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Constant Noise Figure Circles.

We can write the noise figure of a two-port N/w as.

$$F = F_{min} + \frac{r_n}{g_s} \left| y_s - y_{opt} \right|^2 \qquad -(1)$$

$r_n \rightarrow$ equivalent normalized noise resistance $\left(r_n = \frac{R_n}{Z_0} \right)$

$y_s = g_s + j b_s$, normalized source admittance $y_{opt} = g_{opt} + j b_{opt}$ - normalized source admittance that results in minimum (or optimum) noise figure, called F_{min}

y_s & y_{opt} can be represented in terms of reflection coefficient Γ_s and Γ_{opt} as

$$y_s = \frac{1-\Gamma_s}{1+\Gamma_s} \qquad y_{opt} = \frac{1-\Gamma_{opt}}{1+\Gamma_{opt}} \qquad -(2)$$

Substituting (2) in (1) and solving we get

$$F = F_{min} + \frac{4 r_n \left| \Gamma_s - \Gamma_{opt} \right|^2}{\left(1 - |\Gamma_s|^2\right) \left| 1 + \Gamma_{opt} \right|^2} \qquad -(3)$$

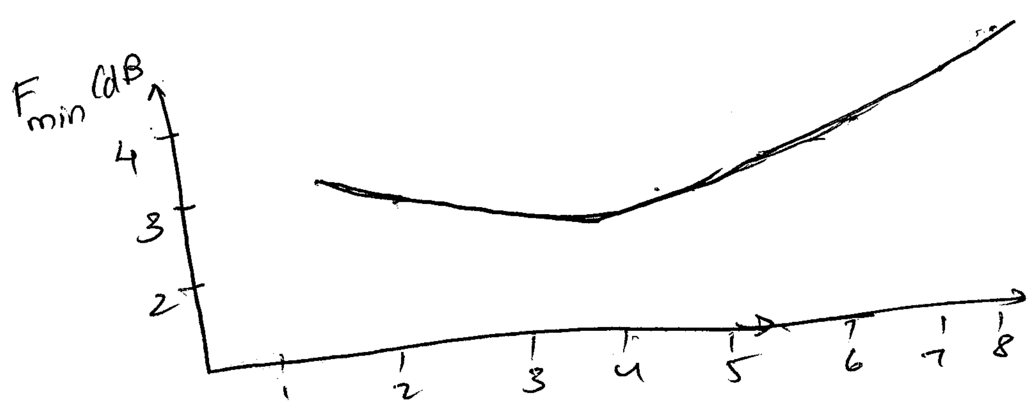
The equation (3) depends on F_{min}, r_n and Γ_{opt}. These quantities are known as noise parameters and are given by manufacturer

→ The source reflection coefficient can be varied until a minimum noise figure is read on a noise figure meter.

→ The value of F_{min}, which occurs when $\Gamma_s = \Gamma_{opt}$ can be read from the meter, and the source reflection coefficient the produces F_{min} can be determined accurately using a N/w analyzer. → The noise resistance r_n can be measured by reading the noise figure when $\Gamma_s = 0$, called $F_{\Gamma_s = 0}$

$$r_n = (F_{\Gamma_s=0} - F_{min}) \frac{|1+\Gamma_{opt}|^2}{4|\Gamma_{opt}|^2} \quad -(4)$$

F_{min} is a function of the device operating current and frequency, and there is one value of Γ_{opt} with each F_{min}. Figure shows a typical plot of F_{min} versus current for a BJT



We can use (3) to design Γ_s for a given noise figure $F = F_i$.

If we rearrange (3) in the following manner

$$\frac{|\Gamma_s - \Gamma_{opt}|^2}{1 - |\Gamma_s|^2} = \frac{F_i - F_{min}}{4 g_n} |1 + \Gamma_{opt}|^2 \qquad -(5)$$

we notice that for a given noise figure F_i RHS of (5) is a constant. Defining the noise figure parameter N_i as

$$N_i = \frac{F_i - F_{min}}{4 g_n} |1 + \Gamma_{opt}|^2 \qquad -(6)$$

we can write (5) as.

$$\frac{|\Gamma_s - \Gamma_{opt}|^2}{1 - |\Gamma_s|^2} = N_i \qquad \left[|\Gamma_s - \Gamma_{opt}|^2 = (\Gamma_s - \Gamma_{opt})(\Gamma_s^* - \Gamma_{opt}^*)\right]$$

which when expanded gives

$$|\Gamma_s|^2 - \frac{2}{1+N_i} Re(\Gamma_s \Gamma_{opt}^*) + \frac{|\Gamma_{opt}|^2}{1+N_i} = \frac{N_i}{1+N_i} \qquad -(7)$$

