Amplifier Load Mismatch Design Using MMICAD

by D. Fitzpatrick

Introduction

The versatility of MMICAD's **PROC** block has been demonstrated in a number of application notes. This note couples this capability with the equally versatile **OUT** block and, in particular, the **OUTCIRCLE** command needed for user specified circles.

Background

The graphical technique for simultaneous low noise and good input VSWR for amplifiers was originally described by T. Narhi (MW & RF April 1986). You would be excused for asking yourself at this point: "Why a graphical technique? I thought computers were supposed to eliminate the need for this." Well, you would be partially correct. MMICAD (or any other optimizing simulator) could certainly include input and output VSWR and gain as optimization goals. However, during optimization the amplifier topology is fixed, and it may not be the best configuration to take advantage of feedback, particularly at larger bandwidths. A graphical technique may be a better compromise. However, using a Smith chart can be laborious and time consuming. MMICAD relieves the designer of these tedious tasks, resulting in more freedom and time to concentrate on refinements and novel approaches.

In order to match a FET for lowest noise figure there usually has to be a sacrifice of VSWR. For a good match, isolators or balanced designs are used, but these have inherent loss which add directly to the noise figure. However, because a FET has bilateral characteristics (finite S12, hence Γ_{IN} depends upon the load impedance). There may be load conditions which allow optimum noise match, and good VSWR.

Design Approach

This graphical technique uses the established method of drawing constant gain circles on the load impedance plane, thus showing the effect different loads have on amplifier gain. In a similar way, circles for a constant VSWR can be drawn on the same load impedance plane. Thus the simultaneous values of **VSWR** and gain can be read off the Smith chart.

If,

$$\Gamma_{IN} = S11 - \frac{S12 \cdot S21 \cdot \Gamma_L}{S22 \cdot \Gamma_L - 1}$$

Γ_L = load reflection coefficient

Using the substitutions,

a = (S11 · S22) - (S12 · S21)
b = -S11
c = S22

then,

$$\Gamma_{IN} = \frac{a\Gamma_L + b}{c\Gamma_L - 1}$$

Hence Γ_{IN} is a bilinear transformation of Γ_L. So if Γ_L draws a circle on the Smith chart, so does Γ_{IN}. This circle has a centre Γ_o and a radius r, and has a constant magnitude for Γ_{IN}

i.e. $|\Gamma_{IN}| = R$

The equations for Γ_o and r were derived by Narhi,

$$\Gamma_o = -\left(\frac{a * b + R^2 c^*}{|a^*|^2 - R^2 |c^*|^2} \right)$$

$$r = \left[|\Gamma_o|^2 - \left(\frac{|b|^2 - R^2}{|a|^2 - R^2 |c|^2} \right) \right]^{1/2}$$

These equations do not deal specifically with a FET, but with a two port network. Thus the S-parameters can include feedback to improve stability, or modify the load match.

These equations have been included in the **PROC** block of MMICAD, which then outputs the value of Γ_o and r. These are passed to the OUT block, which, using the **OUTCIRCLE** command on the Smith chart, produces circles of constant input reflection coefficient. Thus a range of input reflection coefficients can be analyzed (using MMICAD's **PARAM** block and variational analysis) and the trade-off between load impedance and input VSWR can be determined.

Design Example

A typical amplifier configuration is shown in Figure 1. The input network is designed to provide the lowest possible noise figure to the first transistor in the 900-to-1700-MHz band. At 900 MHz, the S-parameters of the first transistor and input matching network are

S11 = 0.55 ∠160 deg.,
S12 = 0.044 ∠0 deg.,
S21 = 5.48 ∠67 deg., and
S22 = 0.76 ∠-30 deg.

The interstage network should be designed to improve Γ_{IN} without reducing gain excessively.

The circuit file in Figure 2 shows the equations used to compute Γ_o and r. They have been left in an expanded form so that the reader can easily follow the calculations.

