Practical Papers, Articles and Application Notes

Flavio Canavero, Technical Editor

The first article of this issue is entitled "Practical Techniques for Measurements and Computations of Near-Field Absolute Values" by Sergey Yuferev and Esa Saunamaki from Nokia Co. in Tampere, Finland. In this paper, the authors discuss practical procedures to determine calibration factors for electromagnetic fields measured or simulated around an electronic module. This contribution responds to the need of compliance verification by means of near-field measurements over modules composing consumer devices of common use. Since such modules are designed by third-party suppliers without knowledge about their future position inside the device, emission and immunity limits are imposed to ensure the proper functioning of the device and the absence of noise and interference between modules. Without knowledge of the calibration factor of EMC scanners, it becomes impossible to verify compliance during the integration phase of the design.

The second article is entitled "Simple Device for Electromagnetic Interference Shielding Effectiveness Measurement" by Horacio Vasquez, Laura Espinoza, Karen Lozano, Heinrich Foltz, and Shuying Yang from the University of Texas Pan-American in Edinburg, Texas. In this paper, the authors present the design, construction, and calibration of a simple flanged coaxial device for the measurement of the shielding effectiveness of materials. This device represents an improvement over the existing standard shielding effectiveness tester, since it requires smaller specimens and operates over a broader frequency range during testing. The interest in this new development is motivated by the crucial need of determining the properties and potential applications of newly developed materials.

In conclusion, I encourage (as always) all readers to actively participate in this column, either by submitting manuscripts they deem appropriate, or by encouraging other authors having something exciting to share with the community. I will follow all suggestions, and with the help of independent reviewers, I hope to be able to provide a great variety of enjoyable and instructive papers. Please communicate with me, preferably by email at canavero@ieee.org.

Practical Techniques for Measurements and Computations of Near-Field Absolute Values

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Abstract—The problem of obtaining absolute (as opposed to normalized) values of the magnetic field emissions radiated from a printed circuit board is considered. In the area of near-field measurements a practical technique to represent output data of EMC scanner in a form independent of the measurement setup is presented. In the area of simulations we proposed the technique to approximate ("tune") parameters of the EM source in numerical models for 3D EM computations using measured data. A workflow combining both techniques is presented to verify compliance of a module with EMC interoperability limits by numerical modeling. Examples of measurements and simulations of the magnetic field radiated by the voltage-controlled oscillator (VCO) module are included to illustrate the techniques.

I. INTRODUCTION

High frequency wireless consumer devices like mobile phones are becoming increasingly complex since they are actually combinations of different modules such as cameras, sensors, radios, computers etc. Each module contains a printed circuit board (PCB) with active components such as integrated circuits (ICs) generating RF currents that may cause emission and, consequently, EMI problems in the device. Most of modules are designed by third-party suppliers without knowledge about future position of the module inside the device. To ensure functioning of the device without noise and interference between modules, the emission and immunity interoperability limits are introduced as maximum acceptable values of the EM fields specified at a certain distance from each module. Compliance with interoperability limits can be verified by near-field measurements over the module.

With decreasing design cycle durations in modern electronic industry, simulations play a more and more important role as an alternative to traditional way of making prototypes and measurements. Numerical analyses are nowadays applied at different stages of the product creation flow, from the module level to the device level. Significant efforts have been made by IEEE EMC Society to develop standards and recommended practice of the use of computational packages for simulation of real EMC problems [1]. By calculating the electromagnetic field distribution inside and nearby outside the module/device, it is very attractive to check compliance with interoperability limits and other EMC regulations well before prototypes are

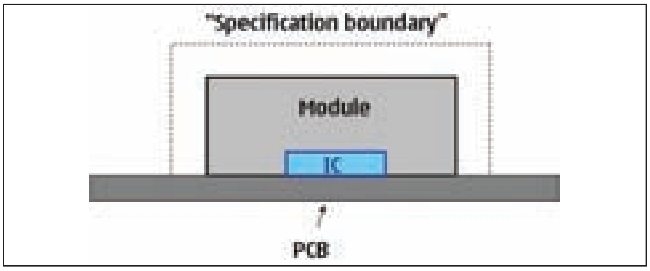

Fig. 1. Specification of the interoperability limit around a module containing the EMI source.

built. Obviously those limits are expressed in terms of absolute numbers and depend on neither conditions of measurements nor of numerical modeling.

A typical emission problem of the module containing RF IC (EMI source) is shown on Figure 1. The module is shielded because the highest magnetic field around the module should not exceed the interoperability limit defined as equal to *x* dBm at *y* mm from the module. One of simulation targets is optimization of the shield design. Rigorous consideration requires field—circuit co-simulations using SPICE-like model of components. With fast progress in development of commercial codes, such simulation workflows may become routine procedures in the near future, but today they are still considered as advanced "state of the art". One of the reasons is that models of active components are frequently unavailable, which makes circuit part of the workflow meaningless. In those cases source parameters are defined using reference data known a priori (for example, 2 mW and 50 Ohm) and simulations are performed using code for three-dimensional electromagnetic field computations only. This approach cannot take into consideration real electromagnetic behavior of the source (IC) and, therefore, cannot provide accurate computation of the magnitude of the field. Of course, if the excitation in the numerical model is assigned correctly (for example, to the PCB net carrying the highest current), numerical results will indicate accurately enough the areas of highest and lowest concentration of the electromagnetic field. But it does not answer the following question we frequently get from EMC designers: "How *high* are simulated high fields and how *low* are low fields?" In other words, inaccurate setup of parameters of the EM source in numerical model does not allow comparing computed fields with interoperability limits.

