A SERIES OF CAD TECHNIQUES FOR DESIGNING MICROWAVE FEEDBACK AMPLIFIERS AND SIMPLIFYING THE DESIGN OF REACTIVELY MATCHED SINGLE-ENDED AMPLIFIERS

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ABSTRACT

A series of CAD techniques is introduced which is useful for modifying the characteristics of transistors for use in microwave amplifiers. Two applications are presented: In the first, some of these techniques are applied to the design of feedback amplifiers and in the second two transistors are modified for easier matching and a flat transducer power gain versus frequency response in a single-stage amplifier configuration.

INTRODUCTION

Several useful techniques for designing single-ended microwave amplifiers have been introduced in the last decade. Some of these are the real-frequency techniques introduced by Carlin, Yarman and Komiak (1) (2) (3), the graphical methods for designing feedback networks and lossy matching networks introduced by Villar, Perez and Ortega (4) (5) and the lossy matching techniques introduced by Zhu, Sheng and Wu (6) (7).

In this paper a series of device modification techniques is introduced which is complementary to those of Villar, Perez and Ortega.

The amplifier design philosophy followed in this paper is to use lossless networks for impedance matching. The effect of losses and parasitics can be taken into account and reduced with a general-purpose optimizer once the basic design is completed. This approach yields excellent results as long as the losses are not severe, which is usually the case.

Impedance matching is done with the transformation-Q "real-frequency" technique described in (8). The equivalent passive problem as defined in (8) is used to define the matching problem to be solved in each case.

Before synthesizing a matching network, the associated active device is first modified to

i. Stabilize it.
ii. Remove or reduce the inherent gain slope.
iii. Improve the VSWRs of the impedances to be matched.

In the device modification techniques to be described here, intelligent systematic searches are done to find suitable modification components. The ten best solutions found in such a search are then optimized. This approach increases the probability of finding the globally optimum solution and frees the designer from having to provide initial solutions.

The following modification combinations will be considered here:

i. Simultaneous voltage-shunt feedback and shunt resistive-loading at the input or output terminals of the active device.

ii. Simultaneous voltage-shunt and current-series feedback.

Based on the theory presented here, it is a simple matter to derive the equations necessary to search for the optimum components associated with other combinations. In general, the circuit designer would be interested in combinations of voltage-shunt feedback, current-series feedback, shunt resistive-loading and series resistive-loading.

It is assumed that each modification section consists of only two components (series or parallel RL or RC). This implies a total of four unknown elements for each modification problem.

The theory underlying these techniques is described below. The results obtainable with some of these techniques are then illustrated with examples.

SIMULTANEOUS VOLTAGE-SHUNT FEEDBACK AND SHUNT RESISTIVE-LOADING AT THE INPUT OR OUTPUT TERMINALS OF THE ACTIVE DEVICE

Assuming, initially, that no matching networks will be used to improve the performance of the amplifier (single-stage), the basic problem in this case is to find values for the four components associated with Y_F and Y_I in Fig. 1 which will result in a flat transducer power gain versus frequency response and low input and/or output VSWRs over the pass band of interest.

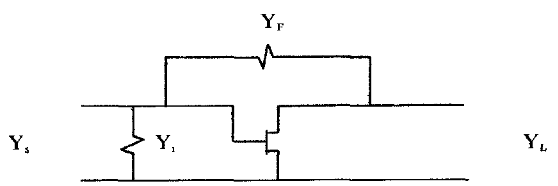

Figure 1. Simultaneous voltage-shunt feedback and shunt loading.

Such values can be found by doing a systematic search on all the combinations which will yield the required transducer power gain (G_T) at any specific frequency in the pass band, with the input or output impedance of the device assumed to be perfectly matched. A number of the best initial solutions found can then be optimized for best performance over the whole pass band.

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In order to do the search, it is necessary to derive the equations for the locus of feedback admittances (Y_F) which will result in the operating power gain (G_w) of the modified device being equal to the required transducer power gain (G_T) at the frequency of interest (input impedance assumed to be matched). Alternatively, the search can be done on combinations which will yield some specified value of available power gain (G_a; output impedance assumed to be matched).

It can be shown that the locus of the required Y_F-values is a circle in both cases. A unique Y_i-value (Y_o-value) exists for each Y_F-value. For some points on the Y_F-circle circumference the real-part of Y_i (Y_o) may be negative.

The equations defining the center ($Y_F = G_F + jB_F$) of the Y_F circle and its radius (R_F) are the following:

$$G_F = (\alpha g_x + g_{21})/(1-\alpha) \quad (1)$$

$$B_F = (\alpha b_x + b_{21})/(1-\alpha) \quad (2)$$

$$R_F^2 = (|y_{21}|^2 - \alpha |y_x|^2)/(\alpha-1) + |Y_F|^2 \quad (3)$$

where

$$g_x + jb_x = y_{22} + Y_L \quad (4)$$

$$\alpha = G_w G_s / G_L \quad (5)$$

The equations for a specified value of the available power gain (G_a) at a given frequency are identical if y_{22} is replaced with y_{11}, Y_L with Y_s, G_s with G_L, and Y_i with Y_o (Y_i or Y_o is chosen to provide a conjugate match at the relevant port).

