Consider: Stability, power gain, bandwidth, noise, dc bias. Start with a set of specifications and select proper transistor. Next, determine transistor loading (source and load reflection coeff.) for particular stability and gain criteria.

Power gain equations

see fig. 3.2.1 for various powers. Gain definitions:

$$G_T = \frac{P_L}{P_{avs}} = \frac{\text{power delivered to load}}{\text{power available from source}} = \text{ transducer} \quad (1)$$

$$G_p = \frac{P_L}{P_{in}} = \frac{\text{power delivered to load}}{\text{power input to network}} = \text{ operating} \quad (2)$$

$$G_A = \frac{P_{avn}}{P_{avs}} = \frac{\text{power available from network}}{\text{power available from source}} = \text{ available} \quad (3)$$

$$G_T = \frac{1-|\Gamma_s|^2}{|1-\Gamma_{IN}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \tag{4}$$

$$G_T = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-\Gamma_{OUT}\Gamma_L|^2} \tag{5}$$

$$G_P = \frac{1}{1-|\Gamma_{IN}|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} = f(\Gamma_L,[S]) \tag{6}$$

$$G_A = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}|S_{21}|^2\frac{1}{1-|\Gamma_L|^2} = f(\Gamma_s,[S]) \tag{7}$$

$$\Gamma_{IN} = S_{11}+\frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L} \quad \Gamma_{OUT} = S_{22}+\frac{S_{12}S_{21}\Gamma_s}{1-S_{11}\Gamma_s} \tag{8}$$

- Source and load mismatch factors:

$$M_s = \frac{P_{IN}}{P_{AVS}} = \frac{\left(1-|\Gamma_s|^2\right)\left(1-|\Gamma_{IN}|^2\right)}{|1-\Gamma_s\Gamma_{IN}|^2}\left(= \frac{4R_sR_{IN}}{|Z_s+Z_{IN}|^2}\right)$$

$$M_L = \frac{P_L}{P_{AVN}} = \frac{\left(1-|\Gamma_L|^2\right)\left(1-|\Gamma_{OUT}|^2\right)}{|1-\Gamma_L\Gamma_{OUT}|^2}\left(= \frac{4R_{OUT}R_L}{|Z_{OUT}+Z_L|^2}\right)$$

Use M_s and M_L to relate various powers and gains:

$$P_{IN} = P_{AVS}M_s = P_{AVS}\big|_{\Gamma_{IN}=\Gamma_s^*}$$

$$P_L = P_{AVN}M_L = P_{AVN}\big|_{\Gamma_L=\Gamma_{OUT}^*}$$

$$G_T = \frac{P_L}{P_{AVS}} = \frac{P_L}{P_{IN}}\,\frac{P_{IN}}{P_{AVS}} = G_p\frac{P_{IN}}{P_{AVS}} = G_pM_s$$

$$G_A = \frac{P_{AVN}}{P_{AVS}} = \frac{P_L}{P_{AVS}}\,\frac{P_{AVN}}{P_L} = \frac{G_T}{M_L}$$

Stability

Stability = resistance to “spontaneous” oscillations. Possible if either input or output port has negative resistance, i.e. $|\Gamma_{IN}| > 1$ or $|\Gamma_{OUT}| > 1$. For unilateral device that means $|S_{11}| > 1$ and $|S_{22}| > 1$. See fig. 3.3.1 .

Unconditionally stable at f if real parts of Z_{IN} and Z_{OUT} are greater than zero for all passive load and source impedances.

If 2-port is **not unconditionally stable** it is **potentially unstable**, i.e. some passive load and source terminations result in input and output impedances with $Re(Z) < 0$.

Conditions for unconditional stability:

$$|\Gamma_s| < 1, \quad |\Gamma_L| < 1 \tag{9}$$

$$|\Gamma_{IN}| = \left| S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \right| < 1 \tag{10}$$

$$|\Gamma_{OUT}| = \left| S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{22}\Gamma_s} \right| < 1 \tag{11}$$

From this determine where $|\Gamma_{IN}| = |\Gamma_{OUT}| = 1$

$$\left| \Gamma_L - \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2} \right| = \left| \frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2} \right| \tag{12}$$

$$\left|\Gamma_s - \frac{(S_{11} - \Delta S_{22}^*)^*}{|S_{11}|^2 - |\Delta|^2}\right| = \left|\frac{S_{12}S_{21}}{|S_{11}|^2 - |\Delta|^2}\right| \tag{13}$$

with $\Delta = S_{11}S_{22} - S_{12}S_{21}$ is S-matrix determinant.