When detailed specifications and models needed for circuit-field co-simulations are not available, actual characteristics of the EM source may be approximated with the use of measured near field distribution over IC: parameters of the source in the numerical model are tuned (calibrated) in order to reach agreement between measured and computed fields. This task is an example of *inverse problems* that are widely known in nondestructive testing, geophysics, medical imaging (such as computed axial tomography), remote sensing, etc. Therefore, near field measurements can be applied at two stages of EMC: for improvement of the numerical model and final verification of compliance with interoperability limits. At the first stage the electromagnetic field is measured over the IC (if possible) whereas at the second stage measurements should be done over whole module. In both cases we want to obtain absolute values of the field magnitudes that are related with output data of measurements via correction or calibration factor [2]. The latter depends on the measurement setup (properties of a probe, preamplifier, cables etc). In spite of the growing popularity of near field measurements using EMC scanners, we have not found in the literature any general procedure to convert output voltage of the magnetic probe into absolute values of the magnetic field. Without knowledge of the calibration factor, we have to deal with only relative values that cannot be compared with interoperability limits.

In this paper practical procedures to measure and simulate absolute values of the electromagnetic field around a module are considered. The methodology for conversion of near field measured data into absolute values of the magnetic fields independent of the measurement conditions is given in Section 2. We obtain the calibration factor using a reference PCB that should be simple enough to admit accurate analytical or numerical solution for the electromagnetic field distribution. Near field measurements for the reference PCB should be performed with the same setup as the normal IC emission measurement. Section 3 describes practical application of this methodology to near-field measurements over a real VCO block. Section 4 contains methodology how to approximate ("tune") EM sources in numerical models using measured data. Simulations to verify compliance of the module with interoperability limits are considered in Section 5.

2. CONVERSION OF MEASURED NEAR-FIELD VALUES: PRACTICAL PROCEDURE

Near-field measurements are increasingly being used to provide information regarding the electric and magnetic fields in the vicinity of IC cips printed circuit boards [3]–[5]. One of the reasons is that measurement of only input and output signals using a network analyzer is not sufficient to analyze the performance and errors because, in many cases, the information obtained is not sufficient to localize the cause of errors.

One of the popular methods to measure emissions radiated from a PCB is the magnetic probe method. In this method we measure the output voltage (V_{px}, V_{py} and V_{pz} for x-, y- and z-orientations of the probe, respectively) of the magnetic probe. The magnetic field components H_x, H_y, and H_z are related with V_{px}, V_{py} and V_{pz}, respectively, via correction or calibration factor C_f as follows [2]:

$$H_x = V_{px} \cdot C_f \,; \quad H_y = V_{py} \cdot C_f \,; \quad H_z = V_{pz} \cdot C_f \qquad (1)$$

or

$$H_{x\_dB} = V_{px\_dB} + C_{f\_dB} \,; \quad H_{y\_dB} = V_{py\_dB} + C_{f\_dB} \,;$$
$$H_{z\_dB} = V_{pz\_dB} + C_{f\_dB} \qquad (2)$$

Here V_{p_dB} is V_p value in dB V and C_{f_dB} is C_f value in dB S/m.

Therefore, the calibration factor must be known to convert the output voltage to the magnetic field using (1)–(2). If the calibration factor is unknown, we can obtain only relative (normalized) values of the magnetic field. According to our experience, application of analytical formulae and/or calibration characteristics of commercial probes are not reliable so we had to choose another approach, namely: the calibration factor can be obtained using a reference (test) PCB that should be simple enough to admit accurate analytical or numerical solution for the magnetic field distribution. Near field measurements and simulations for the reference PCB should be performed with the same setup as the normal IC emission measurement. In this case the calibration factor will be the same for IC and reference PCB measurements so that the calibration procedure will include the following steps:

1. Near-field measurements over target IC to obtain $V^{IC}_{px\_dB}$, $V^{IC}_{py\_dB}$ and $V^{IC}_{pz\_dB}$
2. Near-field measurements over reference PCB to obtain $V^{ref}_{px\_dB}$, $V^{ref}_{py\_dB}$ and $V^{ref}_{pz\_dB}$.
3. Numerical modeling of reference PCB to obtain H^{ref}_{x}, H^{ref}_{y} and H^{ref}_{z}.
4. Calculation of the calibration factor C_{f_dB} using one of the following formulae:

$$C_{f\_dB} = H^{ref}_{x\_dB} - V^{ref}_{px\_dB} \quad \text{or} \quad C_{f\_dB} = H^{ref}_{y\_dB} - V^{ref}_{py\_dB} \quad \text{or}$$
$$C_{f\_dB} = H^{ref}_{z\_dB} - V^{ref}_{pz\_dB} \tag{3}$$

5. Conversion to the magnetic field values $H^{IC}_{x\_dB}$, $H^{IC}_{y\_dB}$ and $H^{IC}_{z\_dB}$ using (2).

In the next section the procedure described is illustrated.

