Large signal models validation at circuit and device level by defining different metrics

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I. INTRODUCTION

Large-signal (LS) empirical models

✓Used at circuit & device levels, useful in MMICs desing. Many models proposed: analytical, table based…

✓Difficult to determine the best model for a circuit or device, and a given application. Different behaviour has to be predicted and, as a consequence, different figures of merit can be of relevance depending on the applications.

This Work:

✓Metrics to validate/compare LS models investigated.

✓Metrics validity studied comparing – static & dynamic-predicted and measured performance in the case of a **LDMOS PA** and different transistors (**HBT**, NMOS).

✓Joint effort within the NoE TARGET.

II. METRICS

DC

M1_DC =	$\frac{1}{N}\sum_{N}\left\lvert I_{C,measured} - I_{C,simulated}\right\rvert$
M2_DC =	$\frac{1}{N}\sqrt{\sum_{N}\frac{\left(I_{C,measured} - I_{C,simulated}\right)^2}{I_{C,measured}^{\,2}}}$
M3_DC =	$\sqrt{\frac{\sum_{N}\left(I_{C,measured} - I_{C,simulated}\right)^2}{\sum_{N} I_{C,measured}^{\,2}}}$
M4_DC =	$\frac{\sum_{N}\left\lvert I_{C,measured} - I_{C,simulated}\right\rvert}{\sum_{N}\left\lvert I_{C,measured}\right\rvert}$

N: no. bias points

Small-Signal

M1_SP$_{xy}$ =	$\sqrt{\frac{\sum_{M}\sum_{N}\left\lvert S_{xy}^{measured} - S_{xy}^{simulated}\right\rvert^2}{\sum_{M}\sum_{N}\left\lvert S_{xy}^{measured}\right\rvert^2}}$
M2_SP =	$\sqrt{\frac{\sum_{M}\sum_{N}\left(G_{Tu,measured}^{Max} - G_{Tu,simulated}^{Max}\right)^2}{\sum_{M}\sum_{N} G_{Tu,measured}^{Max\;2}}}$
M3_SP =	$\sqrt{\frac{\sum_{M}\sum_{N}\left(K_{measured} - K_{simulated}\right)^2}{\sum_{M}\sum_{N} K_{measured}^2}}$

N: no. bias points, M: no. frequency points

Large-Signal

M1_LS =	$\sqrt{\frac{\sum_{M}\sum_{N}\sum_{f_1}^{H}\left\lvert Pout^{meas} - Pout^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\sum_{f_1}^{H}\left\lvert Pout^{meas}\right\rvert^2}}$
M1_LS_W =	$\sqrt{\frac{\sum_{M}\sum_{N}\sum_{f_1}^{H}\frac{\left\lvert Pout^{meas}\right\rvert}{\max\left\lvert Pout^{meas}\right\rvert}\left\lvert Pout^{meas} - Pout^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\sum_{f_1}^{H}\left\lvert Pout^{meas}\right\rvert^2}}$
M2_LS =	$\sqrt{\frac{\sum_{M}\sum_{N}\left\lvert I_D^{meas} - I_D^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\left\lvert I_D^{meas}\right\rvert^2}}$
M3_LS =	$\sqrt{\frac{\sum_{M}\sum_{N}\left\lvert Gain^{meas} - Gain^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\left\lvert Gain^{meas}\right\rvert^2}}$
M4_LS =	$\sqrt{\frac{\sum_{M}\sum_{N}\left\lvert PAE^{meas} - PAE^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\left\lvert PAE^{meas}\right\rvert^2}}$
M4_LS_W =	$\sqrt{\frac{\sum_{M}\sum_{N}\frac{\left\lvert PAE^{meas}\right\rvert}{\max\left\lvert PAE_n^{meas}\right\rvert}\left\lvert PAE^{meas} - PAE^{sim}\right\rvert^2}{\sum_{M}\sum_{N}\left\lvert PAE^{meas}\right\rvert^2}}$

H: no. harmonics, N: no. bias points, M: no. input power levels

Most convenient the use of normalized metrics

III. LS MODEL VALIDATION & METRICS EVAL

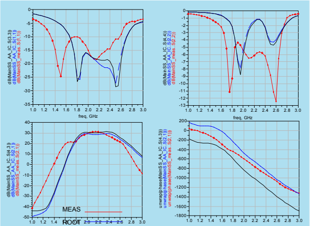
A.Circuit Level Evaluation: RF **LDMOS PA** for W-CDMA base station applications (MW4IC2230, Motorola & Freescale Semic.). LS models: **MET** & **ROOT**

	Static I/V	S-Parameters	LS-Parameters
VDS	28 V	28 V	28 V
IDS	60/250/300mA	60/250/300mA	60/250/300mA
Freq	-	1-3 GHz step 200 MHz	2.14 GHz
Pin	-	-	[-14,16]dBm step 2 dBm

Measurements by Freescale

DC & S-parameters

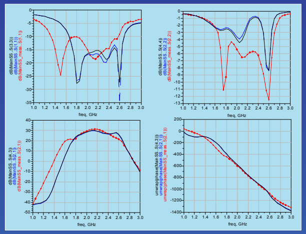
Non-accurate textfixture model



	Measured	Root	MET
ID 1st Stage	60 mA	59.68 mA	72 mA
ID 2nd Stage	250 mA	250.1 mA	377 mA
ID 3rd Stage	300 mA	299.6 mA	310 mA

