Understanding Electromagnetic Effects using Printed Circuit Board Demos
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Abstract—Electromagnetic fields are considered by many students as a difficult subject. Unwanted electromagnetic fields are even tougher for students. We have developed many experiments as demonstrations (demos) to show the effect of electromagnetic fields in real life products. This paper gives a brief overview of these demos.

1. INTRODUCTION
Demos are often used in electromagnetic (field) courses. We have developed many types of demos and used also demos developed by others, such as those described in the IEEE EMC Education Manual [1], or the demo developed within the ASEAN-EU University Network Program [2], or within PATO [3]. Two main drawbacks could be observed: we could easily show the fundamental aspects such as Lenz Law, or crosstalk, in an idealized world, but this was not taken for granted by practicing engineers: these engineers needed a link to their own world. Especially people involved in signal and power integrity issues, ground bounce and interconnects: Their world is often a printed circuit board. The other drawback was that huge size of many of the demos. Transportation of such demos is therefore a problem. Therefore we decided to develop a series of demos on Eurocard (100x160mm) printed circuit boards (PCB)[4]. Test equipment consists of a basic generator, a dual channel oscilloscope, and, if available, a basic spectrum analyzer. The detailed description of the demo PCBs are available on a website, for free. The demo kit was presented at the several EMC conferences [5] and many, many people were interested. Therefore a new generation was developed. In the next section the prototype kit is described briefly. In Section III the new boards are presented, with some experimental results.

2. DESCRIPTION OF DEMO PCBs
A picture of the prototype kit is shown in Figure 1. This kit contains demos for showing the effect of:

- Lenz 1 – foldable
- Lenz 2 – fixed loops
- Proximity
- Ground Slot 1 – active
- Ground Slot 2 – passive
- Via Bypass
- Symmetry – signal
- Symmetry – power
- Inductance of Capacitors
- Grounding or floating heat sink
- Ground Bounce – DIL vs. SMD
- Ground Bounce – power layout

Fig 1: The demo PCB kit
A short description of every demo is available, giving:
- Description
- Expected result
- Practical result
- Explanation
- Lesson learned

The demos are also used in a practical training, and then students have to measure the effects, give an explanation themselves and draw conclusions from the experiments. We use different questionnaires for this hands-on training.

As an example, two demos are described in detail in this paper: the “Lenz, fixed loops” and the “Ground bounce” demo.

A. Lenz, fixed loops.
1) Description
Four signal tracks with the same load, but different lay-out and width. The Loop4 is the widest, and thus has the lowest resistance. (But it is the largest loop, and thus high inductance…….)
2) Expected result (students)

The signal travels best via the lowest resistance path.

3) Practical result

The signal is switched between all four tracks. Track 1 matches the original signal best, thus nearly all current flows in the loop with highest resistance (dark blue). The other loop show lower amplitude, thus less current (light blue).

4) Explanation

A return path via the ground plane is available only below signal track 1 (top). Therefore a large current loop is created in the bottom three signal paths. At 100 MHz, this is a large inductance which adds to the total path impedance. Actually the narrowest and longest track is best because it has the lowest inductance.

5) Lesson Learned

Impedance is not only resistance, but also includes inductance. Be aware of loops in your design: keep signal track and return path close together.

B. Ground bounce

1) Description

Two demos, one with different packages: DIL and SMD. The other with the same package, but with different pins used for power: edge or center pin. The drawing of the latter is shown in Figure 5. The picture of the experiment is presented in Figure 6.
1. The ground bounce differences between two package types: the DIL package shows much more ground bounce.

2. The ground bounce differences as function as the pin location: it is reduced for outputs pins close to the IC’s ground pin as shown in Figure 7.

Fig. 7: Ground bounce in a package with edge pin and center pin power supply, measurement results

4) Explanation

The inductance of the DIL package is higher than the inductance of the SMD package. The ground pin is shared, i.e. a common impedance. Switching current of one output driver will develop a voltage over the inductance. And this voltage is also seen by the non-active driver.

5) Lesson Learned

The inductance of the package can have a large influence on the behavior of the component.

3. NEW GENERATION

The demos appeared to be very attractive. Therefore a new generation, suitable for series production, has been developed. The design has been made freely available on the web and the demo boards are available at cost for other universities. The demo’s include:

1. Lenz law: (current) path of lowest inductance
2. Inductance of Capacitors 1:
   a. influence of capacitor value on parasitic inductance
   b. effect of track length on parasitic inductance
3. Inductance of Capacitors 2: effect of dielectric
4. Inductance of Capacitors 3: parasitic effect of package
5. Coax cable: (current) path of lowest inductance
6. Crosstalk
7. Track over a ground slot
8. Effect of discontinuities and stubs on signal propagation
9. Transference impedance
10. Ground bounce due to package (DIL, SOIC, TSSOP)
11. Ground bounce due to layout (asymmetric-symmetric)
12. Grounding of filter and more to come.

The demonstrations can be used for several purposes, such as for a class room audience, or for students to perform individual practical work in a course on EMC. Measurements are being performed now. Some results are shown hereafter.

The difference in amplitude shows that at higher frequencies the current prefers to flow through the path which forms the smallest current loop. The position of the ground trace (return path) is very important. The thickness, i.e. resistance, and length of the trace is less important.
The impact of a longer track towards the via connecting the capacitor to the ground plane is very obvious.

The different types of dielectric have an impact on the impedance of the capacitors. The electrolytic has poor high-frequency performance.

These results have been obtained using surface mounted capacitors.

These are the results using leaded components. For detailed comparison, the impedance of a 1 nF capacitor with leads and using SMD mounting has been shown in the figure below:
4. CONCLUSION

Demos and experiments are very useful in educating novice engineers, as well as providing practical insight to experienced engineers. It creates an ‘aha’ effect which cannot be achieved by equations alone.

REFERENCES

[3] PATO, Post Academic EMC course, The Netherlands