3. EXAMPLE: MAGNETIC FIELD OVER A VCO BLOCK

3.1 Near-Field Measurements Over VCO

Voltage-controlled oscillator is well-known in EMC design as a source of radiation emission that usually needs to be reduced by shielding. Our first aim was measurement of the magnetic field over the VCO block shown in Figure 2 at fundamental frequency 3.975 GHz and detection of highest values of emission (maximum amplitudes of the magnetic field components). Measurements have been performed in XY-plane (parallel to the PCB) for opened VCO shield using commercial EMC scanner with spectrum analyzer and magnetic probes with and without preamplifier. Figure 3 presents distributions of components of the magnetic field measured at 3.2 mm from the PCB (1 mm from top of the shield; height of the shield is 2.2 mm). Maximum amplitudes of measured magnetic field at that plane are collected in Table 1.

Note that

$$H^{\max} \neq \sqrt{\left(H^{\max}_x\right)^2 + \left(H^{\max}_y\right)^2 + \left(H^{\max}_z\right)^2}$$

because components have their maximum at different positions so

$$H^{\max}_x = \max\left(H_x(x,y)\right) = H^{\max}_x(x_1, y_1)$$
$$H^{\max}_y = \max\left(H_y(x,y)\right) = H^{\max}_y(x_2, y_2)$$
$$H^{\max}_z = \max\left(H_z(x,y)\right) = H^{\max}_z(x_3, y_3)$$

Here and below $V^{VCO}_{px\_dBm}$ denotes an amplitude of the probe output voltage, measured at point (x,y,z) above VCO, by the probe placed in x-orientation. Maximum amplitude was detected as a result of scanning over PCB in x- and y-directions so

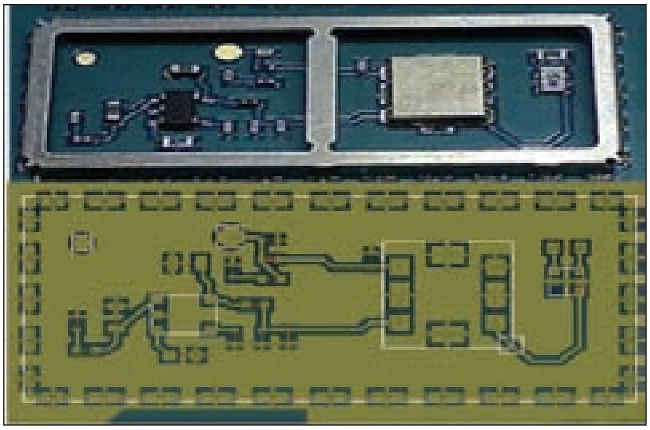

Fig. 2. VCO block.

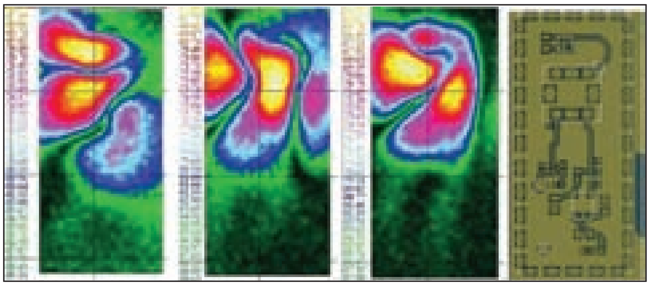

Fig. 3. X-, Y- and Z- components of the magnetic field measured over VCO block.

$(V^{VCO}_{px\_dBm})^{\max} = \max\left(V^{VCO}_{px\_dBm}(x,y)\right)$; z coordinate is fixed and equal to 3.2 mm for data in Table 1.

3.2 Near-Field Measurements Over Reference PCB

As the reference PCB we have used a simple 50 Ohm microstrip line shown in Figure 4. The microstrip line was connected to the source of the same power level as VCO RF output. Figure 5 shows both the VCO board and the reference

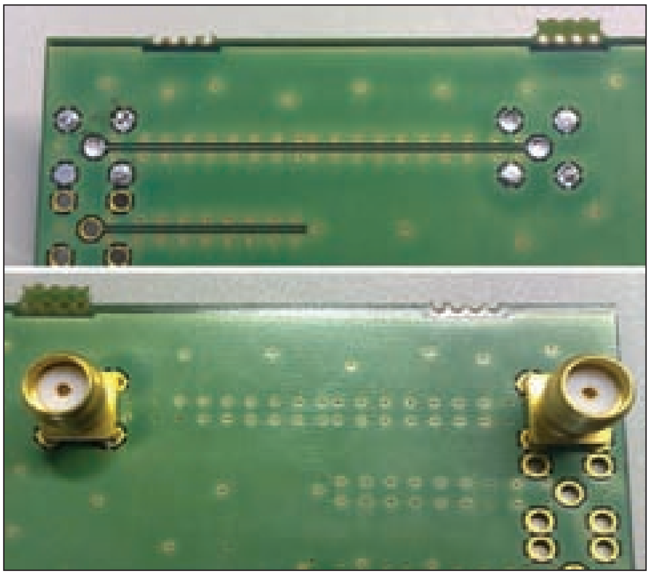

Fig. 4. Reference PCB (50 Ohm microstrip line).

TABLE 1. MAXIMUM AMPLITUDES OF THE COMPONENTS OF MEASURED MAGNETIC FIELD OVER VCO (HEIGHT IS 3.2 MM FROM THE PCB, FREQUENCY IS 3.975 GHz).

