# AN AUTOMATED TECHNIQUE FOR POST PRODUCTION TUNING OF MICROWAVE CIRCUITS

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## ABSTRACT

Tuning, in the form of physical adjustments to microstrip matching networks, is needed for most microwave circuits to meet today's state of the art performance requirements. This is because there is only so much that can be done in the design phase to account for the effects of tolerance variations and parasitics in the components that make up the circuit, and manufacturing variations in assembly and etching of the circuit itself. Presently circuit adjustments are performed manually by highly skilled technicians who must probe the circuit, measure its resulting response and determine how to modify the circuit elements for best overall performance. This iterative process is empirical in nature and consequently highly dependent on the experience level of the technician and his learning skills. It is for most circuits a very time-consuming and therefore costly part of the production cycle.

The tuning technique presented in this paper removes the empirical element from the production cycle and, through automation, expedites and standardizes the circuit alteration process. It therefore provides for reduced tuning time and improved repeatability and producibility of microwave circuits. This technique can be used in a semi-automated mode, with a computer instructing the technician on how to modify the circuit for optimum performance, or as a fully automated workstation with a laser and a robot working per instructions from the said computer.

A description of the technique as well as application data are included in this paper. Data is provided for a single stage L band power amplifier tuned in the automated workstation and for a four stage X band amplifier tuned using the computer-aided approach.

## THE TUNING TECHNIQUE

The process flow for the new tuning technique is illustrated in figure 1. The circuit is connected to the test station, which consists of computer controlled test equipment, and its response (or set of responses) is measured. If it meets all requirements it needs no tuning. However in the overwhelming number of cases its original response falls short of requirements. An error function is then created which relates the untuned circuit response and the target or best possible performance. The tuning process is reduced to an error minimization procedure. The circuit tuning elements (capacitive stubs in most matching networks but also any type of variable component) are perturbed one at a time in a controlled fashion and the resulting effects on the circuit response, or more precisely on the error function, are measured. The resulting data consists of a set of gradient information relating each tuning element to the circuit performance. This data is used in an error minimization algorithm to predict the required adjustments to each of the circuit tuning elements. These adjustments as well as the preceding perturbations can be performed manually or using a robot and a laser or alternatively any suitable computer controlled tool. After the adjustments are performed the circuit is remeasured and the procedure is repeated until the desired "tuned" response is obtained.

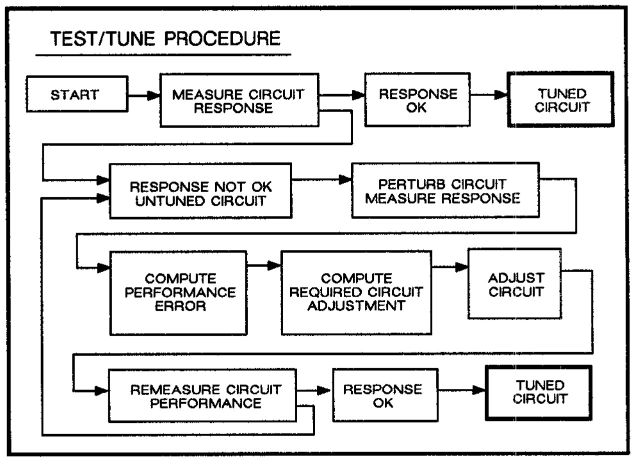


Figure 1. Tuning Process Flow

The error minimization algorithm can be any of several standard gradient algorithms such as used in most Computer-Aided Design (CAD) routines. It requires as inputs the circuit target data together with a stop optimization window, the error function defined over the required measured points or frequencies, the gradient information for each tuning element and any modifying weighting factors and convergence constants. It provides as output a set of tuning instructions for manual or automated implementation. The error function can be a simple RMS of the difference between the target data and the measured data at each of the frequencies modified by appropriate weighting factors over frequency. The convergence constant is established by trial and error (during circuit breadboarding and fixed thereafter) and determines the optimum speed for convergence; it is therefore particular to the circuit being tuned. Figure 2 illustrates the required inputs for the error minimization process.



