ADAPTIVE IDENTIFICATION AND OPTIMAL TUNING OF COUPLED-CAVITY FILTERS

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INTRODUCTION

This document has been initiated after discussions with Dr. Kudsia on March 1, 1984, his request subsequently confirmed March 8, 1984. It is concerned with the processing of frequency response input-output measurements made on single narrow-band coupled-cavity microwave filter units under test. The aim is to reliably determine the actual fixed and tunable model parameters of the physical realization (unit under test) with the following goals: to develop an efficient software system to localize possible manufacturing defects, to estimate manufacturing tolerances, to evaluate parameter deviations from nominal, to ascertain any significant electrical equivalent circuit model imperfections and to deduce possible correlations between filter parameters induced by actual physical tuning elements. Finally, it is required to develop a suitable tuning software system to be integrated into ComDev's hardware facilities. The aim is rapid, accurate and optimal computer-assisted tuning and alignment of actual units under test to improve manufacturing throughput.

COMDEV'S CURRENT CAPABILITIES

Following occasional interaction with Mr. Frenna and Mr. AuYeung over previous months, in which rather brief discussions about current practices at ComDev took place, a serious meeting was held with Mr. AuYeung on March 20, 1984 to discuss in depth the state-of-the-art as Mr. AuYeung perceives it.

Discussions were oriented around measurement capabilities, including amplitude (return loss and transmission loss) and also group delay. It was indicated that, for each in situ adjustment of a unit under test, roughly 5 seconds and 30 seconds of real time should be expected for 10 sample points and 100 sample points, respectively, to be logged digitally. Measurements are normally conducted under matched conditions but the test set-ups for return loss and transmission loss require manual readjustment. Group delay, which is apparently not a preferred measurement, requires similar sampling times under different physical test conditions.

Accuracy of return loss and transmission loss was estimated at ± 0.25 dB on a 0-60 dB scale, ± 0.05 dB on a 0-5 dB scale (insertion loss), but measurement times are then expected to be about 10 times as long. Group delay measurements to ± 0.2 nanoseconds are expected.

Simulated measurements made by Mr. AuYeung considered the perturbation of ideal filter couplings by a few percent, and, using the simulated real and imaginary parts of reflection coefficient, to optimize a least-squares objective to identify the perturbed parameters. This appears to work well up to a 10 x 10 matrix. Individual cavity resonances were also permitted to vary. Employing only the modulus of the reflection coefficient, convergence could be achieved for up to a 6 x 6 matrix. About 50 passband sample points were apparently required and a few out of band transmission loss points were added in to sharpen the results. On the HP1000 about 10 minutes of CPU time are needed for a 6-pole filter.

A brief discussion took place focussing on coupling elements M(1,4) and M(1,6) concerning trade-offs between amplitude and group delay.

Mr. AuYeung summarized some results he obtained on a well-tuned 6-pole experimental filter. All cavity resonances, all physically realizable dominant and stray couplings as well as input-output couplings were treated as variables. Unloaded Q is assumed fixed. The optimized results using measured data turned out to be acceptable when band-edge skirt points were neglected. Assumptions made were circular waveguide wavelength values for bandwidth and resonance calculations, but the M(i,j) were assumed dispersionless. Stray couplings of about 0.02-0.03 were obtained, and principal couplings were typically within ± 0.03. Resonant frequency errors were close to 2 MHz.

Tuning itself appears to take approximately 4 to 5 hours on such a filter, in which one adjustment at a time is made, starting with a totally detuned structure. Return loss and transmission loss are simultaneously monitored continuously to an accuracy of about ± 1 dB. Initially, all the available screw adjustments are made. Then an iris is selected and, by sequentially disassembling the unit, appropriate irises are selectively inserted, one-at-a-time, until the response which appears best is realized. All screws are readjusted when the monitored response appears far from optimally tuned. When very close to the desired response, screws in cavities adjacent to the iris are readjusted.

Input-output coupling faults are apparently detected after all other tuning adjustments have been attempted. If input or output coupling elements need adjustment, subsequent fine tuning of screws in the cavity adjacent to the element needing adjustment are required.

Mr. AuYeung stated that simulation models may be found which reproduce experimentally observed tuned responses fairly closely. However, when a screw adjustment normally associated with the coupling M(1,2) is made other dominant coupling or resonance adjustments take place when the currently used optimization software attempts to verify the change. All the currently declared degrees of freedom are allowed to vary during the optimization procedure, which attempts to identify the model parameters of the detuned filter under test.

DISCUSSION OF POSSIBLE WORK

To be ultimately useful, any newly developed optimization based software system for computer-assisted tuning of the filters under discussion must take into account the following features.