Geometrical interpretation: in polar coordinates these are two circles displaced by some amount from origin.

For $|\Gamma_{IN}| = 1$, Γ_L values satisfying the conditions for unconditional stability will be on one side of the circle which has:

center: $C_L = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2}$ radius: $r_L = \left|\frac{S_{12}S_{21}}{|S_{22}|^2 - |\Delta|^2}\right|$

This is **output stability circle**

Figs. 3.3.2 and 3.3.3. Which side of the circle is unconditionally stable (and which one is not)?

Observe: for $\Gamma_L = 0, Z_L = Z_0 \Rightarrow |\Gamma_{IN}| = |S_{11}|$. For $|S_{11}| < 1$ $\Rightarrow |\Gamma_{IN}| < 1$ when $Z_L = Z_0$ (origin).

$\Rightarrow$ Based on value of S_{11}, origin is either in stable region or not. For $|S_{11}| < 1$ it is part of the stable region. Conversely, if $|S_{11}| > 1$ then origin is part of the potentially unstable region. (fig. 3.3.3).

Note that $|\Gamma_L| < 1$ is required in the above.

Similar analysis for **input stability circle** (fig. 3.3.4).

For unconditional stability circles do not cross S-chart $\Rightarrow$ for no value of Z_L or Z_s will the circuit oscillate. for $|S_{11}| < 1$ we have $||C_L - r_L| > 1$ and for $|S_{22}| < 1$ we have $||C_s| - r_s| > 1$.

Note that $|S_{11}| > 1$ and $|S_{22}| > 1$ are automatically excluded from unconditional stability since $\Gamma_s = 0$ produces $|\Gamma_{OUT}| > 1$ and $\Gamma_L = 0$ produces $|\Gamma_{IN}| > 1$

Different form for the conditions (for unconditional stability)

Define stability factor K

$$K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2}{2|S_{12}S_{21}|} > 1 \qquad (14)$$

$$1 - |S_{11}|^2 > |S_{12}S_{21}| \quad 1 - |S_{22}|^2 > |S_{12}S_{21}| \qquad (15)$$

written differently:

$$K > 1 \ \text{and} \ B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 > 0 \tag{16}$$

or even simpler

$$K > 1 \ \text{and} \ |\Delta| < 1 \ (\Delta = S_{11}S_{22} - S_{12}S_{21}) \tag{17}$$

Ex. on p. 223. : $K > 1$ but $|\Delta| > 1 \Rightarrow$ potentially unstable.

Unilateral amplifier: $K \to \infty$ and for unconditionally stability we only need $|S_{11}| < 1$ and $|S_{22}| < 1$.

It is always possible to make the circuit stable if the total input and output loop resistances are positive (fig. 3.3.1)

$$\text{Re}(Z_s + Z_{IN}) > 0 \quad \text{and} \quad \text{Re}(Z_L + Z_{OUT}) > 0 \tag{18}$$

Accomplished by:

- resistively loading the transistor
- adding negative feedback

Not recommended for narrowband design.

Example 3.3.2.

By adding resistances we change Γ_s and Γ_L, but loose power too. Added resistance can be absorbed into transistor S-matrix (how?)

Negative feedback could be used to make $S_{12} = 0$ to stabilize transistor; not commonly done.

Unilateral network: $S_{12} = 0 \Rightarrow \Gamma_{IN} = S_{11}$, $\Gamma_{OUT} = S_{22}$. In that case: Unilateral transducer power gain:

$$G_{TU} = \frac{1 - |\Gamma_s|^2}{|1 - S_{11}\Gamma_s|^2} |S_{21}|^2 \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} \tag{19}$$

Think of it as a product of three components: $G_{TU} = G_S \cdot G_0 \cdot G_L$. see fig. 3.2.2.

G_s affects the degree of mismatch between Γ_s and S_{11}. It is passive, but can have gain > 1. Since there is an “intrinsic” mismatch loss between Z_0 and S_{11} (i.e. between Γ and S_{11}) $\Rightarrow$ decreasing that loss provides gain. Same for G_L.

