COMPUTER-AIDED TUNING OF MICROWAVE CIRCUITS

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Abstract

A computer-aided tuning procedure for microwave circuits - especially multituned narrowband branching filters - has been developed. The mistuning of all elements after pretuning in a straight forward manner is small enough, thus a specially chosen network function depends nearly linear on the deviations of the tuning screws from their proper positions. These linearized relations and the regular values of the network function can be calculated from the equivalent circuit of the filter with the help of a large computer. They can then be inserted into the small computer of the measurement set-up. The appropriate changes of the tuning elements for sufficient performance of the filter together with clear tuning criteria for the operator are computed from the test values of the pretuned filter. The procedure will be repeated several times, because of the only quasi-linear relations between the deviations of the tuning elements from their proper position and the special network function.

Introduction

The tuning of microwave filters, especially those for branching networks is a highly time consuming and tedious procedure. The reason being, that the components of the microwave filter, resonators and coupling elements between the resonators, cannot be measured separately. This is only possible with the S-parameters of the filter. Furthermore, the tuning elements, mainly tuning screws, influence each other and therefore the turning of one screw tunes at least three elements, the element itself and its immediate neighbours. The tuning procedure can be shortened and simplified by a computer, which calculates the necessary adjustments of the tuning screws from a measurement of the still detuned filter.

The effectiveness of such a procedure depends primarily on the tuning algorithm and the choice of an appropriate tuning criterion. The applied algorithm is based on a complete sensitivity analysis of the nominal filter.[1] The tuning criterion is derived from the phase of the input reflection coefficient of the filter which is short-circuited at its output, exhibiting an almost linear dependence on the deviations of the tuning elements from their proper positions.[2] Because of this quasi-linear dependence the calculation of the necessary adjustments of all tuning elements is nearly correct even during the first step. Thus the iterative tuning procedure converges very fast.

The following describes the algorithm and the tuning procedure with the computation steps in the computer of the test set-up. Its effectiveness is demonstrated for a 6-resonator filter.

Theory

A number of values of a measured network function are needed for the computation of the necessary changes of the tuning elements. This number has to be larger than the number of tuning elements, since the procedure is based on an approximation.[1] Moreover these values should depend as linearily as possible on the deviations of the tuning elements from their nominal values, so that the procedure converges fast. This is the reason why the usual S-parameter-measurements are not well suited for this purpose. In comparison, the frequency deviations of the poles and zeroes of the input reactance of the shortcircuited filter fullfil the second condition very well[2]. In the complex plane of the reflection coefficient (Figure 1) the poles are the crossings of the curve with the positive real axis and the zeroes the crossings with the negative real axis.

Unfortunately, the theoretical number is reduced because of the losses of the resonators as shown by the example of a 6-resonator filter with its 7 crossings. Adding the points of $\pm 90^{\circ}$ results in 15 frequencies. This figure is larger than the 12 tuning elements (6 resonant frequencies and 6 couplers, because the last coupling element is ineffective due to the near short). However, even this is not sufficient for a convergent procedure, because near-linear dependences obviously reduce the number of useful values.

Adding the frequencies of the two minima of the magnitude in the neighborhood of the filter skirts (see Figure 1) completes the system of equations for computing the necessary corrections. It must be stressed, that it is not the magnitude of these minima which depends nearly linear on the deviations of the tuning elements, but the frequency deviations of the minima from their nominal values.

The algorithm for calculating the necessary corrections together with a pretuning procedure is described elsewhere[2]. This procedure tunes the filter to the point, where the nearly linear relations become valid. It should be emphasized, however, that it deals with pure real matrix-operations, the main part of which (the matrix inversion) will be performed in a large computer and only multiplications and subtractions are left to the small computer of the test set-up. The matrix equations, which must be accomplished by the small computer, are first the calculation of the necessary corrections Δa_i of the deviations of the above described frequencies from their nominal values $(F_{meas} - F_{nom})_j$ with the aid of the correction matrix K_{ij}:

$$|\Delta a| = \| K \| \cdot | F_{meas} - F_{nom} | \quad (1)$$

and secondly the calculation of phase changes $\Delta\varphi_i$ at distinct frequencies F_i by multiplying the diagonal matrix of the sensitivities S_{ii} with the deviations Δa_i:

$$| \Delta\varphi | = \| S \| \cdot | \Delta a | \quad (2)$$

These phase changes must be executed by the operator in sequence,one at a time at the given frequencies F_i to obtain a well-tuned filter.

