HIGH YIELD MATCHING STRUCTURES FOR 20% BANDWIDTH MICROWAVE AMPLIFIERS

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ABSTRACT

Circuit yield is used as a criterion to choose among possible input-output, lumped, lossless, two and three element matching structures, considering a bandwidth constraint on the match of 10% and 20%. A new design chart is presented. An amplifier design example shows the use of the design chart and shows yield variations from 0% to 69% as a function of structure choice.

1.0 INTRODUCTION

Matching structures are used in microwave/RF amplifier design to transform impedances. This is necessary so that maximum power transfer or low noise can be achieved. This paper will consider lossless matching networks with lumped elements (L's and C's) which match a load impedance to 50 ohms.

A question that is often overlooked in microwave/RF amplifier design is how manufacturable is the design. During manufacture the component values vary randomly according to some joint distribution. A measure of the manufactureability of a circuit is its yield which is the percent of the circuits which meet specifications during manufacture.

Given a fixed statistical variation on the component values during manufacture, there are two main design decisions which affect the yield of a circuit: the design nominal values and the circuit structure. Choosing the design nominal values for high yield is different from circuit performance optimization and is called design centering [1]. The effect that design centering can have on yield has been demonstrated and has been the subject of research for many years [1]. However, it has been shown only recently that the choice of circuit structure can also strongly affect the yield of a circuit [2,3]. In this past study only two-element matching structures were considered and the effects of frequency variations on the high yield structure choice were not discussed. Presently a circuit designer has no direct way to determine the highest yield 2 or 3 element matching structure when there is a bandwidth constraint on the circuit specification. This paper solves the problem.

2.0 METHODS

The purpose of this study is to use circuit yield as a criterion to choose among possible matching structures for a given load, when there's a specification on the match over a 10% to 20% bandwidth. We will consider both two-element and three-element lossless, lumped structures.

2.1 Two-Elememt Structures

Figure 2.1 shows all of the possible 2-element lossless lumped structures. Not all loads can be transformed to 50 ohms by every structure. Shown in figure 2.2 is a Smith Chart that has been broken into six different regions. Table 2.1 shows which structures can technically match a load impedance in a given region, to a 50 ohms source.

REGION	STRUCTURES
1	3,4,5,6
2	1,2,7,8
3	6,8
4	6,8
5	5,7
6	5,7

TABLE 2.1
THE REGION OF LOAD IMPEDANCES FROM FIGURE 2.2 THAT CAN BE MATCHED BY THE 2-ELEMENT LUMPED STRUCTURES IN FIGURE 2.1.

Using table 2.1 one can choose a matching structure for any load impedance point. But as shown in the table there is more than one structure choice for any load impedance. We will use circuit yield to choose among the possible structures. The design method used for the 2-element circuits is to perfectly match the circuit at the bandwidth center frequency.