For dB-s: $G_{TU}(dB) = G_s(dB) + G_0(dB) + G_L(dB)$.

Optimize (match) Γ_s and Γ_L for max. G_s and $G_L \Rightarrow \Gamma_s = S_{11}^*$ and $\Gamma_L = S_{22}^*$ ($|S_{11}| < 1, |S_{22}| < 1$).

$$\Rightarrow G_{s,max} = \frac{1}{1 - |S_{11}|^2} \quad G_{L,max} = \frac{1}{1 - |S_{22}|^2} \tag{20}$$

$$\Rightarrow G_{TU,max} = \frac{1}{1 - |S_{11}|^2} |S_{21}|^2 \frac{1}{1 - |S_{22}|^2} \tag{21}$$

Constant gain circles: unilateral case

$$G_{TU} = \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \tag{22}$$

or $G_{TU} = G_S \cdot G_0 \cdot G_L$. For general analysis writeG_S, G_L as

$$G_i = \frac{1-|\Gamma_i|^2}{|1-S_{ii}\Gamma_i|^2} \tag{23}$$

Two cases:

1. unconditionally stable: $|S_{ii}| < 1$
2. potentially unstable: $|S_{ii}| > 1$

Case 1. Max. value of $G_i \Rightarrow$ match Γ_i and S_{ii}, ie. $\Gamma_i = S_{ii}^*$

$$\Rightarrow G_{ii} = \frac{1}{1 - |S_{ii}|^2} \tag{24}$$

Terminations that produce $G_{i,max}$ are called optimum terminations.

From definition of G_i, if $|\Gamma_i| = 1 \Rightarrow G_i = 0$. Other values of $|\Gamma_i|$ produce values $0 \leq G_i \leq G_{i,max}$.

Analysis of G_i via S-chart leads to constant gain circles.

Introduce normalized gain factor:

$$g_i = \frac{G_i}{G_{i,max}} = G_i(1 - |S_{ii}|^2), \quad \text{and} \quad 0 \leq g_i \leq 1 \tag{25}$$

Also define $\Gamma_i = U_i + jV_i$ and $S_{ii} = A_{ii} + jB_{ii}$ and plug it into eq. 25. Many manipulations later...

$$\left[U_i - \frac{g_i A_{ii}}{1-|S_{ii}|^2(1-g_i)}\right]^2 + \left[V_i - \frac{g_i B_{ii}}{1-|S_{ii}|^2(1-g_i)}\right] = \left[\frac{\sqrt{1-g_i}(1-|S_{ii}|^2)}{1-|S_{ii}|^2(1-g_i)}\right]^2$$

These are circles with g_i as parameter. Centers are at:

$$U_c = \frac{g_i A_{ii}}{1-|S_{ii}|^2(1-g_i)}, \quad V_c = -\frac{g_i B_{ii}}{1-|S_{ii}|^2(1-g_i)} \tag{26}$$

with radius $$R_i = \frac{\sqrt{1-g_i}(1-|S_{ii}|^2)}{1-|S_{ii}|^2(1-g_i)} \tag{27}$$

Writing differently, distance from origin

$$d_i = \sqrt{U_c^2 + V_c^2} = \frac{g_i |S_{ii}|}{1 - |S_{ii}|^2 (1 - g_i)} \tag{28}$$

and angle

$$\tan \alpha = \frac{V_c}{U_c} \Rightarrow \alpha_i = \tan^{-1} \frac{-B_{ii}}{A_{ii}} \tag{29}$$

Const. gain circles located at distance d_i along the line drawn from origin to point S_{ii}^* ($= A_{ii} - jB_{ii}$).

