ELECTRON TECHNOLOGY
ISSN 1897-2381
http://www.ite.waw.pl/etij/
Internet Journal

ELECTROMAGNETIC EMISSIONS OF DIGITAL CIRCUITS IMPLEMENTED IN XILINX FPGAs XC 4025E AND XCV 800

J. SZCZĘSNY, J. F. KOŁODZIEJSKI, D. OBRĘBSKI

Institute of Electron Technology, al. Lotników 32/46, 02-668 Warszawa, Poland

Received November 14, 2003; modified February 9, 2004; published February 24, 2004

ABSTRACT

The results of testing electromagnetic emissions generated by circuits implemented in Xilinx FPGAs XC 4025E and XCV 800 types are presented. Both radiated and conducted emissions of the circuits were measured as a function of clock frequency. Possible practical re-commendations are discussed.

1. Introduction

Field programmable gate arrays (FPGAs) are digital VLSI ICs currently manufactured in advanced submicron CMOS technologies. FPGAs are composed of two basic elements: configurable logic blocks (CLB) creating the matrix interior and input/output blocks (IOB). Large number of equivalent logic gates in the array, e.g. up to a few million gates, enables the configuration of many application circuits fulfilling various electrical functions. On the other side, desired electrical function can be received with the help of circuit implemented in different FPGA matrices. In these circumstances the application circuits though having the same function may hold different electromagnetic compatibility (EMC) characteristics. A need to know the EMC properties is caused, among others, by general development and proliferation of electronic products. It is worth to underline also one specific reason related to FPGAs: due to the apparent progress in their architecture and fabrication they are applied not only for the verification of correctness of circuit projects as it was before, but also to settle a small scale profitable delivery of practically useful circuits (production volume up to a few tenth thousands per year). FPGAs can be a strong competitor to conventional Gate Arrays, Programmable Logic Devices (PLDs), and other Application Specific Integrated Circuits (ASICs)

All mentioned reasons cause the rise of interest in the investigation of EMC properties of electronic circuits implemented in FPGAs. Some results of measurement of electromagnetic disturbances generated by the circuits designed on the base of two Xilinx FPGAs matrices are given below.

2. Tested objects

For testing the levels of electromagnetic emissions and their spectra, two Xilinx FPGAs were used: XC 4025E and XCV 800 [1]. They differ substantially with regard to their architecture, routability possibilities provided for design the interconnect network and to the number of equivalent logic gates – about 25 thousands for the first circuit (older one) and about 800 thousands for the second, belonging to Virtex family. Both FPGAs are packed in plastic HQ 240 package with 240 pins.

The circuits were installed on the 2 layers PCBs equipped with cooperating elements and components, (Figs. 1 and 2, respectively). To allow programming of the FPGAs each PCB is equipped with a connector for FPGAs serial programming interface. This socket can be connected to external computer's RS-232 standard port via dedicated transceiver. Clock generator mounted on the PCB can be connected to the leads to provide system clock to allow checking of the circuit functioning over the wide frequency range. Relevant circuit supply voltages (separate for core and I/O cells in case of XCV 800) are provided by linear voltage regulators, also placed on test PCBs. On XCV 800 test PCB there was also monolithic transmitter/receiver of RS 232 interface standard and on both PCBs dedicated plugs for connecting the boards to IC tester LV 500 type from Tektronix.

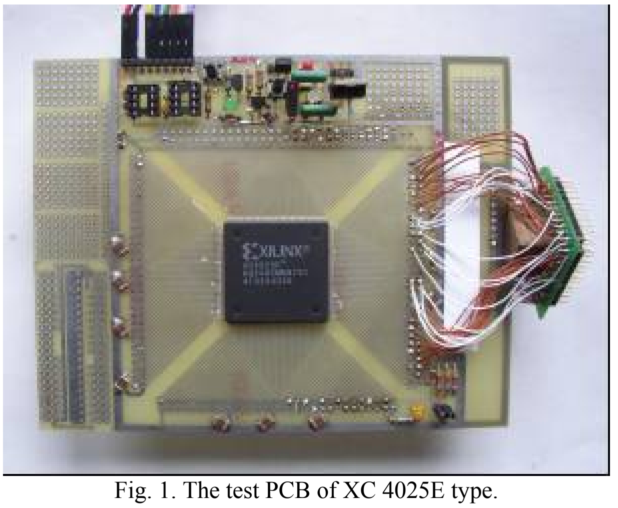


Fig. 1. The test PCB of XC 4025E type.