This equation corresponds to the equation of a ⊙ in the Γ_s plane. which can be expressed in the form

$$\left|\Gamma_s - \frac{\Gamma_{opt}}{1+N_i}\right|^2 = \frac{N_i^2 + N_i(1-|\Gamma_{opt}|^2)}{(1+N_i)^2}$$

For a given N_i the center of the ⊙ is located at

$$C_{F_i} = \frac{\Gamma_{opt}}{1+N_i} \qquad -(8)$$

& radius is

$$r_{F_i} = \frac{1}{1+N_i}\sqrt{N_i^2 + N_i(1-|\Gamma_{opt}|^2)} \qquad -(9)$$

Using (6) we calculate N_i for various F_i &

then use (8) & (9) to obtain a family of constant

noise ⊙s in the Γ_s plane.

→ NOTE

If $F_i = F_{min}$, $N_i = 0$, $C_{F_{min}} = \Gamma_{opt}$ & $r_{F_{min}} = 0$

ie center of F_{min} ⊙ is located at Γ_{opt} with zero radius. The centers of the other noise figure ⊙s are located along the Γ_{opt} vector.

NOTE:

→ In practical applications we observe that there is always a difference between the designed noise figure and the measured noise figure of the final amplifier.

→ This occurs because of

1) loss associated with the matching elements

2) Transistor noise figure variations from unit to unit

→ Typical NF variation can be from a fraction of a decibel to 1dB in a narrowband design.

→ Low Noise Design

→ Tradeoff between gain, noise figure, and VSWRs.

Fig 4.3.3 (a good example of tradeoff between gain and noise figure)

→ Unilateral transistor $[S_{12} = 0]$

For gain (G_s $\odot_s$)

$G_{s,max}$, g_s, C_s, r_s

In this problem maximum gain is 3dB & minimum noise figure is 0.8 dB.

At 3dB $\Gamma_s = 0.7\angle 110^\circ$ (F_{min}, R_n, Γ_{opt} provided)

results in a NF $F_i \approx 4$dB & minimum NF $\cdot F_{min} = 0.8$dB obtained

with $\Gamma_s = 0.6\angle 40^\circ$ results in a gain of -1dB

eg:- $S_{11} = 0.707\angle -155^\circ$ $S_{12} = 0$

$S_{21} = 5.0\angle 180^\circ$ $S_{22} = 0.51\angle -20^\circ$

$F_{min} = 3$dB $R_n = 4\Omega$ $\Gamma_{opt} = 0.45\angle 180^\circ$

Design i/p & o/p matching N/w to produce a power gain of 16dB

Soln

$K = \infty$

$|\Delta| = 0.3606$ → Transistor is unconditionally stable

$$G_{S,max} = \frac{1}{1-|S_{11}|^2} = 3\text{ dB}$$

$$G_{L,max} = \frac{1}{1-|S_{22}|^2} = 1.31\text{dB}$$

$$G_0 = |S_{21}|^2 = 13.98\text{dB}$$

$G_{TU\,max} = 3 + 1.31 + 13.98 = 18.29$dB (max gain)

We want 16dB gain

We can design for $G_s = 1.22$dB & $G_L = 0.78$dB

$g_s = ?$ $C_{gs} = 0.5634\angle 155^\circ$ $C_{gL} = 0.4655\angle 20^\circ$

$r_{gs} = 0.3496$ $r_{gL} = 0.2581$

Determine 3.5dB noise figure ⊙

$C_{F_i} = 0.3658 \angle 180^\circ$

$r_{F_i} = 0.3953$

- Draw the ⊙s

Choose a point on the 1.22dB ⊙ as Γ_s, the noise figure for this value would stay within 3.5dB.