Tuning Procedure

The tuning procedure will be explained with a hp automatic network analyzer (ANA), but can in principle be transferred to an arbitrary computer-aided test set-up, because of the small storage requirements. It is a characteristic of the ANA, that measurements can only be made at those frequencies, at which the system error has been measured previously, the socalled calibrated frequencies. These frequency points (max. 200) are distributed over the frequency range of interest, so that the highest density occurs in the region of the filter skirts, because that is where the largest phase-change is found. After storing the calibration data, the above described K_{ij}-matrix, the S_{ii}-digonal-matrix, the vector of the appropriate frequencies F_i and the vector of the nominal frequencies F_{nomj} are stored in the computer. The filter is then connected and shortcircuited. The measured complex reflection coefficient S_{11} is shown in Figure 1. A special procedure searches for those points of this curve which are nearest to the axis crossings. The frequencies of the axis crossings F_{measj} are found by linear interpolation. Since the distance between the frequency points is 0.5 MHz, the error is negligible. The searching for the two frequencies with the minimal magnitude is slightly more difficult. At first the computer looks for the two frequencies with the smallest magnitude of the reflection coefficient. Then the small circles are replaced by parabolic approximations in the neighborhood of the two frequencies and after that the frequencies of the minima of the two parabola are calculated. Again the error of the approximation is sufficiently small.

Equation (1) is now solved and the result displayed on the C.R.T., to indicate to the operator, which tuning elements have the greatest deviation from their nominal values. Afterwards the second equation is computed and the result displayed line by line with system interrupts. Each time the associated frequency F_i is adjusted and the operator is called to turn the screw with the index i. This method avoids choosing a wrong frequency, which could happen if the operator looks at the whole curve. Additionally, only a phase-change and not an absolute value is prescribed, so that the moving of the phase point can be observed directly without measuring in the automatic mode.

In principle the operator can execute all indicated corrections after each measurement. However, the real tuning screws differ from the theoretical tuning elements by influencing their adjacent elements. Changing the resonant frequency of a cavity resonator by a capacitive load, for example, changes the field distribution at the coupling holes to the adjacent resonators as well. This means, turning one screw involves the correction of at least three elements. As it turns out the element in the center needs the largest amount of correction. If, however, more than one element is detuned, the result of the calculation reflects by no means the real detuning. Only one thing is certain: The element with the largest correction value must be tuned. Therefore, if the filter is highly detuned, the operator is asked to correct only the element with the largest deviation. During the next step, when the errors become smaller, more than one correction may be performed at the same tune. This way, although the number of repetitions increases, the procedure remains straight forward.

A second difficulty arises from the nonlinearity at high detuning, which causes the linear algorithm to calculate slightly erroneous values for the correction. As experiment shows this error can be compensated by an automatic reduction of large correction values to about 70 %.

The limit of the accuracy for the calculation and the measurement will be reached, when the calculated phase changes for the correction are finally smaller than 1^o. The operator is now asked to remove the short and replace it with an absorber. The input reflection coefficient should now nearly fullfil the specification of the filter. For the final tuning the last coupling screw is now turned, which was ineffective due to the adjacent short. If this is only a slight tuning, the reaction on the last resonator may be neglected. Finally the four S-parameters of the filter are measured in the automatic mode of the ANA.