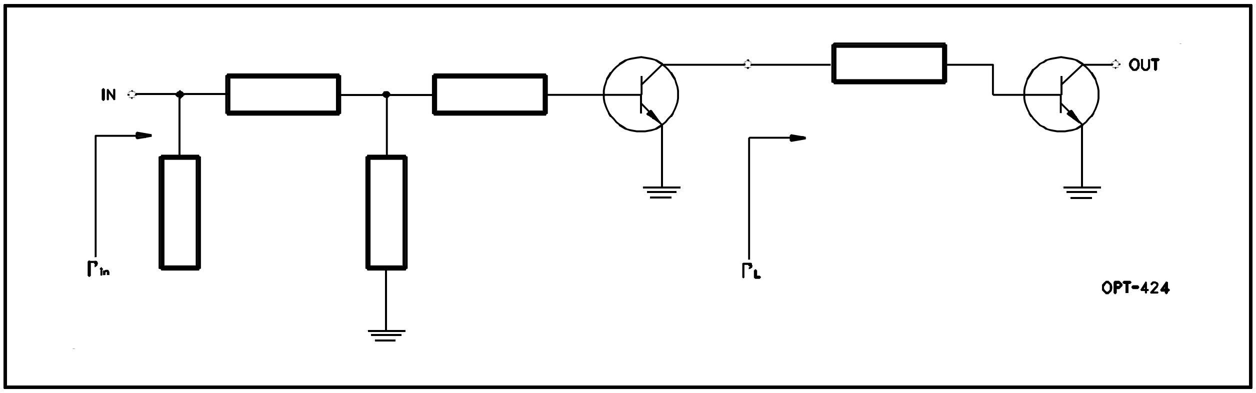

Figure 1

```
!MMICAD 5.0          LINEAR ANALYSIS AND CIRCUIT DESIGN                    OPTOTEK LTD
!
!FILE NAME:          WESSEX.CKT                  AUTHOR: D. FITZPATRICK    30/01/1992
!
!NOTES:    LOAD MISMATCH TECHNIQUE FOR AMPLIFIER DESIGN
!
MODE PARAM

FILES
 C:\MMICAD\WORKING\Q.S2P DEVICE

FREQ
 FIXED 0.9                           !FREQUENCY AT WHICH S-PARAMETERS ARE VALID

PARAM
 FIXED 2
 SWEEP 2.0 3.0 0.5                   !SWEEP INPUT VSWR FROM 2 TO 3

PROC
 LOADR1=(5-J*8-1)/(5-J*8+1)          !OPTIMUM LOAD FOR VSWR=2.0
 LOADR2=(5-J*2-1)/(5-J*2+1)          !OPTIMUM LOAD FOR VSWR=2.5
 LOADR3=(5+J*.2-1)/(5+J*.2+1)  !OPTIMUM LOAD FOR VSWR=3.0
 R=(PARAM-1)/(PARAM+1)         !SWEPT MAGNITUDE OF INPUT REFLECTION COEFFICIENT
 A1=DEVICE S11
 A2=DEVICE S21
 A3=DEVICE S12
 A4=DEVICE S22
 A=A1*A4-A3*A2
 B=-A1
 C=A4
 CENTRE=-( (CNJ(A)*B)+(R^2*CNJ(C)) ) / ( (MAG(A)^2)-(R^2*MAG(A4)^2) )
 RADIUS=SQRT(MAG(CENTRE)^2-(MAG(B)^2-R^2) / ((MAG(A)^2)-(R^2*MAG(A4)^2)))

OUT
 OUTCIRCLE CENTRE RADIUS SMITH
 DEVICE GPCIR  3 5 9  SMITH    !GAIN CIRCLES
 OUTVAR LOADR1 SMITH
 OUTVAR LOADR2 SMITH
 OUTVAR LOADR3 SMITH
 device db[gmax] gmax t

LABEL
 LOAD MISMATCH DESIGN TECHNIQUE
```