Procedure for const. gain circle(s) construction:

- Locate S_{11}^* and draw line from origin to it. At S_{ii}^* gain is $G_{i,max} = 1/(1 - |S_{ii}|^2)$, and the radius is $R_{i,max} = 0$ (point).
- find values for $0 \le G_i \le G_{i,max}$ (using $G_i = (1 - |\Gamma_i|^2)/|1 - S_{ii}\Gamma_i|^2$), and calculate $g_i = G_i/G_{i,max}$.
- determine d_i, R_i for each g_i (eqs. 28 and 27)
- 0 dB circle ($G_i = 1$) always goes through origin, or for $G_i = 1$ $\Rightarrow \Gamma_i = 0$ so that

$$g_{i,0\text{dB}} = 1 - |S_{ii}|^2 \quad \text{and} \quad R_{i,0\text{dB}} = d_{i,0\text{dB}} = \frac{|S_{ii}|}{1 + |S_{ii}|^2} \qquad (30)$$

Example 3.4.1 shows calculation of optimum terminations, various gains, construction of const. gain circles and design based on those circles.

- determine impedances for optimum terminations
- find $G_{s,max} = 1/(1 - |S_{11}|^2) = 2.141$ (= 3.31 dB)
- find $G_{L,max} = 1/(1 - |S_{22}|^2) = 1.046$ (= 0.19 dB)
- find $G_0 = |S_{21}|^2 = 19.8$ (= 12.97 dB); for total sum them up.
- construct table of g_s, d_s, R_s for various G_i-s (fig. 3.4.4) (why no matching for output?)
- construct matching network for given gain (fig. 3.4.5)

Potentially unstable case (case 2)

Unilateral network: $|S_{ii}| > 1$ (i.e. negative input resistance is present). Look at expr. 23; for $\Gamma_i \rightarrow 1/S_{ii} \Rightarrow G_i \rightarrow \infty$. The critical value is $\Gamma_{i,c} = 1/S_{ii}$.

Under "normal" circumstances ($|S_{11}| < 1$) above condition cannot be satisfied by passive terminations.

For $\Gamma_{i,c} = 1/S_{ii}$ real parts of impedances associated with $\Gamma_{i,c}$ and S_{ii} cancel $\Rightarrow$ no resistance in the circuit!! Oscillations follow.

Remember that for negative resistances we plot the inverse, complex conjugate of the original value; here we plot $1/S_{ii}^*$ on S-chart and read resistance circles as negative and reactances as given.

Normalized gain $g_i = G_i(1 - |S_{ii}|^2)$ can be negative! However, the same formulas for R_i and d_i hold (see eqs. 27, 28), except the centers are located along the origin - $1/S_{ii}$ line.

Need to determine stable region: use conditions:

$$\text{Re}(Z_s) > |\text{Re}(Z_{in})| \text{ and } \text{Re}(Z_L) > |\text{Re}(Z_{out})| \quad (31)$$

i.e., the total resistance in the circuit is still positive.

Example 3.4.2 (fig. 3.4.6).

- locate $1/S_{11}^*$ to find Z_{in}
- find $1/S_{11}$ for line on which centers of const. gain circles will be

- Stable region is where total resistance is positive, i.e. inside the shaded const. resistance circle
- optimum output termination from $\Gamma_L = S_{22}^* = 0.6\angle 80^\circ$. After finding Γ_L on S-chart, read off the Z_L value.
- $G_s = 5\text{dB} = 3.16 \Rightarrow g_s = 3.16[1 - (2.27)^2] = -13.123$
- plug g_s into formulas for R_s and d_s: $R_s = 0.217$, $d_s = 0.415$
- for largest stability pick up Γ_s that has largest Re(Γ_s) on any given const. gain circle (pt. A).

Unilateral figure of merit

When is it permissible to take $S_{12} = 0$ (unilateral device)?

$$\frac{G_T}{G_{TU}} = \frac{1}{|1 - X|^2}, \ X = \frac{S_{12}S_{21}\Gamma_s\Gamma_L}{(1 - S_{11}\Gamma_s)(1 - S_{22}\Gamma_L)} \tag{32}$$

bounded by $$\frac{1}{(1 + |X|)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1 - |X|)^2} \tag{33}$$

G_{TU} max when conj. matching provided: $\Gamma_s = S_{11}^*$ etc. giving max error introduced by $S_{12} = 0$.

$$\frac{1}{(1 + U)^2} < \frac{G_T}{G_{TU}} < \frac{1}{(1 - U)^2} \Rightarrow \tag{34}$$

unilateral figure of merit $$U = \frac{|S_{12}||S_{21}||S_{11}||S_{22}|}{(1 - |S_{11}|^2)(1 - |S_{22}|^2)} \tag{35}$$

Simultaneous conjugate match: Bilateral case

What to do if $S_{12} \neq 0$ (or, U is not small)?

