Automated Temperature Compensation of Linearizers with Optimization

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***Abstract*—Linearizers are electronic circuits which work to counteract the nonlinear behavior of amplifiers. In many of these devices, the dynamic relationship between signal gain and temperature is a naturally occurring phenomenon. Temperature compensation can be achieved by the adjustment of potentiometer values such that an RF output signal more accurately maintains its operating characteristics over a certain temperature range. In many cases, these potentiometer values are set by technicians during the manufacturing process. This requires operation of a temperature plate, vector network analyzer, and linearizer controller software running on a desktop computer. When selecting potentiometer values at each temperature interval, the goal is to maintain minimum change of certain output parameters from those measured at ambient temperature. The goal in this process is essentially to solve a multi-variable combinatorial optimization problem. A technician will make these determinations using heuristics; the results of which can be improved with optimization methods. This paper outlines the design and implementation of the entirely software-controlled automation of the temperature compensation and testing process at Linearizer Technology, Inc. The use of optimization involving linear programming for selecting potentiometer values is also discussed.**

Keywords—Linearizer; Automated Testing; Linear Program; Temperature Compensation

I. INTRODUCTION

Linearizer Technology, Inc. is an electronics engineering and manufacturing company that specializes in linearizers. In the quality control stage of this particular industrial pipeline, linearizers must be configured and tested over extreme temperatures. Adjustments must be made by a technician so that changes in the gain and phase of an output signal over temperature can be compensated.

This project is the design of an automated test system to replace the manual procedure (known as "Temperature Compensation") currently used. Since the procedure involves both testing and configuration, the efficiency of the overall process should be improved as a result of the automation and better compensation. Regardless of whether the technician is aware, the goal is essentially to solve a combinatorial optimization problem. A technician will heuristically determine values of digital potentiometers by observing changes shown on network analyzer plots, attempting to select the best settings. Because there are so many output variables to minimize, this process leads to a trend where sufficient values are always selected (otherwise a linearizer would not pass quality control specifications) but optimal values are not always selected.

II. BENEFITS

The motivation for automating any manufacturing or testing process is that the labor costs necessary for human operation are reduced (if not eliminated in some cases). In this case, automation allows for multiple units to be tested simultaneously. This reduction in time required per unit not only can open a potential bottleneck, but allows for even more throughput. The procedural regularity achieved through computer-operated instrumentation and the improved compensation achieved from an optimization algorithm reduce costs that arise from dealing with errors during or post-production. When evaluating output characteristics of a linearizer via a VNA (vector network analyzer), the main considerations are the frequency response and the transfer response. The frequency response measures the gain and phase over the operating bandwidth at both large signal and small signal power levels. The transfer response is a function of power vs. gain or phase at center-band frequency. Including both gain expansion and phase expansion (difference between large signal and small signal in the frequency response), this is a total of eight output characteristics to be maintained over temperature. An optimization algorithm can use the values for each point in a trace when performing computations. This produces more desirable results than the visual-graphical approach used in the manual testing procedure.

Fig 1 and Fig 2 show an example of the output of a temperature compensated linearizer as would be shown on a VNA. Fig. 1 shows a frequency reposnse where the top plot is gain (dB) vs. frequency (GHz) and the bottom is phase (degrees) vs. frequency (GHz). Traces are shown for both large signal and small signal power over the operating frequency bandwidth. Fig. 2 shows a transfer reposnse where the top plot is gain (dB) vs. power (dBm) and the bottom is phase (degrees) vs. power (dBm). Traces are shown at center-band frequency over a power range from small signal to large signal levels. In both Fig. 1 and Fig. 2 traces are parameterized by different temperature points over a range of 100K.

