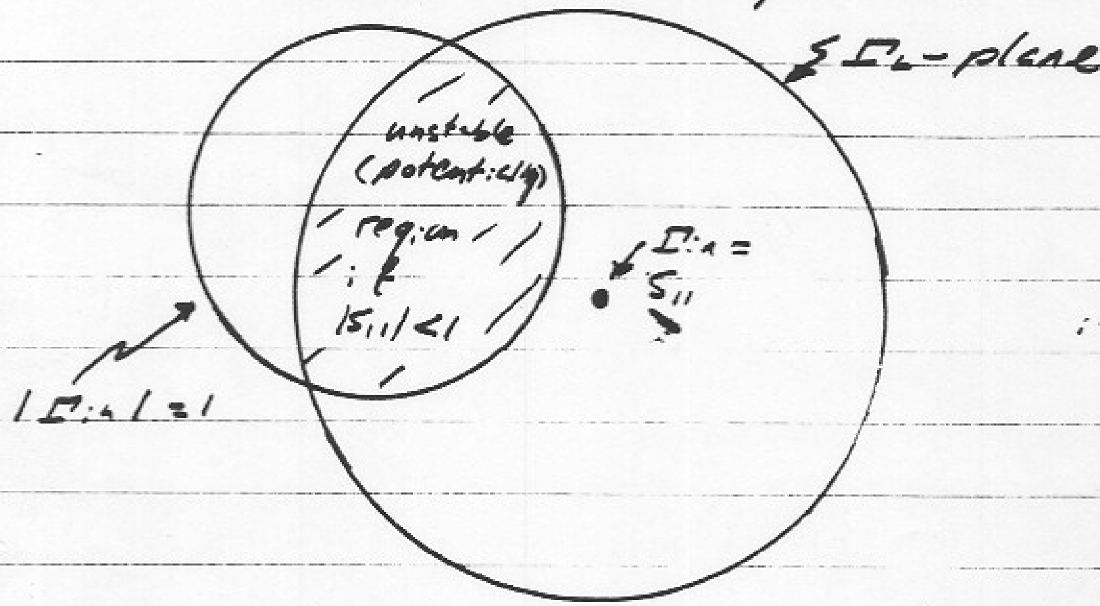
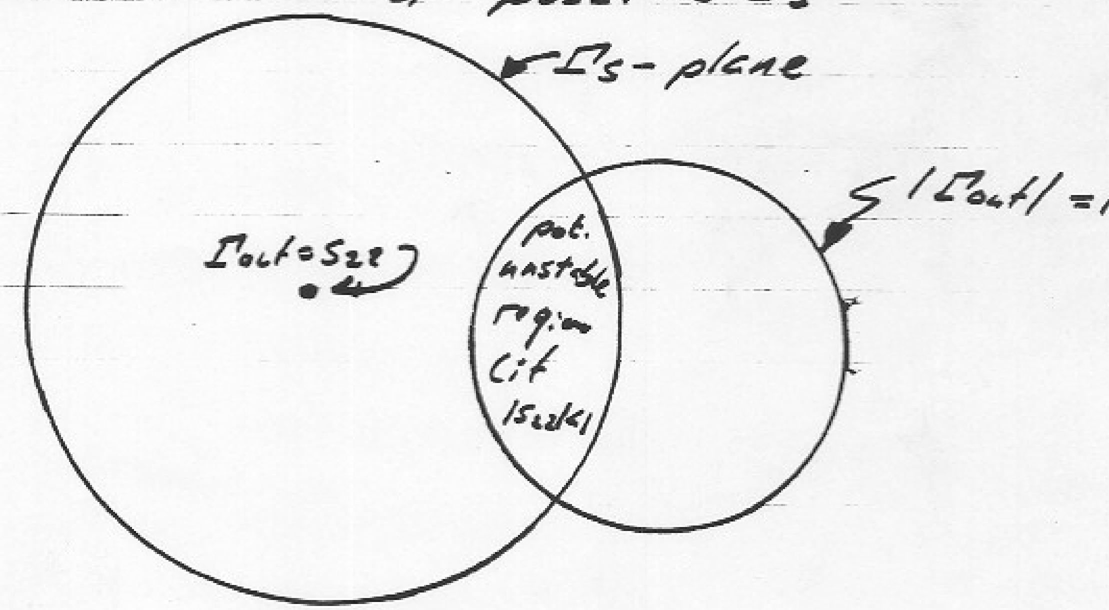
ECE 202A 11/13/89