1. Single Filter Static Modelling

Within about a minute (depending on filter order) on a mainframe computer, it should be possible to process a typical set of measurements from an experimentally optimally tuned filter (return loss, insertion loss, group delay as necessary) to produce by gradient optimization an electrical equivalent circuit capable of reproducing the frequency responses of interest to correlate accurately with the measured data. Least-one, least-squares and minimax packages must be prepared and compared in conjunction with a strategy for selection of useful measurements to be used as input data. User decision to permit selection of candidate variables should be included.

2. Single Filter Dynamic Modelling

Again within a reasonable additional CPU time it should be possible to process, using gradient-based optimization, an additional appropriate set of measurements conducted on an experimental filter, tuned as above, with a few key parameters deliberately perturbed one-at-a-time. The aim of this procedure would be to produce a clearer and more well-defined equivalent circuit with experimentally correlated variables so that the experimental and computer responses created by deliberate perturbations within the range of the processed measurements could be accurately correlated. It is expected that additional software might be designed to identify and evaluate a transformation model correlating the ideal electrical circuit model parameters to account for the influences of the actual hardware perturbation, if necessary.

In this phase the user should have the ability to designate those filter parameters he judges to be unchanged during the corresponding perturbation as constant with respect to perturbation. Thus, the optimization package would simultaneously integrate the responses obtained from all one-at-a-time perturbations, designating as additional independent variables those so prescribed by the user. The software coding scheme for these features are expected to be quite sophisticated, since the constant with respect to perturbation variables remain as common independent optimization variables associated with the entire measurement procedure.

3. Single Filter Incremental Tuning

Within about a minute on a mainframe computer, it should be possible to produce information which will direct a well-defined sequence of hardware adjustments on a moderately detuned design, to substantially improve the response closer to the desired one. The formulation of this software can only be conceived after the software discussed in the aforementioned subsections 1) and 2) work satisfactorily. The aim of this phase of the work is to take most of the guesswork out of making several simultaneous hardware adjustments. This procedure would be repeated as necessary, updating models by computer as necessary, until final optimal tuning is achieved.

4. Single Filter Total Tuning

The finally assembled and available hardware-software system must have ability to assist in tuning and alignment faster in real time than currently possible. This will depend on many factors: speed of logging necessary measurement data, availability of powerful computer facilities on-line at the test bench, degree of ease of interaction between the test engineer, test set-up(s), computer hardware and computer software, including powerful gradient-based optimization procedures and available interactive programs. The availability and reliability of suitable electrical equivalent circuit models for realizations far from optimal solutions and their inclusion in the computer-assisted tuning software may be crucial. Easy tuning adjustments (screws) and difficult tuning adjustments (irises) will necessarily affect the overall strategy to be designed.

PROPOSALS FOR DISCUSSION ONLY

Any software to be developed by OSA will be written in Fortran and tested on a CDC 170/730 and will incorporate the general mathematical principles, definition of responses, declaration of variables, specification of constants, etc., in a manner similar to that currently available in the package MXSOS2, a program for contiguous band multiplexer simulation and optimization, Reports OSA-84-MX-1 through OSA-84-MX-10, when specialized to a single filter.

Items for consideration at this time in the initial phase of the work towards a gradient-based computer-assisted tuning package include:

- agreement on an appropriate equivalent circuit to include any known details of imperfections, losses, manufacturing tolerances, etc.
- exact simulation and sensitivities for return loss
- exact simulation and sensitivities for insertion loss
- exact simulation and sensitivities for group delay
- production of a single filter static modelling program
- production of a single filter dynamic modelling program
- the maximum order of the filters to be considered
- the maximum number of physically allowable couplings: dominant and stray
- the sophistication of any user-oriented interactive facilities
- examples, data, hardware and software facilities supplied by ComDev

Phase I

To develop a Fortran program using suitable efficient optimization techniques to solve the single filter static modelling problem using data from experimentally tuned units under test for coupling matrices of order up to 12 x 12. Minimum estimated time to completion of basic software on the CDC 170/730: two months from start. Expediency of completion of the project to take precedence over computational efficiency, unless otherwise negotiated.

Phase II

Exactly as for Phase I including provisos, but to include the dynamic modelling options from the outset: two additional months.

CONCLUSION

Until the static and dynamic problems are solved in a time and manner satisfactory to ComDev, the "incremental" and "total" tuning problems and their coding into a software system are matters for speculation, therefore, no tightly defined proposal is being formulated at this time. It is clear that general, frequency domain circuit representation to cover a sufficiently wide variety of possible manufacturing outcomes must be discussed on the basis of adequate model parameter identification experience. Discussion to determine the most appropriate frequency domain measurements to be conducted on a unit under test in situ, and the mechanisms of transfer of the digitized response data to be provided to the ultimately designed adaptive parameter identification - tuning package should take place after Phases I and II are satisfactorily executed.