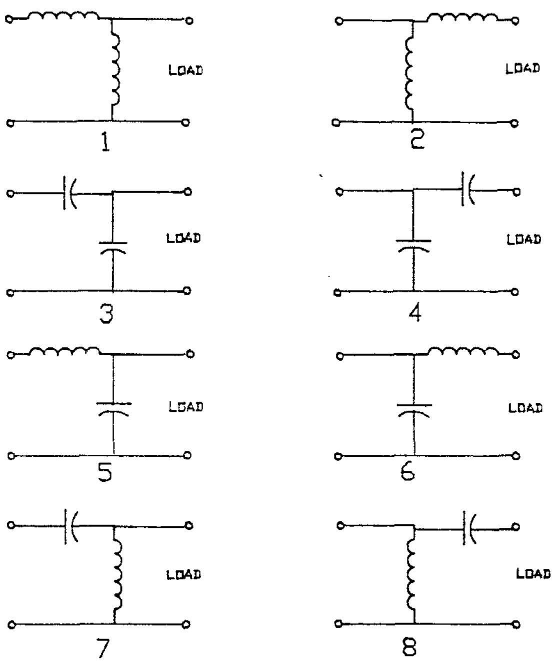

FIGURE 2.1
LUMPED TWO-ELEMENT MATCHING STRUCTURES

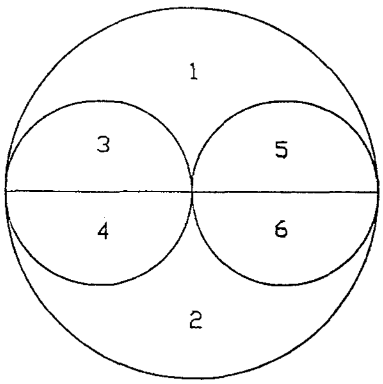

FIGURE 2.2
IDENTIFICATION OF SIX REGIONS
ON THE SMITH CHART

2.2 Three-Elememt Structures

In this study we will consider Pi and Tee 3-element structures. Shown in figure 2.3 are the Pi and Tee structures where each impedance block can be a capacitor or an inductor. Figure 2.4 shows the loads that will be used. These impedance points cover only the top half of the Smith Chart. This is sufficient to predict the yield for all other loads because of the dual symmetry in the structure analysis [3].

Since 3-element lumped structures have three degrees of freedom, for a given structure, any impedance point can be matched with a large number of possible designs. Since in this work we wish to determine the most manufacturable tolerant 3-element input-output structures, we first must determine a good 3-elememt design method.

Two different 3-element design methods will be used, one for load impedances inside the unit circles, (regions 3,4,5,6) and one for load impedances outside the unit circles (regions 1,2). The design method used for load impedances inside the unit circles will be the low internal Q technique [4]. For load impedances outside the unit circles a design method was used where the first element of the 3-element structure moves the load impedance or load admittance to a point on the Smith Chart half way between the load and the point were the two-element design would intersect the admittance unit circle.

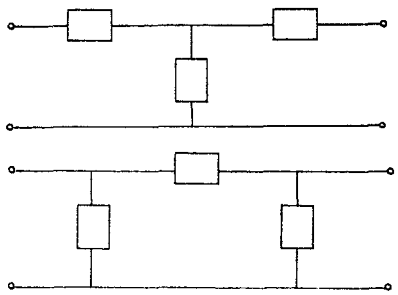

FIGURE 2.3
PI AND TEE STRUCTURES

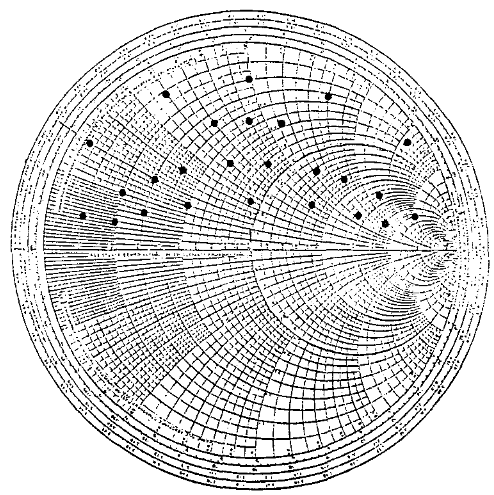

FIGURE 2.4
LOAD IMPEDANCES FOR THE THREE-ELEMENT
SIMULATIONS

3.0 RESULTS

Using the structures and loads and the design techniques given in Section 2, a yield analysis was done for every possible combination, over 10% and 20% bandwidths, using Touchstone Monte Carlo [5]. The circuit parameters were varied +/- 10% with uniform uncorrelated distributions. The results from the numerous yield calculations were analyzed and the highest yield structure for a specific load impedance was identified. Table 3.1 gives a sample of the data from the yield simulations.