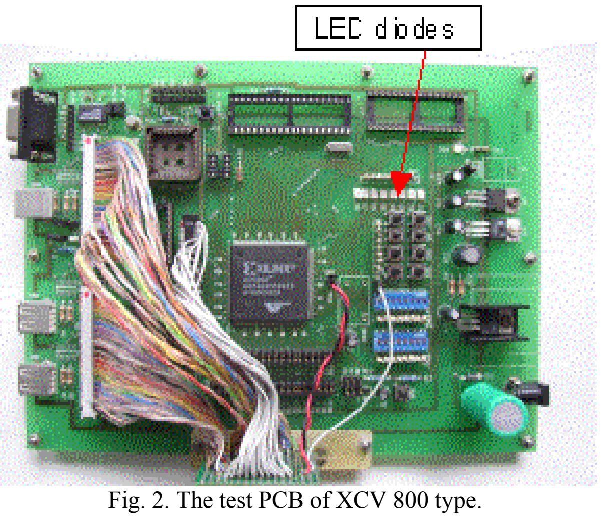


Fig. 2. The test PCB of XCV 800 type.

Elaborated configuration program and chosen electrical function had the aim to activate as many as possible of logic gates consisting the smaller array of XC 4025E type. Since the program and function were afterwards implemented in XCV 800 array in this case the percentage of activated gates was obviously less than before.

Nine periodically switching outputs of the application circuits were accessible on the board. To eight of them the LEDs were connected to monitor the circuit functioning. Temporary intervention in the circuit work could be done by the push buttons also provided on the board.

3. Measurements

Measurements were performed in the near field regions; hence the magnetic *H* and electric *E* components of EM field were determined [2], [3]. Radiated emissions were measured at the close vicinity of the surface of FPGA plastic packages. Conducted emissions, which usually spread out as HF currents inside the networks on the PCB, were measured over the supply and ground tracks, a few centimetres from the IC package.

3.1. Measurement equipment

Magnetic probe type RF 2,5-2 and electric probe type RF E05, together with wide-band preamplifier PA 201, manufactured by Langer (Germany), were used to test the field strength. *H* field probe had a sheath current damping and was electrically screened, while the *E* field probe had its top site shielded and also its sheath damped. Voltage induced at the preamplifier output was measured with the help of LeCroy digital scope type 9370 or displayed as the function of frequency on the screen of PC, which controlled the work of virtual spectrum analyser type ST 100W of EMC Master (Holland). While using oscilloscope we mainly regarded the peak-to-peak values of induced voltage. To avoid the influence of any external disturbances, the measurements at any analysed point were repeated about 100 times and calculated average values were recognized as the useful parameter.

3.2. Measurement procedure

To obtain the distribution of field strength, the area over IC packages was deliberately divided into 36 equal squares (Fig. 3). Measurements of emission levels or their spectra were performed after fixing the position of *H* or *E* field probe in the middle of successive squares.

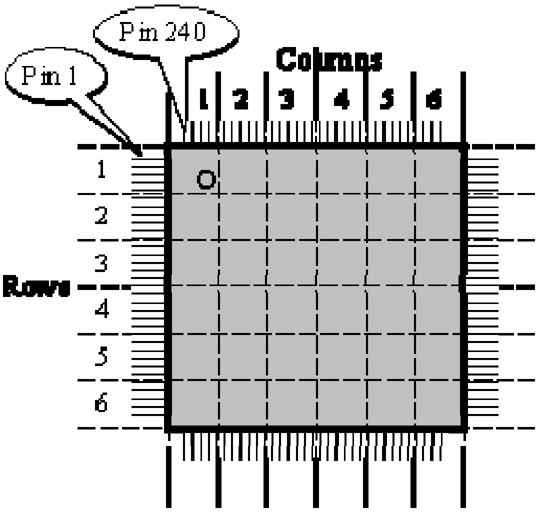


Fig. 3. Partition of the area over IC package.