Example

A 6-resonator filter with a relative 3dB-bandwidth of 5.3 o/oo was chosen to demonstrate the procedure. Considering the losses of the resonators, a computer model was developed and the necessary values (sensitivity- and correction-matrix) were calculated. Only the nominal values of the axis crossing frequencies F_{nomj} were taken from a measurement of the well-tuned filter. Figure 2 shows the input reflection coefficient of this filter. Then three of the resonators were detuned by +1.9 MHz, -1,1 MHz and +1.4 MHz. Figure 3 gives the reflection coefficient of the filter in this state. The computer had calculated a necessary correction of -2.2 MHz, +1.3 MHz and -3.0 MHz respectively and some smaller corrections for the coupler.

It can clearly be seen that the direction of the correction is correct but that the linear calculation gives excessive values. In the first step only the first two resonators are corrected by the calculated values. The deviations of the first two resonators were now sufficiently small to be computed correctly and the deviation of the third resonator was calculated more accurately. In the third step the corrections for the first two resonators were exactly executed and the correction for the third resonator was reduced to 70 %. This concluded the tuning. The reflection coefficient of the filter, after detuning and tuning, is shown in Figure 4. The remaining changes are so small, that they can be tolerated.

Conclusions

A new computer-aided tuning procedure for microwave circuits has been demonstrated. After a pretuning, a linearized algorithm calculates the necessary corrections of the tuning elements from the measurement of the short circuited filter. However, the tuning screws of the filter correspond not exactly to the tuning elements of the model, because they influence their adjacent elements. Because of this only the largest corrections are executed in the first tuning steps. Moreover, large correction values from the linear calculation are reduced to about 70 % to accomodate them to the non-linearity of the tuning criterion. After a few tuning steps the remaining corrections are already small enough, to execute them at once.

Currently, an improved model of the tuning screws and a weighted correction matrix for better convergence are investigated.

Acknowledgement

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References

1. K. Antreich, E. Gleißner and G. Müller, "Computer-aided tuning of electrical circuits" Nachrichtentechnische Zeitschrift , vol 28, No. 6, pp. 200-206, 1975.

2. G. Müller, "On computer-aided tuning of microwave filters", IEEE proc. ISCAS/76, pp. 209 - 211, 1976

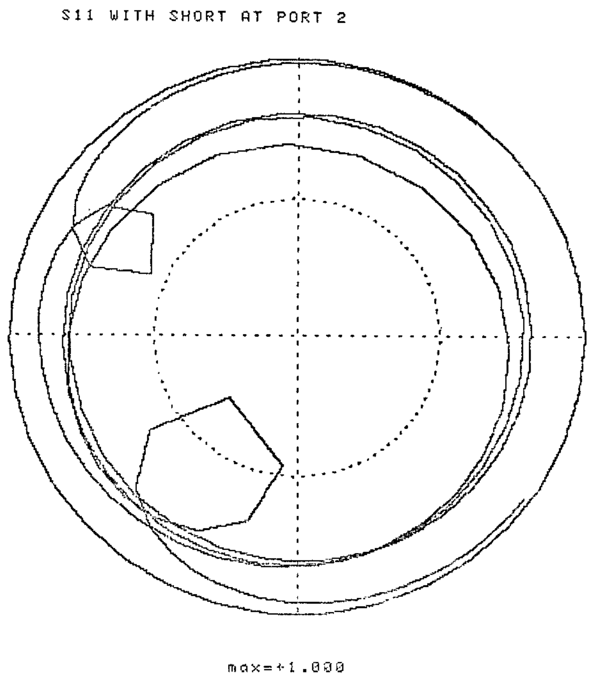

Fig. 1 Reflection coefficient of a 6-resonator filter with short circuited output