stability: stable (unconditionally) if
$|\Gamma_{in}| < 1$ for all possible Γ_L



equivalently: unconditionally stable if
$|\Gamma_{out}| < 1$ for all possible Γ_s



unconditionally stable if

$$K > 1 \; ; \; K = \frac{1 - |S_{11}|^2 - |S_{22}|^2 + |\det S|^2}{2|S_{12}S_{21}|}$$

and $|\det S| < 1$

and $|S_{11}|, |S_{22}| < 1$

---

ok, so now lets' calculate the maximum available power gain (MAG):

To attain this, must have match on both input & output: $\Gamma_S = \Gamma_{in}^{*}$ and $\Gamma_L = \Gamma_{out}^{*}$

but we know that: $\Gamma_{in} = S_{11} + \dfrac{S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$

$$\Gamma_{out} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1 - S_{11}\Gamma_S}$$

solve these simultaneously (or ask Touchstone to)

$$\Gamma_s^* = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L}$$

$$\Gamma_L^* = S_{22} + \frac{S_{12} S_{21} \Gamma_S}{1 - S_{11} \Gamma_S}$$

... $\Rightarrow$ answer Given in Gonzales pp 113.

Maximum available gain = MAG = G_T with $\begin{cases} \Gamma_S = \Gamma_{in}^* \\ \Gamma_L = \Gamma_{out}^* \end{cases}$

so, the values we calculate from above for the matched Γ_S, Γ_L are substituted into the relationship for G_T: (page 4 of 11/6 notes, remember

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

$\Rightarrow$ expression for G_{max}.

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

ok, so, there is! clearly some serious algebra in these steps, which I have skipped. I don't really feel that it is important that you do the algebra... Just that you know the process by which the expression comes about:

$\left\{ \begin{array}{l} \Gamma_{in} \text{ depends on } S, \Gamma_L \\ \Gamma_{out} \text{ depends on } S, \Gamma_S \end{array} \right.$

solve simultaneously to find Γ_S & Γ_L for simultaneous Conjugate match.

$\left\{ \begin{array}{l} G_T \text{ depends on } S, \Gamma_S, \Gamma_L \\ G_T = G_{MAX} \text{ when input \& output are matched} \end{array} \right.$

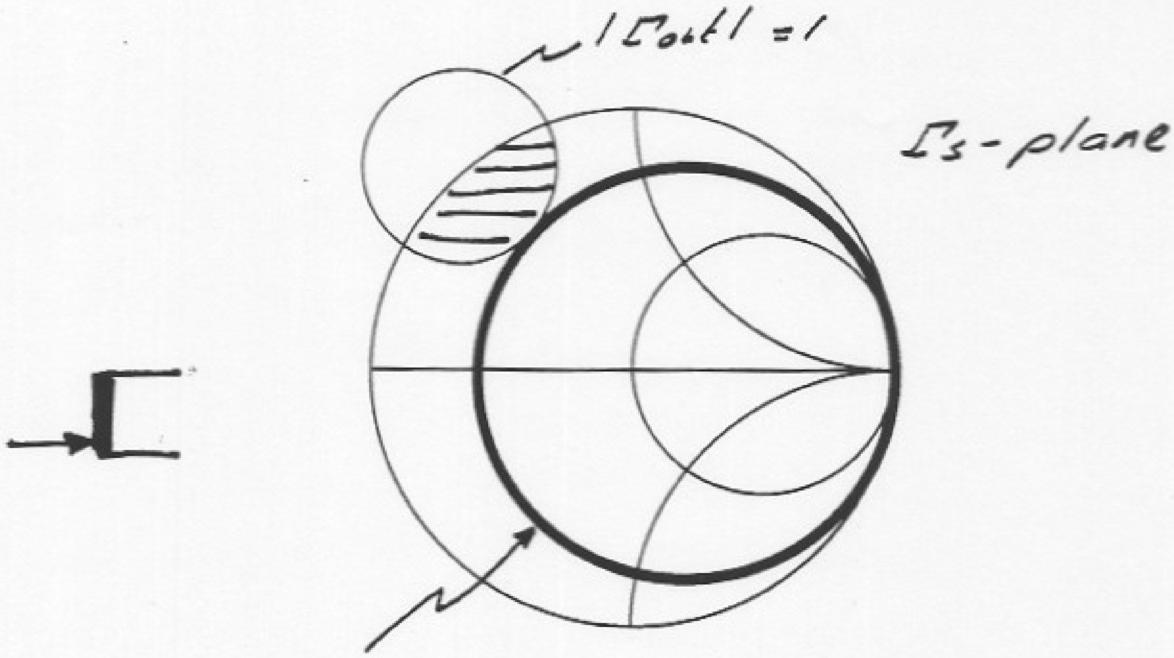
expression for $G_{max} = \dfrac{|S_{21}|}{|S_{12}|}\left(k - \sqrt{k^2-1}\right)$