With the accuracy sufficient for this experiment we could assume the uniform changes of field strength between measuring points. For each point the clock frequency was changed in selected steps, starting from the few tens of kHz up to 45 MHz. The points of conducted disturbances measurements were chosen on the circuit supply and ground tracks in the distance about 5 cm from the entrance of V_{CC} and V_{SS} to the IC package. In both cases the distance between the probe and measured objects was about 1 mm, since the probes touched the IC package and supplying or ground tracks. It provided then steady coupling between *H* and *E* field probes and the field source. The measurements results were presented in the time domain – when the scope was connected to the probes or in frequency domain – when the spectrum analyser was used.

4. Measurement results

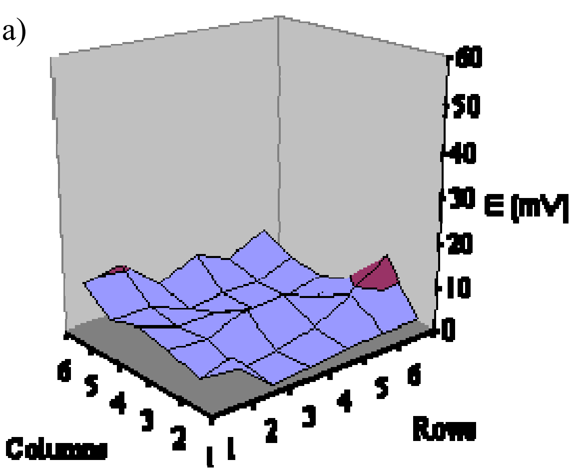
4.1. EM emissions of ICs

Both *E* and *H* components of EM field over the IC packages were measured in each of 36 points for several frequencies of clock signal up to 45 MHz.

4.1.1. Electric component of EM field

In the case of XC 4025E type the distribution of electric field *E* was not uniform and its value changed in various way in measured points as a function of clock frequency (Fig. 4). Inside the chosen frequency range usually 2–3 maxima and minima of the emission were observed in each point for higher frequencies. On the base of measured values of *E* component taken over all measurements points one could conclude that the emission level changed only slightly for small frequencies but fluctuated for frequencies higher than 8 MHz (Fig. 5), probably due to same resonances inside the circuit on PCB.

a)



b)

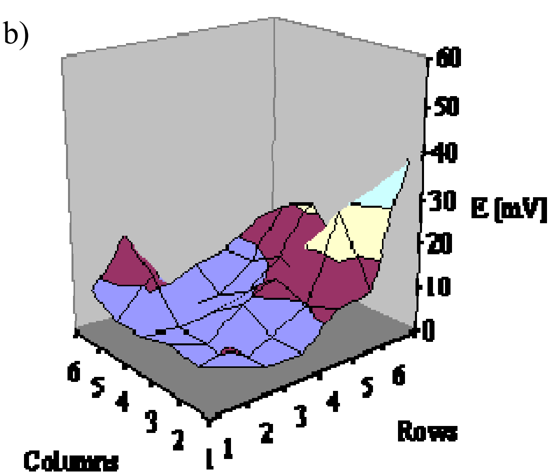


Fig. 4. *E* component distribution over XC 4025E at clock frequency: a) 80 kHz, b) 12 MHz.

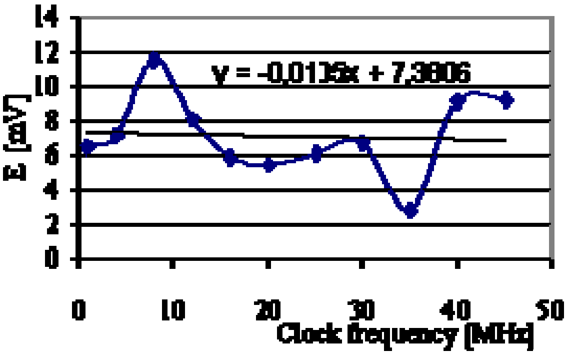


Fig. 5. The average value of *E* over the area of XC 4025E package as a function of clock frequency (linear approximation is also plotted).

This behaviour was also reflected in the spectrum of emitted electric field: initially the spectral lines appeared only as the single moderate value peaks over the considered frequency range, then the peaks become more dense especially for 60 to 200 MHz. At clock frequency 8 MHz also a rather unusual high peak occurred for 900 MHz (Fig. 6).

