Product Sensitivity Analysis on Multithrow TX/RX Switches

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Abstract

A method for data alignment of device characteristics as measured on Process Control Monitors (PCM) with the circuit level performance of adjacent multithrow switch circuits has been developed. This technique provides a powerful method for correlating extrinsic and intrinsic device characteristics with circuit performance. This method provides a valuable tool that is being used to improve device modeling, device development and production yields.

INTRODUCTION

The 2G/3G generations of communication systems including GSM/W-CDMA require components with the challenging combination of high linearity, low distortion, and low losses. A key component in this type of system is a multithrow TX/RX multithrow switch, which transmits high power from a front end module (FEM) in the TX mode and is switched to lower transmission power reception going to filters and linear power amplifiers (LNA) in the RX mode. In the transmit mode, the most important and challenging parameter is low harmonic generation under VSWR conditions. Typically for an input power level of 35 dBm and VSWR of 5:1 from the antenna, the harmonics generated should be below -30 dBm. The WCDMA mode input power is usually relatively low (28 dBm), but has a very challenging linearity requirement associated with the blocker performance and is expressed in Intermodulation distortion products (IMD) [1].

The dominant technology presently used for these multithrow TX/RX switches is GaAs pHEMT. This technology offers excellent power handling capability, but achieving the linearity performance and low harmonic generation remains challenging. One of the first steps needed to address this challenge is to increase the understanding of which extrinsic and intrinsic device characteristics can be correlated to linearity and/or low harmonic generation of multithrow switches. In this paper, a method for aligning and correlating extrinsic and intrinsic device characteristics that are measured on process control monitors with adjacent RF onwafer measured circuit performance is presented. The correlation of the 3rd harmonics of a single pole seven throw (SP7T) switch with extrinsic and intrinsic device characteristics measured on PCM's will be used to demonstrate this powerful technique.

PROCESS CONTROL MONITOR TESTING

Process control monitor structures are included on all production wafers at Skyworks. The PCM structures are designed to be easily autoprobed, and to provide both extrinsic and intrinsic device level data. The extrinsic device characteristics that are measured on PCM's include standard DC type parameters such as; saturated drain source current (Idss), maximum drain source current (Imax), pinch-off voltage (Vp), on-state resistance (Ron), transconductance (Gm), gate leakage currents (Ig), off-state drain leakage current (Ioff), device ideality (Nif), built-in voltage (Vbi) and breakdown voltages (Vb). The intrinsic data is measured at small signal and extracted using a proprietary methodology. These extracted intrinsic parameters include standard linear and saturated resistances, capacitances, and dispersion characteristics.

RF ONWAFER CIRCUIT TESTING

Extensive RF onwafer testing is performed on production pHEMT switch wafers. The circuit and I/O pad geometries are designed to be easily autoprobed. The test stand and probe cards are designed to minimize the effects of impedance on these measurements. Standard production onwafer test includes measuring; insertion loss, leakage, isolation, 2nd harmonics, 3rd harmonics and intermodulation distortion.

PRODUCT SENSITIVITY ANALYSIS METHOD

A product sensitivity analysis (PSA) [2] was performed on a single pole, seven throw multi-mode TX/RX switch. The focus of the analysis was to gain insight into the device level characteristics that are involved with the generation of 3^{rd} harmonics on this product. The PSA was performed on an engineering lot that was fabricated using a process that was slightly modified to provide wafers with varying intrinsic device characteristics.

The product sensitivity analysis technique was used to align the autoprobed PCM data with immediately adjacent onwafer test data as depicted by the wafer map in Figure 1. The dark red colored devices in Figure 1 are PCM's, while the lighter blue colored devices are circuits in a zone immediately surrounding each PCM. The mean and/or median value for the onwafer circuit test data from each zone were calculated then aligned to the PCM data from that site.

