Joint Electromagnetic-Circuit Modeling for Active Antenna Array Synthesis

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Abstract

This paper describes a joint EM/Circuit modeling methodology, dedicated to active antennas arrays, with theoretical and experimental validations. The EM model handles inter-element coupling, while the Power Amplifier (PA) model can take important mismatching into account. Both models are then coupled to form a joint approach for EM/Circuit simulation and then validated using an active array demonstrator. An originality of this work is the elimination of isolators between PA and antennas.

1. Introduction

The development of agile antennas has reached a whole new level concerning designs, modelling and agility. Indeed, agile antennas have numerous advantages, such as the ability to produce multiple agile beams [1]. One of the main difficulties for such type of elements consists in reaching the highest efficiency for the design in order to avoid some critical phenomena such as inaccuracy of the arrays radiation pattern. The main source of these discrepancies is the mutual coupling between elementary antennas which significantly impacts the input impedance of these antennas. Moreover, this mutual coupling is affected by the pointing direction of the array, thus leading to the variation of the antennas impedances. This mismatching clearly affect the PAs performances in terms of gain (AM/AM) and phase (AM/PM), thus modifying the necessary steering weights applied to the array and degrading its efficiency and radiation performance. Therefore, accurate modeling methods are representing a key factor for a successful design, involving EM models for the antenna and behavioral bilateral PA models in order to take into account both effects (EM and nonlinear) and correctly handle the direct interaction between PAs and antennas.

This paper describes briefly each part of the mixed simulation approach, the EM model and the PA model. Various experimental results show their reliability and for the mixed simulation approach as well. The originality of this work is the elimination of isolator between PAs and antennas while maintaining a correct radiation pattern despite high antenna impedance mismatches.

2. EM synthesis method and experimental validation

A synthesis method dedicated to EM analysis was developed [2] in order to address particularly the problem of mutual coupling between each array element and the mismatching between passive (antennas) and active (PAs) elements. This means that a part of the energy radiated by each antenna, due to the coupling effects, is captured by the nearby accesses and interferes with the PAs which are connected to the antenna ports. Therefore, the proposed method develops an EM macro-model of the array which takes into account the mutual coupling while maintaining a zero reflection coefficient by defining accurately the reactive loads of the array, even in the case of large mismatching; this particular point allows avoiding isolators. The model also calculates the exact weightings which satisfy an objective pattern (high gain with low side lobe levels), according to pointing angle and frequency. The theoretical formalism description for the EM method is detailed in [2] with all the mathematical developments leading to the calculation of antennas impedances and the weighting coefficients. In this section, an experimental demonstration of the EM macro-modeling is presented, and Fig.1 depicts the used architecture.

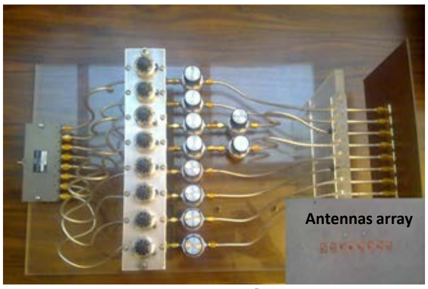

Fig.1 : EM (passive) demonstrator

The experimental prototype (Fig.1) works at 8.2GHz. It consists of a linear 8-element array of patch antennas, whose inter-element distance has been reduced to $0.4\lambda_0$ to increase mutual coupling between antennas, and variable attenuators and phase shifters to manually set the steering weights of the array. A full-wave simulation of the microstrip array is performed with CST MWS. The simulated radiation patterns for -20° and +30° pointing angle obtained by linear combination using CST MWS, are compared to the measured radiation patterns. Figs. 4 and 5 show excellent results despite a large Voltage Standing Wave Ratio (up to 3 for certain antennas).

3. Joint EM/circuit approach

Concerning the circuit model for the PA, it must be able to take mismatching – and even a large one – into account. Therefore, a bilateral behavioral model has been established for the PA [2], and has proven to be valid for Voltage Standing Wave Ratios up to four. Fig. 2 presents comparisons between measurements and simulation results (gain and phase) for three different loading impedances These impedances correspond to antennas' impedances calculated by the EM macromodel, and this in fact constitutes the joint EM/Circuit approach: the PAs' behavioral model is used in the presence of real impedances obtained from the EM macromodel, and the steering weights modifications due to the PAs can be corrected by the array controls to obtain desired array weighting coefficients.