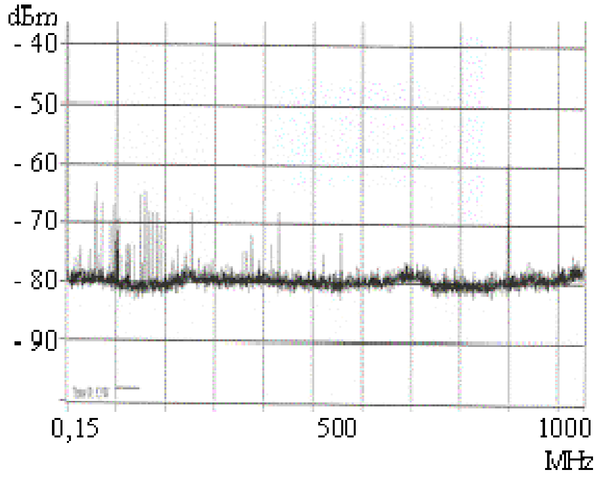


Fig. 6. Spectrum of *E* over the area of XC 4025E package at clock frequency 8 MHz.

As far as the Virtex family FPGA XCV 800 type is concerned, the geometrical distribution of *E* field emission was different than that of XC 4025E type and average emission, although having similar level, exhibited small raising tendency. For small clock frequencies up to 8 ÷ 10 kHz the emission was uniform, rather small and nearly constant. An increase of emissions was observed above 8 kHz with significant higher rate for region I of the package, determined roughly by columns 1–3 and rows 4–6 (see Fig. 3), specifically for frequencies higher than 6 MHz (Figs. 7 and 8). The emission increase may be related to the higher efficiency of pseudo-antennas inside the circuit. To the region I belong pins No 40 to 100, part of which was connected to the bus carrying signals for switching LEDs on the PCB.

Spectra of *E* field over tested circuits were similar for small frequencies but in the case of XCV 800 a few lines in the environment of 720 MHz accompanied spectral lines appearing around 100 MHz. For clock

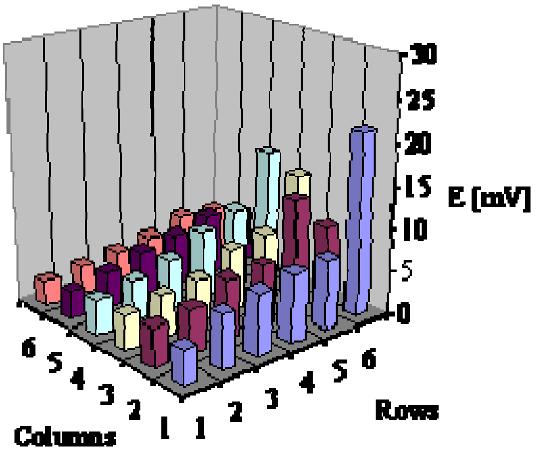


Fig. 7. *E* component distribution over XCV 800 at clock frequency 14 MHz.

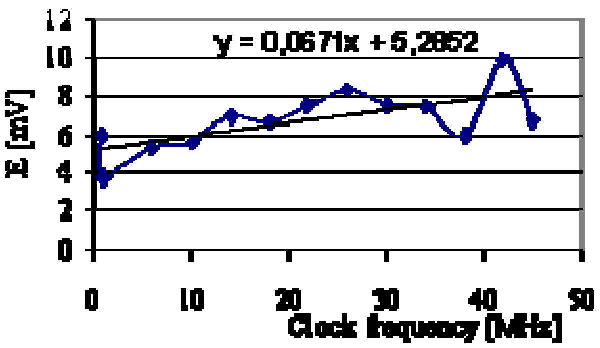


Fig. 8. The average value of *E* over the area of package of XCV 800 as a function of clock frequency (linear approximation is also plotted).