	$\left(V^{VCO}_{px\_dBm}\right)^{max}$, dBm	$\left(V^{VCO}_{py\_dBm}\right)^{max}$, dBm	$\left(V^{VCO}_{pz\_dBm}\right)^{max}$, dBm
Without pre-amplifier	−63	−63	−61
With pre-amplifier	−29	−30	−27

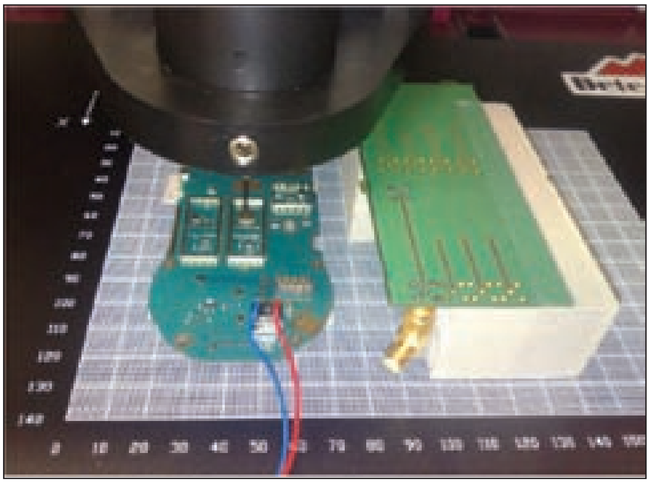

Fig. 5. VCO board (left) and reference PCB (right).

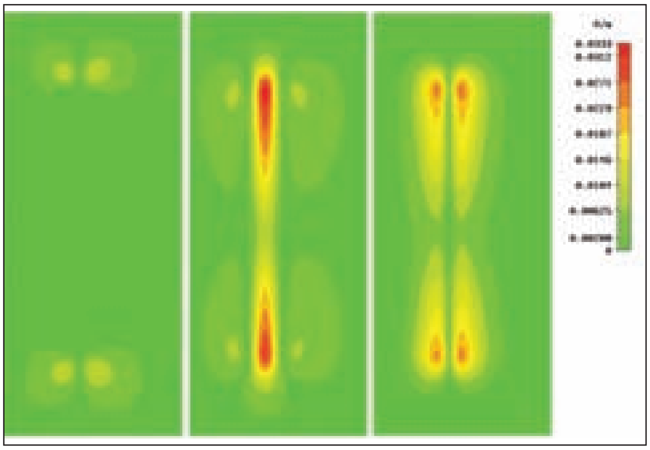

Fig. 7. X-, Y- and Z- components of the magnetic field computed over reference PCB.

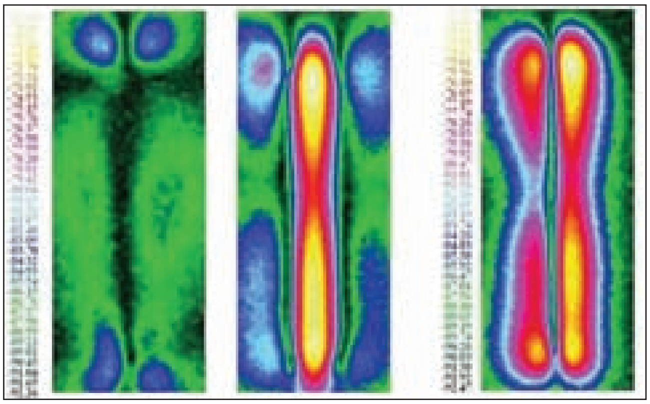

Fig. 6. X-, Y- and Z- components of the magnetic field measured over reference PCB.

PCB. Figure 6 shows the distribution of components of the magnetic field at 3.2 mm from the PCB at 3.975 GHz. Maximum amplitudes of components are shown in Table 2. Measurements of the reference PCB have been performed with the same levels of pre-amplifier as in the case of VCO.

3.3 Numerical Modeling Over Reference PCB

From basic formula (1) it follows that the output of the near-field probe is directly proportional to the field intensity at the location of the probe. This does not allow for the fact that the presence of the probe itself may introduce some perturbation in the field component being measured. Therefore rigorous consideration requires inclusion of the probe in the computational model together with the reference PCB. Since perturbation caused by the probe is usually effect of high order of magnitude, taking it into account is possible only using an accurate and detailed model of the probe as it was done in [6] for handmade probes. In our measurement setup we have used commercial near field probes that made modeling difficult due to lack of information about probe's internal structure. On the other hand, our probes are smaller than those have been used in [6] so we can expect low disturbance within 5% [7]. Thus we decided to restrict ourselves by major effects in simulation of the near-field distribution above the reference PCB and do not include the probe in the computational model. It imposes limitations on the applicability of the technique, but their investigation requires special consideration that is outside the content of this paper. According to our knowledge, similar assumptions have been made in papers [8]–[10] where numerical modeling of the near field measurement setup was also considered.

The electromagnetic behavior of the microstrip line was simulated using different commercial codes for 3-D EM field computations and good agreement between numerical results has been observed. Figure 6 shows computed components of the magnetic field at shown in Figure 7 and their maximum amplitudes can be found in Table 3.

TABLE 2. MAXIMUM AMPLITUDES OF THE COMPONENTS OF MEASURED MAGNETIC FIELD OVER REFERENCE PCB (HEIGHT IS 3.2 MM FROM THE PCB, FREQUENCY IS 3.975 GHz).

