13. APPENDIX: EXPERIMENTAL TESTING - BOARD MODEL

There are two main points in the development of a PCB model. First it is necessary to choose the level of complexity it will involve. Then it is important to translate the real PCB to the model, which will include an estimation of the different structural properties, as well as some geometrical considerations.

The complexity decissions can in this case be almost exclusively reduced to study the influence of the different electronic components. If it is neglectable, the model used will be the bare board. Otherwise it will be necessary to include their effect. This analysis is achieved through experimental testing on three different stages of the production process of a PCB, each of them representing a progressive increase of the complexity of the system.

In the first case, the system consists on the bare board, without printing or any other addition. Besides, the shape choosen will neglect small gaps or protuberances, reducing the board to its simplest geometrical expression, such as a rectangle.

The next step will be the board with the printed circuit and the rest of the preparations before the packaging of the electronic components, such as drilling. Now the real shape of the PCB will be considered.

The greatest complexity will appear in the complete PCB in its ultimate stage, with all the electronic components already packaged on it.

Once the differences in their dynamic behaviour are studied, it will be possible to determine the simplest design phase wich still provide accurate results.

It is then when the different problems of translating reality into the model will appear. There is not a precise value for the structural properties, but only an expected range. It is also difficult to precise the geometry to be considered, especially when related to the boundary conditions. As they are usually far from the ideal conditions used in models, it can be convenient to consider in the model part of the board which should be neglected due to the boundary conditions. This problem, while usually present in modelling, is specially critic in the case of a PCB, since a difference of bare milimeters can be highly influential in the ultimate results.

Since the first design stage, the bare board, does not present significant differences from a theoretical shell model, it will be used to tune the FEM model. The structural properties and geometry will be chosen so the model is able to provide an accurate estimation of at least the first resonant frequency, which will be the essential requirement for the theoretical analysis. The other two stages will be modelled according to this tuning, and their accuracy would be checked comparing their results to the experimental data.

A model will be considered useful only if it approximates accurately a design stage whose dynamic properties are near the final PCB.

13.1 DESCRIPTION OF THE PCB

A square PCB made of FR-4, clamped in the two short edges, will be used for the experimental testing. The dimensions of the board are shown in Table 13-1.

Size (mm)		
Length	Width	Thickness
114.5	24	1.6

Table 13-1.- Dimensions of the PCB.

The length used in the model will be shorter, since part of it is immobilized in the clamped boundary limits. The ultimate value used will be part of the tuning process.

The great weight difference between the different boards shown in Table 13-2 suggests that the effect of the electronic components is far from neglectable. The hypothesis to confirm is then if the increase in weight is the only effect on the board, neglecting the effect on the structural properties. The model used will then be a bare board of FR-4 of the size of the real PCB, but increasing the density to adjust the weight of the board.

Weight (g)		
Board	Board with printing	Board with components
9.4	10.2	15.3

Table 13-2.- Weight of the different stages of the board.

The material of the board is FR-4, whose reference structural properties are shown in Table 13-3, and are in order with the orthotropic character of the FR-4. They have been chosen in order to be representative of the different values appearing in a literature survey. The main part of the tuning process will affect the elastic modulus E_x and E_y, since their sensibility is higher and their values obtained in literature more dispersed, suggesting a broad range.

$E_x = E_y$	20 Gpa
E_z	1.6 Gpa
$\nu_{xz} = \nu_{yz}$	0.12
ν_{xy}	0.2
Density (ρ)	1870 kg / m^3

Table 13-3.- Structural properties of FR-4.

It is important to underline that the density found in literature is not the same that can be calculated experimentally. Since there is agreement on its value in the different sources consulted, the theoretical value will be used, assuming experimental inaccuracy to be the cause of the difference.

13.2 EXPERIMENTAL TESTING

The first measurements were conducted placing an accelerometer on the board and forcing its vibration at different frequencies with a shaker. A new problem appeared then, since the smallest accelerometer available weighted 2.4 grams. This means an increase in weight between 15 % and 25 % depending on the board choosen. The presence and position of the accelerometer produced then noticeable alterations of the dynamic properties of the board, with changes of more than 20 % in the first resonant frequency and important changes in the high frequency spectrum. Although a possible solution is to introduce a 2.4 grams punctual mass in the FEM model, the results can be considered as indicative, but their validity is doubtful.

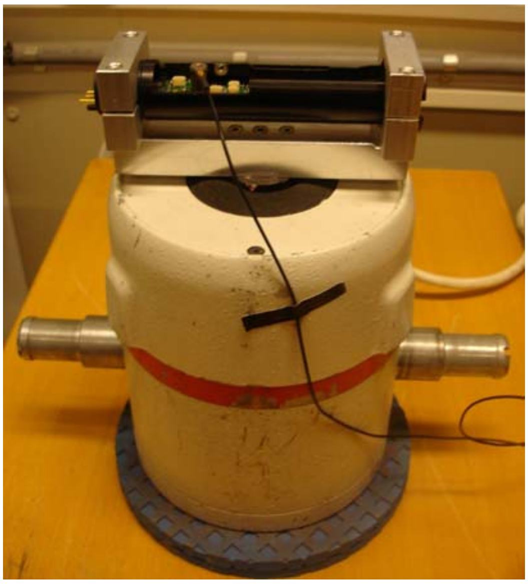

Fig. 13.1.- Experimental testing with accelerometer.