- Design load side matching N/w by choosing Γ_L on the $G_L = 0.78$dB ⊙.

eg 4.3.1

$S_{11} = 0.552 \angle 169^\circ$ $\quad$ $S_{21} = 1.681 \angle 26^\circ$

$S_{12} = 0.049 \angle 23^\circ$ $\quad$ $S_{22} = 0.839 \angle -67^\circ$

$F_{min} = 2.5$dB $\quad$ $\Gamma_{opt} = 0.475 \angle 166^\circ$ $\quad$ $R_n = 3.5\Omega$

Design Amplifier for minimum NF

Soln

① Calculate $K = 1.012$

$|\Delta| = 0.419$

Transistor is unconditionally stable

② $G_{T,max} = \frac{|S_{21}|}{|S_{12}|} (K - \sqrt{K^2-1})$

$= 14.7\,dB$

③ $\Gamma_{ms} = \frac{B_1 - \sqrt{B_1^2 - 4|C_1|^2}}{2C_1}$

$\Gamma_{mL} = \frac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2C_2}$

minimum NF of 2.5 dB is obtained with $\Gamma_s = \Gamma_{opt} = 0.475\angle 166°$

④ Calculate NF Os for different F_i

In this example we take $F_i = 2.5 - 3\,dB$

a) Calculate N_i using (4.3.6)

$$N_i = \frac{F_i - F_{min}}{4 r_n} |1+\Gamma_{opt}|^2 = 0.1378$$

b) $$C_{F_i} = \frac{\Gamma_{opt}}{1+N_i} = 0.417\angle 166°$$

c) $$r_{F_i} = \frac{1}{1+N_i} \sqrt{N_i^2 + N_i(1-|\Gamma_{opt}|^2)} = 0.312$$

(5) Draw gain $\odot$s Γ_s plane

G_A, g_a, C_a, r_a

$$C_a = \frac{g_a C_1^*}{1 + g_a(|S_{11}|^2 - |\Delta|^2)}$$

$$r_a = \frac{[1 - 2K|S_{12}S_{21}|g_a + |S_{12}S_{21}|^2 g_a^2]^{1/2}}{|1 + g_a(|S_{11}|^2 - |\Delta|^2)|}$$

(6) $(\Gamma_L = \Gamma_{OUT}^*)$

$\Gamma_s = \Gamma_{opt}$ $\quad \Gamma_L = \left(S_{22} + \dfrac{S_{12}S_{21}\Gamma_{opt}}{1 - S_{11}\Gamma_{opt}}\right)^* = 0.844\angle 70.4°$

eg 4.3.2 LNA $(VSWR)_{in} < 1.8$

① Calculate $K = 1.172$

② ~~F_s~~ Calculate $|\Delta| = 0.151$

unconditionally stable

③ Calculate Γ_{ms}, Γ_{mL} & $G_{A,max}$

Plot value of Γ_{opt} and Γ_{ms}

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eg $S_{11} = 0.6\angle{-60^\circ}$ $S_{21} = 1.9\angle{81^\circ}$

$S_{12} = 0.05\angle{26^\circ}$ $S_{22} = 0.5\angle{-60^\circ}$

$F_{min} = 1.6\,dB$ $R_n = 20\,\Omega$ $\Gamma_{opt} = 0.62\angle{100^\circ}$

a) Assume the FET to be unilateral and design an amplifier for a maximum possible gain & a noise figure no more than 2.0 dB. Estimate error introduced in G_T due to this assumption.

b) Redesign amplifier for bilateral case

Soln

① $K = 2.778$

$|\Delta| = 0.3713$ } unconditionally stable

$$\frac{1}{(1+U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1-U)^2}$$

$$U = \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

$$-0.501\,dB < \frac{G_T}{G_{TU}} < 0.5938\,dB$$

maximum error in the gain of the amplifier will be in the order of $\pm 0.5dB$

② Calculate $G_{s\,max} = 1.9382dB$

$G_{L\,max} = 1.25dB$

③ $G_o = 5.5751dB$

$G_{TU\,max} = 1.9382 + 1.25 + 5.5751 = 8.7627dB$

③ Design $G_S = 1.5dB$ & $1.7dB$ @s

a) Calculate $g_s = \dfrac{G_s}{G_{s\,max}}$

Calculate

1.5dB $C_s = 0.5618 \angle 60^\circ$ $r_s = 0.2054$

1.7dB $C_s = 0.5791 \angle 60^\circ$ $r_s = 0.1507$

2dB Noise figure. ⊙

$$C_i = \frac{\Gamma_{opt}}{1+N_i} = 0.5627 \angle 100^\circ$$

$$r_i = \frac{1}{1+N_i}\sqrt{N_i^2 + N_i(1-|\Gamma_{opt}|^2)}$$

$= 0.2454$

Bilateral Case

- Use available power gain

For $G_A = 8_{dB}$

$C_a = 0.5274 \angle 64.76^\circ$

$R_a = 0.2339$

~~$G_{A,max}$~~ = Draw these ⊙s