MATCHING STRUCTURES FOR HIGH YIELD AMPLIFIER DESIGN

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ABSTRACT

Circuit yield is evaluated for the commonly used narrowband lumped and distributed parameter matching structures. It is shown that each structure has highest yield for load impedances in a given region on the Smith Chart. A simple design chart is developed which gives the designer a high yield matching structure for any given load impedance. Two examples illustrate its use.

INTRODUCTION

There are three main ways to improve the manufacturing yield of a microwave amplifier. First the component tolerance can be decreased. However the tolerance is generally inversely proportional to the component cost, and components with very narrow tolerance may not be obtainable at any cost. In monolithic microwave integrated circuits (MMICs), some parameters vary as much as +/- 17%, with no way to reduce the variation. The second way to improve yield is through the process of design centering or statistical circuit design [1]. The drawbacks to this method of yield improvement are the software is not readily available and it is very computer intensive. The third method is to choose the most tolerant structure for the design. Very little work has been done in this area [2]. The purpose of this paper is to report the results of an extensive study on the yield performance for some commonly used narrowband microwave matching structures. The results of this paper give the design engineer a simple method of choosing among the matching structures studied to give the highest yield matching design.

METHODS

The matching structures evaluated in this study consist of both lumped and distributed parameter components and are pictured in Figures 1 and 2 respectively. The structures are used to match a complex load impedance to 50 Ohms. In order to determine the yield for each structure at different loads, a total of 34 load values were chosen for the simulation. These values were chosen so that they covered the entire Smith Chart on lines of constant Q (Q=.5,2,5). The yield for each structure at each load impedance was estimated using standard Monte Carlo

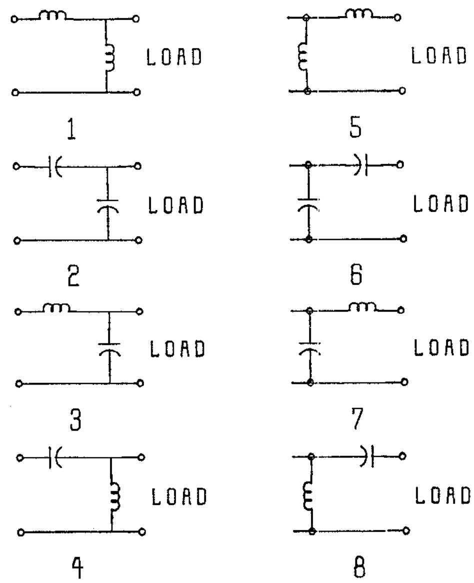

Figure 1 - Lumped Parameter Matching Circuits

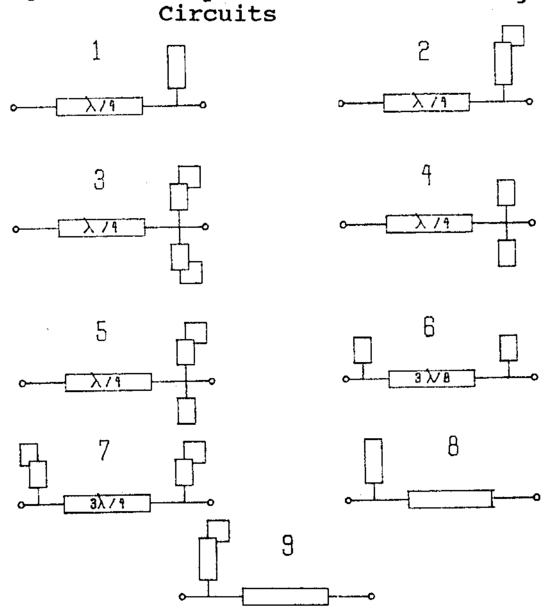

Figure 2 - Distributed Parameter Circuits

techniques [1]. All estimates were made at one frequency. The tolerance on each parameter in the matching structure was +/- 10% of the nominal value and the parameters were assumed to be uniformly distributed and uncorrelated. To conserve computer CPU time, the load was not varied, however these results have also been verified for small load variations. The specification applied to the circuit is |S11| less than a given value. Table 1 shows typical yield calculations for the lumped parameter structures at different load impedances. This data is typical of that generated in this study and is only a small fraction of the total data. In all, approximately 180 CPU hours on an HP 200 series computer were used in this study.