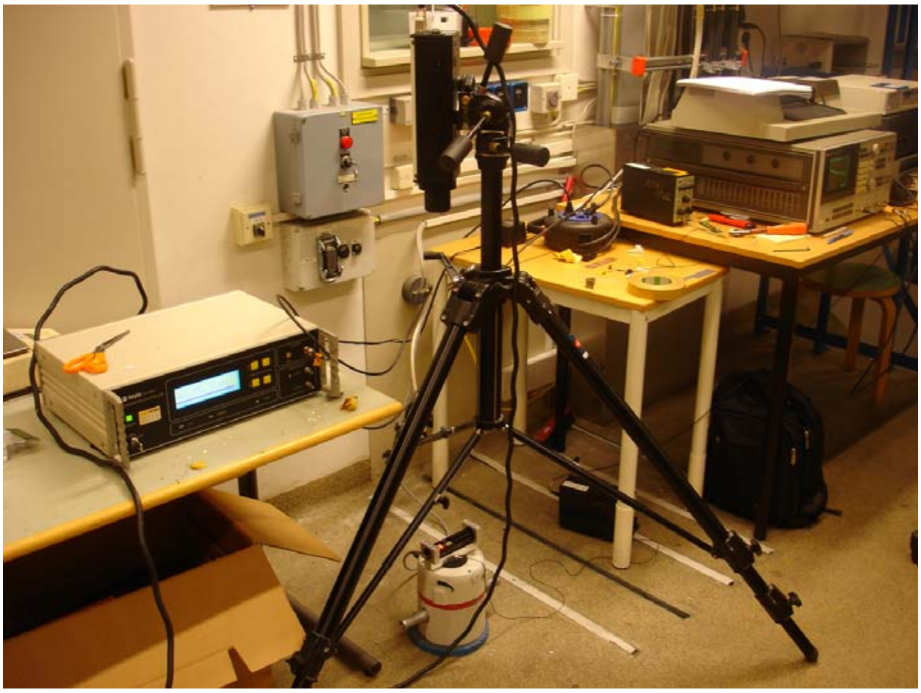

Fig. 13.2.- Complete experimental equipment using laser.

In order to obtain more accurate experimental results, the measurements were repeated using a laser. This process is identical to the previous measurement, except that instead of using an accelerometer a laser beam is directed to a small piece of reflecting tape placed on the board. The disturbances of the reflected signal are used to calculate the velocity of the vibration. Now a direct physical influence on the board was avoided, and the value of the first resonant frequency was proven to be independent of the point chosen to measure. The results of both testing methods are shown in Table 13-4.

First resonant frequency (Hz)			
Method	Board	Board with printing	Board with components
Laser	552.5	467.5	370
Accelerometer	415	348.75	303.75

Table 13-4.- Resuls of experimental testings.

13.3 FEM MODEL AND RESULT ANALYSIS

As it has been stated, the measurements on the FR-4 board where used to refine the model. It was decided to add 2 mm to the free length, and reduce the elastic modulus. The final values used in the model are shown in Table 13-5.

	Board	Board with printing	Board with components
$E_x = E_y$	18.5 Gpa		
Length	97 mm		
Density	1870 kg / m^3	2089.3 kg / m^3	3487 kg / m^3

Table 13-5.- Final values of the model.

The FEM system used was ANSYS. The board was divided in 10 x 20 standard shell elements (Shell63). This is the model used in all the analyses conducted during this work, which were mainly of the static structural type, with clamped conditions in the shorter edges.

A FEM model analysis was conducted on the model and on the model with a 2.4 punctual mass in its center, trying to simulate the presence of the accelerometer. The results are shown in Table 13-6.

First resonant frequency (Hz)			
Model	Board	Board with printing	Board with components
Board	554.74	524. 82	406.22
2.4 g punctual mass	405.04	393.05	335.45

Table 13-6.- Comparison of experimental and analytical results.

The errors in the case of the board with printing and the final board are 12.26 and 9.79 %, respectively. The mass difference between the FR-4 board and the board with printing is very small, so it is not likely that the error is due to an incorrect modelling of its effect, but a reduction of its structural stiffness due to the small holes and alterations that are necessary during the printing process. The reason of the error in the final PCB model is probably the same, its effect slightly minimized due to the higher mass.

The errors in the model including the accelerometer, 12.70 and 10.43 %, are higher due to the additional idealization of modelling the accelerometer as a punctual mass, but still very similar to the values obtained previously.

