STABILITY CONSIDERATIONS OF LOW-NOISE TRANSISTOR AMPLIFIERS WITH SIMULTANEOUS NOISE AND POWER MATCH

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Abstract

Microwave transistor amplifiers may be simultaneously matched for optimum noise and input/output VSWR. This paper demonstrates a combination of mapping techniques, computer optimization and stability considerations through two amplifier designs (70 MHz and 4000 MHz) to achieve these goals.

Discussion

One of the basic problems existing in low-noise transistor amplifier design is the significant difference between the desired source impedances for optimum noise and input match. Although recently device manufacturers have made progress in transforming the impedances closer to each other by either modifying the device geometries or diffusion process, at 4 GHz typically a 2 - 3 dB noise figure degradation is suffered when the input and output are simultaneously matched for minimum reflection in a 50Ω system (see Fig. 1). In such case, some form of an isolator is needed at the input to maintain a reasonable input match when the device is operating at its minimum noise figure. The cost and the associated losses of the isolator may make this approach undesirable.

Using mapping techniques, the effect of feedback can be plotted for the circuit and noise parameters. For example, Figures 2 and 3 show the variation of optimum noise source impedance, minimum noise figure, and the conjugate of the input reflection coefficient for various lossless shunt and series feedback elements at 4 GHz. The plots show that capacitive elements will typically reduce the minimum noise figure and move the optimum noise source away from the optimum power match. Conversely, inductive feedback usually has the opposite effect. Combining the two feedbacks in some cases can move the optimum noise source impedance toward the desired direction, albeit with a small change in the optimum noise figure (this is particularly true at VHF and UHF frequencies where the transistors have higher gain).

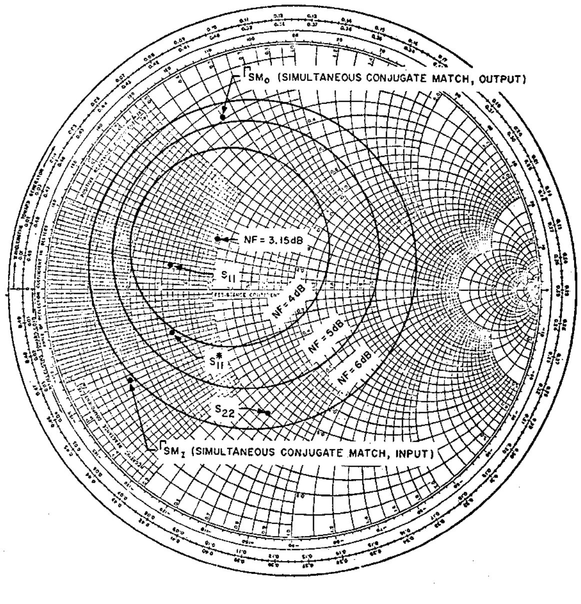

Figure 1
Constant Noise Circles and Simultaneous Conjugate Match of the NEC V-222 at 4 GHz

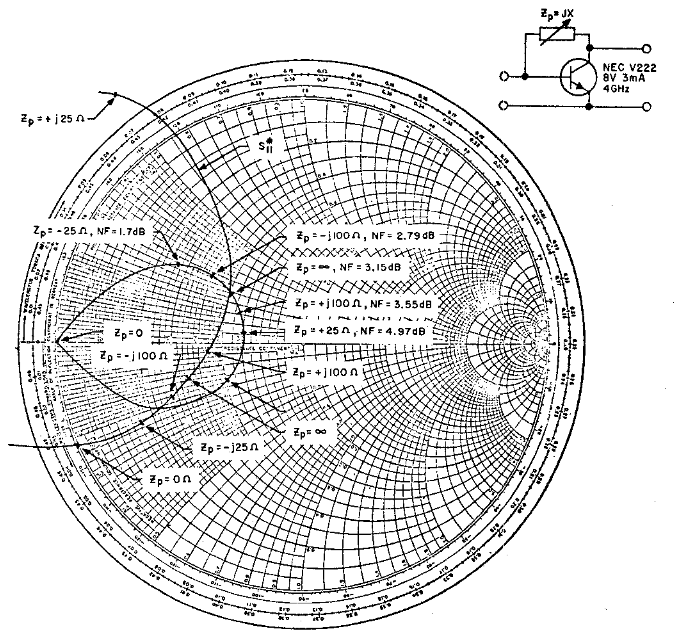

Figure 2
Minimum Noise Figure,
Optimum Noise Source Impedance,
and S_{11}^* vs. Parallel Feedback

Lossless feedback elements can transform the input and optimum noise source impedances until simultaneous match or an acceptable compromise is reached.[1] However, the reactive feedback will change the minimum noise figure as well as the optimum noise source impedance. In addition the gain and the stability factor of the circuit will also change. The latter change in particular will affect the design procedure, as described below. If the circuit reaches a potentially unstable state, both the load and source terminations must be selected with care to prevent oscillation.

The plots may mislead the casual observer. For example in the extreme case, if the shunt feedback is reduced to zero ohm the computed minimum noise figure is reduced to zero. But obviously, the device has no gain and cannot be used for practical purposes. This suggests that the gain of the device should also be considered and the noise measure[2] may be a better parameter for the evaluation.

