APPLICATION OF THE "EQUIVALENT PASSIVE PROBLEM" AND INTELLIGENT SYSTEMATIC SEARCHES TO THE DESIGN OF MICROWAVE AMPLIFIERS

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Abstract: Two of the main deficiencies in many of the amplifier synthesis techniques presently in use are that the non-unilateralness of the active devices used is ignored at some stage or other in the design process and that the designer is required to provide initial solutions to the problems he is trying to solve. These problems can be overcome to a large extent by using the concept of the "equivalent passive problem" and by doing intelligent systematic searches. The power of this approach is illustrated with a number of comparative examples.

INTRODUCTION

Several techniques for designing single-ended microwave amplifiers have been introduced in the last decade [1], [2], [3, 4], [5], [6], [7], [8, 9], [10]. While all of them are very powerful, some of these techniques still suffer from sub-optimalities introduced by ignoring the non-unilateralness of the device at some stage in the synthesis process and also by requiring the user to provide initial solutions to each impedance-matching or device-modification problem.

Apart from convenience, the requirement of initialization is a disadvantage in that optimization to the global optimum can seldom be guaranteed if the initial solution used is not close to the optimum to start with.

It was shown in [11] that the errors resulting from a unilateral assumption are usually not negligible in the case of typical microwave transistors. This problem can be overcome to a large extent by transforming the circle problems (constant operating or available power gain circles, or constant noise figure circles) associated with amplifier synthesis problems to exact equivalent passive problems as described in [5]. Such a transformation is possible, without making any approximations, at each frequency at which the active device is inherently stable, or was compensated to be so. The optimum point on the relevant constant gain or noise figure circle can be chosen to complete the specification of the equivalent passive problem at those frequencies at which the active device is potentially unstable.

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The problem of poor initialization can be overcome with intelligent systematic searches [5], [10].

If the right parameters are searched intelligently, these systematic searches can be done in realistic times with fast personal computers. When an impedance-matching network is synthesized, the transformation-Qs of the network can be used to do such a systematic search efficiently. When an active device is modified to decrease its inherent gain slope and/or to improve the VSWRs of the impedances to be matched, specialized algorithms can be developed based on the performance at any specific frequency in the pass band - that is, a systematic search can be done on all networks which approximate the desired performance at at least one of the passband frequencies.

Algorithms based on these principles were developed and are implemented in a commercial impedance-matching, amplifier and oscillator CAD synthesis package, MultiMatch.

The usefulness and value of the equivalent passive problem and such intelligent systematic searches are illustrated below by providing alternative solutions, as synthesized with MultiMatch, to some of the problems solved in the literature.

EXAMPLES

<u>Example 1</u>:

Single-stage, two-stage and three-stage MGF2124 11.7 - 12.2 GHz amplifiers were synthesized in [1] with the technique proposed. Two-element lowpass networks were used for impedance-matching. The gain obtained with the designed two-stage amplifier was 6.77 ± 0.63 dB and the gain for the three-stage amplifier was 8.6 ± 0.98 dB. In the latter case the input VSWR was less than 3.0 and the output VSWR less than 2.2.

It was shown in [11] that the internal feedback in an MGF2124 is not negligible and making an assumption of unilaterness can therefore be expected to yield sub-optimum results. In this particular technique, this assumption is made when the termination at the output port of the device is assumed to be the normalization impedance [8] for the purpose of finding the load impedance for the matching network connected to the input port of the active device.

This assumption is, however, not the only reason for the sub-optimal results obtained. Better results for the input VSWR could be obtained by not using it to remove some of the inherent gain slope of the device [1]. However, using this network for gain sloping should not have a negative effect on the overall transducer power gain response.

In a multi-stage design, the gain slope should preferably be removed with the interstage matching networks.

The two-stage amplifier shown in Fig. 1 was designed to provide a good input and output match and flat gain response over the pass band of interest with the same transistor. The gain levelling was done with the interstage network. The equivalent passive problem was used in each case to define the matching problem to be solved.

