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Public report on the developed adapting practices with benchmark results in Task 2.2 Adaptivity in Harmonic Balance

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Overview of Task 2.2

The objective of Task 2.2 is the development of sophisticated diagnostic tools and adaptivity techniques to increase performance of the standard Harmonic Balance (HB) algorithm in APLAC and TITAN circuit simulators of AWR-APLAC Corporation and Infineon Technologies AG, respectively. The specific tasks to achieve these are presented in this document

Equation adaptivity

The adaptivity in HB equations is desired because it enables more fundamental changes in the HB algorithm than what can be achieved by just fine-tuning the algorithm parameters like maximum iteration counts or Krylov-subspace size.

By adaptivity in HB equations we mean the ability to select the frequencies that are taken into account when HB analysis is performed. The equations are not changed or reformulated if we look at a frequency that is taken into account in the analysis, i.e., a contribution of an element, say voltage-controlled current source, into the overall equations at a single frequency remains the same.

The equation adaptivity was utilized e.g. to determine when the HB solution is accurate enough in terms of comparing the difference of the fundamental signal magnitude to the last harmonic magnitude. As can be seen from Figures 1 and 2, the ability to detect insufficient number of harmonics improves the result reliability.

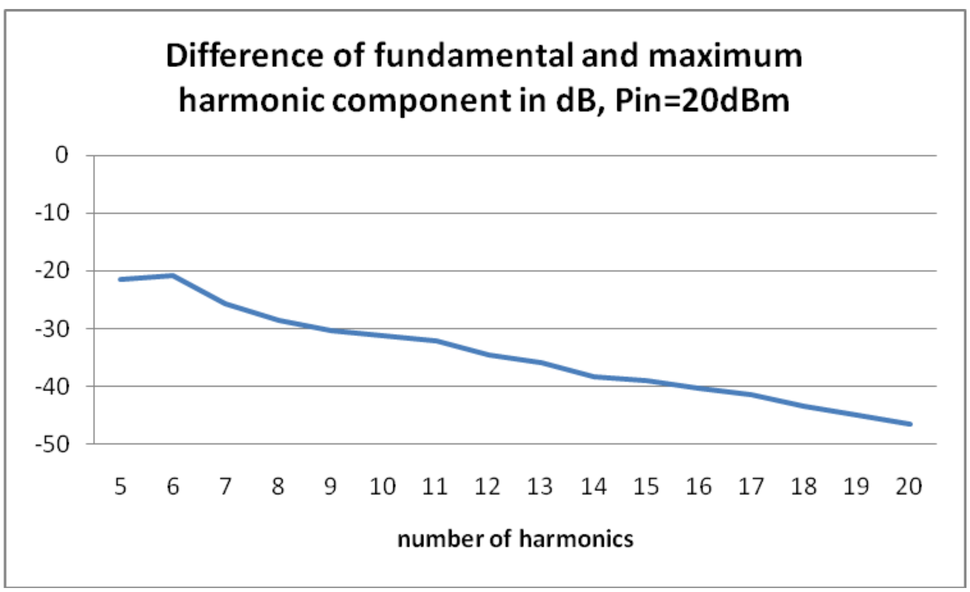

Figure 1. The difference between the fundamental component and the maximum harmonic component in the amplifier output with an input power of 20 dBm.

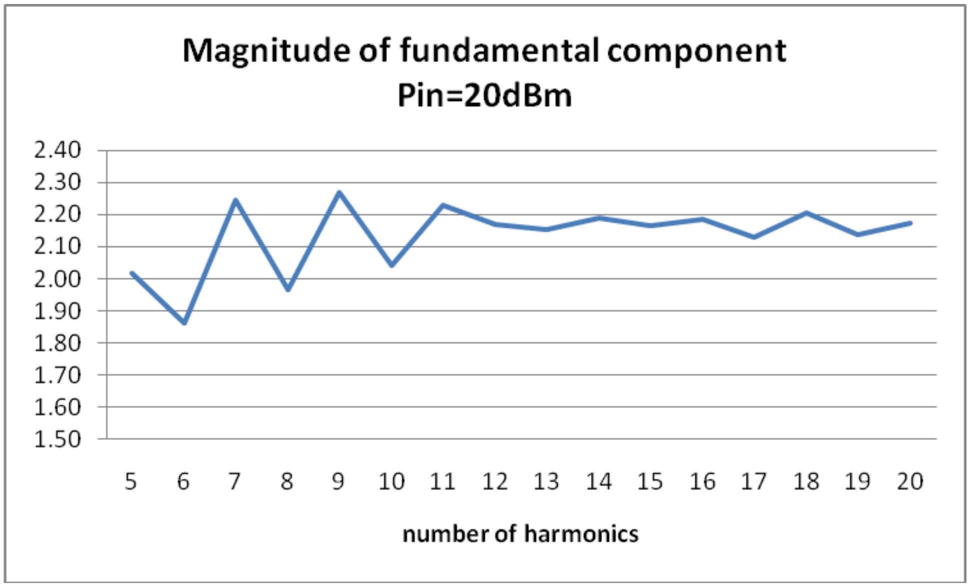

Figure 2. The fundamental component magnitude in the amplifier output with an input power of 20 dBm.

Adaptivity was also developed for the preconditioning part in the iterative HB analysis. The algorithm is able to detect growth in iteration count caused by growth in the nonlinearity due to increased input power. The preconditioning algorithm can be changed to a more computationally expensive method and decrease the simulation time by decreasing the iteration count. Example of this for an amplifier power sweep is shown in Figure 3.