Figure 2

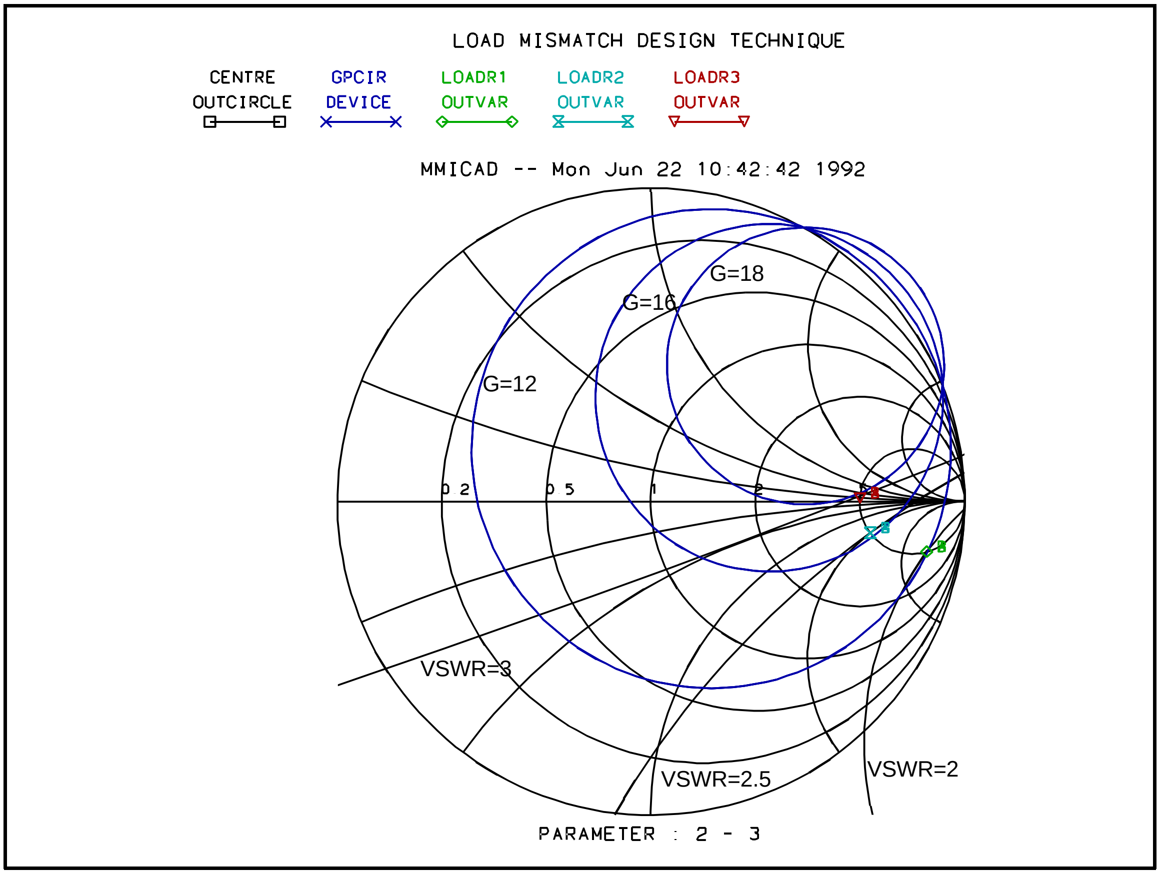

Figure 3

Figure 3 shows circles of constant input reflection coefficient for values of 0.33, 0.43, 0.50 (representing input VSWRs of 2.0, 2.5, and 3.0 respectively). Also shown are circles of constant power gain for the first stage, G. The Smith chart indicates that a capacitive load impedance will improve the input VSWR. For example, if Z_L = 5 - j8, the input VSWR =2.0 and the power gain is 12 dB. If this gain is too low, a Z_L of 5 - j2 increases gain to 16 dB and VSWR to 2.5.

The chart also shows that there exists a locus of optimum load impedances - i.e., those values of Z_L that provide a minimum input VSWR for a fixed gain. The desired optimum load impedance versus frequency can be determined by drawing constant VSWR and constant gain circles at several frequencies in the design bandwidth (three is enough in this case). The configuration of the interstage network can then be selected to approximate this desired impedance.

The selection of an interstage network for a practical low-noise amplifier design must take into account the noise contribution of the second stage, as well as the equalization of the gain over the wide bandwidth.

Conclusion

The **PROC** block in MMICAD is one of its most powerful features. It allows engineers to take complicated mathematical formula and integrate them easily into their design software, with few worries about data handling. This is especially useful for iterative calculations which previously rendered some design approaches prohibitive because of time.