The gain obtained with this design was 7.93±0.9dB, the input VSWR was less than 2.33 and the output VSWR less than 1.37. While these results are very close to those obtained for the three-stage design in [1], even these results are sub-optimal. If a three-element interstage network is used, the gain improves to 8.28±0.37dB and the input and output VSWRs to less than 1.90 and 1.31, respectively.

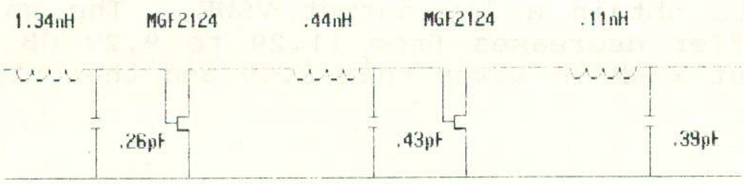

Figure 1. A two-stage MGF2124 amplifier synthesized with MultiMatch.

Because of the compromise made in synthesizing the interstage network, the performance of the two-element amplifier synthesized can be improved by optimizing it with a general-purpose optimizer.

The problem of initialization is not important in this example because of the simplicity of the networks used.

Example 2.

The single-stage amplifier shown in Fig. 2a was used in [8] as an example of the results obtainable with the lossy network synthesis technique introduced by the authors. With the component parasitics specified in [9], the gain of the amplifier is 9.58±0.9dB and the input and output VSWRs are lower than 2.8 and 2.9, respectively.

This technique maps a lossy network to a lossless one and uses the simplified real-frequency technique introduced by Yarman and Carlin [1] to synthesize matching networks for an amplifier. Apart from the extension to lossy synthesis, it is an improvement on Yarman's technique in that the output port of the transistor is assumed to be terminated in the conjugate of its output impedance when the input network is synthesized (it is not clear how this impedance is known if the device is not unilateral).

The amplifier shown in Fig. 2b was synthesized with MultiMatch. The networks synthesized were assumed to be lossless for the purpose of synthesis. With the losses taken into account, the gain of this amplifier is 9.50±0.67dB, the input VSWR less than 2.09 and the output VSWR less than 1.63. Since the design is based on lossless matching networks, it is likely that the performance can benefit from optimization with a general-purpose optimizer.

From a comparison of the two circuits, it is clear the topologies of the matching networks are different and that the second amplifier has an extra element in its output matching network. If only two elements are used in the output network, the response of the first amplifier is better than the second. However, this can be attributed to the fact that two elements solve the output matching problem poorly.

In order to allow some comparison to be made, MultiMatch was used to synthesize a three-element output matching network for the first amplifier. Since the output match of the second amplifier is good, the goal was to obtain a low output VSWR. The gain of the re-designed amplifier decreases from 11.29 to 9.29 dB over the pass band, the input VSWR is lower than 2.69 and the output lower than 1.35.

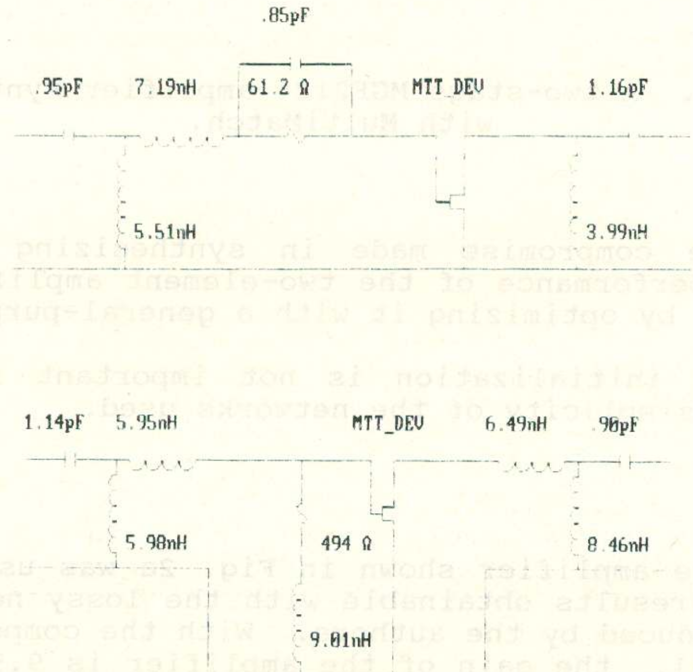

Figure 2. (a) The lossy matching-network amplifier synthesized in [8]. (b) An alternative amplifier synthesized with MultiMatch.