Most general expressions for Γ_{IN} and Γ_{OUT} still hold:

$$\Gamma_{IN} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L} \quad (= \Gamma_s^*) \tag{36}$$

$$\Gamma_{OUT} = S_{22} + \frac{S_{12}S_{21}\Gamma_s}{1 - S_{11}\Gamma_s} \quad (= \Gamma_L^*) \tag{37}$$

For max. power transfer $\Gamma_{IN} = \Gamma_s^*$ and $\Gamma_{OUT} = \Gamma_L^*$. fig. to illustrate.

Solve two eqs. with two unknowns: Γ_L, Γ_s. Call the solution Γ_{Ms} and Γ_{ML} (for simultaneously matched case).

Solution:

$$\Gamma_{Ms} = \frac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2C_1} \quad \Gamma_{ML} = \frac{B_2 \pm \sqrt{B_2^2 - 4|C_2|^2}}{2C_2} \tag{38}$$

$$C_1 = S_{11} - \Delta S_{22}^* \quad B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2 \tag{39}$$

$$C_2 = S_{22} - \Delta S_{11}^* \quad B_2 = 1 + |S_{22}|^2 - |S_{11}|^2 - |\Delta|^2 \tag{40}$$

Which sign to use above? First, $|\Gamma_{Ms}|,\ \Gamma_{ML} < 1$ is necessary for unconditional stability.

Further analysis shows the necessary condition to be $K > 1$ where K is stability factor! From before we know the additional requirement: $|\Delta| < 1 \Rightarrow B_1 > 0$ and $B_2 > 0$

All of this $\Rightarrow$ negative signs (-) should be used in Γ_{Ms}, Γ_{ML} when calculating the simultaneous con. match for unconditionally stable two-port network.

Potentially unstable case: analysis done in terms of G_P, G_A (but see recent literature).

What is the max. G_T associated with Γ_{Ms}, Γ_{ML}?

$$\begin{aligned} G_{T,max} &= \frac{(1-|\Gamma_{Ms}|^2)|S_{21}|^2(1-|\Gamma_{ML}|^2)}{|(1-S_{11}\Gamma_{Ms})(1-S_{22}\Gamma_{ML})-S_{12}S_{21}\Gamma_{Ms}\Gamma_{ML}|^2} \\ &= \frac{1}{1-|\Gamma_{Ms}|^2}|S_{21}|^2\frac{1-|\Gamma_{ML}|^2}{|1-S_{22}\Gamma_{ML}|^2} \end{aligned} \tag{41}$$

(see eq. 3.2.1 — no Γ_{IN} or Γ_{OUT} present there).

Further manipulation:

$$G_{T,max} = \frac{|S_{21}|}{|S_{12}|}(K - \sqrt{K^2 - 1}) \tag{42}$$

note: $G_{T,max}$ depends only on transistor parameters (S-matrix). Γ_{Ms}, Γ_{ML} don't enter the picture because they are determined by conjugate matching requirement.

If we had some control of [S], what would max. $G_{T,max}$ be? Since $K - \sqrt{K^2 - 1}$ falls monotonically to 0, max value is for $K = 1$. The value of $G_{T,max}$ for K=1 is called maximum stable gain (MSG), $G_{MSG} = |S_{21}|/|S_{12}|$. Condition K=1 can be achieved by resistive loading or by feedback

Constant gain circles: bilateral case

Conditions: $K > 1$ and $|\Delta| < 1$.

Design may call for $G_T \neq G_{T,max}$ (produced by conjugate matching); what to do then? Need to choose Γ_s, Γ_L differently. Start with:

$$\begin{aligned} G_T &= \frac{1-|\Gamma_s|^2}{|1-\Gamma_{IN}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \\ &= \frac{1-|\Gamma_s|^2}{|1-S_{11}\Gamma_s|^2}|S_{21}|^2\frac{1-|\Gamma_L|^2}{|1-\Gamma_{OUT}\Gamma_L|^2} = G_s^{'}\, G_0\, G_L \end{aligned} \tag{43}$$

$$G_s^{'} = \frac{1-|\Gamma_s|^2}{|1-\Gamma_{IN}\Gamma_s|^2} \quad G_0 = |S_{21}|^2 \quad G_L = \frac{1-|\Gamma_L|^2}{|1-S_{22}\Gamma_L|^2} \tag{44}$$

