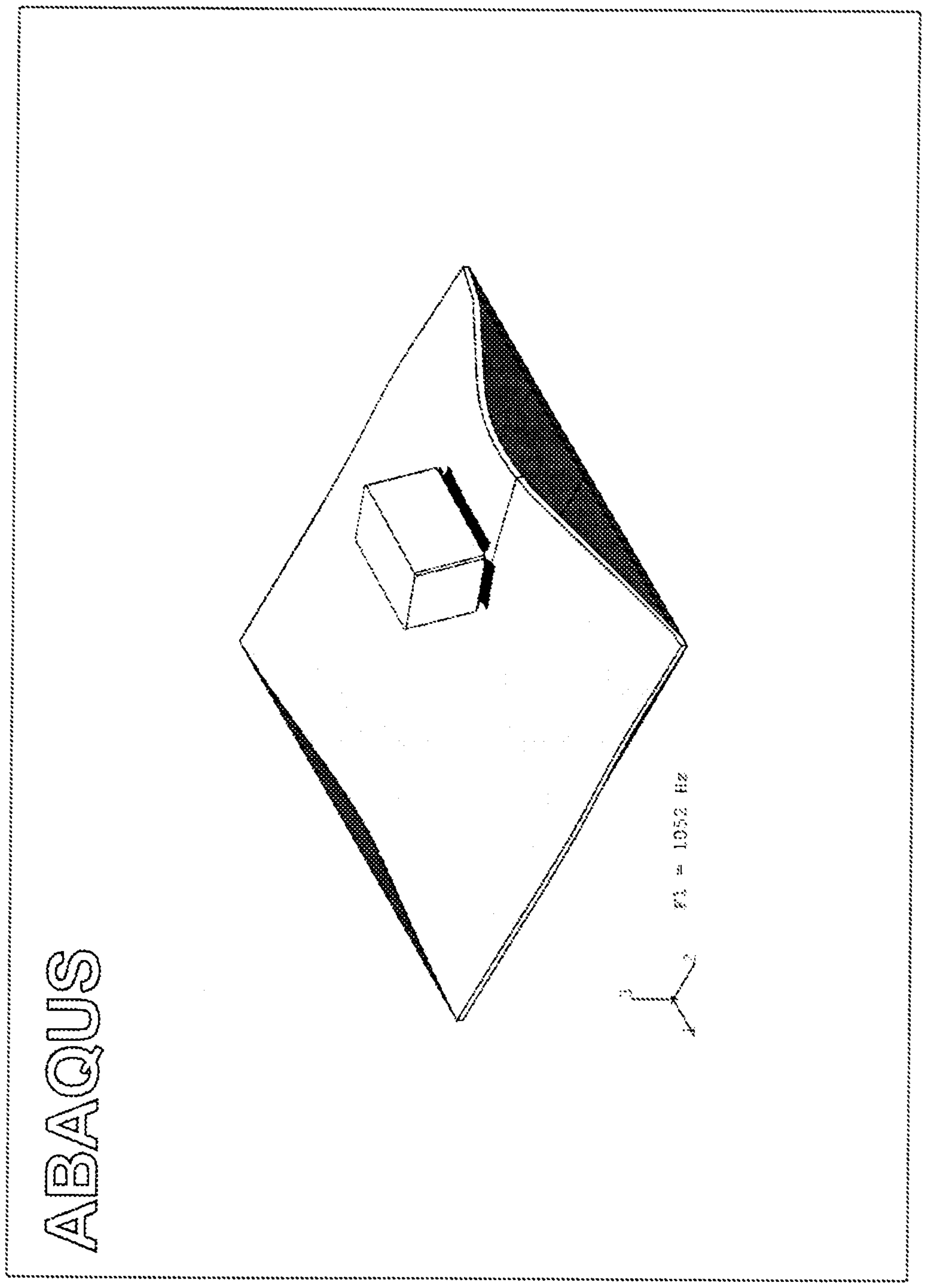

Fig. 8

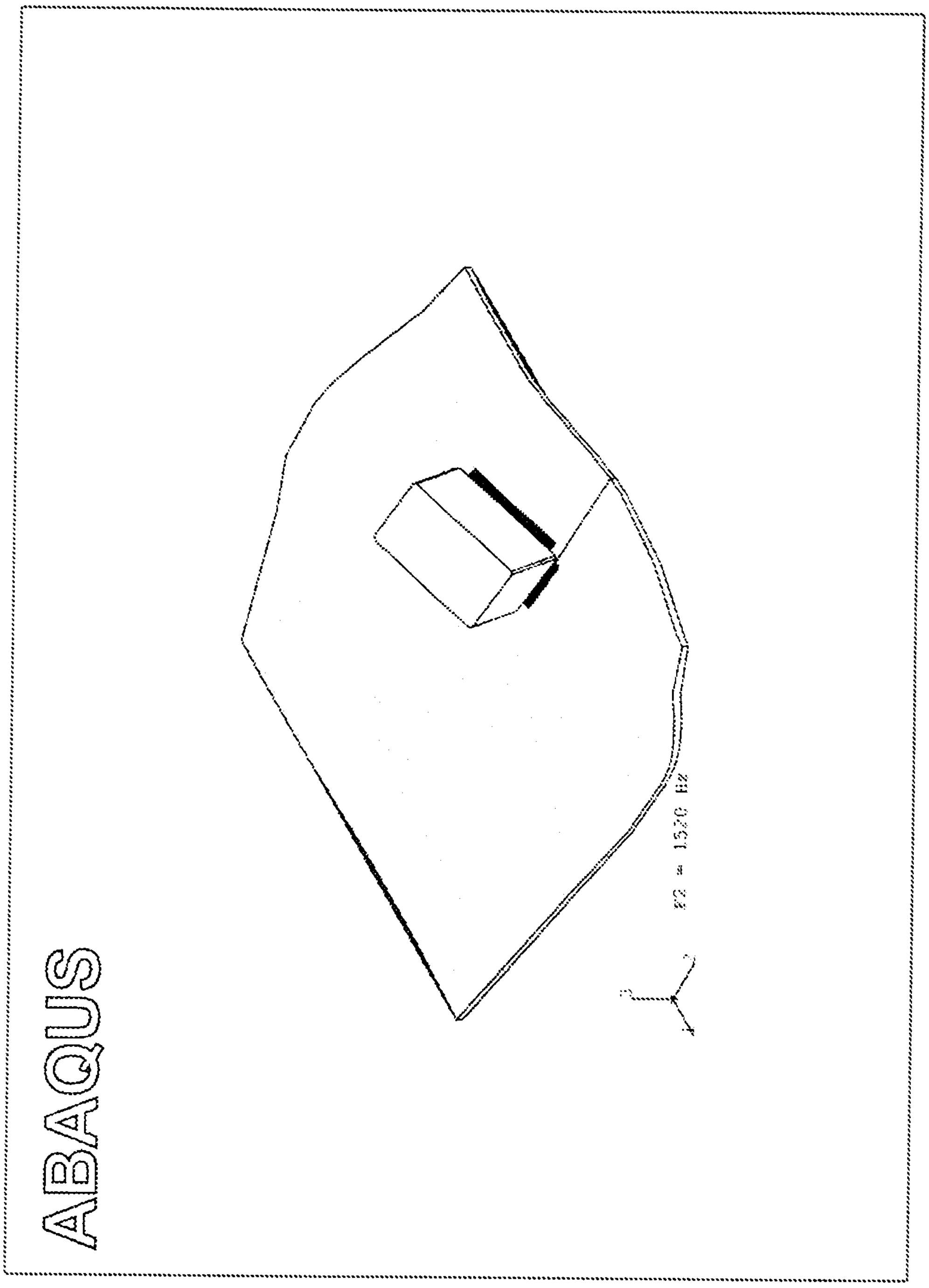

Fig. 9

