# MPC 5534 Case study

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Abstract: This application note presents the electromagnetic emission (EME) modeling of a 32-bit microcontroller designed for automotive purposes. The effect of different ball grid array (BGA) packages is investigated in terms of parasitic emission and associated EME model in conducted and radiated modes. Good agreements between measurements and simulations demonstrate the ability of ICEM-based model to handle the emission prediction of complex micro-controllers mounted in high-density, high-performance BGA packages

*This work has been sponsored by the European Research Program PIDEA+ "EMC Pack".*

*Keywords: near-field scan, emission prediction, localization of ground return current, ICEM model, substrate coupling*

*Files may be found in IC-EMC directory "case_study/mpc5534"*

## 1 Device Description

The integrated circuit used in this study is the MPC5534 Freescale Semiconductor 32-bit microcontroller widely applied in the most recent automotive electronic systems [1]. This IC is manufactured in 0.13-µm CMOS technology. In this case study, we focus on the BGA 324-pins package version, which is 23 x 23 mm (Fig. 1).

The package consists of six-layer high-density FR4 substrate, 1 mm-pitch array of balls, conventional leads and bonding to the silicon die. Three metal layers of the HDI package are dedicated to supply planes: the ground, the low and high voltages.

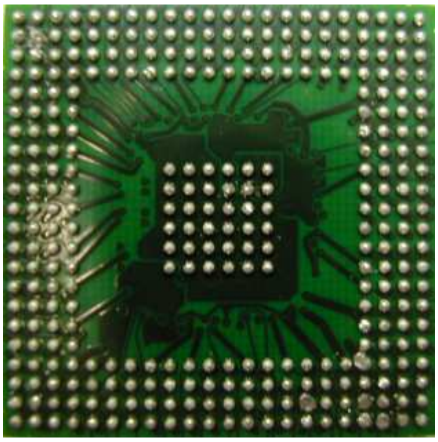
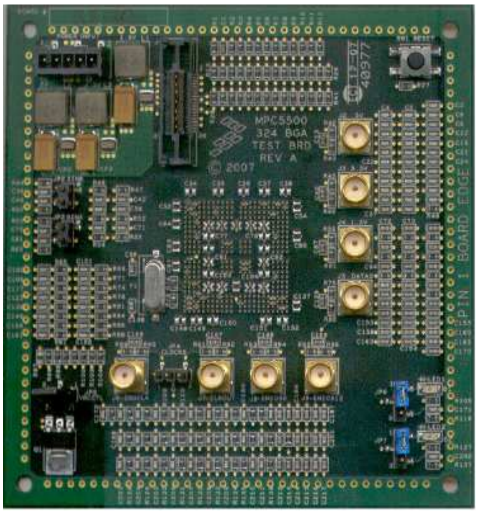
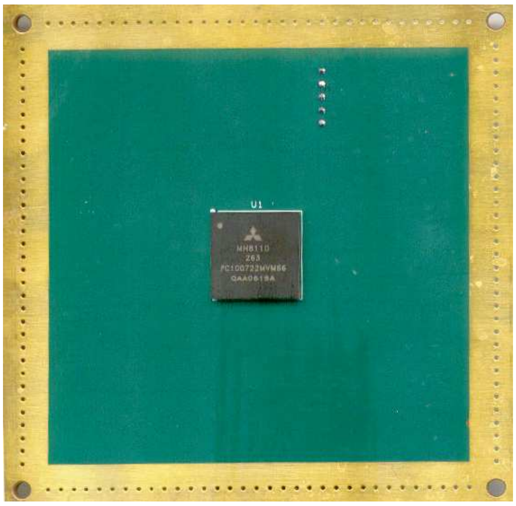


*Figure 1 : Bottom side of the 324-pin BGA package of MPC5534*

The microcontroller is mounted on a specific test board with external components and supplies required for its operation and dedicated EMC measurement structures, presented in figure 2.



(a) interface components – outside the TEM cell



(b) MPC 5534 alone – inner part of the TEM cell

*Figure 2: Test board for the EMC characterization of the MPC5534*

This board is specially designed for EMC characterization of the DUT, according to the IEC 61967 standard [2]. Its 10 x10 cm dimensions correspond to the TEM/GTEM cell aperture for radiated emission measurements. In addition, some SMA connectors are mounted on the board, with associated passives, for conducted emission measurements. Three different supply voltages (5V, 3.3V, and 1.5V) are supplied to the DUT via specific connectors. The I/O ports are supplied at 5 V, the phase-locked loop (PLL) is supplied at 3.3 V, and the digital core is supplied at 1.5V.