STRUCTURE NUMBER	LOAD IMPEDANCE .1+j2	.3+j.6	.8+j1.6	2+j4	4-j2	.9-j.45
1	---	73	74	---	---	---
2	---	---	---	---	---	57
3	28	---	---	---	---	74
4	35	52	81	---	---	---
5	---	35	36	---	---	---
6	---	---	---	---	---	54
7	---	72	46	33	42	---
8	---	---	---	65	33	100

Table 1 - Typical Yield Calculations

RESULTS

Despite the massive amounts of data generated, the results of this study are very concise and are easily presented graphically on a Smith Chart. Figure 3 presents the results for the lumped element structures and Figure 4 presents the results for the distributed element structures. Each arrow in these figures associates the highest yield structure for each region of load impedances on the Smith Chart. As can be seen from Figure 4, of all the distributed parameter structures, only two consistently gave high yield for the load impedances studied. For load impedances in the top half of the Smith Chart, the quarter wave transformer and an open parallel stub consistently gave the highest yield, and for load impedances in the bottom half of the Smith Chart a quarter wave transformer and a shorted parallel stub gave highest yield. At a few of the load impedance points studied, the results of Figure 4 were violated, however the high yield structure outperformed the given structure only slightly and the higher performance was maintained only over a small set of load impedances. Figures 3 and 4 give the design engineer a useful guideline for choosing among matching structures when performing a narrowband amplifier design. The effect of the structure choice on circuit yield can be significant, as is illustrated in the following examples.

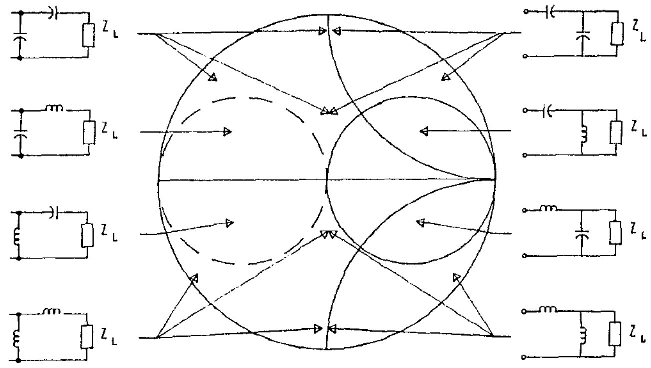

Figure 3 - High Yield Lumped Parameter Matching Circuits

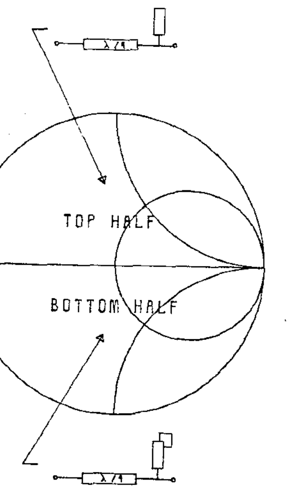

Figure 4 - High Yield Distributed Parameter Matching Circuits

LUMPED PARAMETER DESIGN EXAMPLE

A 4GHz single stage amplifier design is examined. The specifications for the amplifier are |S11| < -20dB, |S22| < -20 dB, and no specification on S21 and S12. This example uses lumped element matching structures to match the input and output to 50 Ohms. The S-parameters of the transistor at 4 Ghz are: S11 = .52/-80, S12 = 0, S21 = 2.0/80, and S22 =.54/-46. The unilateral assumption was made on the transistor because the results of this study were developed using one-ports. All possible circuit configurations using the lumped matching structures in Figure 1 are shown in Figure 5. Plotting S11 and S22 on Figure 3 shows that the high yield input structure is series L, shunt L and the high yield output structure is shunt C, series L. Table 2 gives the yield calculation for each circuit shown in Figure 5. As the table shows, structure A6 has the highest yield, as predicted by the