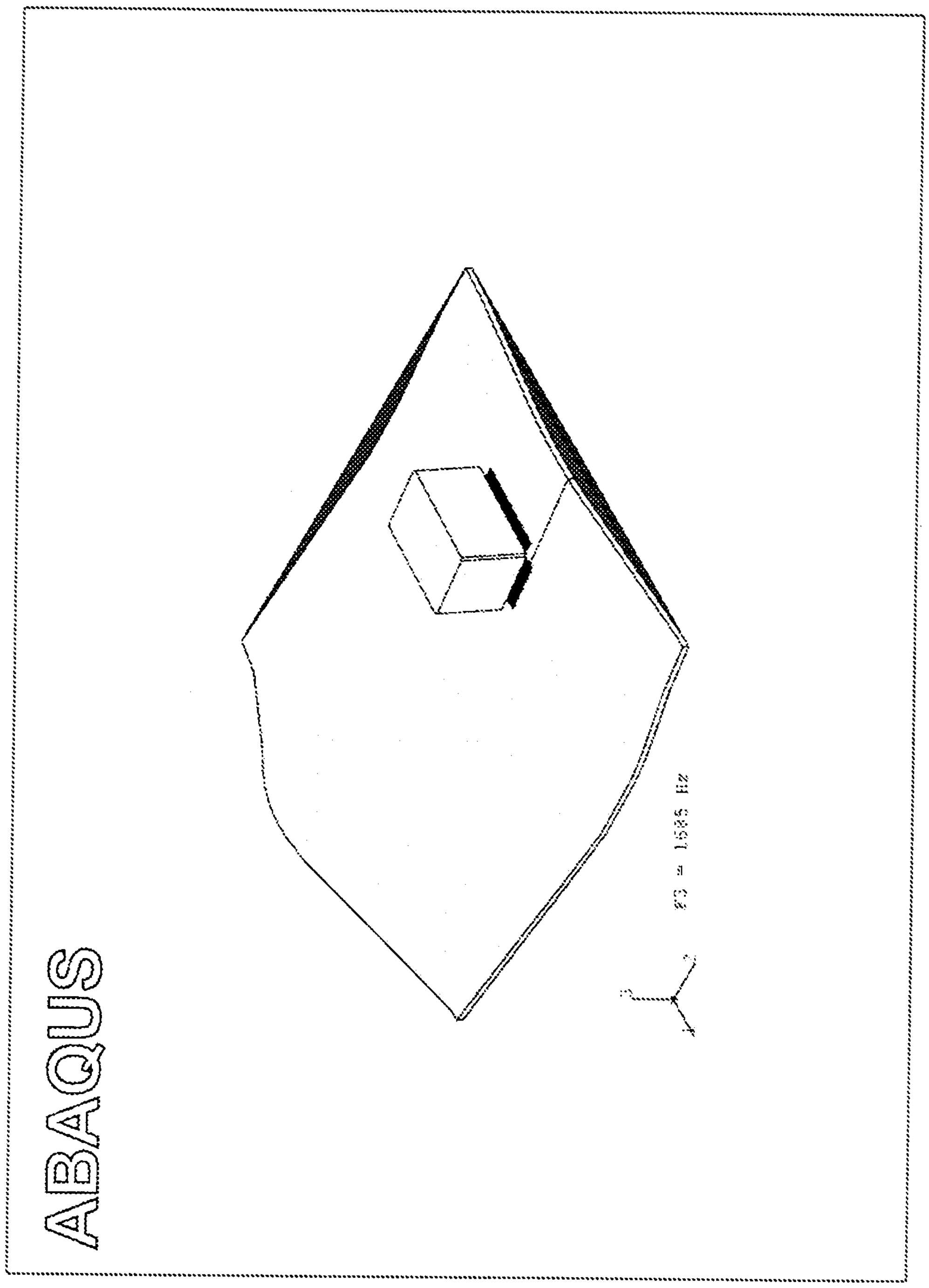

Fig. 1c

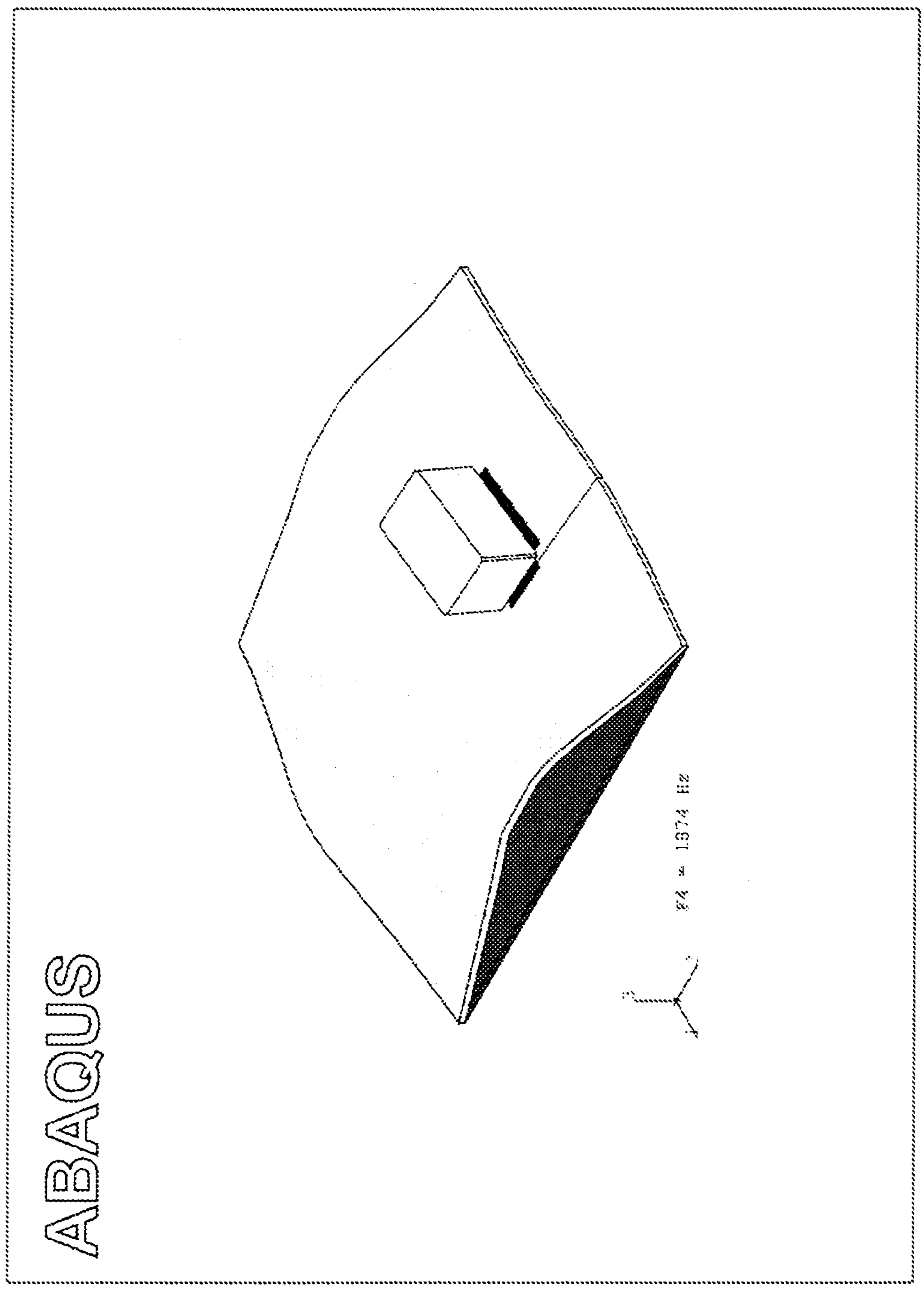