LOAD	CIRCUIT	% YIELD	LOAD	CIRCUIT	% YIELD
.06+j.3	A	90.7	.1+j.1	5	0
.06+j.3	B	0	.1+j.1	6	38.6
.06+j.3	C	99.7	.1+j.1	7	44.2
.06+j.3	D	56.4	.1+j.1	8	87.2
.06+j.3	E	97.3			
.06+j.3	F	99.7	.3+j.3	5	0
			.3+j.3	6	12.6
.35+j.7	A	44.3	.3+j.3	7	91.9
.35+j.7	B	0	.3+j.3	8	91.6
.35+j.7	C	84.0			
.35+j.7	D	0	2.5+j2.5	1	0
.35+j.7	E	77.5	2.5+j2.5	2	25.4
.35+j.7	F	92.2	2.5+j2.5	3	96.9
			2.5+j2.5	4	94.6
.45+j.9	A	70.9			
.45+j.9	B	0	1.25+j1.25	1	0
.45+j.9	C	68.1	1.25+j1.25	2	62.2
.45+j.9	D	0	1.25+j1.25	3	86.9
.45+j.9	E	89.8	1.25+j1.25	4	90.7
.45+j.9	F	88.5			

CIRCUIT A - SERIES C, PARALLEL C
CIRCUIT B - SERIES C, PARALLEL L
CIRCUIT C - PARALLEL C, SERIES C
CIRCUIT D - PARALLEL C, SERIES L
CIRCUIT E - PARALLEL C, SERIES C, PARALLEL C
CIRCUIT F - SERIES C, PARALLEL C, SERIES C
CIRCUIT 1,...,8 as labeled in Figure 2.1.

TABLE 3.1
SAMPLE OF YIELD CALCULATIONS

It can be seen by examination of all the data (and illustrated in the sample data) that a 3-element structure always has the highest yield no matter whether the load impedance is inside or outside the unit circles. And furthermore certain 3-element structures have the highest yield for certain load impedance regions.

Figure 3.1 shows the results of the yield simulations in graphical form. This figure associates with each region of load impedances on the Smith Chart the 3-element structure which gives the highest yield. When two high yield structures are associated with a specific region, the designer is advised to check each structure to see which gives the highest yield.

4.0 EXAMPLE

This example uses a single transistor amplifier. It demonstrates the design procedure for choosing the highest yield amplifier design using two or three-element input-output lumped matching networks with the aid of the design chart in figure 3.1.

The S-parameters, at 4 GHz, for the transistor in this example are given below.

S_{11} = .84/-136, S_{21} = 2.36/92,
S_{12} = 0 (unilateral), S_{22} = .86/-52.

The unilateral assumption is used in this example because the design chart in figure 3.1 was developed for one-ports and the chart is not valid otherwise. For this example a 20% bandwidth was chosen. The S-parameters are constant over frequency.

The design procedure is as follows:

1) Plot S_{11} and S_{22} on the Smith Chart.
2) Refer to figure 3.1 and determine which set of high yield input output structures should be used for the given S-parameters.
3) Continue normal single frequency design procedure.

Plotting S_{11} and S_{22} on the Smith Chart, figure 3.1 shows that the high yield input structure is a series L, shunt L, series L, and the high yield output structure is a shunt L, series L, shunt L where the load is on the right. Table 4.1 lists the different amplifier configurations for 2-element (A1-A16) and 3-element (A17-A20) input-output lumped structures.

