Electromagnetic PCB Pattern Modeling Techniques for RF Hardware Simulation of Mobile Phones

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***Abstract*— Various different types of PCB pattern modeling methods for new RF co-simulation technique are presented and applied to wireless phone application. PCB electromagnetic (EM) modeling is essential part of new RF combinational simulation - RF components plus PCB 3D pattern concurrently modeled, however, it takes typically few-hours burdensome modeling time. In this paper, several intermediate forms of PCB modeling methods are evaluated in terms of S-parameters and RF specification such as WCDMA adjacent channel leakage ratio (ACLR) and PCB pattern was pick up from actual mobile phone design in 10-layered FR4 PCB stack-up. Compared to full 3D PCB pattern models, divided pattern model shows competitive accuracy within 0.6~2.0dBm ACLR average difference and seems to be worthy to replace full PCB pattern models. Experimental data shows that divided pattern modeling technique requires only about 12% of practical full 3D PCB modeling time.**

***Keywords*— RF, EM, MBM, PCB, ACLR, EVM, STD, WCDMA, PAM, FEM**

I. INTRODUCTION

A RF hardware design is traditionally most critical part of a wireless system. Also a RF hardware design heavily depends on the engineer previous experience and hands-on skills. Moreover, there is a common ground believing that the RF hardware is hard to predict its performance in advance by a exact simulation ahead of prototype measurements. The primary factor to make RF simulation difficult to adopt is insufficient precise models for RF constitutional components. Once reliable models are available, local impedance matching and entire RF system performance could have been analyzed ahead of prototyping.

New wholly combined RF simulation methodology has been addressed recently [1][2]. Basic configuration of RF simulation platform for mobile phone application is shown in Fig. 1. Major two different type of modeling is required to constitute RF hardware. Firstly, PCB pattern models taking into account of via holes and adjacent transmission lines should be modeled by using 3D electromagnetic (EM) solver. Secondly, typical RF components such as power amplifier module (PAM), SAW filters, duplexer should be modeled, too. In this paper, measurement based modeling (MBM) is used to get a precise RF component models and explained in detail in section.2.

Although basic RF system analysis platform has been introduced, few-hours-taking (per pattern) modeling for the simulation are still burdensome to industrial hardware engineers. As an alternative, several different PCB pattern modeling techniques are studied in this paper and reached to time-saving solution with little accuracy sacrifice. Various alternative modeling techniques are compared to actual measurement data and full 3D pattern model in terms of impedance and primary RF specification, adjacent channel leakage ratio (ACLR) for transmission path. Details are in section. 3 and 4.

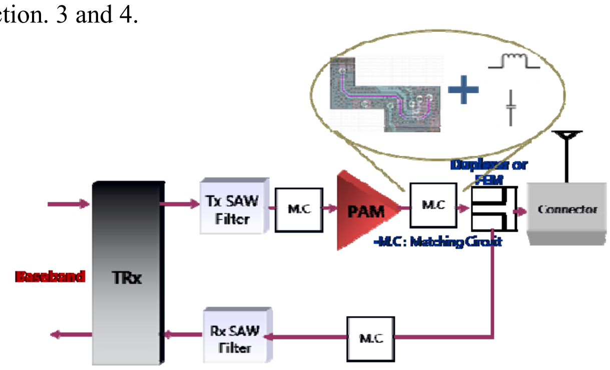

Figure 1. RF configuration of wireless system.

II. RF CO-SIMULATION PLATFORM CONFIGURATION

According to recent device technology, only a few typical components is required to accomplish wireless handset RF design as shown in Fig.1. It consists of PCB patterns, active/passive devices including a power amplifier module (PAM), transceiver IC(s), other RF components and RLC elements.

A. Measurements based Modeling (MBM)

Component models are often available from IC vendors, however, most of those S-parameter models is insufficient in terms of accuracy at interested frequency band for the simulation. So self-measurement method called MBM has been applied to develop RF component models for the RF system simulation.