Fig. 1

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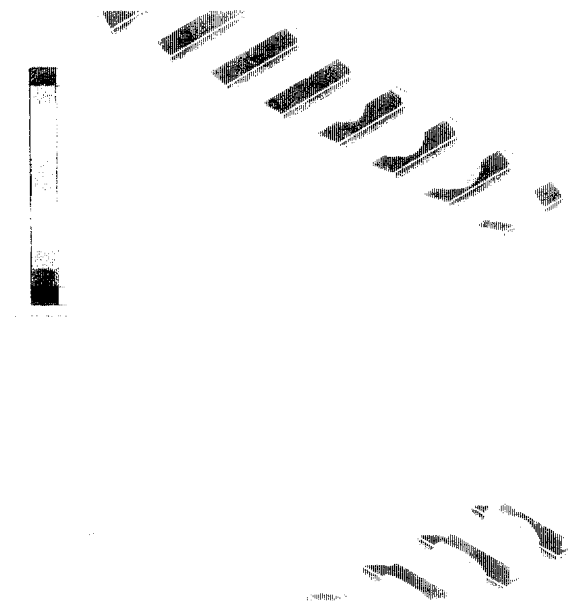

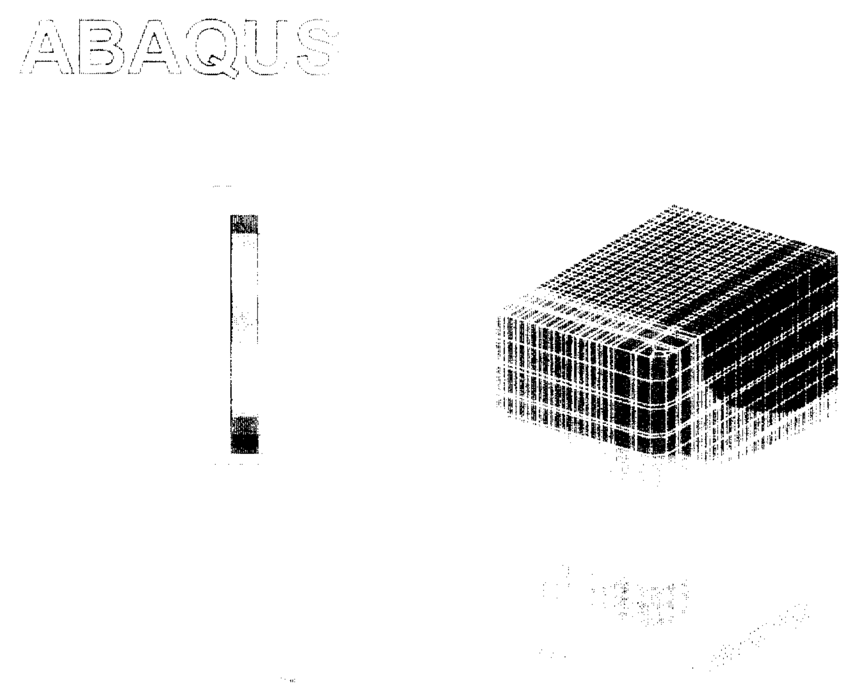
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