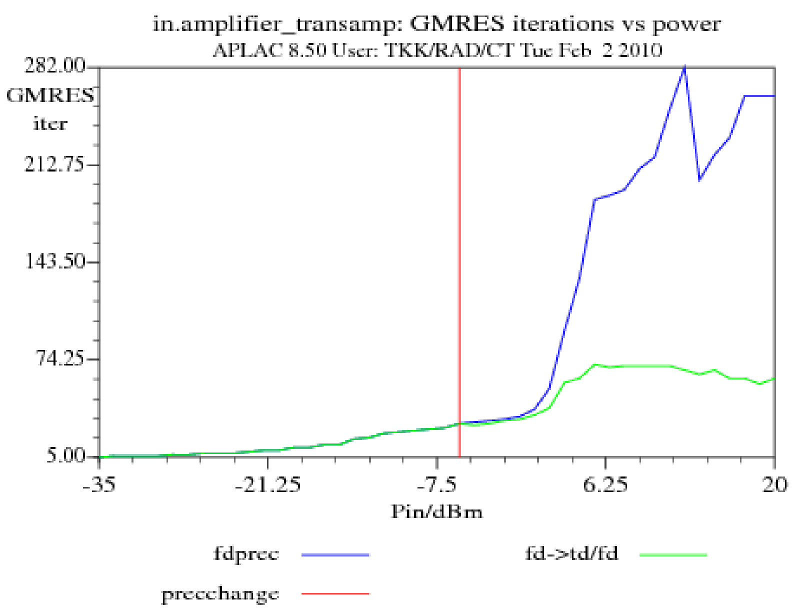

Figure 3. Number of GMRES iterations required for successful analysis as a function of power level.

Initial guess

For N-tone analysis a new initial guess method was developed to speed up the first point of the analysis. The method utilizes the frequency adaptivity as follows

1. Find the dominant excitation frequency f_x, i.e., the frequency of the source with the highest power
2. Form HB equations for single tone analysis, $FC=f_x$
3. Solve the 1-tone problem and use the result as an initial guess for N-tone analysis

The method is typically a lot faster than traditional purely DC-based initial guess. The results for a QPSK circuit are presented below.

Initial guess	DC [s]	1-tone HB [s]	2-tone HB [s]	TOT CPU time [s]
Old	0.7	-	9.2	9.9
New	0.7	0.7	4.1	5.5

HB diagnostic tool

HB diagnostic tools have been implemented in APLAC and TITAN simulators. The purpose of these tools is to give more detailed information on HB analysis enabling changes in the way the analysis is performed. The diagnostic tool is meant to be used both as a post processing tool as well as for detection of convergence problems during the simulation. Therefore it serves both the users and the HB algorithm. Usually this data could be manually generated but it would require inside knowledge about the algorithm and simulator reporting system. Some of the needed information is not generally available and even though it were, it would be very time consuming task to collect the data and post process it. Therefore that type of information is not collected or produced by designers at all.

The APLAC diagnostic tool addresses the HB analyzer state and provides information related to the algorithm metrics, such as iteration counts and convergence aids used. It also has information about the circuit linear and nonlinear element counts. The tool has already been used in adaptive algorithms, where the number of iterations is monitored for each HB analysis performed. If the increase in iterations required goes over certain limit, the HB analysis preconditioner is changed to a more robust and computationally expensive one. This is typical in power sweeps, where the higher power levels cause compression and spectral regrowth.

The HB diagnostic tool in TITAN addresses mostly a user-side of HB diagnostics. Depending on a requested level of verbosity, the information on the violators preventing the HB convergence is output, assisting a user in tracing possible causes of the simulation failure due to the suboptimal design or modeling error. Even while under development, the HB diagnostic tools have already been successfully used to trace down the cause of HB convergence problems observed in 65 nanometers and smaller technologies. Furthermore, the HB diagnostics in TITAN is now able to detect possible zero solution in oscillator analysis, to detect a poor initial guess in the line-search Newton solver as well as to indicate an ill-conditioning of the linear solver. After the completion of the development and validation phase, the user-friendly HB diagnostic tool will be made available to TITAN users worldwide.

Conclusions

Harmonic Balance adaptivity was improved in several different ways. The authors worked with the APLAC Simulator and the TITAN solver and added new algorithms that are able to adapt to the simulation task and perform changes that increase the robustness and speed of the simulations.

Both simulators added diagnostic tool which can be used to give new information about HB analysis internal operation. The diagnostic tools are able to find problems in the circuit topology (floating nodes), solution accuracy (trivial solution in oscillators) as well as monitor e.g. the analysis time and iteration counts for every analysis performed.

A new Harmonic Balance formulation was developed, where the number of analysis frequencies can be altered during the analysis. The ability is used in the methods developed for finding a HB solution with good accuracy by increasing the number of harmonic components and monitoring the change in HB spectrum either locally or globally. The frequency adaptivity was also utilized in a pre-analysis with reduced frequency set as an initial guess for N-tone analysis. The approach results in faster analysis.

The preconditioner change during HB analysis was implemented. A change from frequency domain preconditioner to a mixed frequency-time-domain preconditioner was developed to decrease the growth in GMRES iterations during power sweeps. The results are promising and in the future monitoring the iteration count combined with dynamic preconditioning seems to be a good way of adding both speed and robustness to the simulator.

The development made shows that adaptivity can be achieved in Harmonic Balance simulator so that the analyzer robustness increases without causing slow down in the simulator. The diagnostic tool enables also future development for even increased adaptivity.