	$\left(V^{ref}_{px\_dBm}\right)^{max}$, dBm	$\left(V^{ref}_{py\_dBm}\right)^{max}$, dBm	$\left(V^{ref}_{pz\_dBm}\right)^{max}$, dBm
Without pre-amplifier	−81	−69	−72
With pre-amplifier	−48	−37	−41

TABLE 3. MAXIMUM AMPLITUDES OF COMPUTED MAGNETIC FIELD COMPONENTS OVER REFERENCE PCB (HEIGHT IS 3.2 MM FROM THE PCB, FREQUENCY IS 3.975 GHz).

$(H_x^{ref})^{max}$, A/m	$(H_y^{ref})^{max}$, A/m	$(H_z^{ref})^{max}$, A/m
0.010	0.034	0.026

3.4 Calculation of the Calibration Factor

Formula (3) requires results of measurement and computation of only one component of the magnetic field to obtain the calibration factor. In our case measurements of all components have been done using the same setup so the calibration factor should not depend on selection of the component. For verification we have performed calculations using max amplitudes of Hx, Hy, and Hz separately and results are in good agreement (+/−2 dB). As it follows from data in Table 4, the calibration factor in series 1 and 2 (without and with pre-amplifier) is equal to 53 and 19, respectively. Measurements were done for various positions of the probe in x-, and y- directions. It was observed that the calibration factor does not depend on the probe position.

Measurements, simulations and calculations of calibration factors have been repeated for other distances between the probe and PCB, and results are shown in Table 5. Note that the calibration coefficients relating x-, y-, and z-components of the magnetic field to the probe voltage have almost equal values at short distances between the probe and PCB since the electromagnetic field near a large current would be dominated by the magnetic field. However, difference between the calibration factors for components is growing with increase of the distance because the probe output might also be influenced by the electric field.

TABLE 4. CALCULATION OF THE CALIBRATION FACTOR FOR MEASUREMENTS WITHOUT AND WITH PREAMPLIFIER (SERIES 1 AND 2, RESPECTIVELY), HEIGHT IS 3.2 MM FROM THE PCB, AND FREQUENCY IS 3.975 GHz.

	Measured output voltage (reference PCB)		Computed magnetic field (reference PCB)		Calibration factors
H-field comp.	$\left(V^{ref}_{px,py,pz\_dBm}\right)^{max}$	$\left(V^{ref}_{px,py,pz\_dBV}\right)^{max}$	$\left(H^{ref}_{x,y,z}\right)^{max}$	$\left(H^{ref}_{x,y,z\_dB}\right)^{max}$	$C_{f\_dB} = H^{ref}_{dB} - V^{ref}_{p\_dB}$
x-	−81 (series 1) −48 (series 2)	−94 (series 1) −61 (series 2)	0.01	−40	54 (series 1) 21 (series 2)
y-	−69 (series 1) −37 (series 2)	−82 (series 1) −50 (series 2)	0.034	−29	53 (series 1) 20 (series 2)
z-	−72 (series 1) −41 (series 2)	−85 (series 1) −54 (series 2)	0.026	−32	53 (series 1) 18 (series 2)

TABLE 5. CALCULATION OF THE CALIBRATION FACTOR FOR MEASUREMENTS WITH PREAMPLIFIER FOR VARIOUS DISTANCES FROM THE PCB (FREQUENCY IS 3.975 GHz).

		Measured output voltage (reference PCB)		Computed magnetic field (reference PCB)		Calibration factors
Distance, mm	H-field comp	$\left(V^{ref}_{px,py,pz\_dBm}\right)^{max}$	$\left(V^{ref}_{px,py,pz\_dBV}\right)^{max}$	$\left(H^{ref}_{x,y,z}\right)^{max}$	$\left(H^{ref}_{x,y,z\_dB}\right)^{max}$	C_{f_dB}
5.2	x-	−54	−67	0.0036	−49	18
	y-	−44	−57	0.011	−39	18
	z-	−49	−62	0.0087	−41	21
10	x-	−61	−74	0.001	−60	14
	y-	−56	−69	0.0019	−54	15
	z-	−59	−72	0.0019	−54	18

TABLE 6. CONVERSION OF THE MEASURED OUTPUT VOLTAGE TO THE MAGNETIC FIELD OVER VCO.

	Measured output voltage (VCO)		Magnetic field (VCO)	
H field comp.	$\left(V^{VCO}_{px,py,pz\_dBm}\right)^{max}$ dBm	$\left(V^{VCO}_{px,py,pz\_dBV}\right)^{max}$ dB V	$H^{VCO}_{dB} = C_{f\_dB} + V^{VCO}_{p\_dB}$ dB A/m	$\left(H^{VCO}_{x,y,z}\right)^{max}$ A/m
x-	−63 (series 1) −29 (series 2)	−76 (series 1) −42 (series 2)	−23 (series 1) −23 (series 2)	0.071 (series 1) 0.071 (series 2)
y-	−63 (series 1) −30 (series 2)	−76 (series 1) −43 (series 2)	−23 (series 1) −24 (series 2)	0.071 (series 1) 0.063 (series 2)
z-	−61 (series 1) −27 (series 2)	−74 (series 1) −40 (series 2)	−21 (series 1) −21 (series 2)	0.082 (series 1) 0.082 (series 2)

TABLE 7. MAGNETIC FIELD OVER VCO (3.2 MM FROM PCB, 3.975 GHz): MEASURED, COMPUTED WITH DEFAULT PARAMETERS OF THE PORT AND COMPUTED WITH TUNED PARAMETERS OF THE PORT.