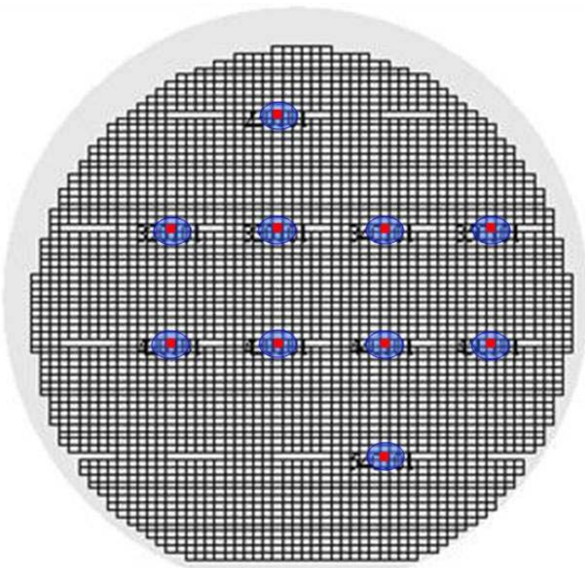


Figure 1 Product Sensitivity Analysis Wafer Map

A sample of the results of PSA data alignment is shown in Table 1. This method provides a direct site specific alignment of PCM test data with onwafer circuit test data. The format of the resultant data set supports most available statistical analysis techniques.

TABLE 1
PRODUCT SENSITIVITY ANALYSIS DATA ALIGNMENT SAMPLE

lot_id	wf_id	site	RFPCM Idss-CS	RFPCM Cg2	RFPCM Vbgd3-Se3G	Onwafer q2-2Harm	Onwafer q2-3Harm
3357553	13607422	320101	147.5	1077.5	29.0	88.8	82.5
3357553	13607422	450101	144.0	1070.2	29.0	89.9	82.1
3357553	13607422	540101	147.2	1090.9	29.1	88.2	80.9
3357553	13607423	230101	145.3	1161.8	29.1	87.4	80.8
3357553	13607423	350101	144.6	1169.7	28.9	88.3	81.2
3357553	13607423	450101	148.4	1143.4	28.5	88.2	80.5

PRODUCT SENSITIVITY ANALYSIS RESULTS

A statistical analysis of the PSA data from the engineering lot with slightly varying intrinsic device characteristics was performed. An iterative multiple linear regression analysis was performed on this dataset. The results of this analysis indicated that 85% of the variation in 3rd harmonics could be explained using five PCM parameters. The five PCM parameters used are Idss, Vp1, Nif, Id6, and DifGm. The Nif parameter is the device ideality, while Id6 is a drain leakage current. DifGm specifies the percentage difference between RF_Gm and DC_Gm [3].

The analysis that was performed was a full factorial to the 2nd degree. It included variables to assess the effect on 3rd harmonics of interactions between the PCM parameters. Only two factor interactions were assessed in this analysis. The multiple regression analysis generates a multilinear equation that models the 3rd harmonics of this dataset using these 5 PCM parameters and the two factor PCM parametric interactions. The multilinear equation with interactions takes the form of:

$$3Harm = b_0 + b_n P_n + b_n I_n \quad \textbf{(1)}$$

Where b_0 is the Y intercept, b_n are the coefficients, P_n are the PCM parametric values and I_n are the parametric interaction cross products. To eliminate the effect of units of measure on the coefficients, the values of P_n and I_n are scaled to have a mean value of zero and a range of two.

The normalized actual 3rd harmonics versus the 3rd harmonics predicted from the modeled multilinear equation is shown in Figure 2. The Rsquare value of 0.85 shows a reasonably good correlation between the measured and predicted 3rd harmonics. The P value of less than 0.0001 indicates a low probability that this relationship is due to random chance.

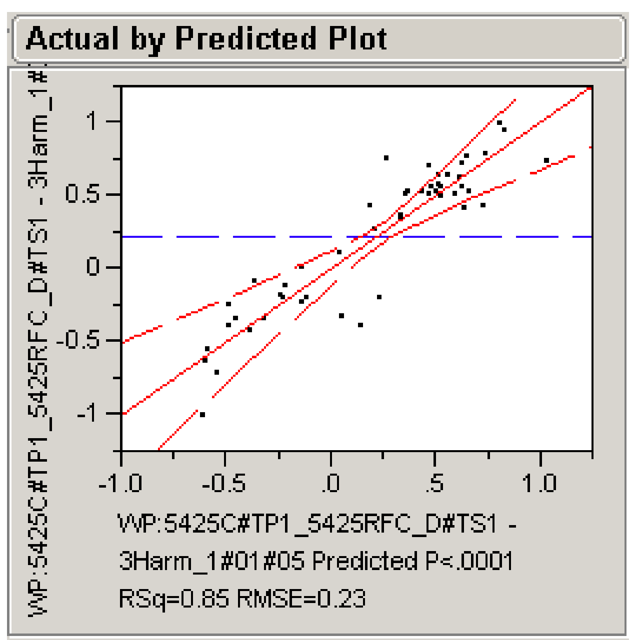
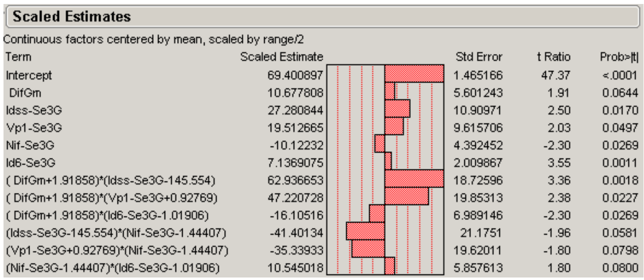