The same equations can be used to search for suitable initial solutions if the maximum available power gain of the device (MAG) is to be controlled instead of the transducer power gain (G_T). This is necessary when matching networks will be used to improve the performance. The error function used during the search and optimization phase is then obviously different.

SIMULTANEOUS VOLTAGE-SHUNT AND CURRENT-SERIES FEEDBACK

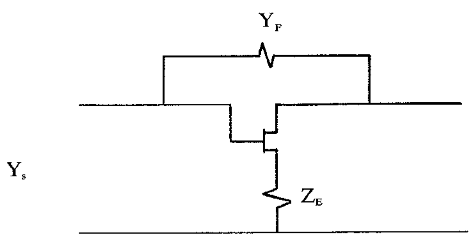

Figure 2. Simultaneous voltage-shunt and current-series feedback.

The derivation of the equations applicable to this combination is similar to that of the voltage-shunt feedback / shunt resistive-loading case. If suitable approximations are made, the locus of required Y_F-values is again a circle. A unique value of Z_E is associated with each Y_F-value.

The effect of the approximations made can be reduced by doing a one dimensional search along the radius of the circle for the correct Y_F-value at each angular position.

EXAMPLES OF FEEDBACK AMPLIFIER DESIGNS

In this first series of examples, a number of transistors are modified for use without any reactive matching, that is, the transducer power gain versus frequency response is levelled. The input and output VSWRs are good enough in each case not to require any reactive impedance matching.

<u>Example 1</u>:

In this example an MAR8 transistor was modified over the pass band 0.1 - 1.5 GHz. The transducer power gain resulting from the voltage-shunt / current-series feedback combination is 18.50$\pm$0.21dB, the input VSWR is less than 1.27 and the output VSWR less than 1.10. The S-parameters of the device before and after modification are shown in Fig. 3, with the associated circuit (s_{12} is not ignored, it is simply not shown).

The transducer power gain resulting from the voltage-shunt feedback / shunt resistive-loading combination is 18.51$\pm$0.14dB, the input VSWR is less than 1.57 and the output VSWR less than 1.20. The required components are R_F = 482Ω, L_F = 28.6nH, R_i = 213Ω and L_i = 24.6nH.

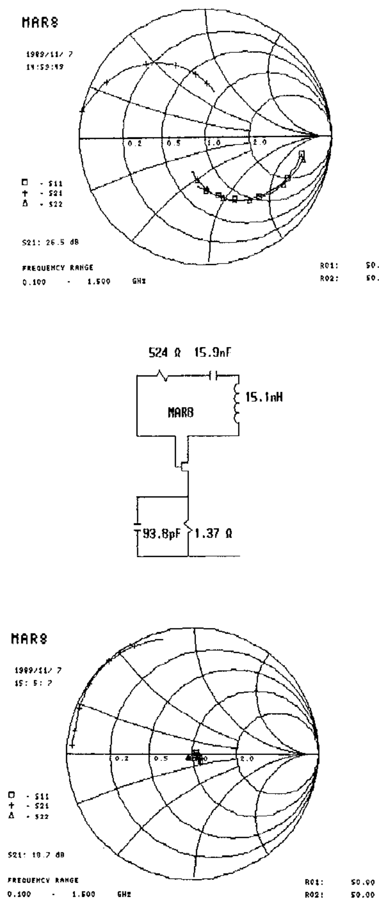

Figure 3. (a) s_{11}, s_{21} and s_{22} of the MAR8 before modification. (b) A possible modification circuit and (c) the associated S-parameters.

Example 2.

In this example an AT572 was modified over a 100 - 400 MHz pass band for use in a 75Ω system.

The transducer power gain resulting from the voltage-shunt / current-series feedback combination is 15.22±0.22dB, the input VSWR is less than 1.21 and the output VSWR less than 1.45. The parameters of the device before and after modification are shown in Fig. 4, with the associated circuit.

The transducer power gain resulting from the voltage-shunt feedback / shunt resistive-loading combination is 14.97±0.28dB, the input VSWR is less than 1.56 and the output VSWR less than 1.68. The required components are R_F = 620Ω, L_F = 100.0nH, R_i = 176Ω and L_i = 43.2nH.