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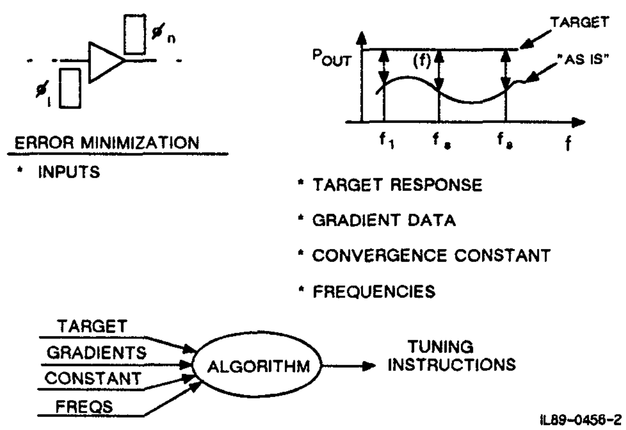


Figure 2. Minimization Algorithm Inputs

For the extraction of gradient information, a perturbation technique for microstrip stubs was developed. The requirements of the circuit perturbation technique are such that the technique needs to accommodate both manual and automated implementation, it must be repeatable, and its effect on the circuit tuning element (in terms of physical length) and on the circuit performance must be small enough to correspond mathematically to a partial derivative of the circuit performance parameter (in terms of the error function) with respect to the length of the tuning element. The perturbation technique consists of placing a dielectric chip (an alumina chip with a metalized top surface has been used) at the tip of the stub element as shown in figure 3. Note that the tuning stub is made symmetrical about the circuit input-output line so that one side can be used for tuning, in the form of foil addition or metalization trimming, and the other side for placing the dielectric chip (circuit perturbation). The size of the dielectric chip determines the magnitude of its effect. However, since the chip acts upon the fringing fields on the surface of the microstrip its effect is typically very small (even for sizable chips) so that it can be considered a gradient. The size of the chip is chosen to have an effect typically equivalent to that of a stub length addition of less than 8 mils (this is verified during the breadboard testing of the circuit).

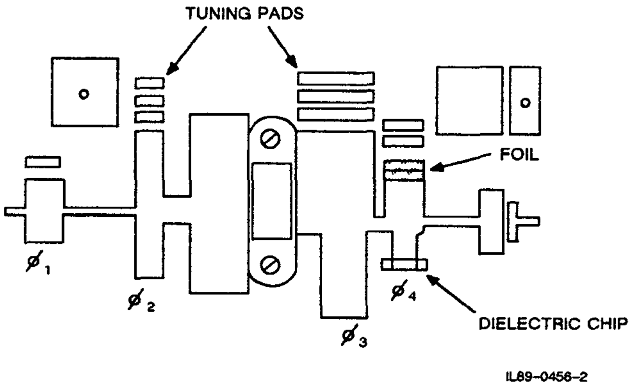


Figure 3. Matching Network Tuning Stubs

## THE AUTOMATED WORKSTATION

A workstation architecture for full automation of the tuning technique has been established and preliminary implementation of its piece parts has yielded the data presented in this paper. Figure 4 shows the components of the workstation and also a possible physical layout. A PC is used as station controller, it contains the algorithm routines and the software for addressing the microwave test equipment and all the associated workstation components (laser, robot, etc) and peripherals. A Q-switched YAG laser is used to trim the microstrip tuning elements (stubs) in the circuit per instructions from the algorithm. The stubs are made longer than they need to be so that tuning consists of trimming the lengths of the stubs (these need to be designed with care during circuit breadboarding to avoid performance instabilities). A manipulator or robot is utilized for placing dielectric chips on the tuning elements for the

