Development of a Smart RF Gain Equalizer for Broadband Power Amplifier Applications

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1 Abstract

This paper describes a generalized analytical-numerical model of “Smart” RF equalizer, for ultra-wideband power amplifiers (PA) applications. The novelty of this study consists of generating a universal gain-equalizer database, set from electromagnetic (EM) software, and processed with analytical tools, to deal with any random PA gain profile in real time. A numerical tool is then developed to compute lumped elements values , from a random gain response imported in S2P file format , to achieve given specifications in terms of gain flatness and frequency band. These values are finally injected in a 3D EM realistic simulation to ensure a final accurate validation of the Equalizer. A concrete example of a microstrip equalizer is illustrated in the frequency band [1 GHz to 6 GHz] and experimental results are depicted to validate the proposed method.

2 Introduction

In the few last decades, microwave power modules (MPMs) have known a significant growth in RF Power Amplifiers technology as a key element for a variety of broadband applications including radars, EMC measurements and military systems [1]. The revolutionary combination of integrated power conditioner (IPC), solid state amplifier (SSA) and a vacuum power booster traveling wave tube (TWT) within a single module, has resulted in a unique solution of efficient, compact, lightweight, high power, high gain, and low noise microwave amplifier [2], [3]. However, a common limitation appears in such broadband devices, where they often struggle with excessive passband ripple and gain slopes [4]. The use of gain equalizer has become then a fundamental solution to compensate the increasing attenuation and the gain fluctuation versus the frequency and to provide an optimal gain flatness [5]-[7]. Furthermore, this gain slope could randomly change for a wide range of MPMs on an industrial scale.
Therefore, Prana and Inoveos companies, as a broadband PA manufacturer and RF components expert respectively, worked together to deal with a generalized solution of a gain equalizer with adaptative response according to the input random gain profile. This internal tool can eventually be used without the need of EM software, since it was experimentally validated showing a great correlation between analytical, numerical and measurement results.

3 Broadband RF Equalizer Synthesis

3.1 RF Equalizer Topology

The equalizer circuit (Fig. 1), based on a Pi-attenuator, presents good characteristics in terms of linear slope, good matching, and low excess loss [5]. For a better slope margin i.e., the maximum and minimum attenuation difference, a two-stage circuit is chosen.

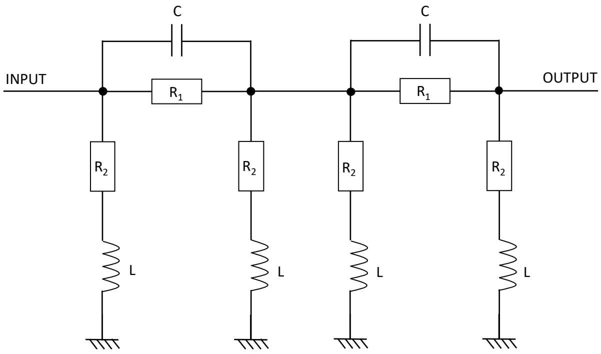


Fig. 1: Circuit diagram of the equalizer

3.2 Simulated RF Equalizer and Database Construction

The circuit depicted in Fig. 1 is then simulated on CST studio suite (Fig. 2) by considering 50 Ω microstrip lines and SMD lumped elements. Input/output lines are linked to SMA connectors.

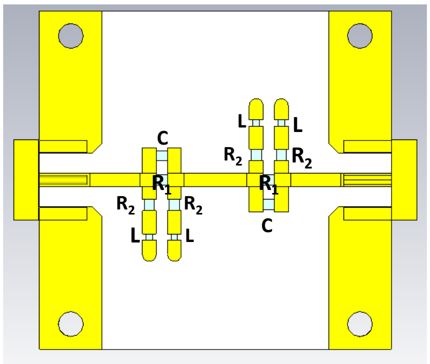


Fig. 2: Numerical equalizer model using CST software

Starting from this numerical model, a parameter sweep combination of the 4 lumped elements (L, C, R_1, R_2) is performed for a given frequency band, to build a database of S-parameters i.e., attenuation and return losses curves. A first example is set with 4 values per lumped element which represents $4^4 = 256$ runs and as many s2p files to export. The number of iterations is arbitrary chosen and can be extended to higher orders for more precision of the proposed generalized model. The second step concerns the generation of an extended database on MATLAB, from the initial simulated database (Fig. 3). The s2p files are read and organized in a 4-D table according to the frequency. The objective being to refine the possibilities and the optimal response, therefore a 4-D polynomial interpolation (Spline) is carried out.