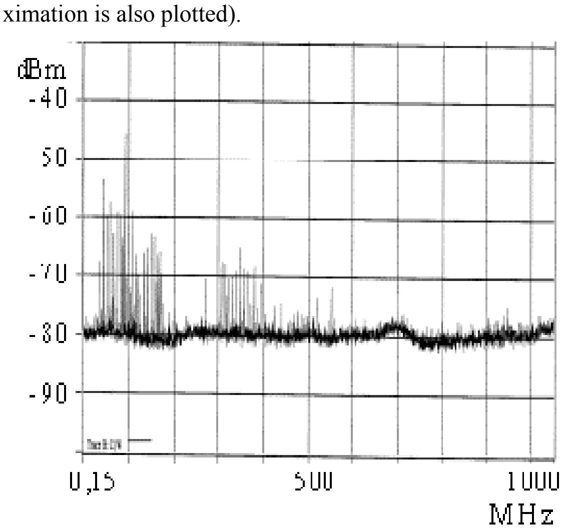


Fig. 9. Spectrum of *E* over the area of package of FPGA XCV 800 type, clock frequency 8 MHz.

frequencies higher than 8 MHz, the harmonics appeared inside 3 bands: 30 ÷ 200 MHz, 270 ÷ ÷ 520 MHz and 900 ÷1000 MHz (Fig. 9).

4.1.2. Magnetic component of EM field

The geometrical distribution of magnetic component for FPGA type XC 4025E could be taken as uniform for all considered clock frequencies. Emission level raised steadily as a function of clock frequency with one dip around 20 MHz. On the other hand, the *H* field distribution for FPGA XCV 800 type was not uniform over the whole package. In the above-mentioned region I (columns 1–3, rows 4-6) emission level was higher already at small clock frequencies and reached its maximum at 800 kHz (Fig. 10).

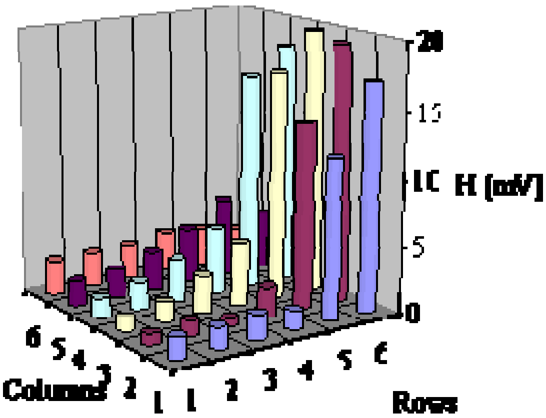


Fig. 10. *H* component distribution over XCV 800 at clock frequency 800 kHz.

The emission of *H* field from the rest part of the IC package (region II), where less percent of activated gates were located, rose also with the frequency but at the lower rate. The plot of averaged values of magnetic field versus clock frequency for both measured circuits is given in Fig. 11.

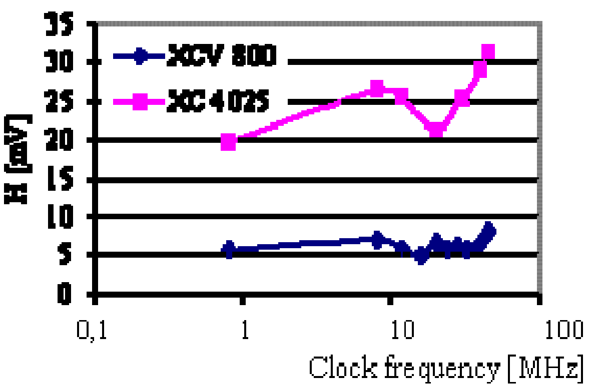


Fig. 11. The average value of *H* over the area of IC packages as a function of clock frequency.

It should be noticed that the emission levels for XC 4025 were a few time higher than for XCV 800. Linear approximation of these functions could be described by following equations:

$$y = 0.1856\,x + 21.316 \text{ for XC 4025,} \quad (1)$$
$$y = 0.0354\,x + 5.4965 \text{ for XCV 800.} \quad (2)$$

First few harmonics in the spectrum of *H* field of XCV 800 circuit appeared around 50 MHz at clock frequency about 100 kHz while harmonics rich picture was obtained at clock frequency equal or higher than 8 MHz (Fig. 12).