Fundamental modeling technique[5] is based on Agilent™ using Agilent network analyzer, interface software,

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Connection Manager™ environment. For passive devices such as duplexer and SAW filters, the S2P formatted data are transferred to host computer via GPIB interface. Active device, PAM model is most important but rarely available from chip vendors.

RF device measurement based modeling technique is characterizing RF devices over the frequency and the power to create a simulation model embedded with PCB pattern model. A single set of S-parameters describes the behavior of a circuit at a specific power level. Multiple set of S-parameters measured at different power levels are combined to create a nonlinear device behavioral model for PAM model. The behavioral model is suitable for use in a circuit or system simulation to determine characteristics such as insertion loss, gain compression and phase distortion over operating frequency and/or input power. Characterized device data can be converted from network analyzer to ADS™ P2D format and be used as component library for the combined RF simulation. Typical setting of power sweeping for WCDMA PAM device is -10dBm to 3dBm in 0.1dB step. Power sweep setting for GSM PAM is usually -3dBm to 3dBm in 0.1dB step according to the datasheet.

New modeling methods are still under development to model ideal non-linear power amplifier [6]. Although P2D modeling is most popular way of PAM behavioral modeling in ADS environment, new modeling named polyharmonic distortion (PHD) counting multi harmonic frequency characteristics is under development [7]. The simple configuration of PAM modeling is shown in Fig.2.

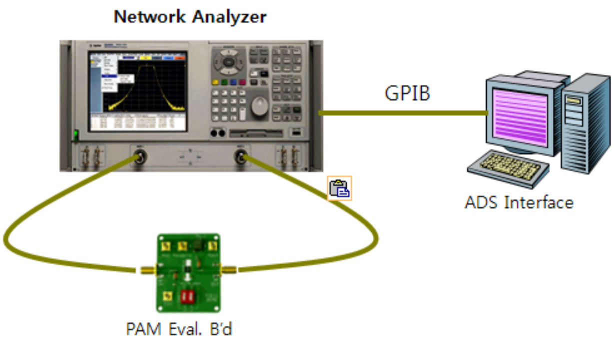


Figure 2. PAM modeling configuration.

B. PCB 3D EM Modeling [3][4]

EM simulation refers to the process of obtaining solutions for a specific problem by numerically solving Maxwell equations under given boundary condition. The RF part of PCB layout is taken out of the whole phone CAD. Mostly, the RF layout should be partitioned into several pieces in order to reduce EM modeling time. Although the 2D or 2.5D modeling had been considered due to burdensome modeling time in this paper, full 3D modeling was finally chosen because accuracy is the primary factor of simulation representing RF performance closed to measurements. In Fig.3, an example of RF area cut and partitioned pattern are shown.

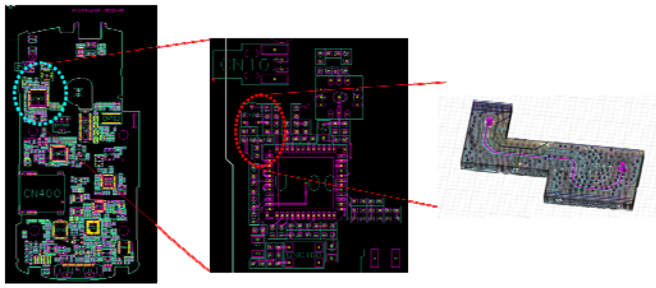


Figure 3. Different types of PCB pattern modeling methods.