Further resonance modes

Although the first mode is usually the sole determinant factor of the dynamic behaviour of the PCB, it is however interesting to know how many modes can be predicted accurately.

The frequencies of the first four modes predicted by the model are shown in Table 13-7. The experimental response of the printed board is shown in Fig. 13.3. It is clear that the transmissibility is not enough to identify the modes. In this case, it will be necessary to study the phase of the response, also shown in the figure.

Resonance frequencies (Hz)
406.22
519.86
1120.6
1293.9

Table 13-7.- Predicted resonance frequencies.

In the single degree of freedom system, resonance conditions are related to an abrupt change in phase, usually of about 180º. This behaviour can be expected also in the first mode of a system with several degrees of freedom. The next modes will present similar phase shifts, less pronounced as frequent increases. It is important to mention that this phase may not have direct physical meaning, but be just an indicative of the resonance conditions in the board.

Four different points were choosen for the measurements. Their distribution was conditionated to the conditions of the testing, since the laser requires a flat surface that is sometimes difficult to find in a PCB. Despite of this problem, the two first modes appear on the experimental results, at frequencies 370 and 530 Hz. Another mode is hinted at 930 Hz. It is possibly the overlapping of the third and four modes, but it is difficult to assure. The difference in frequency is much higher than with the former modes, but inaccuracy is expected to grow with the frequency. The fifth mode is horizontal, so it will not appear with vertical excitation. Further modes do not resemble the predictions in a way that can be considered useful.

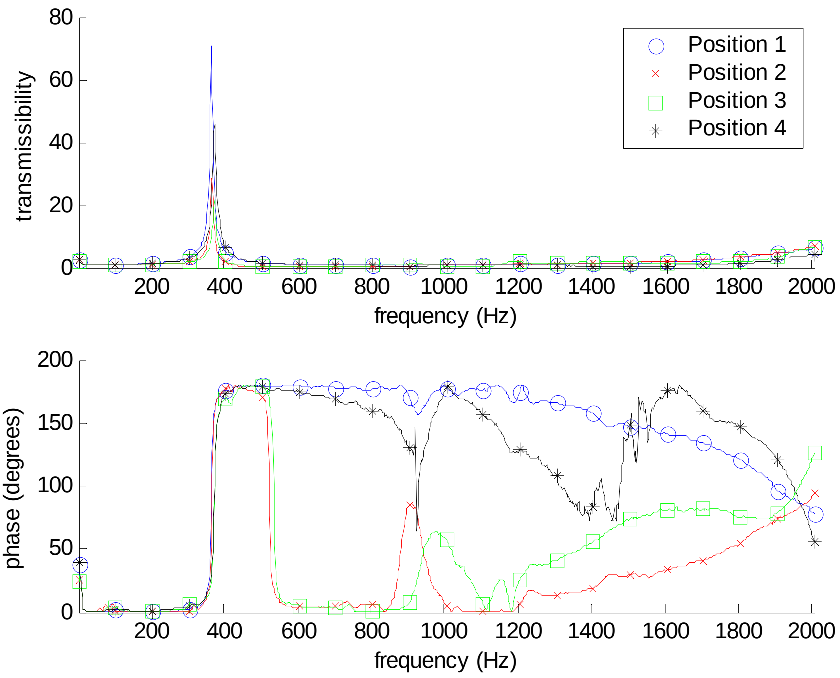

Fig. 13.3.- Response of the PCB

In conclussion, the two first modes can be accurately predicted, while for the following the error is at least of the 20 %. A FEM analysis, however, is usually very accurate. The problems here are probably due to the differences between reality and the model and errors in the experimental process.

The model used is homogeneous in all the surface of the board, including the effect of the electronic components. In the real PCB, however, the effect of the components and the printing will be different in each part of the board. This discordance is of little effect in the first global mode, but it will be able to noticiable alter modes in the high frequency range, whose shape is much more complex.

As fas as experimental errors are concerned, the most important problems are probably the boundary limits. The prediction was done according to ideal clamped conditions, which can be hard to achieve in reality. In fact, during some measurements the transmissibility on the first mode was not highest on the center of the board, but next to that point. That means that the

13.4 SUMMARY

The PCB has been modelled as a plate, with the same structural properties as the original board before the printing process started, and the density increased in order to simulate the inertial effects of the electronic components. The results predicting the first resonance mode are reasonably accurate, with errors in the range of 10 %. The only drawback is that the error is not in the safety side, since the resonance frequencies provided are higher than the actual ones. This would suggest than the sytem is more reliable than it really is, which should be taken into account during the analysis process.

For the further modes, it is only possible to assure the accuracy of the model up to the second mode, although the result suggests that the model might be also valid for higher frequencies. It is recommended to conduct more testing in different experimental samples, properly evaluating the real accuracy of the model.