The minimum gain of this amplifier (9.29dB) is somewhat higher than that of the second (8.83dB), the gain ripple (slope) is larger, the input VSWR is worse and the output VSWR is of similar quality. From the viewpoint of having low input and output VSWRs and a flat gain response, one could therefore conclude that the input network is sub-optimal. It should be designed to remove the 2 dB gain slope still present in the response too and to yield a lower input VSWR.

Example 3.

This example consists of a comparison between the NEC70000 amplifier synthesized in [6] and some of the results obtained with MultiMatch.

Difficulty was experienced in [6] to obtain good results with the NEC70000 when matching networks with less than 10 elements were synthesized. No difficulties were experienced to get acceptable results with 3 element networks when MultiMatch was applied to the problem. The amplifier synthesized is shown in Fig. 3 (G_T = 5.05 ± 0.54 dB; VSWR-I ≤ 1.61; VSWR-O ≤ 2.03).

The main reason for the difficulties experienced in [6] is that analytical gain-bandwidth and filter synthesis theory was used to generate initial solutions to the matching problems solved.

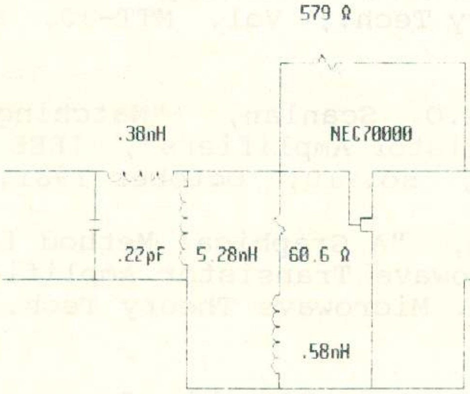

Figure 3. An NEC70000 amplifier synthesized with MultiMatch.

Example 4.

It was mentioned in [3] that the authors experienced some difficulty in obtaining a good response with an NE464194 transistor over the 3.7 - 4.2 GHz pass band without using feedback. An attempt was made with MultiMatch to get acceptable results without using feedback. On observing the results obtainable with the different built-in options, it was found that series resistive-loading on the input was the best option. The synthesized amplifier is shown in Fig. 4. The gain is 10.49 ± 0.10dB, the input VSWR is less than 1.70 and the output VSWR less than 1.49. The Linville stability factor is less than 0.76 over the pass band (K > 1.3).

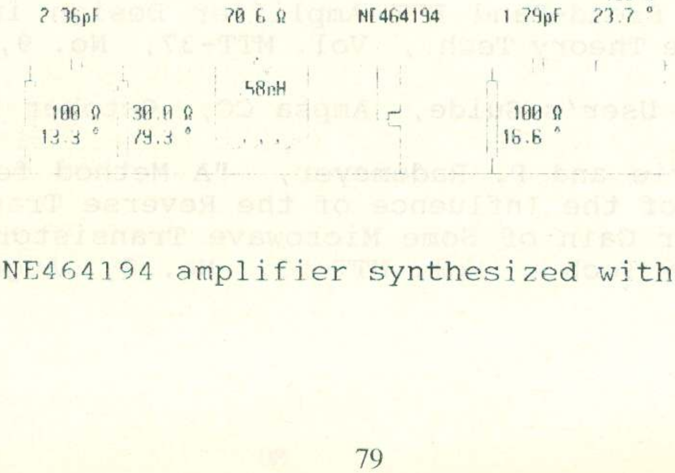

Figure 4. An NE464194 amplifier synthesized with MultiMatch.

SUMMARY

It was shown that some of the amplifier synthesis techniques presently in use yield sub-optimal results. The main reasons for this are the unilateralness assumption made at some point or other in the synthesis process and the initialization requirement. Possible solutions to these two problems were considered and the results obtainable with these techniques were compared to some of the published results.

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