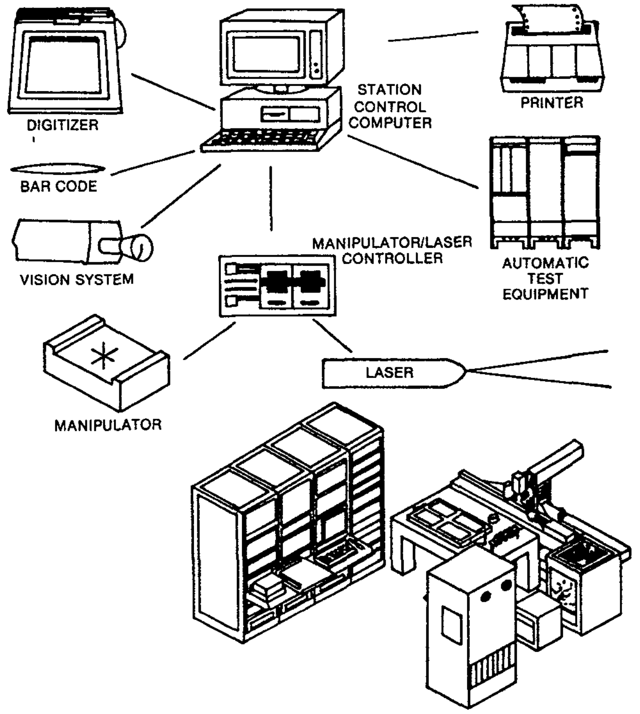


Figure 4. Station Architecture and Layout

extraction of gradient information. The circuit tuning element coordinates are input into the system using a digitizer or alternatively, and more accurately, by down loading information from a computer based layout of the circuit artwork such as can be obtained from a Computer Vision system. Vision calibration is used to register the circuit and the positioning of the perturbation tools. Finally a bar code reader can be used in a production line to input all the circuit dependent information into the system. The set of test equipment connected to the workstation is also circuit dependent and may consist of power meters, network analyzer, noise figure meters, voltmeters etc.

## APPLICATIONS/PERFORMANCE

The automated tuning technique was used to tune a single stage L band power amplifier capable of delivering

180 watts peak at 5% duty cycle.This circuit is shown in figure 5. It contains four tuning elements of which three were modified to achieve the desired response. Three tuning iterations were required, resulting in three laser cuts on one of the stubs. Figure 6 shows the untuned power response for the amplifier and the subsequent improvements from each iteration. The required power output is 180 W minimum and the target was set at 250W, the resulting response is 200 W minimum.

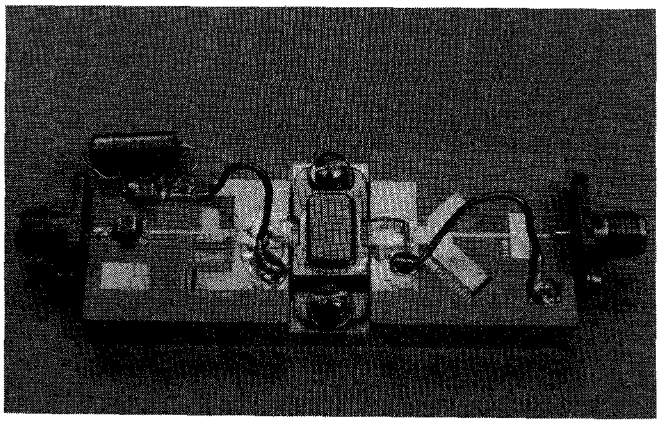

Figure 5. Single Stage L-Band Power Amplifier

The limits of the technique in the computer-aided (semi-automated) mode were tested with an application at X band. At higher frequencies the tolerances in the repeatability of the perturbation technique become more critical and so do the interactions between tuning elements. The four stage amplifier is shown in figure 7. It operates between 9.3 and 10.1 GHz and has a requirement for 32 dB gain minimum and a gain flatness of +1 dB. Figure 8 shows the response improvement after each iteration. Again 3 iterations were required to achieve optimum performance. The curve labeled "0" is the untuned module power gain. The first two iterations ("1" and "2") improved the overall gain of the amplifier, and the final iteration "3" provided the required gain flatness across the frequency band.