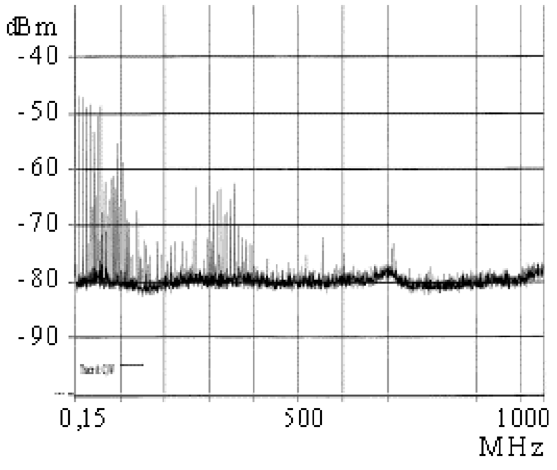


Fig. 12. Spectrum of *H* over the area of package of XCV 800 at clock frequency 8 MHz.

It well correlates with the appearance of some fluctuations on the $U = f(f_{clock})$ characteristic, given in Fig. 11.

4.2. Emissions from application circuits

Electric field *E* over the supply and ground tracks on PCB, roughly at 5 cm distance from the IC package rose at certain rate to around 8 ÷ 10 kHz. Finally, for the highest clock frequencies, the field level started to fluctuate – with significantly greater amplitude in the case of XC 4025E circuit (Figs. 13 a, b).

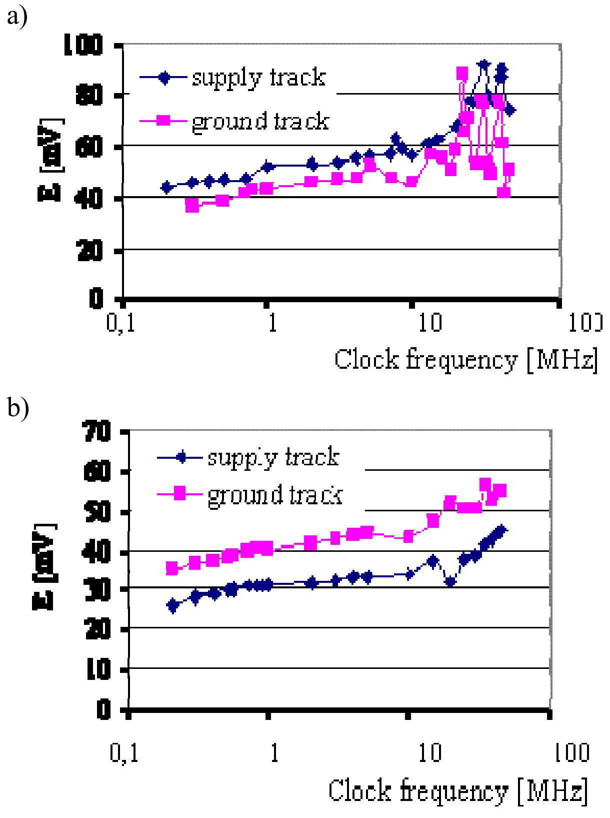


Fig. 13. Electric field *E* over the supply and ground tracks as a function of clock frequency: a) XC 4025E, b) XCV 800.

Electric field *E* was always higher for XC 4025E and – what is interesting – for this circuit the field level over the supply track was higher comparing with ground track, while for XCV 800 opposite situation was observed. The possible reason is that for XCV 800 array the ground track is common for core and I/O cells, while the supply tracks are separated (2.5 V for core and 3.3 V for I/Os). In case of XC 4025E, supply voltage is common for both I/O and core cells, and the ground track has heavier capacitive load than supply track. Placement of de-coupling capacitors seems to be another important factor. In case of XCV 800 PCB these mentioned capacitors (SMD type) are located very closely to the FPGA leads – at the opposite side of PCB, while in the XC 4025E PCB length of the supply and ground paths between FPGA leads and decoupling capacitors is about one inch.

Influence of clock frequency on magnetic component *H*, measured over the supply and ground tracks, are presented in Figs. 14 a, b for XC 4025E and XCV 800 circuits, respectively.