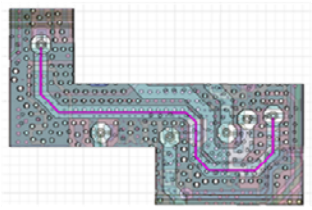
III. ALTERNATIVE PCB PATTERN MODELING TECHNIQUES

To alleviate time-consuming PCB EM modeling, several different RF PCB pattern modeling approach has been addressed. Figuring out which is most economic solution of below different modeling approaches with model accuracy and modeling time trade-off is main objective. Four modeling types are graphically exposed in Fig.4 starting from

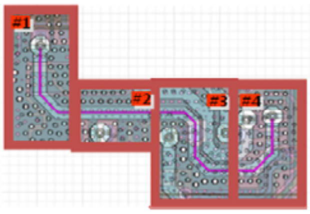
1) Full 3D model
2) Divided 3D model
3) Segmented physical library model
4) ADS built-in library model

Fig.4(a), full 3D modeling takes longest simulation time, but most accurate. In this paper, actual RF PCB pattern in the typical 10^{th} layered FR4 stack-up was taken with neighboring ground vias and other signal patterns. Fig.4(b) is divided actual PCB pattern with de-embedding which shows lower accuracy but faster modeling time as exposed in fig.5. Number of divide is in inverse proportional to the modeling time. Modeling time was measured at HFSS™, HP xw8400 64-bit computing environment.

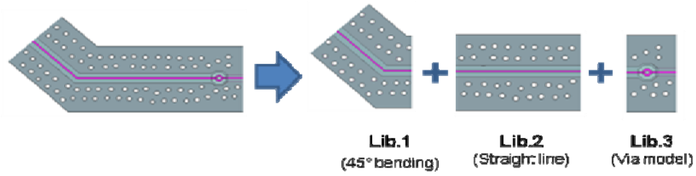
Left side of fig.4(c) is puzzle-like segmented 3D EM models and similar to divided EM models. But this conceptual modeling technique is devised for building up massive PCB pattern library in advance and making real pattern modeling unnecessary. Once three categorized pattern library – straight transmission line model, via model, bended transmission line model – are ready and trustful, zero modeling time could be achieved. Lastly, fig.4(d) is ADS built-in library. By entering stack-up and pattern information such as width and length, substituent library would works.



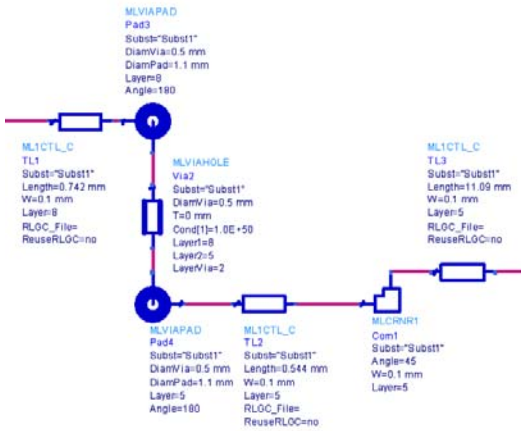
(a) Full pattern



(b) Divided pattern (4 pieces)



(c) Segmented physical pattern library

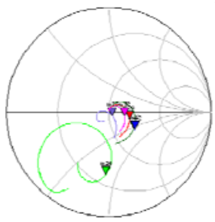


(d) ADS™ built-in library example

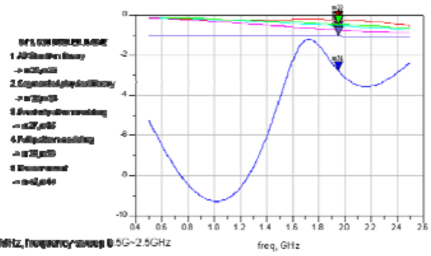
Figure 4. Different types of PCB pattern modeling.

IV. Simulation vs. Measurement

To evaluate different type of modeling techniques, full path RF circuit modeling similar to fig.1 has been done. Three PCB pattern models and RF component models including MBM PAM model are combined to do the co-simulation. Three PCB patterns based on 10-layered stack-up are the ones – pattern #1 from antenna connector to FEM, #2 from FEM to duplexer and #3 from SAW filter to transceiver, respectively. Most of RF device models including PAM are regenerated by MBM technique due to that vendor model mostly has not considered de-embedding.