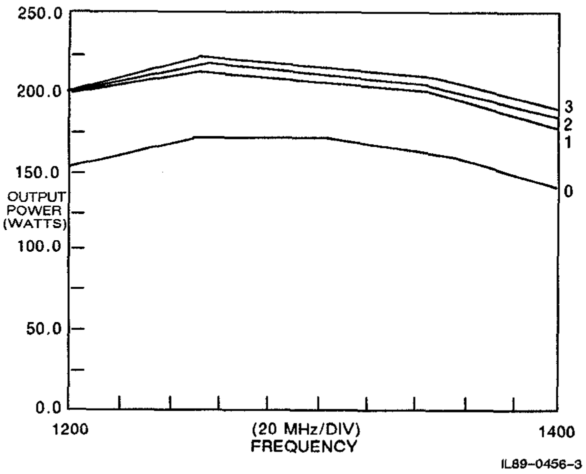


Figure 6. L-Band Amplifier Data (0 = Untuned, 3=Final

For both applications a standard gradient optimization algorithm was used with the addition of second order gradient information. This was obtained by using two sets of perturbation chips of different sizes and calculating the difference between the resulting effects with respect to the difference in dielectric chip sizes.

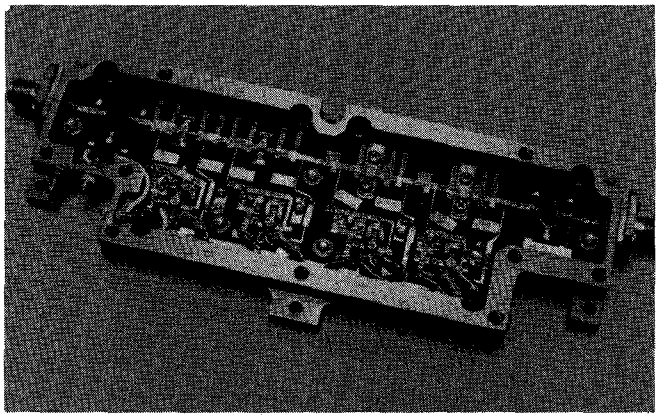

Figure 7. Four-Stage X-Band Amplifier

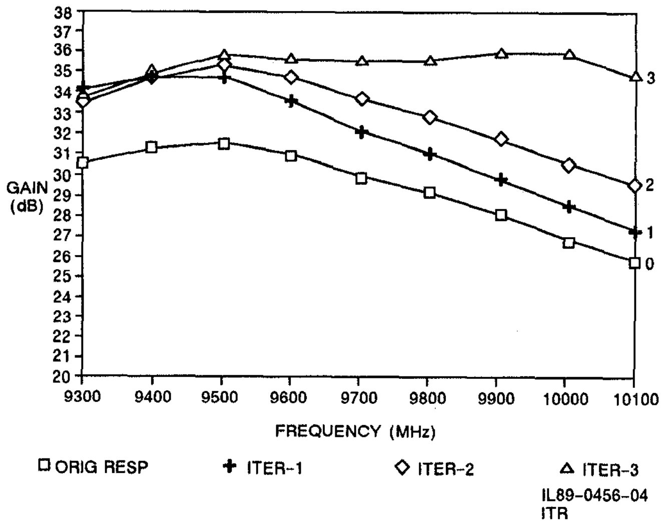


Figure 8. X-Band Amplifier Data

## CONCLUSION

A computer-aided tuning technique has been developed which allows for full automation of the post production tuning of microwave circuits. It its applicable to linear as well a non linear circuits and provides for repeatability and reduced tuning cycle times. It is adaptable to many circuit response functions such as gain, power output, efficiency, noise figure etc (for functions which can be easily related mathematically such as gain/power output and efficiency a new quality function can be defined and the technique will optimize for it). An automated configuration for the technique which uses a laser and a robot has been established which results in additional benefits for the mass production of state of the art microwave circuits at least cost.