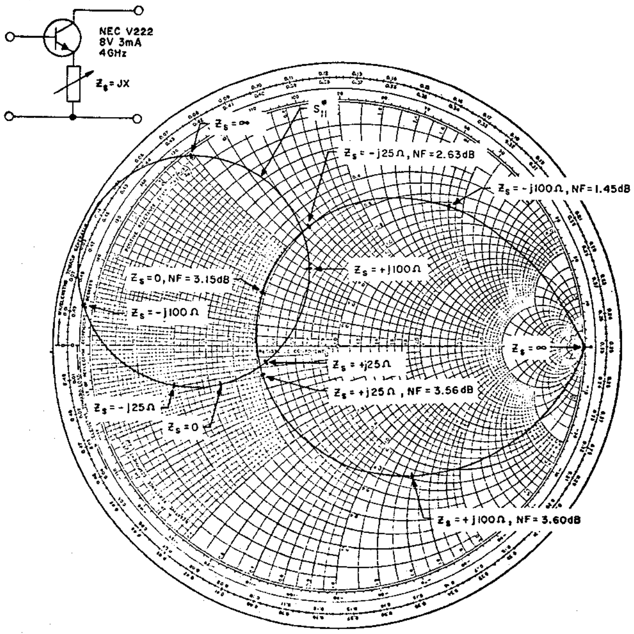

Figure 3
Minimum Noise Figure, Optimum Noise Source Impedance, and S_{11}^* vs. Series Feedback

The transformation of the noise parameters[3,4] is computed through two-port additions as follows:

$$Y_{opt} = \frac{G_n' + R_n' \left(\mathrm{Re}\,(Y_c')\right)^2}{R_n'} - j\,\mathrm{Imag}\,(Y_c')$$

$$F_{min}' = 1 + 2R_n' \left(\mathrm{Real}\,(Y_c') + \mathrm{Real}\,(Y_{opt}')\right)$$

R_n', G_n' and Y_c' are the functions of R_n, G_n and Y_c of the active device and the noise transformation parameters, which are:

$$N_s = \left[\begin{array}{c|c} 1 & z_{11}^a - \frac{z_{21}^a}{z_{21}^b}\, z_{11}^b \\ \hline 0 & \frac{1}{1 + \frac{z_{21}^a}{z_{21}^b}} \end{array}\right] \quad \text{for series connections}$$

$$N_p = \left[\begin{array}{c|c} \frac{1}{1 + \frac{y_{21}^b}{y_{21}^a}} & 0 \\ \hline y_{11}^a - \frac{y_{21}^a}{y_{21}^b}\, y_{11}^b & 1 \end{array}\right] \quad \text{for parallel connections}$$

where the "a' superscripts refer to active two port and the "b" superscripts refer to the passive two-port.

Since there is a strong interaction between the feedback elements and the load and source terminations, each of the plots (e. g. Fig. 2 and 3) is only valid for a specific combination of element values. Therefore, the plots should only be used to determine the initial values for the subsequent computer optimization.

Although the reactive feedback will typically reduce the transducer power gain and the stability factor, the Maximum Stable Gain (MSG) of the circuit may still be very close to GMAX of the transistor.

The computer aided design procedure is the following:

1. Map the optimum noise source impedance, the optimum noise figure, and the conjugate of s_{11} as functions of the series and shunt feedback.

2. Select a combination of feedback elements that transforms the optimum input match and optimum noise source impedance toward the same region without causing a significant increase of the optimum noise figure. Select the appropriate matching circuit configuration and determine the initial component values from the Smith Chart.

3. Optimize the above circuit for simultaneous input match and noise figure.

4. Run a stability analysis on the resulting circuit. If the circuit is potentially unstable, plot the stability circle for the output plane and select the load impedance in the stable area. Compute GMAX or MSG, whichever is applicable.

5. Perform a final optimization to achieve simultaneously low noise and low input VSWR. The value of GMAX (or MSG) of Step 4 should be the gain specified during optimization.

6. If the results do not satisfy the desired specifications, change the relative values of the weighting factors assigned to GMAX, VSWR, and noise figure, and repeat step 5.

This design approach was tested at two extreme frequencies: at 70 MHz with an NEC V021 transistor, and at 4000 MHz using an NEC V222 device. A general purpose microwave circuit optimization program, COMPACT,[5] was used through commercial timesharing of United Computing Systems. The final optimization of the 4 GHz amplifier stage is shown in Table 2. The target of this run is to achieve 7. 5 dB gain, low noise figure as well as low input/output VSWR. The optimized circuits are shown in Figure 4 and 5. The circuit performances are summarized in Table 1. Note that in both cases the actual noise figure is within a few tenths of a dB of the optimum while the input VSWR is kept at low values.