Compare this with expressions in unilateral case

$$G_s = \frac{1 - |\Gamma_s|^2}{|1 - S_{11}\Gamma_s|^2} \quad G_L = \frac{1 - |\Gamma_L|^2}{|1 - S_{22}\Gamma_L|^2} \tag{45}$$

$\Rightarrow \Gamma_{IN}$ replaced S_{11}

General procedure follows unilateral case, but it is iterative because Γ_{IN} depends on choice of Γ_L.

Procedure:

- Pick Γ_L for given G_L gain (see eq. above). Const. gain circles can be drawn using unilateral gain formulas

$$g_L = G_L/G_{L,max} = G_L(1 - |S_{22}|^2) \tag{46}$$

$$R_L = \frac{\sqrt{1-g_L}(1-|S_{22}|^2)}{1-|S_{22}|^2(1-g_L)} \tag{47}$$

$$d_L = \frac{g_L|S_{22}|}{1-|S_{22}|^2(1-g_L)} \tag{48}$$

angle determined by S_{22}^*: line connecting the origin with S_{22} will have centers of circles on it.

- Calculate Γ_{IN} from $\Gamma_{IN} = S_{11} + S_{12}S_{21}\Gamma_L/(1 - S_{22}\Gamma_L)$
- $G_s^{'}$ const. gain circles drawn using the same eqs. (46, 47, 48) but Γ_{IN} goes where S_{11} would normally go:

$$g_s = G_s^{'}/G_{s,max} = G_s^{'}(1-|\Gamma_{IN}|^2) \tag{49}$$

- $$R_s = \frac{\sqrt{1-g_s}(1-|\Gamma_{IN}|^2)}{1-|\Gamma_{IN}|^2(1-g_s)} \tag{50}$$

  $$d_s = \frac{g_s|\Gamma_{IN}|}{1-|\Gamma_{IN}|^2(1-g_s)} \tag{51}$$

  angle determined by Γ_{IN}^* (instead of S_{11}^*)
  Select the desired Γ_s for a given $G_s^{'}$ gain. The available values of $G_s^{'}$ may not be satisfactory, e.g. $G_{s,max} = 1/(1-|\Gamma_{IN}|^2)$ may be too small, or values of possible Γ_s may not be good etc $\Rightarrow$ go back to start and choose different Γ_L and repeat the procedure.
- Once Γ_s and Γ_L are picked up, design matching networks as before.

Example 3.6.1. Operate at 6 GHz with $G_{T,max}$. Fig. 3.6.3.

- calc. K and $|\Delta|$ for stability: $K = 1.504$, $\Delta = 0.301\angle 109^\circ$ (is it unconditionally stable?)
- is FET unilateral? calculate $U = 0.1085$ so that

$$-0.89 \text{ dB} \leq \frac{G_T}{G_{TU}} < 1 \text{ dB} \Rightarrow S_{12} \neq 0 \tag{52}$$

- calc. simultaneous conjugate match (need B_1, B_2, C_1, C_2) $\Rightarrow$ $\Gamma_{Ms} = 0.76\angle 177^\circ$, $\Gamma_{ML} = 0.71\angle 103^\circ$
- from $K, S_{21}, S_{12} \Rightarrow G_{T,max} = 11.3$ dB.
- given Γ_{Ms}, Γ_{ML} find matching networks. From S-chart: $Y_{Ms} = 7.2 - j1.23 = 0.144 - j0.0246$ S, and $Y_{ML} = 0.414 - j1.19$, $= 0.0083 - j0.0238$ S. See fig. 3.6.3 and 3.6.4 for design.

- calc. real lengths for given material (say, Duroid)
- check other frequencies to make sure that chosen Γ-s provide stable operation.

How about potentially unstable bilateral case ($K < 1$ or $|\Delta| > 1$)?

Turns out that design procedure based on G_T is not good and is better done based on operating power gain equation.

Conclusion on bilateral case: anything but design for $G_{T,max}$ is tedious (and better alternative exists); if transistor is unconditionally stable simultaneous conjugate match can be found resulting in $G_{T,max}$.