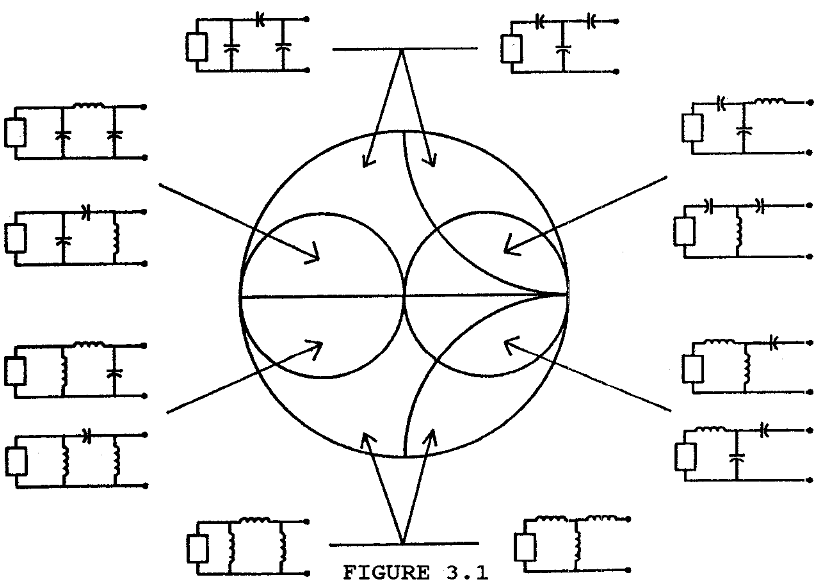

FIGURE 3.1
10% AND 20% BANDWIDTH HIGH YIELD MATCHING STRUCTURE CHART

AMP DESIGN	INPUT STRUCTURE	OUTPUT STRUCTURE
A1	shunt L-series L	series L-shunt L
A2	shunt L-series L	shunt L-series L
A3	shunt L-series L	series L-shunt C
A4	shunt L-series L	shunt L-series C
A5	series L-shunt L	series L-shunt L
A6	series L-shunt L	shunt L-series L
A7	series L-shunt L	series L-shunt C
A8	series L-shunt L	shunt L-series C
A9	shunt C-series L	series L-shunt L
A10	shunt C-series L	shunt L-series L
A11	shunt C-series L	series L-shunt C
A12	shunt C-series L	shunt L-series C
A13	series C-shunt L	series L-shunt L
A14	series C-shunt L	shunt L-series L
A15	series C-shunt L	series L-shunt C
A16	series C-shunt L	shunt L-series C
A17	series L-shunt L-series L	series L-shunt L-series L
A18	series L-shunt L-series L	shunt L-series L-shunt L
A19	shunt L-series L-shunt L	shunt L-series L-shunt L
A20	shunt L-series L-shunt L	series L-shunt L-series L

TABLE 4.1
POSSIBLE STRUCTURE COMBINATIONS
FOR EXAMPLE ONE

Table 4.2 shows the results of the yield calculations for each of the amplifier designs listed in table 4.1. The simulations were performed for S_{11} <-10 dB, S_{22} <-10 dB, no criteria on S_{21}, a 10% variation on all component values and calculated over a 20% bandwidth. As table 4.2 shows, amplifiers A17 through A20 have the highest yield, as predicted by the design chart (figure 3.1). The data in table 4.2 shows the importance of structure choice on circuit yield. The structure choices caused yield variations from 0% to 69.7%.

DESIGN NUMBERS	% YIELD
A1	47.4
A2	44.1
A3	.1
A4	0
A5	54.6
A6	53.1
A7	.5
A8	0
A9	0
A10	0
A11	0
A12	0
A13	25.2
A14	24.2
A15	0
A16	0
A17	68.7
A18	69.7
A19	66.3
A20	65.6

TABLE 4.2
YIELD CALCULATIONS FOR
EXAMPLE ONE

5.0 SUMMARY

Using 2-element and 3-element designs as described, an extensive yield simulation study was presented. For all impedance points a three-element structure always had a higher yield than any of the 2-element structures. A 10% and 20% bandwidth, high yield structure choice chart was developed which shows the high yield structure(s) for any load impedance. An example conclusively shows that structure choice affects yield.

REFERENCES

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[4] Thomas, L. Robert, A Practical Introduction to Impedance Matching, Artech House, 1976.
[5] EEsof Inc., Westlake Village, CA.