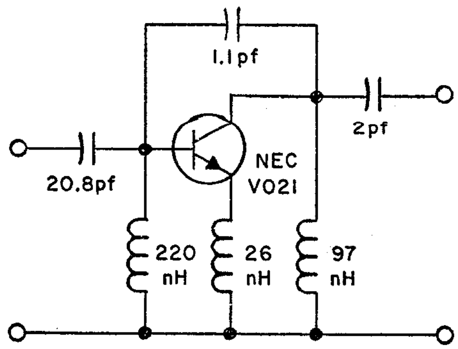

Figure 4
70 MHz Low Noise Amplifier

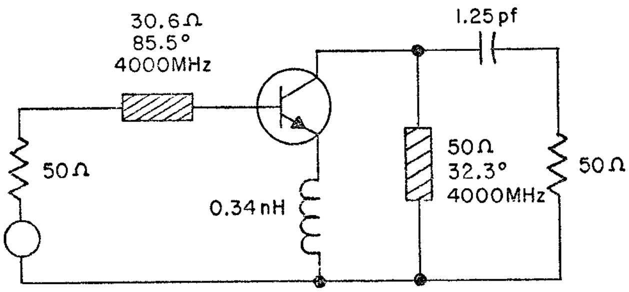

Figure 5
4000 MHz Low Noise Amplifier

Conclusion

Simultaneous match for minimum noise and VSWR of bipolar transistor amplifiers may be obtained by introducing appropriate lossless feedback to the active device. However, the gain and the stability of the circuit must be monitored and considered during the computer optimization. A similar effort is being undertaken elsewhere for GaAs FET amplifiers.

TABLE I

Device Parameters				Circuit (Single Stage)				
Freq. MHz	GMAX or MSG	NF_{opt} (dB)	DC Bias V/mA	Shown in Fig.	NF (dB)	VSWR Input	VSWR Output	Gain (dB)
70	21.8	1.1	10/5	4	1.23	1.6	1.6	20
4000	8.3	3.15	8/3	5	3.45	1.8	1.6	7.5

References

1. J. Enberg, "Simultaneous Input Power Match and Noise Optimization Using Feedback, Fourth European Microwave Conference, Montreaux, Switzerland, Sept. 1974.

2. H. Fukui, "Available Power Gain, Noise Figure and Noise Measure of Two-Ports and Their Graphical Representations", IEEE Transaction on CT, June 1966.

3. K. Hartmann, J. J. D. Strautt, "Changes on the Four Noise Parameters Due to General Changes of Linear Two-Port Circuits", IEEE Trans. on ED, Oct. 1974.

4. George Vendelin, Private Communications.

5. Les Besser, "COMPACT User Manual", Version 3.3, April 1975.

6. George Vendelin, "Feedback Effects on the Noise Performance of GaAs MESFET's", IEEE International Microwave Conference, May 1975.

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                     CIRCUIT OPTIMIZATION WITH  5 VARIABLES

INITIAL CIRCUIT ANALYSIS:

                     POLAR S-PARAMETERS IN   50.0 OHM SYSTEM

  F         S11            S21            S12            S22        S21    K
 MHZ   (MAGN ANGL)   ( MAGN ANGL)   ( MAGN ANGL)   (MAGN ANGL)      DB    FACT.

4000.0 ( .37< -77) ( 1.93  -61) ( .269< -11) ( .48< -39)   5.72      .78     Initial Analysis

                          NOISE FIGURE DATA
FREQ.      OPT. NOISE FIG.   OPT. NOISE SOURCE    ACTUAL NF   NORMALIZED
 MHZ            DB             MAGN.    ANGLE        DB           RN
4000.0          3.42            .33      179        3.51         .228

OPTIMIZATION BEGINS WITH FOLLOWING VARIABLES AND GRADIENTS

    VARIABLES:                       GRADIENTS:
                                                                       Initial Variables
  ( 1):     40.000                ( 1):      5.867                           and
  ( 2):    110.000                ( 2):      5.069                    Partial Gradients
  ( 3):       .600                ( 3):      -.276
  ( 4):     50.000                ( 4):     12.958
  ( 5):      2.000                ( 5):     -1.966
 ERR. F.=    3.528   CUM. CPU TIME (INCL. PREMIUM)=  .45 SECONDS
        ----♦♦♦♦----
  ( 1):     30.679                ( 1):       .005                      Final Variables
  ( 2):     85.519                ( 2):      -.044                           and
  ( 3):       .343                ( 3):      -.015                    Partial Gradients
  ( 4):     32.354                ( 4):       .043
  ( 5):      1.251                ( 5):       .060
 ERR. F.=     .142   CUM. CPU TIME (INCL. PREMIUM)= 5.91 SECONDS
        ----♦♦♦♦----
FRACTIONAL TERMINATION WITH ABOVE VALUES. FINAL ANALYSIS   FOLLOWS
                                                                          Final Analysis
 4000.0 ( .27< -30) ( 2.36<  -3) ( .225<  27) ( .21<  55)   7.47     1.04

                          NOISE FIGURE DATA
FREQ.      OPT. NOISE FIG.   OPT. NOISE SOURCE    ACTUAL NF   NORMALIZED
 MHZ            DB             MAGN.    ANGLE        DB           RN
4000.0          3.31            .35      164        3.47         .233
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Table 2 – Final Optimization Printout of COMPACT for the 4 GHz Amplifier Stage