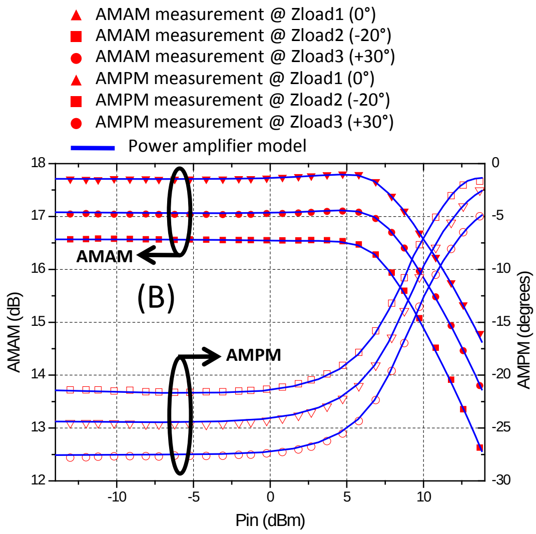

Fig.2. AMAM and AMPM vs. Input power for calculated EM model impedances (Z_{load1} = 46.1+j·9.7, Z_{load2} = 42.3+j·21.5, Z_{load3} = 25.5+j·18.5). Model (lines) compared to load-pull measurement (symbols). F0=8.2 GHz

Fig. 2 shows a perfect agreement, which clearly demonstrate the efficiency and accuracy of the PA behavioral model, even in the presence of the actual loading impedances of the antennas. Finally, to demonstrate the effectiveness of the proposed mixed simulation approach, an active antenna demonstrator was realized, based on the one presented in Fig. 1, with the addition of eight PAs directly connected to antennas and without the use of isolators between the antennas and the PAs (Fig. 3).

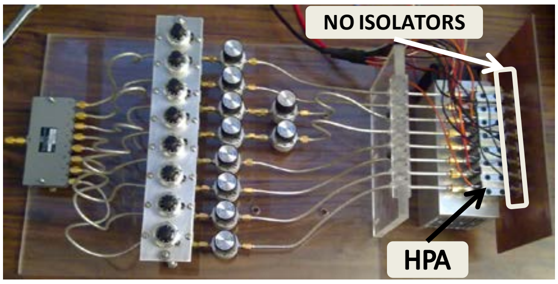

Fig.3 : Active demonstrator

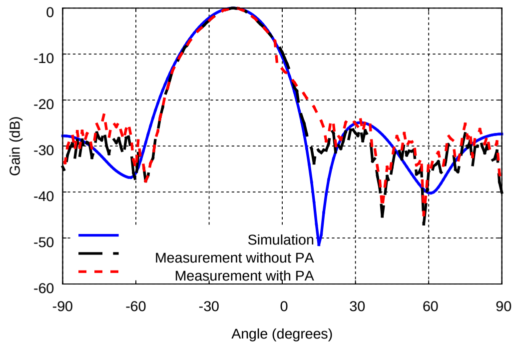

Fig.4. Radiation pattern comparison (-20°). Active demonstrator measurement (solid line). Passive demonstrator measurement (no PA) (big dashes). EM macro-model simulation (small dashes). Fo=8.2 GHz.

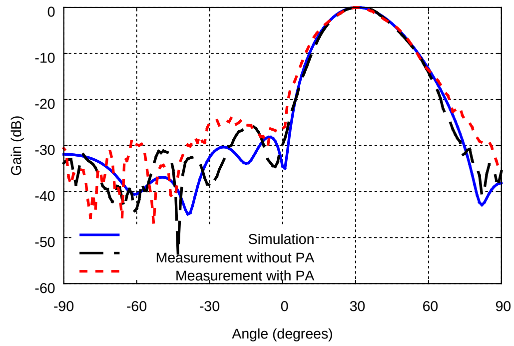

Fig.5. Radiation pattern comparison (+30°). Active demonstrator measurement (solid line). Passive demonstrator measurement (no PA) (big dashes). EM macromodel simulation (small dashes). Fo=8.2 GHz.

Figs. 4-5 show a very good agreement between the different radiation patterns configurations. The main lobes are maintained correctly even with the presence of PA. Some slight differences on the side lobe levels can be noticed, which have been related to some imperfections in the measurement setup.

4. Conclusions

In this paper, we clearly demonstrate the efficiency and accuracy of both the EM macromodel and PA behavioral model. This constitutes a system-level modeling tool providing a robust solution to new designs verification capabilities for active antennas applications. Moreover, integrating the whole model in the array control should allow achieving optimal array efficiency for any pointing angle, while eliminating isolators from the TX chain.

References

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[2] G. Zakka El Nashef, F. Torrès, S. Mons, T. Reveyrand, E. Ngoya, T. Monedière, M. Thévenot, R. Quéré, An accurate modeling technique for antennas and nonlinear RF power amplifier mixed simulation, *International Journal of Microwave and Wireless Technologies*, volume 3, issue 6, December 2011, pp. 647-655.