In the 324-pin version, 53 GND pins and 56 POWER pins used, which feed the IC with sufficient DC current, while reducing the access inductance and thus limiting the switching noise effects on the supplies.

## 2 Ibis Model

An IBIS model of the component is provided by Freescale for the 324 pin version. As listed below (Fig. 3) hidden keywords for ball and package dimensions are added in the [Package model] section to reconstruct a realistic view of the package (Fig. 4).

```
| Keywords added by E. Sicard for
IC-Emc
| Data given by Freescale
[Package model] bga
|pack_width=23.0e-3
|pack_height=23.0e-3
|pack_ball=0.32e-3
|ic_width= 6.3e-3
|ic_height= 5.8e-3
|ic_xstart= 7e-3
|ic_ystart= 7e-3
|pack_pitch=1.0e-3
|pack_cavity=15e-3
|ic_altitude=1.1e-3
|ic_thickness=0.279e-3
```

*Figure 1: hidden keywords in the IBIS description of the MPC 5534 (mpc5534-324.ibs)*

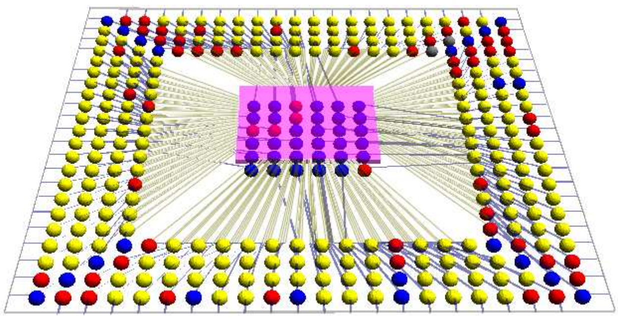


*Figure 2: 3D view reconstructed from MPC 5534 BGA 324 IBIS file (mpc5534-324.ibs)*

# 3 ICEM model construction

## 3.1 Passive Distribution Network impedance

We tune the VDD/VSS supply impedance from Z(f) measurements [3], that will form the PDN elements of the ICEM model. It can be seen from Fig. 5 that a 35 nF on-chip capacitance in series with 0.2 Ω, and 8 nH inductance give a good match with measured impedance up to 1 GHz. We split the 8 nH into two equal inductances, one on the VSS path, the other on the VDD path.

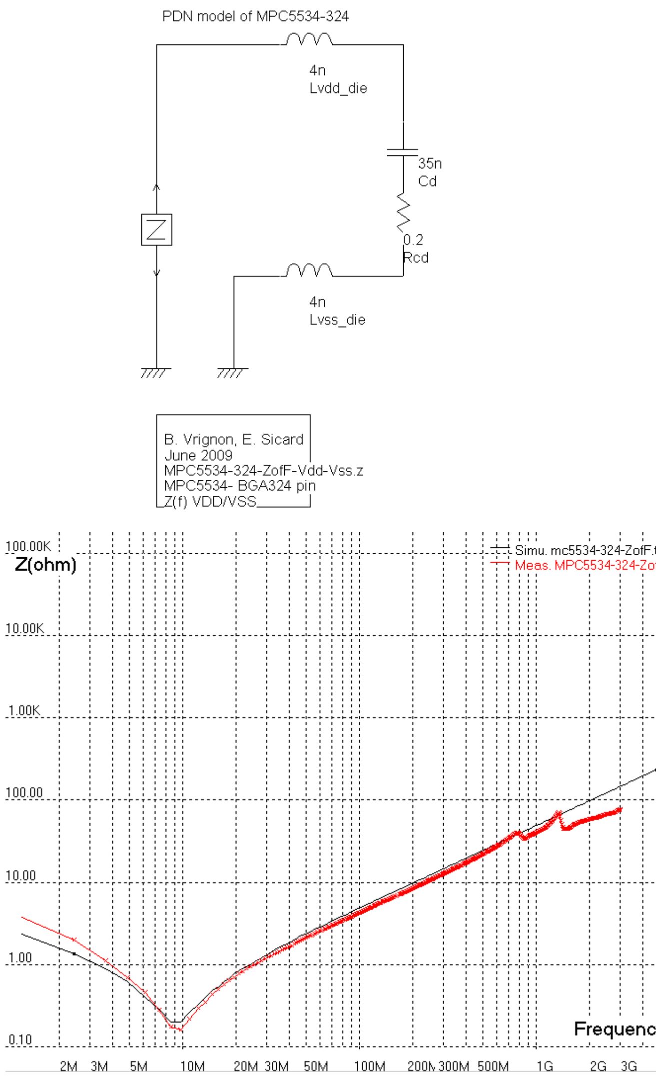



*Figure 1: Z(f) between VDD and VSS of the MPC 5534 BGA (mpc5534-324-ZofF.sch, mpc5534-324-ZofF-Vdd-Vss.z)*

## 3.2 Internal Activity Model

The proposed IA is composed of a two-phase system, with regular current peaks (0.3 A, 0.5 ns edge) at a 80 MHz rate, and a supplementary peak at 20 MHz rate. The voltage on a 1 Ω resistance is plotted in Fig. 6. The peak current parameters are adjusted from Freescale IC design information.

