A Graphical Design Method for an Optimum Low-Noise Amplifier

최적의 성능을 위한 저잡음 증폭기의 도식적 설계기법

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요 약

본 논문에서는 스미스 도표 상의 Γ_{IN} 평면에 도시되는 정합원를 사용한 저잡음 증폭기의 도식적 설계기법을 제시하였다. 입·출력의 각 정합원은 저잡음 증폭기의 최적화된 성능을 위하여 정재파비 등의 설계 파라미터를 결정할 때 발생되는 반복적인 설계작업의 번거로움을 최소화하기 위한 도식적 설계 기법에 이용할 수 있다. 이를 증명하기 위한 방안으로 저잡음 증폭기를 설계하여 제시하였다.

ABSTRACT

This paper presents a graphical design method for a low noise amplifier using the match circles plotted in the Γ_{IN} plane on the smith chart. Each circle would be useful for reducing some trial and error efforts resulting from making a trade-off for an optimized performance of a single stage amplifier. A design example is presented to illustrate the design procedure.

Key words : low-noise amplifier, VSWR, graphical design method

I. Introduction

A low-noise amplifier (LNA) is one of the most important building blocks in the RF front end of a telecommunication system. It determines the noise figure and input VSWR of the overall system, because the first block signal fed from the antenna which it meets is the LNA[1].

When designing LNA, it is well known that the noise matching for achieving a minimum noise figure results in higher input VSWR. This is because the source reflection coefficient for the optimum noise match is usually very different from source reflection coefficient for the maximum power gain match[2]. If required to compromise in selecting the source reflection capable of providing an available power gain and desirable noise figure, LNA design typically begins with the selection of source reflection coefficient for low noise figure and then trading-off for the optimized performance can be made using the circles[3] ~ [6]. A drawback of these proposed graphical approach is that the trial and error iteration is often required to obtain acceptable performance, and inevitably, circuit optimizations are required.

Therefore we consider a graphical approach for reducing trial and error and simplifying design procedure using the match circles plotted together with gain and noise circle in the Γ_{IN} plane when

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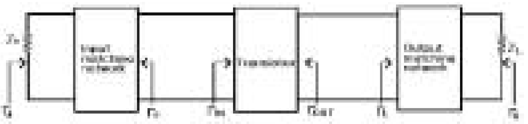

Fig. 1. The configuration of a single stage LNA.

selecting the trade-off values capable of providing a lower input VSWR and a desirable transducer power gain at the same time without increasing the noise figure.

II. Match Circles for the Trade-Off

Let us refer to a single-stage amplifier driven by the matched source and delivering power to the matched load as shown in Fig. 1. Consider the relationship linking together the amplifier reflection coefficient magnitude $|\Gamma_A|$, the source reflection coefficient Γ_S, and the input reflection coefficient Γ_{IN}.

Under the hypothesis of a lossless input impedance transformer, a well known relationship occurs [2].

$$|\Gamma_A| = \left| \frac{\Gamma_{IN} - \Gamma_S^*}{1 - \Gamma_{IN}\Gamma_S} \right| \tag{1}$$

where Γ_{IN} is a function of the device scattering parameter and of the load reflection coefficient Γ_L.

$$\Gamma_{IN} f(\Gamma_L) = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \tag{2}$$

For the specified values of Γ_s and $|\Gamma_A|$, (1) defines a set of input match circles in the Γ_{IN} plane on the smith chart and is used to plot the values of Γ_{IN} that result in constant value of $|\Gamma_A|$ from the center of point (A) ($\Gamma_{IN}=\Gamma^*_S$) with input VSWR of unity as shown in Fig. 2. The conformal transformation represented by equation (2) maps such circles into other circles on the Γ_L plane for the output port termination impedance, and its impedance value can be obtained using the following inverse function, $f^{-1}(\Gamma_{IN})$.

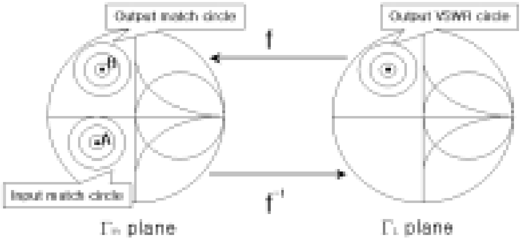

Fig. 2. Match circles.