note that if $k<1$ (unstable)

G_{max} doesn't exist.

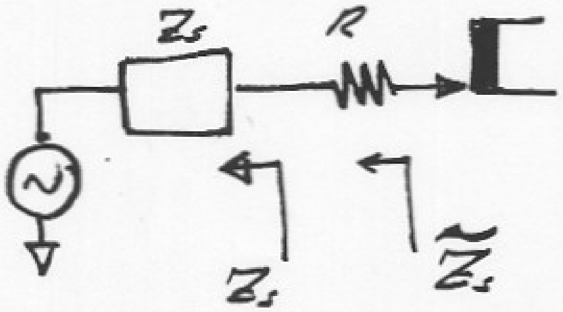
$\Rightarrow$ of Course! unstable = can build an oscillator

<u>stablization</u> How to make <u>sure</u> it doesn't oscillate



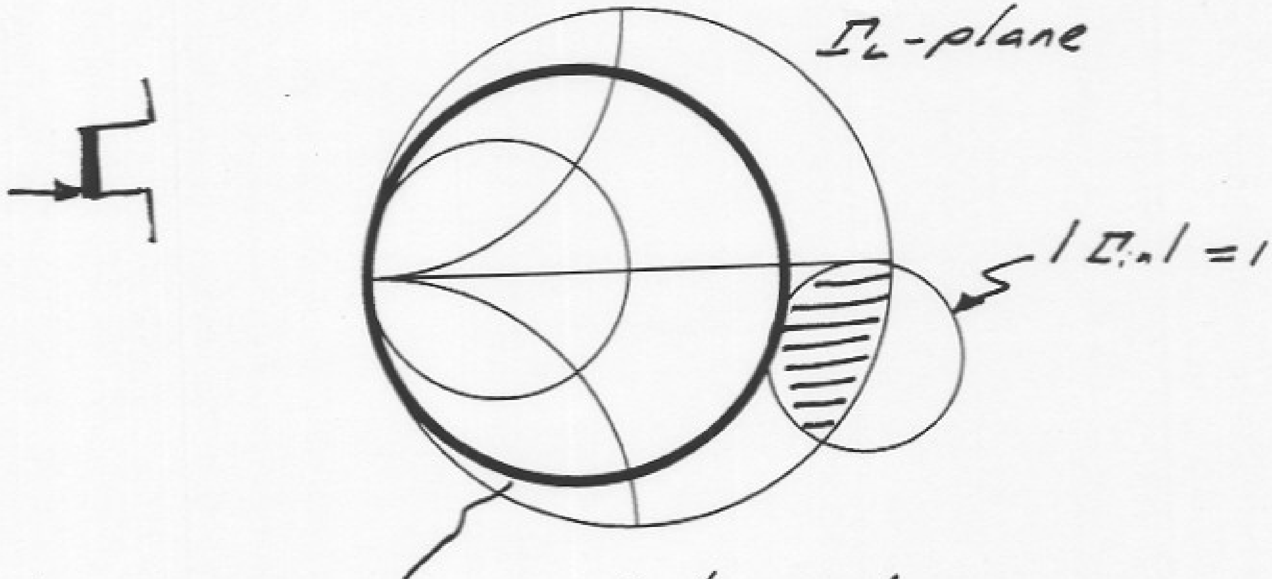
Circle corresponding to constant normalized resistance $= r$