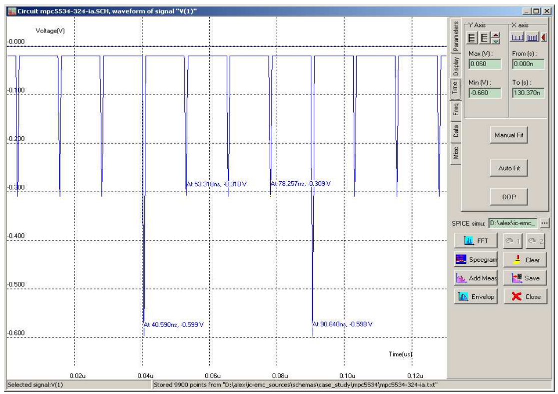


*Figure 2: Internal Activity model with a two-phase system, 20 and 80 MHz (mpc5534-324-ia.sch)*

# 4 Emission Modeling

## 4.1 Conducted Emission using a 120 Ω probe

The evaluation of conducted emission on supply rails is performed by measuring the parasitic currents on a 120-Ohm resistance and a 6.8nF capacitance placed in parallel with the supply pin [4]. The voltage drop is measured on a 50-ohm termination thanks to a spectrum analyzer. As the probe is external, the main problem is to model the supply rail and the on-board decoupling. This is done as shown in the left part of Fig. 7, where the 3 on-board capacitances (33µF, 1p and 100nF) are represented, together with a 4.7µF serial inductance.

The measurements are compared to simulation in Fig. 8. We have a good agreement for major harmonics. The simulation overestimates the 20 MHz harmonics.

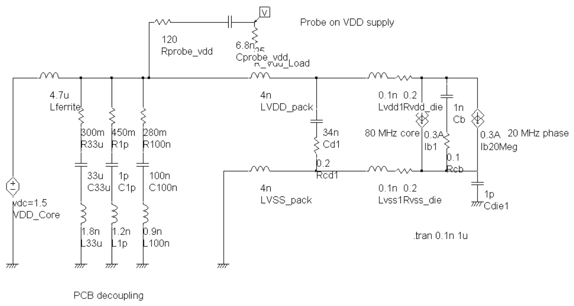



*Figure 1: The 120-Ω and 6.8nF probe on VDD supply for monitoring the conducted noise on the VDD supply rail (mpc5534-324-120ohm-vdd.sch)*

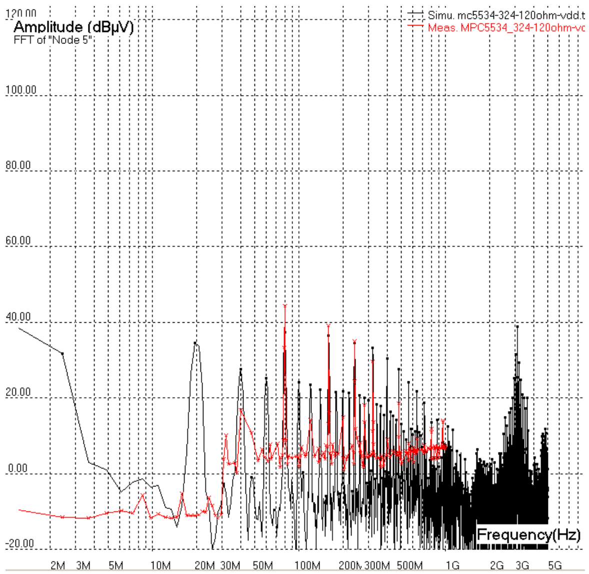



*Figure 2: Conducted noise simulation and measurements on the VDD supply rail (mpc5534-324-120ohm-vdd.sch)*

From measurements, it seems that the 40 MHz peak is more significant, meaning that the IA model could be modified (remove 20 MHz peak and replace by a 40 MHz peak).