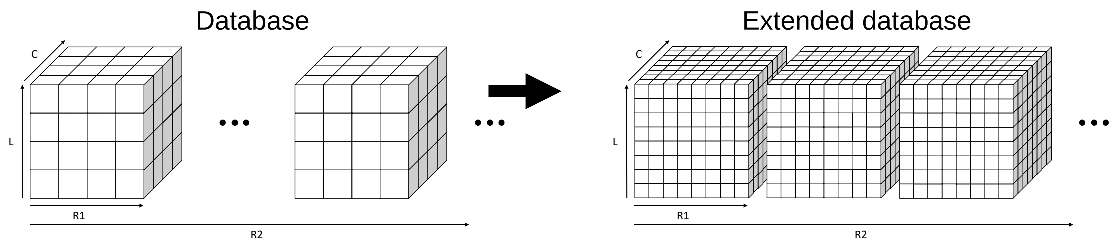


Fig. 3: 4-D interpolations of S-Parameters database imported from EM simulations

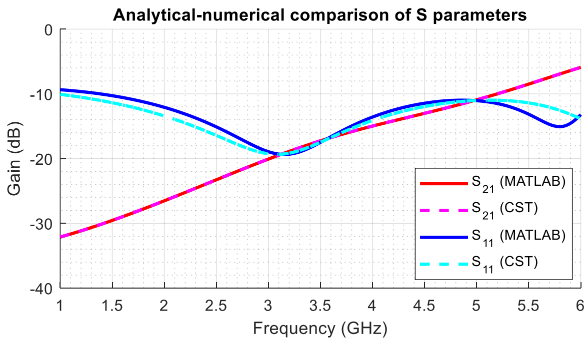
The data processing is implemented in two steps: linear interpolation of the parameters L, C, R_1 and R_2 and polynomial interpolation of the S-parameters ($S_{11} = S_{22}$; $S_{12} = S_{21}$) for each frequency point. The interpolated data are then saved, constituting the bank to be used for the equalizer optimal response according to a given gain slope specification.

3.3 Algorithm for Picking Optimal Equalization Response

To provide the optimal combination of components (C, L, R_1, R_2) according to a gain slope (S_{21}) to be corrected, a selection algorithm is then performed. This algorithm consists of selecting the combination (C, L, R_1, R_2) from the database, bringing the minimum error ($\varepsilon_{\min}$) for a given strategy (gain specification). To optimize the response of the corrector, especially in reflection, the selection algorithm can integrate the return losses specification (S_{11} - S_{22}). The algorithm then scans the database to extract the best solutions for flatness. Among these answers, the one with a minimum return loss will be chosen. If the specification in S_{11} is not met, it is possible to configure the picker to relax the constraints on flatness. Indeed, the weight distribution for optimization between flatness and matching is configurable.

4 Experimental Validations

To validate the proposed optimization algorithm, many examples are performed, according to different input gain slopes. The considered gain profile to be corrected is depicted in Fig. 4 as an example.



