Design and Characterization of an Automated Calibration and Test System for RF Tunable Active Devices

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***Abstract*— A complete hardware-software system for automated calibration and test of RF tunable active devices is presented in this paper. The proposed system aims to optimize and tune the response of voltage controlled RF devices, such as active filters, by means of a modified and customized Differential Evolution approach. It consists of a Vector Network Analyzer (VNA), which is used to acquire the S-parameters of the Device Under Test (DUT) as main information of the optimization process, a programmatic multi-output voltage generator, that is directly interfaced with the control pins of the DUT and a computation platform (which could be a PC, for instance). The latter is responsible for the numerical processing of the measuring information, by means of a custom evolutionary algorithm, and acts on the device's control pins in search of the best tuning solution, accordingly on the desired calibration goals. This automatic calibration system allows achieving good performances in terms of convergence speed and precision, in a scenario where novel RF tunable active devices are emerging and a manual setup is not trivial and even time consuming.**

***Index Terms*— Automatic calibration, control systems, Differential Evolution, active filters, tunable systems.**

I. Introduction

THE development of new technologies and novel architectures for RF applications have allowed, in the last years, the emergence of new tunable RF building blocks and systems. In particular, innovative circuits for tunable active filters recently have been investigated as a response to IC exigency of implementation. In effect, RF filters still represent a major challenge for IC integration, especially when advanced features are required. In this perspective, the Faculty Mentor and Others from University of L'Aquila, recently have proposed a new approach for the implementation of active inductors and filters [1-2] with high linearity and wide dynamic range; filters using Tunable Active Inductors (TAI) have proven good potential for IC implementation and high-frequency operation. Consequently, some prototypes of novel RF tunable, TAI-based active filters have been implemented. On the other hand, such filters require a relative large number of control signals in order to achieve good performance, making a manual tuning action quite difficult and time consuming. In this scenario, a novel hardware/software system for auto calibration and test of two ports RF devices has been developed.

The proposed auto calibrating system includes a main optimization software, a Vector Network Analyzer (VNA) and a programmable, multi output, voltage generator. The basic principle of operation consists on the acquisition through the VNA, at run time, of the Device Under Test (DUT) S-parameters. The measured values are sent to the computation hardware via the GPIB bus, compared with a user-defined optimization goal and processed by the optimization algorithm. Therefore, a set of digital information is generated and properly coded, then it is real time sent to the programmable voltage generator via USB, in order to generate a new combination of voltage control signals. This procedure is repeated until the optimization target is achieved.

II. Auto-tuning Algorithm and Hardware Interface

The calibration algorithm is composed by a main optimization section, which is the core of the whole tuning system, and other sub-routines for GUI (Graphic User Interface) management and digital communication management with peripheral devices. The optimization process is totally independent from the DUT, which is treated as a black box, and interacts with it by means of an objective function. The latter is a particular error function, which holds properties of the DUT behavior and optimization goals. The target of the tuning software is to find the global minimum of this function, which corresponds to the optimal voltage control set. In the case of RF active filters, we designed the error function using the measured S21, S11 and S22 parameters of the device and comparing them to the desired goals.

For what concern the optimization method, a customized Differential Evolution (DE) strategy was implemented. The algorithm is a population based evolutionary method [3], with a simple and efficient heuristic scheme for adaptive global optimization. The basic idea is to create a population of control parameters (voltage controls required for tuning action), which could be seen as a NxM matrix, where M is the number of controls involved (this number is filter dependent) and N indicates the number of voltage control sets (control vectors) that compose the population. At the beginning, this

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population is properly initialized among the space of solutions, defined by voltage constrains for each control pin. This population is then modified trough an evolution process and compared with respect to the original one: every vector of the population produces a specified set of control voltages, applied to the DUT and so modifying the S parameters of the device. Therefore, the error function is computed with respect to each control vector of the current population. This operation is then repeated with the modified population and then results are compared, producing a new generation of control voltages as evolution of the previous one. This process is cyclically repeated until the optimization goal is accomplished. The evolution process at each iteration is composed by three steps, suitable customized and modified for this application: mutation, recombination and selection.

The generation of control voltages for automatic tuning action is made by a custom-designed hardware sub-system. This module consists of a microcontroller and an executive hardware core with a master-slave relation. The first one interfaces with the optimization algorithm, hosted on a computation platform via USB and is demanded to receive and decode information, coded with a custom data structure, in order to activate the core for a congruous generation of control voltages. The second one is mainly composed by eight integrated high resolution Digital to Analog Converters (DACs) which are independent from each others and guarantee a resolution in the order of microVolts. An output gain stage is also provided, in order to broaden the output voltage range, according to the features of the DUT. A Cyclic Redundancy Check (CRC) method is also implemented for the communication between the calibration algorithm and the programmatic voltage generator, in order to avoid transmission error that can block and affect the optimization process.

III. Results and Conclusions

The test campaign was made on two TAI-based tunable RF filters with three and six voltage controls, respectively. Both are band-pass filters with a center frequency of 0.9 GHz. The three control device is a first order filter and has a 70 MHz bandwidth, while the six controls one is a second order filter, with a bandwidth of 30 MHz. Since the implemented optimization process provides different evolution methods for the population of control voltages, best results for each of this method are shown in table I and table II. The number of evaluations shown in these tables is intended as the number of time the error function is evaluated, that implicitly includes a change of control voltages and an acquisition of new S-parameters. These results are repeatable and show a high convergence speed, despite the complexity of the DUT, intended as number of control voltages involved in the auto-tuning action. The effective calibration time is strongly dependent on the VNA performance. The faster is the acquisition of the S-parameters within the measuring span, the smaller is the convergence time of the auto-calibrating system.

TABLE I.

RESULTS FOR THREE CONTROLS FILTER

Tests	**Results**	
	evaluations	***Minimum error achieved***
Method 1	103	0.04356
Method 2	104	0.071406
Method 3	106	0.056324
Method 4	147	0.08768
Method 5	192	0.358967
Method 6	92	0.02685

TABLE II.

RESULTS FOR SIX CONTROLS FILTER

Tests	**Results**	
	evaluations	***Minimum error achieved***
Method 1	73	0.00003
Method 2	98	0.00004
Method 3	167	0.158452
Method 4	181	0.094899
Method 5	158	0.006532
Method 6	42	0.00002

IV. Acknowledgment & Career Plans

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