	$(H_x^{VCO})^{max}$, A/m	$(H_y^{VCO})^{max}$, A/m	$(H_z^{VCO})^{max}$, A/m
Computed with default parameters (1 W, 50 Ohm)	0.68	0.47	0.75
Computed with "tuned" parameters (0.012 W, 50 Ohm)	0.074	0.052	0.082
Measured	0.071	0.063	0.082

3.5 Representation of Measured Magnetic Field in A/m

Conversion of maximum amplitudes of the components from dBm to A/m was performed using (2) and results are shown in Table 6. It is easily seen that data measured without and with pre-amplifier (series 1 and 2, respectively) led to very close values of the magnetic field (disagreement is 1dB). So results do not depend on the measurement setup and do indeed give absolute values of the magnetic field components.

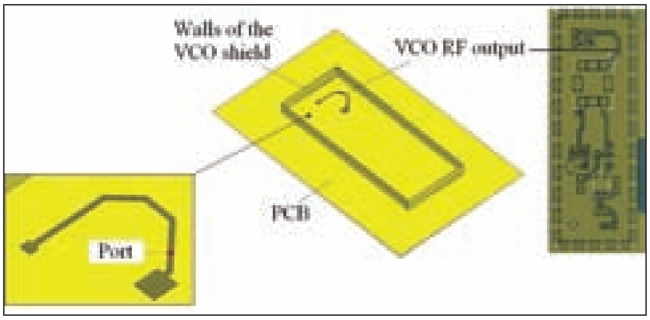

Fig. 8. Simplest model of the VCO block without cover of the shield.

4. "TUNING" PARAMETERS OF THE EM SOURCES IN NUMERICAL MODELS USING MEASURED DATA

Consider now the computation of the magnetic field around IC when no data for rigorous modeling of the source behavior is available. One of the most popular approaches to setup excitation in commercial tools for 3D EM field computation is definition of characteristics of current flowing through a conductor using so-called discrete or lumped port (physical representation similar to Hertzian dipole). Usually power (P) and resistance (R) of the port should be defined, default values are 1 W and 50 Ohm, respectively, but how can we know actual values in a given case? The answer becomes clear if we have already measured the magnetic field over the PCB: parameters of the port can be approximated by solving inverse problem. In many practical cases the problem is linear and advanced commercial codes allow P and R to vary at the post-processing stage so the procedure consists of the following steps:

1. Model real IC by set of ports assigned to the nets carrying highest current. This requires a priori knowledge about general EM behavior of the module/device.
2. Run simulations with default values of parameters of the ports.
3. Compare computed and measured distributions of the EM field at specified height over the PCB and "tune" parameters of the port to reach agreement between measured data and numerical results.

Consider again our VCO block. From specification it is known that the highest current is flowing in the "RF output" net. The simplest model of the VCO block consists of this net with assigned port, PCB represented as solid metal brick and walls of the shield (Figure 8). All parts are assumed to be copper.

Numerical results before and after tuning are shown together with measured data in Table 7. It is easily to see that setting up the port power and resistance equal to 0.012 W and 50 Ohm, respectively, provides good agreement between measured and computed components of the magnetic field at 3.2 mm from the PCB. Those parameters can then be used in 3D EM simulations of all problems where this VCO is the excitation source.

Although the port in our numerical model is assigned to one particular net (RF output), parameters of the port are tuned using the highest values of emission from whole VCO block. Therefore, VCO output power, related with current flowing in the RF output net, should not be mixed with tuned power of the port in the numerical model. As it is seen on Figure 3, maximum in the EM field distribution takes place not over the RF output net so VCO output power, equal to 2 mW according to specification, is significantly less than 0.012 W.

It is natural to ask the question: will the port with parameters tuned for one distance from the IC to observation point describe correctly EM field at other distances? From theoretical point of view—yes, as long as this distance remains much larger than characteristic size of the IC. In other words, until the Hertzian dipole approximation can be applied. Therefore, it is enough to tune parameters of the port just once for a certain frequency and then apply them for the EM field computations at wide range of distances.

Figures 9(a)–9(c) show measured and computed distributions of maximum amplitudes of the components of the magnetic field with increase of distance from VCO. Radiation in VCO takes place not only from RF output net as it is assumed in our simplest numerical model. This is the most probable reason of some disagreements between measured and computed curves in Figures 9(b)–9(c). Another reason may be related with the fact that converted measured data are less accurate at "far" distances from the board as it was discussed in Section 3.4.