$$\Gamma_L = f^{-1}(\Gamma_{IN}) = \frac{S_{11} - \Gamma_{IN}}{\Delta - S_{22}\Gamma_{IN}} \tag{3}$$

where $\Delta = S_{11}S_{22} - S_{12}S_{21}$

Similarly to the input port, at the output port, $|\Gamma_B|$ is given by

$$|\Gamma_B| = \left| \frac{\Gamma_{OUT} - \Gamma_L^*}{1 - \Gamma_{OUT}\Gamma_L} \right| \tag{4}$$

where Γ_{OUT} is a function of the device scattering parameter and of the source reflection coefficient Γ_S

$$\Gamma_{OUT} = f(\Gamma_S) = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S} \tag{5}$$

For the specified values of $\Gamma_{OUT}(\Gamma_S)$ and $|\Gamma_B|$, (4) defines a set of output VSWR circles in the Γ_L plane. As the conformal transformation represented by (2) maps such circles into the Γ_{IN} plane, we can obtain output match circles and they will plot the values of Γ_{IN} that result in the constant value of $|\Gamma_B|$ from the center point (B), $\Gamma_{IN}(\Gamma^*_{OUT}(\Gamma_S))$ with output VSWR of unity as shown in Fig. 2.

III. Design Trade-off for the Optimum Performance

In this section, we consider the trade-off among the design parameters using the match circle presented here. For an input matching circuit, a graphical design procedure of the LNA typically begins by selecting the source reflection coefficient to the one point along the upper straight line drawn on the overlapped noise and available circle in Fig. 3 to make easily trade-off between the noise and gain. Next for output matching circuit, when one point of $\Gamma_{IN}=\Gamma^*_S$ is chosen along the lower straight line as shown in Fig. 3, we can directly evaluate some degrees of the gain and noise figure values simply by moving along the upper straight line and also get the desirable noise figure and matched input port. But this case often gives the lower transducer power gain than achievable and the higher output VSWR with possibility of an oscillation.

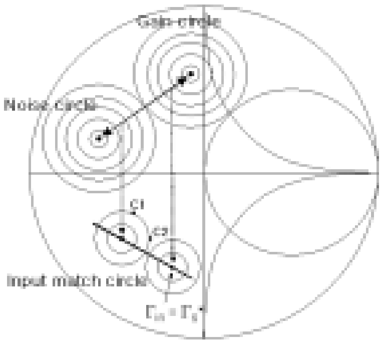

Fig. 3. Design trade-off using the input match circle.

In such way, the other value of Γ_{IN} for the output port termination impedance can be selected by making trade-off between VSWR to obtain the optimized performance. To this end, the input match circle in Fig. 1 has been drawn to provide the higher transducer power gain and lower output VSWR as shown in Fig. 3.

The input match circle that lie on the constant value from the center of ($\Gamma_{IN}=\Gamma^*_S$) results in the same value of input VSWR. But the value of output VSWR varies with the location on the constant circle (e.g., C1 has VSWR(out)=1, C2 has VSWR(out)=1.8 in Fig. 3). and the trial and error to complete the design is occurred. Hence the output match circle in Fig. 2 has been plotted together with input match circle to reduce the trial and error effort in making trade-off values as shown in Fig. 4.

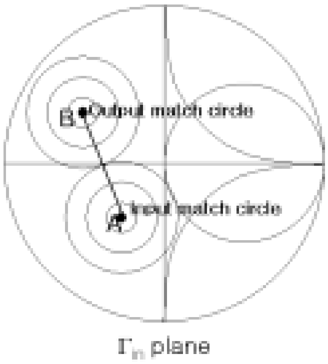

Fig. 4. Trade off between gain and VSWR.

To select the location of Γ_{IN} that produces the best compromise between the transducer gain and VSWR, we divide the line into several equal increments from center A(input VSWR=1) to center B(output VSWR=1) as shown in Fig. 4. and then, calculate the values of gain and VSWR for each selected values of Γ_{IN}. The distance of straight line between the point (A) and (B) are related to the values of VSWR and transducer power gain. As the point of Γ_{IN} selected along the straight line gets far away from point (A) and reaches closer to point B, the input VSWR is gradually increased, but the output VSWR become smaller and the transducer gain is increased. Therefore, the various trade-offs between the gain and VSWR for the optimum performance are possible using the input and output match circle.

Ⅳ. Design Example and Its Results

In this design example, we determine the trade-off values involved the noise figure, gain, and

Fig. 5 Available gain and noise figure circle.

VSWRs for optimum performance by designing the single stage amplifier at 12 GHz with design target constrained below.

Gt>12 dB, noise figure<0.5dB, VSWR(in)<1.5, VSWR(out)<1.5

NEC 3210S01 with the minimum noise figure of 0.34 dB, the maximum available gain of 13.5 dB and unconditionally stable condition($k>1$, $|\Delta|<1$) at 12 GHz is used.