Figure 2 Normalized actual versus predicted 3rd Harmonics of SP7T TX/RX Switch

Since the parametric and interaction values are scaled, the relative weighting of the effects of each parameter or interactions between parameters on 3rd harmonics can be determined by looking at the absolute value of the coefficients used in the multilinear equation. The scaled estimates of the effects of each PCM parameter, and two factor PCM interactions on the 3rd harmonics of this circuit are shown in figure 3.



Scaled Estimates

Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	69.400897	1.465166	47.37	<.0001
DifGm	10.677808	5.601243	1.91	0.0644
Idss-Se3G	27.280844	10.90971	2.50	0.0170
Vp1-Se3G	19.512665	9.615706	2.03	0.0497
Nif-Se3G	-10.12232	4.392452	-2.30	0.0269
Id6-Se3G	7.1369075	2.009867	3.55	0.0011
(DifGm+1.91858)*(Idss-Se3G-145.554)	62.936653	18.72596	3.36	0.0018
(DifGm+1.91858)*(Vp1-Se3G+0.92769)	47.220728	19.85313	2.38	0.0227
(DifGm+1.91858)*(Id6-Se3G-1.01906)	-16.10516	6.989146	-2.30	0.0269
(Idss-Se3G-145.554)*(Nif-Se3G-1.44407)	-41.40134	21.1751	-1.96	0.0581
(Vp1-Se3G+0.92769)*(Nif-Se3G-1.44407)	-35.33933	19.62011	-1.80	0.0798
(Nif-Se3G-1.44407)*(Id6-Se3G-1.01906)	10.545018	5.857613	1.80	0.0800

Figure 3 Scaled estimates of SP7T circuit 3rd harmonics to PCM parameters

The results of the scaled estimates from this PSA indicate that the interaction of DifGm with Idss has the largest effect on 3rd harmonics. The interaction of DifGm with Vp1 has the second largest effect on the 3rd harmonics of this circuit. It should be noted that Idss, Vp1 or DifGm by themselves are significantly less important than the interactions between these parameters.

As the name suggests, one of the typical uses for PCM testing is to monitor the control of the fabrication process. Historically, DC type PCM measurements were considered the most critical to TX/RX switch performance. This PSA highlighted the need to decrease the variability, and improve the control of DifGm on multithrow TX/RX switch products that require low harmonic generation under VSWR conditions.

In the specific case of the SP7T switch, further refinements of methods to control the level and variability of DifGm were implemented. This resulted in a 43% reduction in the number of devices that fail at RF onwafer test on this product.

CONCLUSIONS

A method for the alignment of device level characteristics as measured on process control monitors with the circuit level performance of adjacent multithrow circuits has been developed and implemented. This technique provides a powerful method for correlating extrinsic and intrinsic device level characteristics with circuit performance. This technique is being used to improve our understanding of which device level characteristics are correlated to linearity and low harmonic generation. This increased understanding is being used to improve device modeling, device development and production yields.

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[2] Product Sensitivity Analysis (PSA) module is part of the *data*POWER® application from PDF Solutions, Inc.

[3] C.-J. Wei, A. Klimashov, Y. Zhu, E. Lawrence, G. Tkachenko "Large-Signal PHEMT Switch Model, Which Accurately Predicts Harmonics and Two Tone Intermodulation Distortion" 2005 IEEE MTT-S International Microwave Symposium Digest, pp. 1155-1158

ACRONYMS

pHEMT: Pseudomorphic High Electron Mobility Transistor
GSM: Global System for Mobile communication
W-CDMA: Wideband Code Division Multiple Access
PCM: Process Control Monitors
IMD: Intermodulation Distortion
SP7T: Single Pole Seven Throw Switch
PSA: Product Sensitivity Analysis
FEM: Front End Module
VSWR: Voltage Standing Wave Ratio