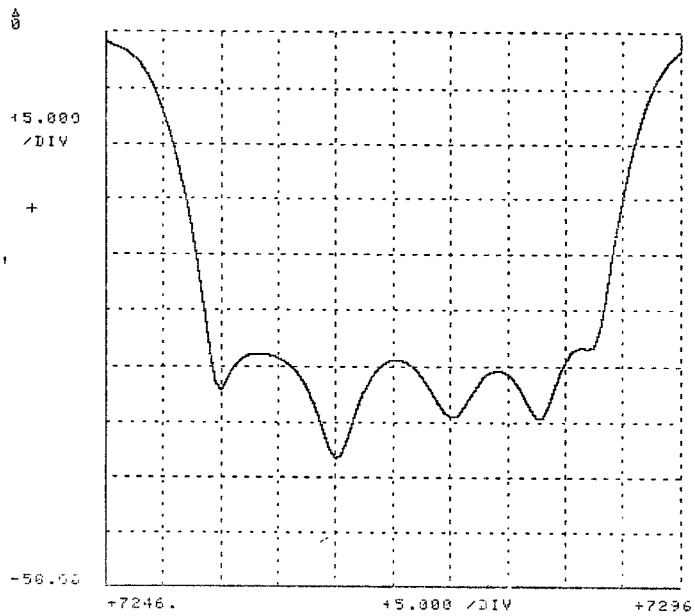

Fig. 2 Return loss of the 6-resonator filter before detuning

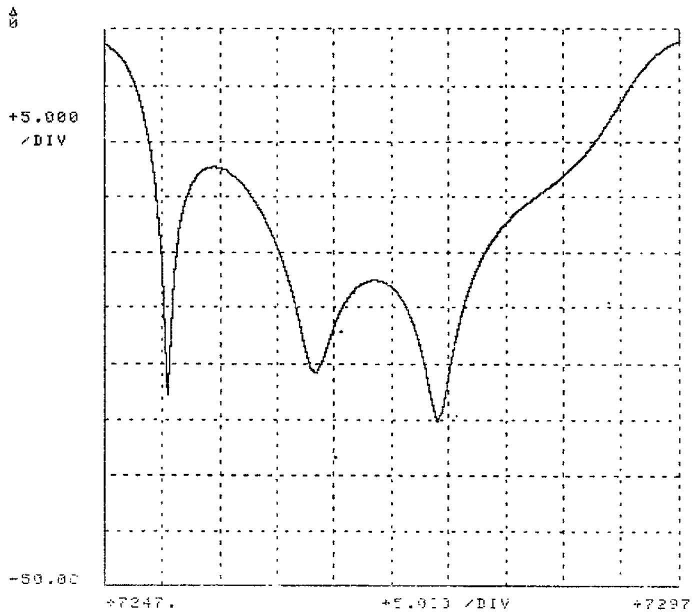

Fig. 3 Return loss of the detuned
6-resonator filter

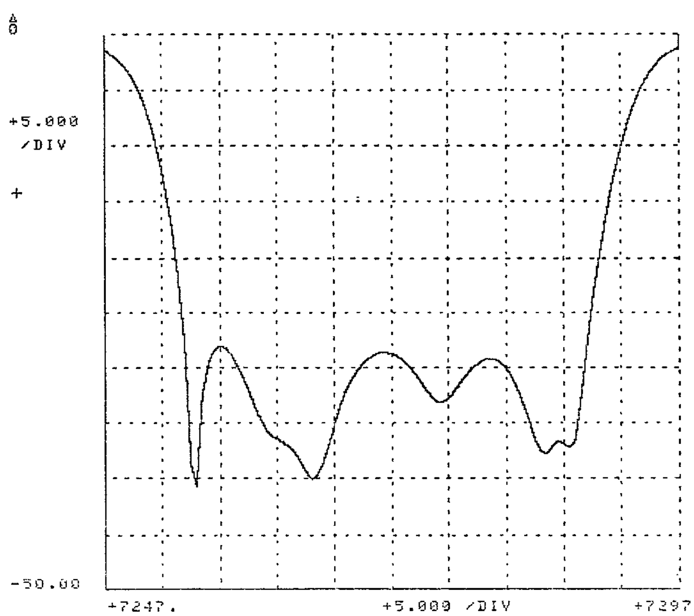

Fig. 4 Return loss after computer-aided
tuning of the 6-resonator filter