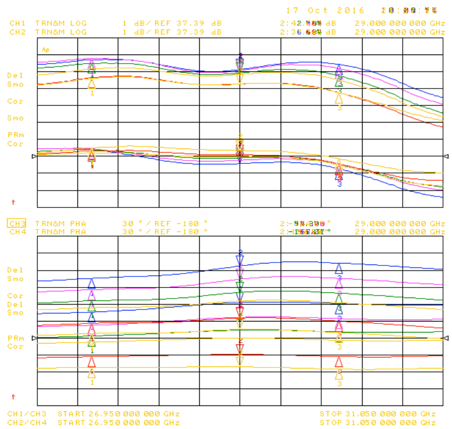

Fig. 1. Frequncy Reponse for 253K, 273K, 293K, 313K, 333K, and 353K

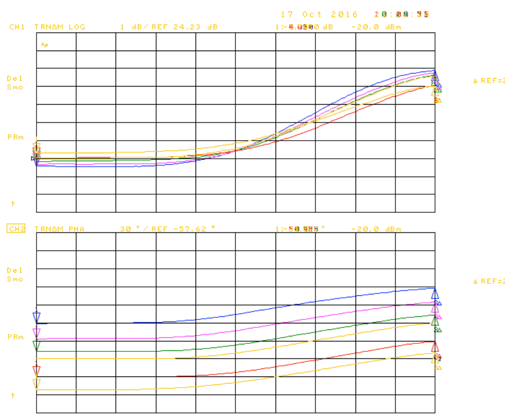

Fig. 2. Transfer Response for 253K, 273K, 293K, 313K, 333K, and 353K

III. DESGIN

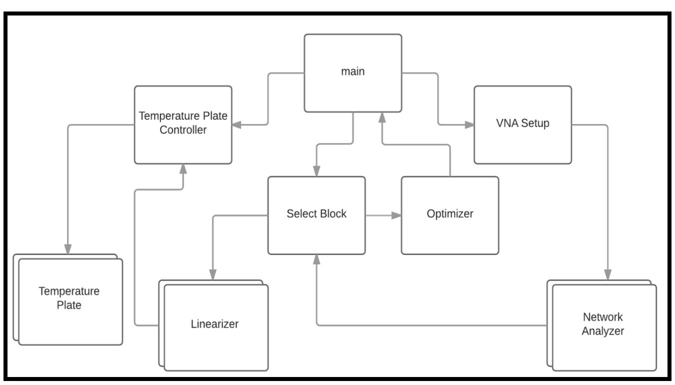

Fig. 3. System Components with Major Dependencies

A. VNA Setup

This module communicates with the network analyzer using VISA (Virtual Instrument Software Architecture) via GPIB (General Purpose Interface Bus). Commands are written to configure all settings necessary for the process, save data traces in memory (register states), and save the register states to the VNA memory. It is designed to work regardless of the previous state or settings of the selected register.

B. Temperature Plate Controller

This module communicates with the temperature plate on which the linearizer is mounted using VISA via GPIB. The temperature is set appropriately by sending the command for the set point and the command for switching on the compressor. Using a serial-parallel or parallel-parallel interface, the actual temperature of the linearizer (which is not necessarily the same as the temperature of the plate at the time) is continuously queried. The heating or cooling process is terminated once the linearizer temperature is within + or - 1K of the corresponding temperature interval. The set point is kept lower than the corresponding interval when decreasing in temperature and higher when increasing in temperature to avoid a deadlock (oscillatory) situation in which the temperature is never reached.

C. Select Block

During each temperature interval, after the temperature plate controller is finished executing, this module increments potentiometer values, and then reads data from the VNA for each active channel, which is subsequently stored in a multidimensional array. At first, five markers (maximum allowed by the VNA) per channel, which are set during the execution of VNA setup, were used as the data points for each trace. This can be insufficient since the shape of frequency response traces and the gain of the transfer responses can vary greatly amongst different types of linearizers. This method was replaced by using a command not available on the VNA front panel to output an entire trace as an array. These arrays are the same size as the "Number of Points" setting on the VNA.

D. Optimizer

For each temperature interval, this module determines the final potentiometer values. It aggregates arrays from the Select Block for each active channel: large signal gain, small signal gain, large signal phase, small signal phase, power sweep gain, and power sweep phase. A linear program solver is included in the LabVIEW framework used with constraints set according to the aforementioned quality specifications (e.g. < 1dB of gain, < 10 degrees of phase, etc.). The potentiometer values associated with the linear program solution are returned as an n by m matrix where n is the number of potentiometers and m is the number of different temperature points. The matrix form of a linear program is shown where $\mathbf{x}$ is the vector of variables to be determined, $\mathbf{c}$ is the vector of known coefficients of the objective funtion (to be minimized or maxmized), $\mathbf{b}$ is a vector of known coefficients, and $\mathbf{A}$ is a matrix of known coefficients [1].

$$\max\{\mathbf{c}^{\mathrm{T}}\mathbf{x} \mid A\mathbf{x} \leq \mathbf{b} \wedge \mathbf{x} \geq 0\}$$

E. Main

This is the script which runs the entire process and contains all other modules as sub-VIs. Execution begins once data specific to the linearizer is manually entered. After the potentiometer value selection is completed for every temperature interval, the table containing optimal values is interpolated and extrapolated as a .csv file and is written to the EEPROM on the linearizer to function as a look-up table during real-time operation.

IV. Results

The functionalities of each module were first tested piecewise. The overall system was tested with a linearizer, temperature plate and VNA. After dealing with some minor logical and communication errors during integration, the system is functional. As of the date of this paper, this project is undergoing further testing and comparative analysis (in relation to the manual procedure currently used) in order for it to be consistently used in everyday operations in production.

V. Future Plans

To further reduce the search space, an additional technique is currently being explored to use archived temperature tables, compute averages for each type of linearizer to create type-specific seed values as starting points. This can be done by involving some sort of machine learning approach or simpler statistical methods.

Acknowledgments

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