(a) S11



(b) S21

Figure 5. S11 and S21 for pattern #3.

Fig.4(b) is pattern #3 divided by 4. Finalized divided number for 3 PCB pattern in this experiment are 7, 5, 2 for pattern #.1, 2, 3 each and the number depends on mostly length of patterns.

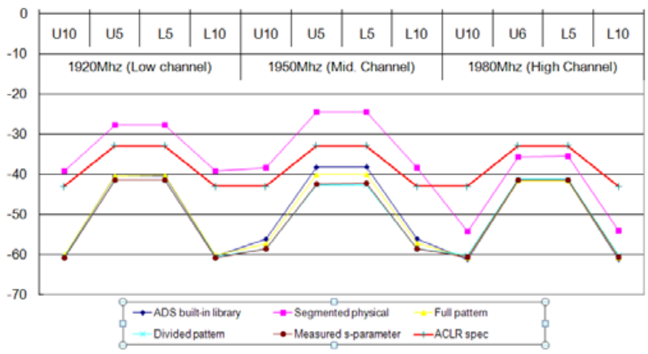


Figure 6. WCDMA ACLR comparison.

Furthermore, most typical RF specification, ACLR graph in the range of full WCDMA band at upper and lower offsets (±5, ±10MHz) indicates that ACLR values of segmented physical library is out of specification and segmented physical library modeling technique is no more to be considered. ADS built-in library seems to be effective for replacing actual full models, however, average difference of S11 value has some distance from divided 3D model and measurement data compared to full 3D model as shown in table.1. The values in the table were calculated by eq. (1).

In table.2, ACLR data are compared between the cases by using full pattern model, divided pattern model and measurement data. ACLR values using divided pattern modeling technique seems to be very competitive with measurement data and close enough to full 3D modeling value. The average difference data are calculated by eq.(2). N is the number of divided patterns.

Table 1. Average ACLR difference of divided pattern modeling and measured data from full pattern modeling

	Divided pattern modeling	**Measured data**
Average difference	-0.675	-0.775
Minimum difference	-2.5	-2.2
Maximum difference	0.6	0.3

Table 2. ACLR difference from full pattern modeling accuracy.

Modeling techniques	**∑ΔS11rms**
ADS built-in library modeling	+26.6
Divided pattern modeling	-17.9
Measured s-parameter modeling	-18.4

$$\Sigma\Delta S11_{rms} = \sum_{1}^{N}\left(\sqrt{S11_{real-term}{}^{2} + S11_{condugate\text{-}term}{}^{2}}\Big|_{full3D} - \sqrt{S11_{real-term}{}^{2} + S11_{condugate\text{-}term}{}^{2}}\right) \quad (1)$$

$$ACLR_{AVG-DIFF} = \sum_{1}^{N}\left(ACLR\big|_{full3D} - ACLR\right)/N \quad (2)$$

Experimental modeling time for full pattern modeling and divided pattern modeling is shown in table.3. Pattern modeling time decreases rapidly when bigger number of divide is selected.

Table 3. Each pattern modeling and full path modeling time

	Full pattern modeling [hour:min.]	**Divided pattern modeling [hour:min.], [divide number]**		**Simulation time reduction rate, max.**
Pattern2	**10:34**	**2:03**	**1:14**	**88.3%**
		3	**5**	
Pattern3	**8:48**	**1:42**	**1:07**	**87.3%**
		4	**7**	

V. CONCLUSION

Various different types of PCB pattern modeling methods for new RF co-simulation technique are presented and applied to wireless phone application. PCB modeling time saving activity is essentially required especially for wireless handset development. As an intermediate technique, the divided pattern modeling shows considerable modeling time saving without sacrificing accuracy. Almost 10 times faster PCB EM modeling can be achieved by proposed divided pattern modeling technique. Optimized size of divided pattern and number of divide would be researched in near future.

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