If we put a resistor in <u>series</u> with input...
$(R = r Z_0)$



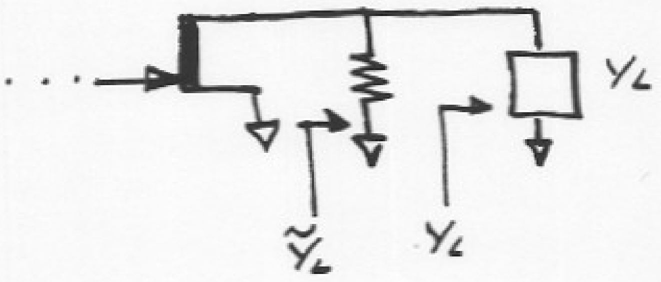
... no matter what Z_s is, $\tilde{Z}_s$ has to lie within the <u>bold</u> circle above

$\Rightarrow$ can't oscillate.



circle corresponding to constant normalized conductance g

If we put a resistor in parallel with output...
($R = Z_0/g$)

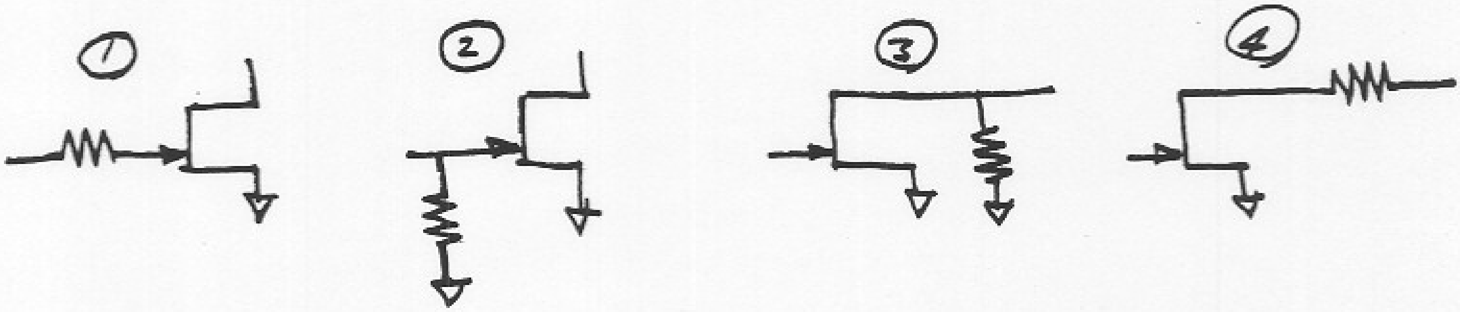


... no matter what Y_L is, $\tilde{Y}_L$ has to lie within

the bold circle above

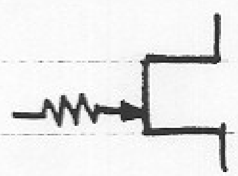
$\Rightarrow$ can't oscillate

there are, in principle, 4 possible methods

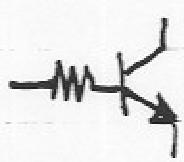


... feasibility simply depends upon where the stability circles lie ... solutions 1 & 3 usually most appropriate