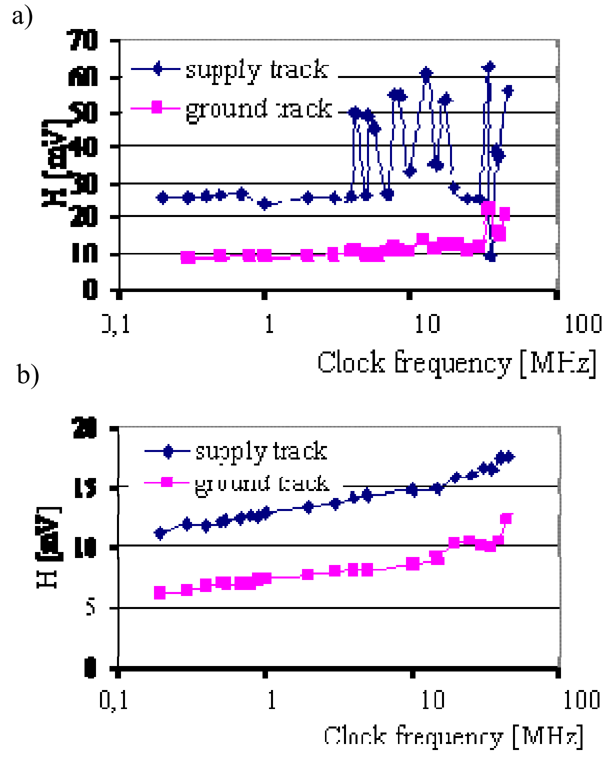


Fig. 14. Magnetic field *H* over the supply and ground tracks as a function of clock frequency: a) XC 4025E, b) XCV 800.

Again the values for XC 4025E were generally greater than for XCV 800; they changed less regularly and strongly fluctuated – at frequencies above a few MHz for supply track and above a few tens of MHz for ground track.

5. Discussion of the measurement results

Some conclusions and practical recommendations can be drawn on the base of obtained measurement results. Part of them is rather obvious and confirmed generally accepted relations while the other part is pertinent to the tested objects. They are as follows:

– miniature near field probes (“sniffer probes”) together with appropriate wide-band pre-amplifier, an oscilloscope and spectrum analyser can allow to locate and identify the sources of EM disturbances generated within electronic circuits [4];
– information on the localization of EM disturbance sources and on their levels can help circuit designers to properly chose circuit components, especially ICs, and interconnection networks as well as to make the comparison of EMC properties of the components and circuit layout;
– new generations of ICs, designed with regard to obtain good EMC properties, exhibit usually significantly lower EM emission levels, as it was seen in the case of tested FPGA XCV 800 type and what is also observed e.g. for new families of microcontrollers, produced by various manufacturers;
– both *H* and *E* components of emitted EM field for the two tested FPGAs were strongly depended on the clock signal frequency;
– emission fluctuations appeared for the highest applied clock frequencies (of few tens MHz), more pronounced for XC 4025E, although the functioning of both circuits according to the proposed program was not violated – these fluctuations can be ascribe to certain resonances appearing inside the circuits and their connections;
– average values of magnetic field *H*, generated by XC 4025E, were about 3 times greater than these of XCV 800 – it can be explained if one assumes that the magnetic field component is mainly related to the currents and current loops area on the chip;
– the average levels of electric field were similar for the two tested FPGAs: it can be justified because the circuits performed the same electrical function and because some voltage differences inside the circuits as well as connected conductors and cables are usually responsible for the electric emissions;
– more or less active parts (areas) of the chip can be easily differentiate on the base of measurements of EM emissions – as it was for tested FPGA XCV 800 type;
– the whole circuit activity finds its reflection in the HF currents flowing in the power supply lines V_{DD} and V_{SS};
– both electric and magnetic field components over the supplying lines had higher values for XC 4025E circuit than for XCV 800 circuit and the emission level fluctuations appeared here even earlier than over the IC packages;
– spectral characteristics of EM emissions of the chip, measured over the IC packages, as well as of the emissions of supplying lines, were in good agreement with the characteristics observed in the time domain – detail analysis of the spectra could reveal the same characteristic points related e.g. to changes a slope of the plots, places of appearing the fluctuations, etc.

References

1. Data Source CD-ROM rev. 8 Q1-2003
2. J. F. Kołodziejski, J. Szczęsny, *Measurement Methods of Electromagnetic Disturbance*, Elektronizacja, 2001, **6**, 2–5 (in Polish).
3. J. F. Kołodziejski, J. Szczęsny, *Electromagnetic Disturbances Generated by Integrated Circuits*, Elektronizacja, 2002, **10**, 21–23 (in Polish).
4. M. Mardiguian, *Radiated-Emissions Problems with Digital Clocks Above 100 MHz*, Compliance Eng., 2000, Annual Ref. Guide, 14–20.