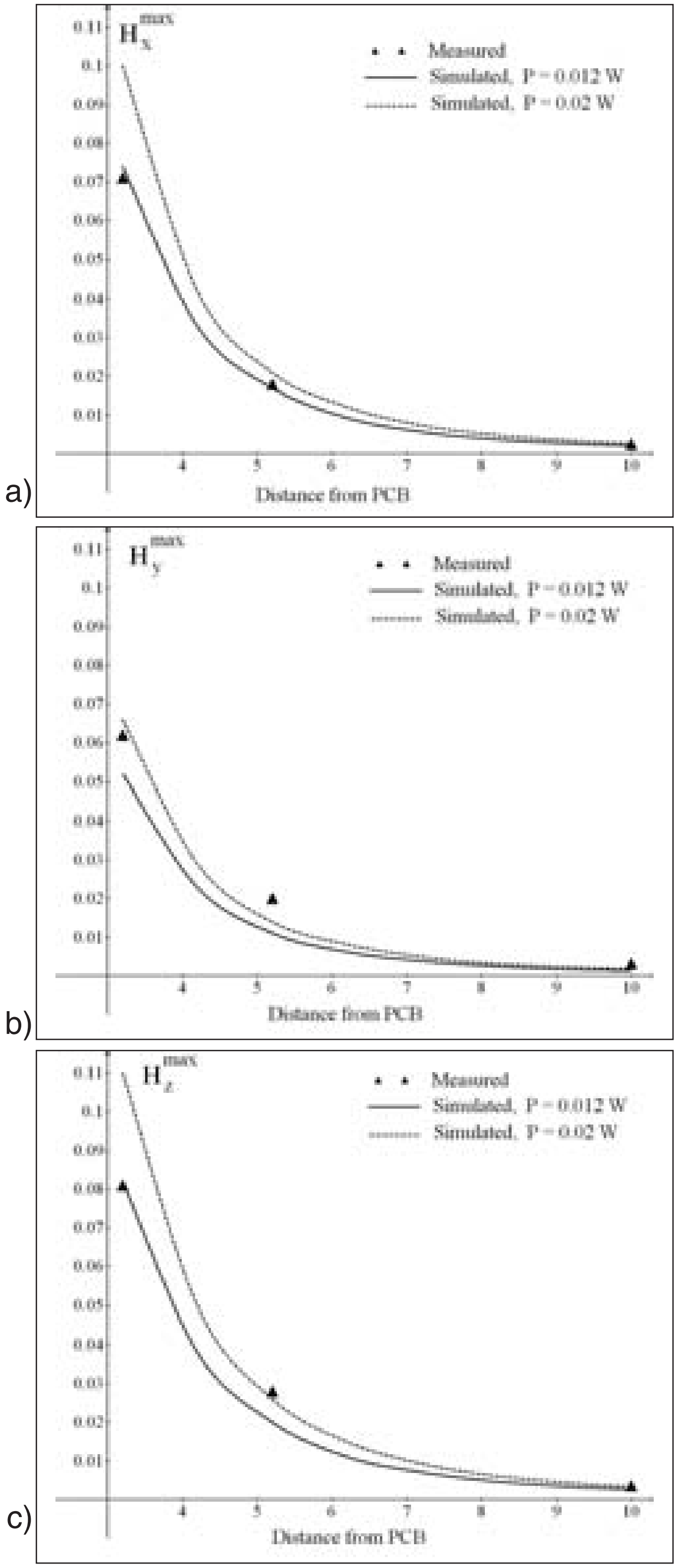

Fig. 9. (a) Maximum amplitude of x-component of the magnetic field as a function of the distance from PCB. (b) Maximum amplitude of y-component of the magnetic field as a function of the distance from PCB. (c) Maximum amplitude of z-component of the magnetic field as a function of the distance from PCB.

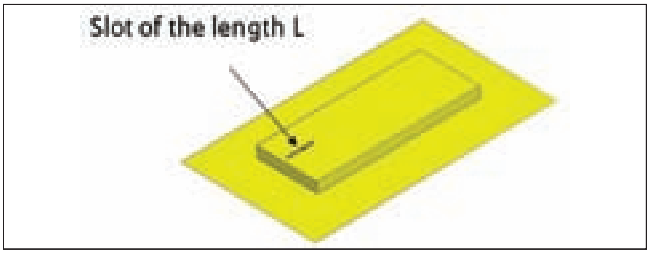

Fig. 10. VCO shield.

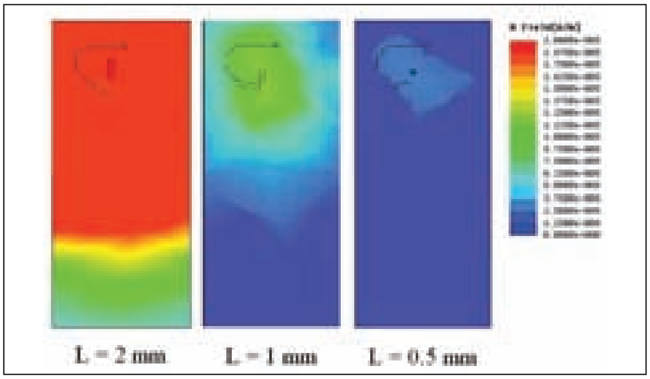

Fig. 11. Magnetic field (magnitude) at 5 mm above the VCO shield.

5. VERIFICATION OF COMPLIANCE WITH INTEROPERABILITY LIMITS BY SIMULATIONS

In practice IC components are supplied by third-party vendors and frequently it is much easier to get results of near field measurements than detailed specifications and models needed for circuit-field co-simulations. In such cases measured data can be used for numerical modeling of EM behavior of the module/device and verification of compliance with interoperability limits.