## 4.2 Radiated Emission in TEM cell

The radiated emission is measured using the TEM cell method. We reuse the same ICEM model as for the conducted-mode emission. A coupling model between the IC and the die is added to the ICEM model (Fig. 9) and connected to the IC ground between the package and the die.

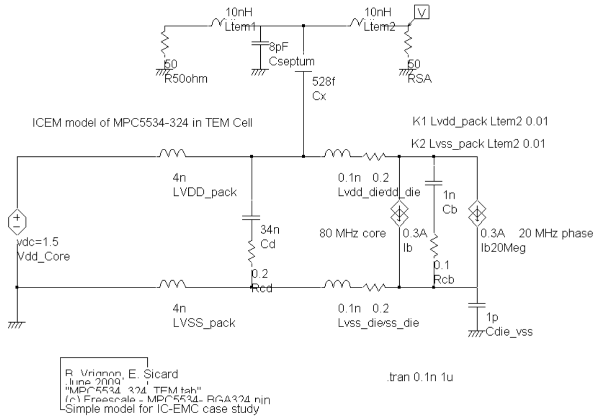



*Figure 3: Adding the TEM cell model to the MPC5534 ICEM model (mpc5534-324-tem.sch)*

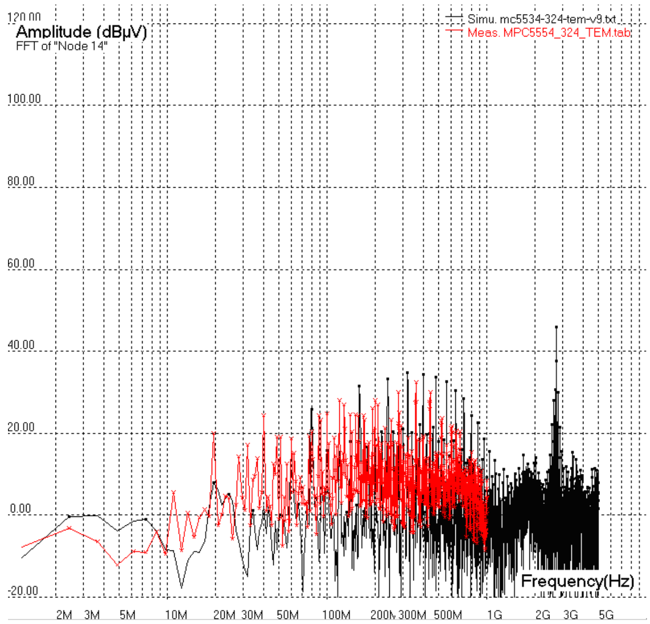



*Figure 4: Comparing measured and simulated MPC5534 performances in TEM cell (mpc5534-324-tem.sch, mpc5534-324-tem.tab)*

The septum model, shown in Fig. 9, can be considered as two inductors and a coupling capacitor. For symmetry reason, the septum inductor is split into two inductors LTEM1 and LTEM2. The value is 10 nH each.

The capacitance of the septum in relation to the ground is around 8 pF. This model is valid up to 1 GHz due to the inductance behaviour of the measurement setup capacitance above this frequency.

Concerning the internal IC model, notice that we have placed a 1nF-capacitance close to the IA model. This accounts for the local decoupling. We have no information about LVdd and RVdd from the core to the external supply but this might be adjusted for model tuning, or extracted from Freescale IC design information. As shown in figures 8 and 10, the correlation between measurement and simulation is acceptable. The emission level and the envelop trend is predicted with a good accuracy.

## 5 Summary

In this 32-bit micro-controller case-study, we achieved a correct matching between measurements and simulations, again using an ICEM-based model philosophy. The emission prediction of such a complex microcontroller, mounted in high-density, high-performance BGA package has been achieved with minimum knowledge of the internal structure of the IC. A more in-depth study of this component, with various packages and software configurations, may be found in [3].

### References

[1] MPC5534 Reference Manual, Freescale Semiconductor, 2006, www.freescale.com

[2] IEC 61967-2, “Methods of Radiated Emission – TEM Cell Method and Wideband TEM Cell Method 150 KHz to 8 GHz”, International Electrotechnical Commission, Geneva, Switzerland, March 2002

[3] E. Rogard, B. Vrignon, J. Shepherd, E. Sicard, "Characterization and Modelling of Parasitic Emission of a 32-bit Automotive Microcontroller Mounted on 2 Types of BGA", accepted for oral presentation at IEEE EMC Symposium Austin, Texas, USA 2009

[4] IEC 61967-4: “Measurement of conducted emission, 1 Ohm/150 Ohm method”, www.iec.ch