	Root	MET
M1_SP11	1.654	1.660
M1_SP12	1.006	1.008
M1_SP21	1.538	1.694
M1_SP22	1.036	1.025
M2_SP	0.931	1.590
M3_SP	1.581	1.051

Accurate textfixture model

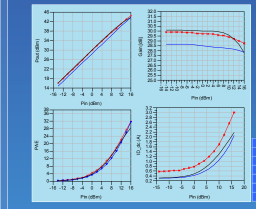


	Measured	Root	MET
ID 1st Stage	60 mA	60.2 mA	62.32 mA
ID 2nd Stage	250 mA	251.4 mA	260.8 mA
ID 3rd Stage	300 mA	300.3 mA	307.4 mA

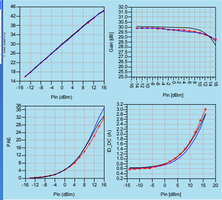
	Root	MET
M1_SP11	1.279	1.263
M1_SP12	0.696	0.681
M1_SP21	0.396	0.414
M1_SP22	1.305	1.304
M2_SP	0.893	0.836
M3_SP	0.961	0.935

Single-tone LS excitation

Non-accurate



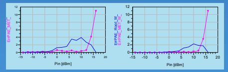
Accurate textfixture model



	Root	MET
M1_LS	0.03	0.067
M1_LS_W	0.023	0.058
M2_LS	0.095	0.049
M3_LS	0.014	0.056
M4_LS	0.158	0.082
M4_LS_W	0.143	0.066

MEAS
ROOT
MET

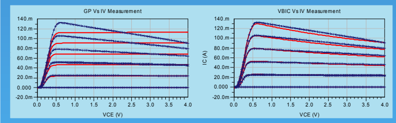
	Root	MET
M1_LS	0.171	0.12
M1_LS_W	0.144	0.115
M2_LS	0.11259	0.11254
M3_LS	0.241	0.071
M4_LS	0.083	0.078
M4_LS_W	0.056	0.072



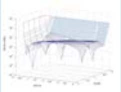
Metrics show model behaviour: better model accuracy lower values. Weighted metrics, M1_LS_W, M4_LS_W, less influenced by errors at low input power levels.

B. **Devic Level Evaluation:**

A. HBT: LS models: VBIC & Gummel-Poon



HBT	GP	VBIC
M1_DC	4.1 m	1.5 m
M2_DC	197.5 m	198.6 m
M3_DC	95 m	32.9 m
M4_DC	75.6 m	26.7 m



M3_DC more suitable: normalized, sensitive, not so influenced by big errors at low currents.

S-parameters

	All Frequencies	4-8 GHz	8-12 GHz	f_1=2GHz 10 Harm
All Bias Points	A	B	C	/
A Class	D			

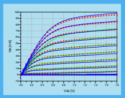
	M1_SP$_{xy}$ (GP)		M1_SP$_{xy}$ (VBIC)		Best Performance$_{xy}$	
A	0.201	0.350	0.128	0.287	VBIC	VBIC
	0.336	0.519	0.214	0.418	VBIC	VBIC
B	0.184	0.266	0.09	0.204	VBIC	VBIC
	0.301	0.508	0.184	0.368	VBIC	VBIC
C	0.151	0.387	0.110	0.331	VBIC	VBIC
	0.354	0.549	0.253	0.453	VBIC	VBIC
D	0.115	0.500	0.131	0.578	GP	GP
	0.298	0.482	0.238	0.446	VBIC	VBIC

	M2_SP (GP)	M2_SP (VBIC)	Best Performance
A	0.561	0.534	VBIC
B	0.557	0.379	VBIC
C	0.543	0.376	VBIC
D	0.523	0.502	VBIC

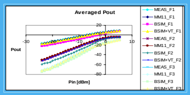
	M3_SP (GP)	M3_SP (VBIC)	Best Performance
A	0.653	0.929	GP
B	0.700	0.486	VBIC
C	0.612	0.680	GP
D	0.772	1.126	GP

All AC metrics behave accordingly to model accuracy for each meas. set. But difficult to determine the best model. AC metrics open question.

A. NMOS: LS models: BSIM3v3 & MM11



meas.: red, MM11: blue, BSIM3v3: green



Power averaged over bias points

	NMOS MM11 Model	NMOS BSIM3 Model
M1_LS	166m	236
M2_LS	51m	348m
M3_LS	149m	821m
M4_LS	126m	570m
M1_LS_W	2.7m	5.7m
M4_LS_W	17m	78m

Metrics in general in accordance to the fact that MM11 model behaves better then the BSIM3.

IV. Conclusions

We have validated and compared LS models for devices and circuits. We studied different metrics in order to compare the accuracy of those models. Normalized metrics are more appropriate for such comparison. In the case of DC validation, metrics M3_DC & M4_DC are the more suitable. In the case of small-signal AC metrics, still more work is required. Large signal metrics show consistency with model behaviour and they seem to point out in the right direccion.

V. Acknowledgments

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VI. References

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