Consider the following "toy" example to illustrate the methodology. Suppose the cover of the VCO shield has a slot as shown in Figure 10. Let our target be optimization of the length L of the slot: it should be as long as possible, but magnitude of the magnetic field at 5 mm from the top of the VCO should not exceed −90 dBm. Note that this task cannot be achieved by calculation of shielding effectiveness without taking into account EM source characteristics.

Three-dimensional EM field computations have been performed using the port parameters tuned in the previous section. Examples of magnetic field distributions for slots of various lengths are shown in Figure 11. It is easily seen that increase of length from 0.5 mm to 2 mm causes sharp growth of the electromagnetic field emission from the shield. Figure 12 demonstrates maximum magnitude of the magnetic field at 5 mm over the shield as a function of length of the slot. From this figure is follows that interoperability limit will be exceeded for slot longer than 0.9 mm.

Procedures of tuning parameters of the port, verification of compliance with interoperability limit and optimization of design are summarized and shown as the workflow in Figure 13.

CONCLUSIONS

In the present paper a set of two principal methodologies have been described:

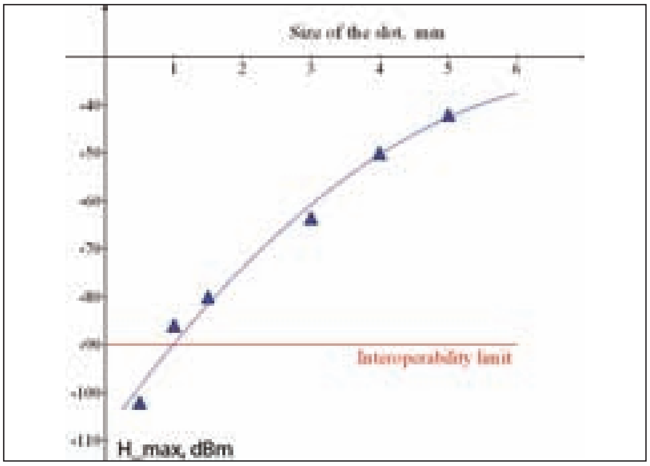

Fig. 12. Maximum magnetic field (magnitude) at 5 mm above VCO shield as function of length of the slot.

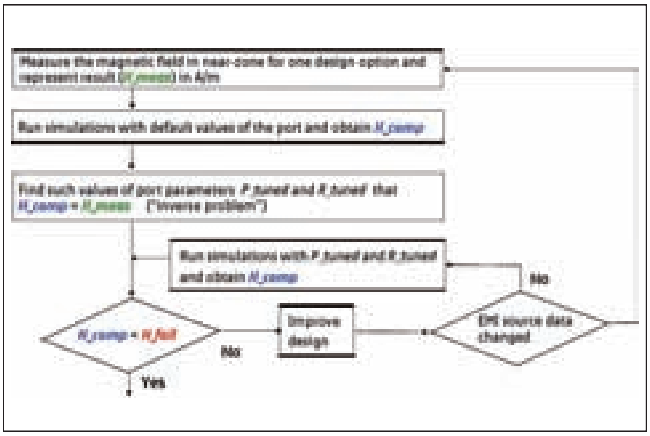

Fig. 13. Proposed workflow to verify compliance with interoperability limits by numerical modeling.

1. Methodology to convert EMC scanner output data (voltage measured in dBm) into absolute values of magnetic fields independent of the measurement conditions and expressed in A/m. This is done using reference PCB that is simple enough to enable accurate numerical modeling. Results of measurement and modeling of reference PCB are used to obtain the calibration factor that is then applied to IC measured data.
2. Methodology to calibrate (tune) EM sources in numerical models using measured data by solving the inverse problem. It enables the simulation of absolute (as opposed to normalized) values of EM field emission without detailed knowledge of the source properties.

Validation of the methodologies is done by:

- Calculation of the calibration factor for different components of H-field at various positions of the probe (to make sure the calibration factor does not depend on the probe position).
- Numerical modeling of reference PCB using various commercial simulation tools.
- Repeating measurements with and without pre-amplifier (different calibration factors), leading to the same absolute values of the magnetic fields

Application of both methodologies to a test problem of emission from a VCO IC is demonstrated. Numerical modeling of the electromagnetic behavior of reference PCB (to obtain calibration coefficients) has been performed neglecting the probe interaction with the field measured. This assumption can be avoided by inclusion of the probe into computational model of the measurement setup and it would be the next step in this work. Numerical results being compared with interoperability limit enable to make verdict "Ok/Not Ok" for various design options of the VCO shield.

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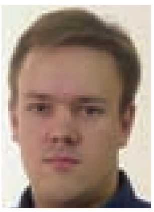
BIOGRAPHIES

Sergey Yuferev *was born in St. Petersburg, Russia, in 1964. He has received the M.Sc. degree in computational fluid mechanics from the St. Petersburg Technical University in 1987 and the Ph.D. degree from the A.F.Ioffe Institute in 1992. From 1987 to 1998, he was with the Dense Plasma Dynamics Laboratory of the A.F.Ioffe Institute. From 1999 to 2000, he was a Visiting Associate Professor of Electrical Engineering at The University of Ohio, in Akron. Since 2000, he has been with Nokia Corp., Finland. His current research interests are in the areas of numerical modeling of electromagnetic fields, EMC/EMI problems of mobile phones, perturbation methods in electromagnetics, and surface impedance concepts.*



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