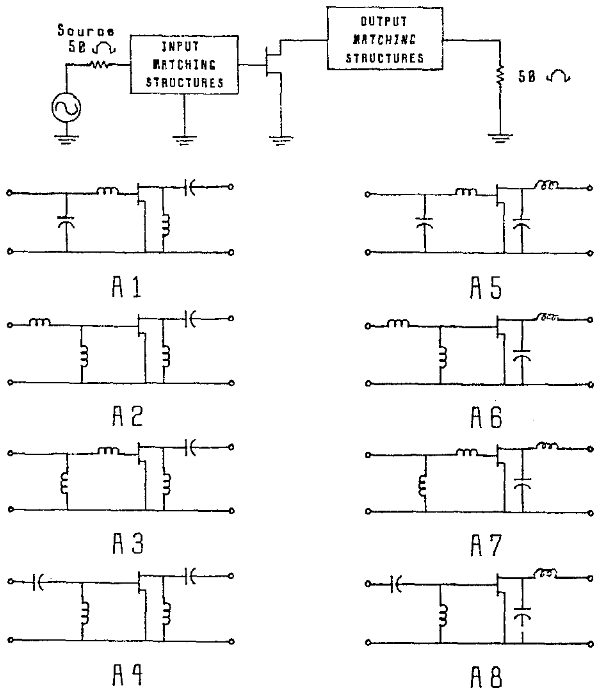

Figure 5 - Example Matching Structures

DESIGN NUMBERS	% YIELD
A1	68.2
A2	74.8
A3	66.9
A4	61.2
A5	78.9
A6	84.7
A7	76.0
A8	70.0

Table 2 - Example Yield Calculations

Smith Chart in Figure 3. An important point to note from this example, aside from the fact that the Figure 3 Smith Chart predicted the highest yield structure, is that the structure changes caused yield variations from 61.2% to 84.7%. The effect that structure has on circuit yield is not universally known, and as a result lower yield circuits are sometimes designed and manufactured.

DISTRIBUTED PARAMETER AMPLIFIER EXAMPLE

In this example, two amplifiers were designed to test the validity of the results of the distributed parameter Monte Carlo study. The S-parameters (at 4 GHz) to be used are listed below:

S11 = .895/-33.53
S21 = 2.5/95
S12 = 0 (i.e., unilateral assumption)
S22 = .821/-91.27

The first amplifier (amp 1) will use a quarter-wave line and a shorted stub matching structures for the input and output. This structure is labeled #1 in Figure 6. The second amplifier (amp 2) will use quarter-wave lines and open stubs which are labeled #2 in Figure 6. For this transistor both S11 and S22 are in the lower half of the Smith Chart. From an examination of Figure 4, Amp 1 is predicted to have the highest yield. The two amplifiers were designed and a yield calculation was done for :

|S11| < -8 dB
|S22| < -8 dB,

and no criteria was placed on S21. A +-10% uniform distribution was used on the line length and width parameters. The analysis was done at a single frequency. Amp 1 was found to have a yield of 23% and Amp 2 was found to have a yield of 7%. Not only did Amp 1 have the higher yield as predicted, but Amp 1 has a yield that is three times higher! This dramatically demonstrates the effect that structure can have on manufacturing yield.

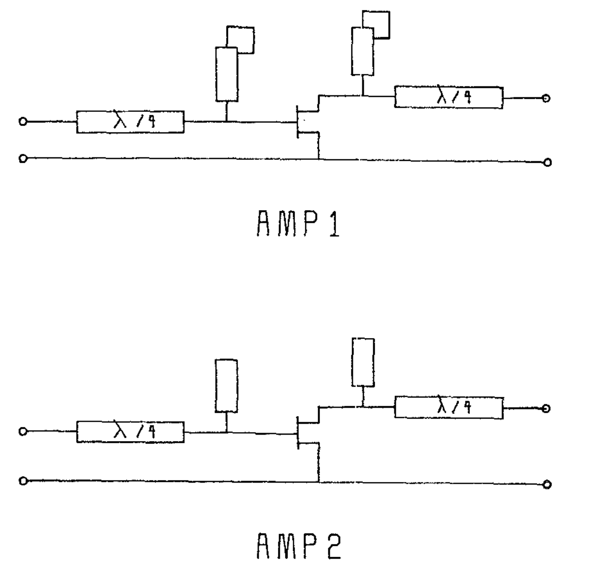

Figure 6 - Example Amplifiers

CONCLUSIONS

One of the accomplishments of this paper is to demonstrate conclusively the strong effect circuit structure has on circuit yield. In the example, circuit yield varied from 61% to 84% when the circuit structure was changed. Since circuit structure strongly affects circuit yield, the circuit designer needs a method for evaluating circuit yield for the different structure choices. This paper presents the results of an extensive simulation study which, for the first time, gives the design engineer such a method. The extensive data generated in this study simplifies to the design charts presented in Figures 3 and 4 for lumped and distributed narrowband matching structures respectively. The example demonstrates how the charts can be used to make high yield circuit matching structure choices. We have verified that the high yield matching structure is also the widest bandwidth structure, although there appears to be no numerical relation between bandwidth and yield. Also in the distributed parameter case we observe that small structures usually give the highest yield.

A theoretical study to estimate the yield of the simple lumped element matching structures in closed form has also been accomplished. These theoretical results explain the symmetry seen in the Figure 3 Smith Chart. The theoretical results are in total agreement with the simulation results presented here. The details of this theoretical study will be presented in a later publication.

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REFERENCES

[1] MacFarland, A., Purviance, J., Loescher, D., Diegert, K., and Ferguson, T., "Centering and tolerancing the components of microwave amplifiers," Proc. 1987 IEEE MTT-S International Symposium.

[2] Kumar, M., Taylor, G., and Huang, H., "Design considerations for monolithic GaAs FET amplifier," 1980 GaAs Symposium, Paper 13.