Non contact test points

A high frequency measurement technique for printed circuit boards

This thesis was about measuring signals within a printed circuit board. It might sound like a very simple task to measure signals in an electrical device. After all, the signals are right there, just waiting to be extracted. But the reality is not that simple. A golden rule within the engineering community (and the cause of much headache indeed) is to never allow a measurement to have any significant effect upon the object it aims to study. This is why the concept of doing measurements without direct contact is such an appealing thought.

Printed circuit boards

Everybody has probably seen a printed circuit board (or PCB, as it will be denoted from here on). They are flat boards with different components mounted on the top. In case the reader needs his or her memory refreshed, a 3-dimensional model is shown in figure 1 below.

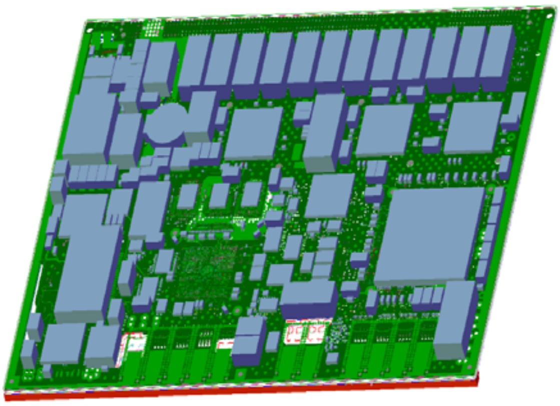

Figure 1. *A 3D model of a printed circuit board. The blue boxes symbolize components, mounted on the top.*

The components are connected by copper traces that can run both on the inside and the outside of the board. This is what a circuit board is; just the travel distance between different components. When a calculator reports the correct answer to an equation it is within one of the components that the calculations have been done, the board just allows the electrical signals to travel. It all sounds very simple, almost like if the board design could be auto-generated by some clever computer program, but it turns out that these are far more advanced than they seem and that their designs require immense care. The scales, on which the designers operate, give a good indication upon the complexity of the PCB; the blueprints do not define the geometries in centimeters, or even millimeters, but in micrometers (one millimeter is made up of 1000 micrometer). That is a precision no brain surgeon can match.

Even with traces that thin, a PCB is usually incredibly dense and often there is shortage of space. To counter this, the multilayered PCB was introduced. The idea is very simple, just adding several different layers on top of each other to increase the amount of space.

If these multilayered boards are thought of as skyscrapers (a person can walk anywhere on one floor, independently of how people are moving below him) then structures called *vias* would constitute the elevators. They are constructed by drilling round holes through the board and filling the surfaces with conducting materials. If two traces on different layers get connected to the via, then they will get connected to each other as well. These are the very basics of PCB's.

The problem

So what is the problem then? It is obviously possible to extract a signal from within a PCB, why can it not be measured?

First of all, what a "signal" actually is needs to be explained. Most people hear electrical signals and think of currents (even some engineers are prone to this mistake), but it is actually voltages (or electric potential, to use the scientific term) that constitute the signal. The information within this signal is made up of changes in the voltage level (switching between two different levels, thereby producing so called binary information). In figure 2 below, an example of how such a signal could look is shown.

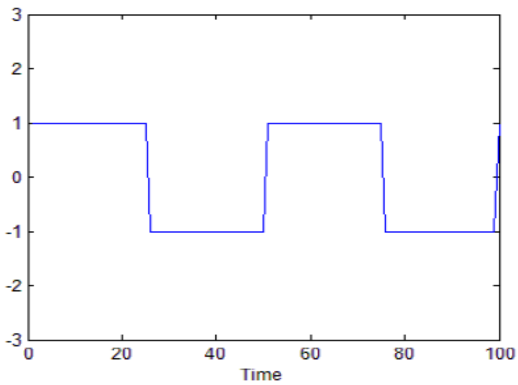

Figure 2. *An example of a signal, carrying binary information. The information is transported as "bits", one bit represented by one high or one low level voltage.*

Now, if you are new to electronics, you are probably asking yourself one of these two questions: Is this kind of signal actually worth something? And could really any useful information be transported by simply switching between two different voltage levels? Yes, quite a lot actually (that is the reply to both questions). This kind of signals are one of the basis for the modern age, no electronics of today would work without them.

To that answer you might reply: But wouldn't it take enormous amounts of bits to transport information? This time, you would be correct. In fact, during this thesis project the bit rate (bits per second) was measured in Giga bits per second (billion bits per second).

So now you know what a signal is, then why is it so hard to measure it? Think of the signal as a windmill (yes, it is a crazy metaphor, but stick with it), and let the bit rate be how fast the sails rotate. If you would like to measure the rotation speed, how would you do that? For lower bit rates it would be very simple to just observe the rotation and count. But as the speed increase you would have to somehow touch the mill's mechanics to get more accurate information, and this would undoubtedly disturb the rotation. This is the kind of problem that was central to this thesis work.

The proposed solution

So how would you solve the windmill problem? One simple way (never mind that it is costly) would be to build another windmill behind the first one. The sails of this one would be driven by the original's and rotate slower, so you could easily measure it without affecting the first windmill (see, there was a plan for that metaphor all along). If you could then somehow find a relationship between the rotation speeds, you would have enough information to describe the original rotation.

That is the kind of solution that was evaluated in this thesis, doing measurements without any direct contact. In fact, the principle within a PCB is the same; you place two traces next to each other and a signal in one of them will generate a signal in the other one. This physical effect is known as crosstalk, and is related to electromagnetic theory (have no fear- that theory will not be discussed further in this article).

Is it so simple that the signal in the second trace (generated by the crosstalk) is a perfect replica of the original signal? Unfortunately not. Remember the windmills? Their rotation speeds were not the same, you had to find a relation between them and use it with the measurements from the second mill to find out the rotation speed of the first.

In engineering, such a relation is called a *transfer function*. Books have been written about the theory relating to these functions and to make an honest attempt to describe it here would be pointless. But if you are unfamiliar with the concept, try looking at it like this: the *transfer function* between the windmills describes how some of the rotation is transferred from the first to second one, and the *transfer function* between the traces describe how some of the signal is transferred into the second trace. Hopefully that description helps a little.

The produced solution

All of this might sound fantastic; with such a function one could predict [a small part of] the future! That is correct, some predictions are possible. But it is not easy to obtain a *transfer function*. During this project two different techniques were used: simulations and measurements.

By performing a variety of simulations I was able to determine the optimal geometries of the trace exposed to the crosstalk and derive an approximation of the transfer function. And by, later on, producing a PCB with these structures implemented, I was able to obtain more correct *transfer functions* by the use of advanced measurement equipment.

Once these functions had been obtained, a computer program was created, designed to perform the necessary calculations. The program was capable of using a transfer function to analyze the signal from the second trace and reconstruct the original.

I would be exaggerating if I said that everything worked flawlessly, but good results were obtained. This is often the case with technology; the question is not if it is perfect, the question is whether it is good enough. In this case I would say: probably…

There is little doubt that a signal is actually measured and that the principle works. However, if the precision was good enough is impossible to say for the general case, it will have to be decided upon individual basis.

Conclusions

The aim was to measure an electrical signal within a PCB without any direct contact, and this was successfully accomplished. Though perfecting the technique will require further studies.

I wish to end this article by addressing the future of this technique. In order to do that, the windmills will be revisited.

Remember that the bitrate was symbolized by the rotation speed of the sails? What if that speed increased further? Then the second mill’s sails would catch even more wind, and the measurement technique would work even better! That is true for crosstalk as well; a higher bitrate will yield more crosstalk. This fact paints a positive future for this method.

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