The noise figure and available power gain circles are plotted to decide the value of Γ_S for the input port termination impedance as shown in Fig. 5. The noise figure is 0.34 dB in the center, and then is increased in 0.1 dB for each new circle. The gain is 13.5 dB in the center and its new circle are plotted from 13.4 dB to 12 dB. The inspection of two circles reveals that it is impossible to obtain the optimum noise and maximum available gain performance simultaneously, and thus the trade-off between the noise and gain is required.

The first work for design is to choose the value of Γ_S that falls within the overlapping region of available gain circle and noise figure circle. The selection of $\Gamma_S=0.337\angle 162$ at point A in Fig. 5 and $\Gamma_L=\Gamma^*_{OUT}$ result in the noise figure of 0.4 dB, (Ga=Gt) of 13 dB and unity of output VSWR, but the input VSWR is 1.83.

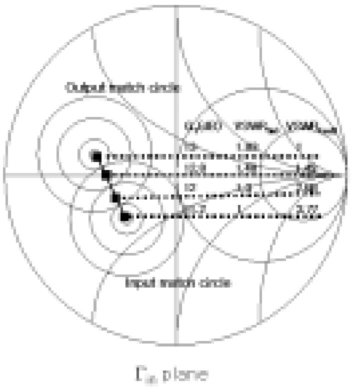

Fig. 6. Trade-off for the optimum performance.

Since the value of VSWR(in)=1.83 is higher than that of value of output VSWR, trading-off between input and output VSWR is needed to meet example design specification without increasing noise figure. To this end, plot input and output match circle in Γ_{IN} plane to determine trade-off value for the optimum performance. Next, draw a straight line from the center of input match circle to the center of output match circle as shown in Fig. 6 and then, start design optimization by making trade-off between input and output VSWRs on the straight line to pick up the new output port termination impedance.

The resulting values tabulated in Table 1. show that optimum performance can be achieved throu-

Table 1. Trade-off values

Noise figure 0.4 dB @$\Gamma_S = 0.337\angle 162$				
Γ_{IN}	Γ_L	G_T(dB)	VSWR(in)	VSWR(out)
0.516/ 174	0.293/ 155.3	13	1.83	1
0.451/ 180	0.181/ -165	12.8	1.48	1.49
0.370/ -169	0.290/ -97	12	1.3	2.68
0.337/ -162	0.419/ -85	11.2	1	3.77

gh trade-off between VSWR without degrading noise performance. Additionally, Gain, noise, and match circle plotted together into Γ_{IN} plane could be use of to expect amplifier performance and to reduce trial and error iteration.

Upon the determination of the source and load termination impedance with the first and fourth low in Table 1, respectively, input and output matching network were designed. The microstrip implementation of amplifier is shown in Fig. 7. The circular stub present RF short circuits to the microstrip section to which they are connected and provide a convenient dc bias path to the base and collector of the transistor. Coupled line dc block is used to isolate the bias voltage instead of series chip capacitor. Upon completion of the design, the circuit were simulated. The simulation results of the circuits shown in Fig. 8 yield a transducer power gain of 12.7 dB, VSWR(in) of 1.49 and VSWR(out) of 1.49.

Ⅴ. Conclusion

In this paper, a graphical design method has been shown to reduce the trial and error effort in making trade-off between VSWRs for optimum performance by plotting match circles in the Γ_{IN} plane. The match circles serve as a graphical design aid on smith chart, and would be use of to consider the optimum performance for LNA.

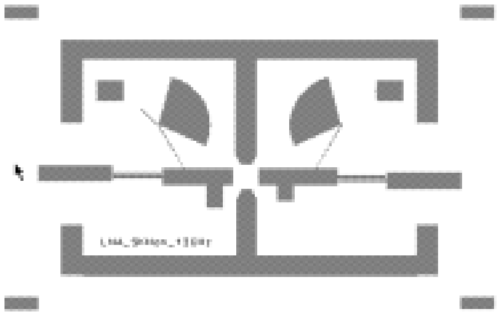

Fig. 7. Amplifier layout.

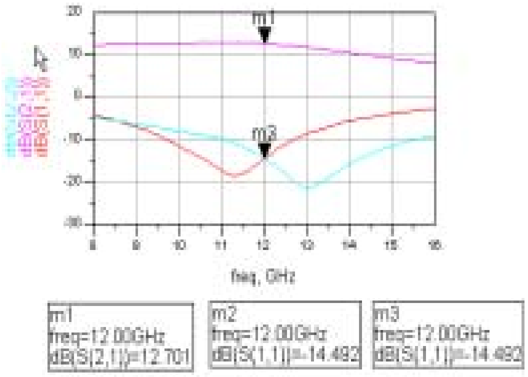

Fig. 8. Simulated Results.

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