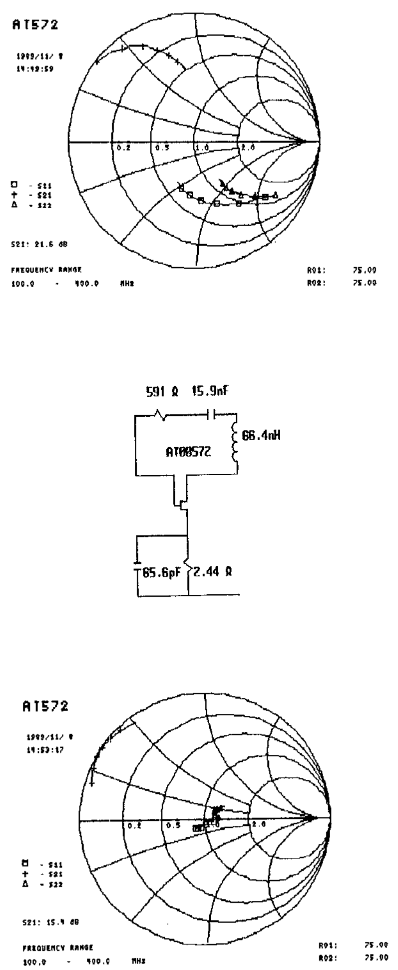

Figure 4. (a) s_{11}, s_{21} and s_{22} of the AT572 before modification. (b) A possible modification circuit and (c) the associated S-parameters.

EXAMPLES OF REACTIVELY-MATCHED AMPLIFIERS

In this second set of examples the maximum available power gain (MAG) and VSWRs of two devices are modified. Reactive impedance matching is then used to improve the VSWRs further and to extract the maximum possible transducer power gain from each device over the pass band of interest.

Example 3.

In this example an NEC70000 was modified for use over the 2 -18 GHz pass band. Matching networks were then synthesized to complete the design of the amplifier. The designed amplifier is shown in Fig. 5, with the circuit. The gain of the amplifier is 5.05±0.54dB, the input VSWR is less than 1.61 and the output VSWR less than 2.03.

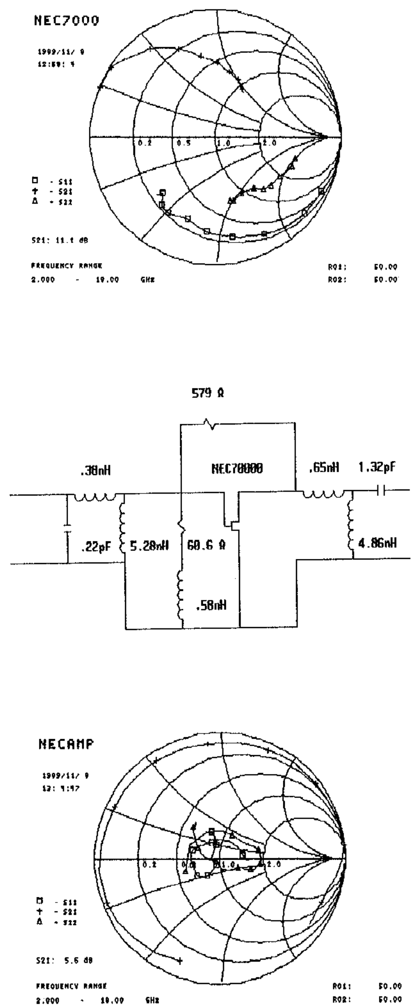

Figure 5. (a) s_{11}, s_{21} and s_{22} of the NEC70000 before modification. (b) An amplifier synthesized with the modified device and (c) the associated S-parameters.

Example 4.

In this example a BFR91A transistor was modified for use over the 0.1 - 1.0 GHz pass band. Matching networks were synthesized to complete the design of the amplifier. The designed amplifier is shown in Fig. 6, with the circuit. The gain of the amplifier is 10.32±0.27dB, the input VSWR is less than 1.50 and the output VSWR less than 1.69.

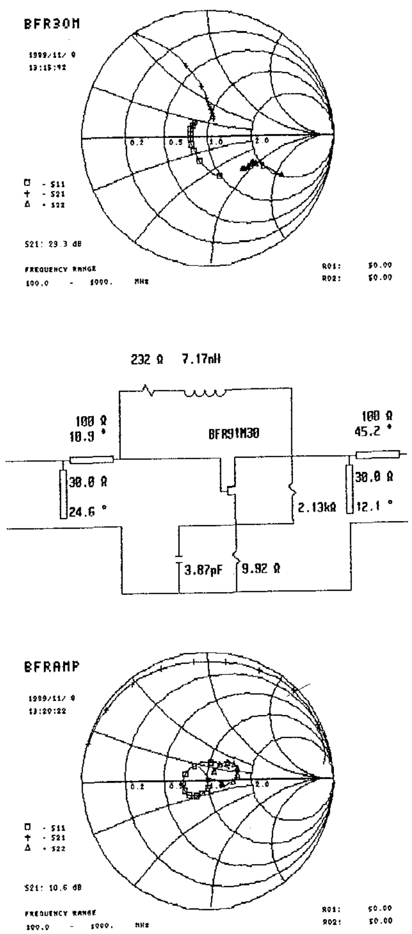

Figure 6. (a) s_{11}, s_{21} and s_{22} of the BFR91A before modification. (b) An amplifier synthesized with the modified device and (c) the associated S-parameters.

SUMMARY

A series of CAD techniques for designing microwave feedback amplifiers and simplifying the design of reactively matched single-ended amplifiers was decribed. The results obtainable with some of these techniques were illustrated with examples. The usefulness of the proposed techniques is apparent from these examples.

ACKNOWLEDGMENT

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