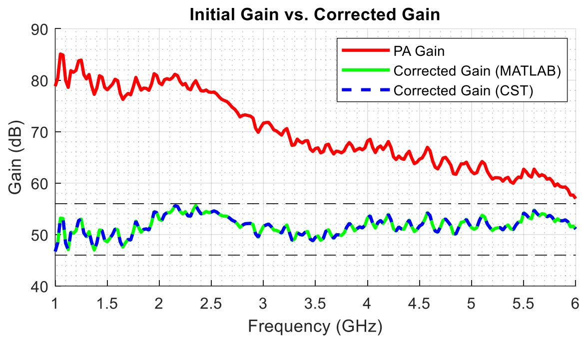
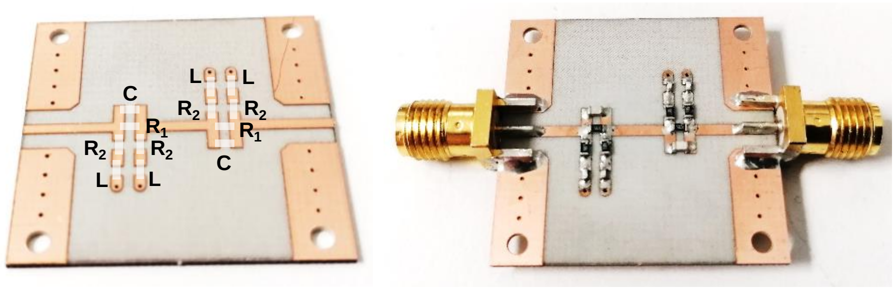
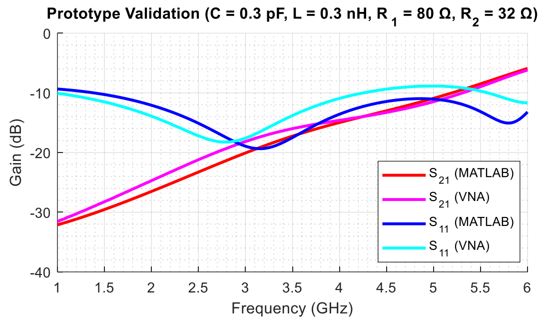


Fig. 4: Example of the proposed analytical tool to determine the optimal lumped elements for a given gain flatness specification (a). Corrected Gain (b).

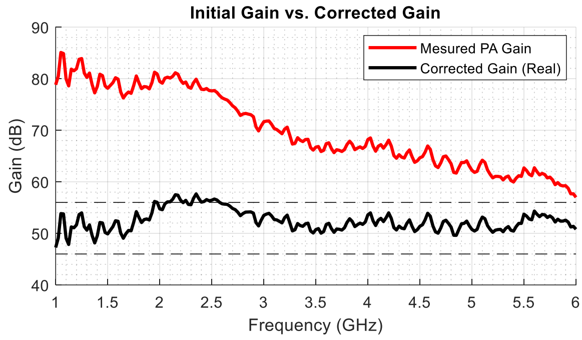
A combination of 4 lumped elements values is determined by the optimization algorithm. The program also proposes to plot the equalization curve as well as the final gain response with optimized required flatness. Indeed, a flatness goal is fixed at ±5 dB around 51 dB average gain. A return losses level is also fixed at – 10 dB (min) for all the frequency band. Moreover, the same lumped elements values are injected to the EM 3D simulation for more comparison and validation of the program as shown in Fig. 4.



(a)



(b)



(c)

Fig. 5: Realized optimized broadband equalizer (C = 0.3 pF, L = 0.3 nH, R_1 = 80 Ω, R_2 = 32 Ω) (a) Optimal lumped elements for a given gain flatness specification (b). Corrected Gain (c).

The obtained parameters are C = 0.3 pF, L = 0.3 nH, R_1 = 80 Ω and R_2 = 32 Ω. The printed circuit board (PCB) is then manufactured and the corresponding components are soldered as shown in Fig. 5. Although it is possible to observe a slight deviation in response , caused by the tolerances of the selected CMS values and the PCB manufacturing tolerance, the results obtained with the prototype are in good agreement with the parameters values proposed by the method. A broadband gain equalizer has been realized, without the need of EM simulations to be optimized.

5 Conclusions

A smart RF equalizer with adaptative response is demonstrated in this paper. The optimal equalization parameters are obtained for a given gain requirement. The algorithm is validated with EM 3D simulation and a prototype measurement. Therefore, the solution can eventually be used independently of any external commercial EM software. Some improvements are in progress to extend the model to other frequency ranges and to enhance the analytical tool interface such that the user can automatically retrieve standards SMD components elements, leading to a fast and user-friendly industrial tool. Furthermore, a combination of such equalizer with a high pass filter was developed to reduce the wideband noise of high-power amplifiers. As a matter of fact, the implementation of the filter equalizer between the low-level amplifier and the intermediate one allows reducing the out of band and the wideband noise.

References

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