note that

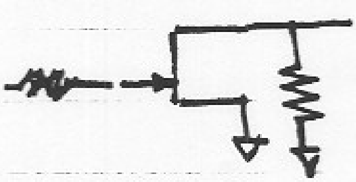


or

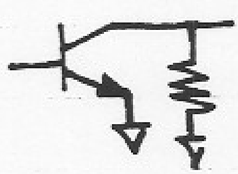


is like increasing r_g or $r_{b'b}$

and that

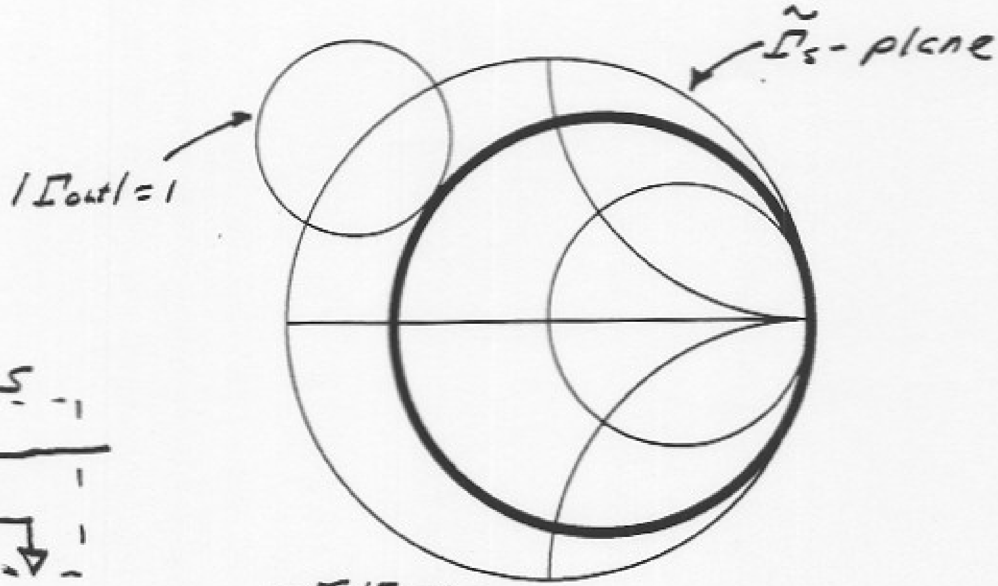


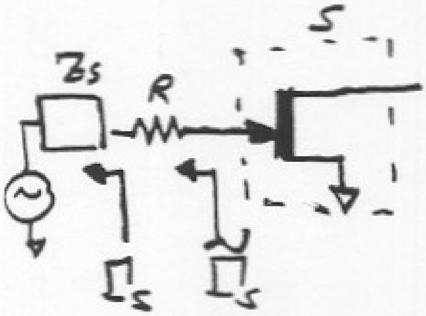
or

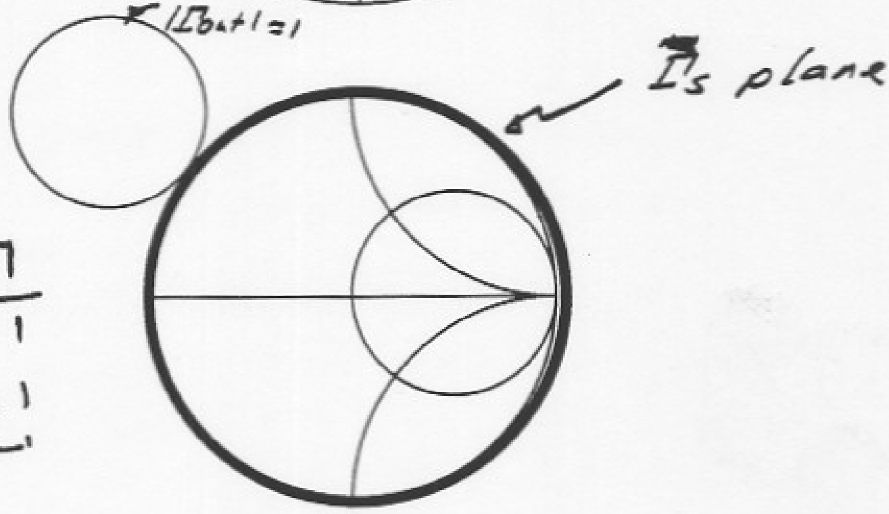


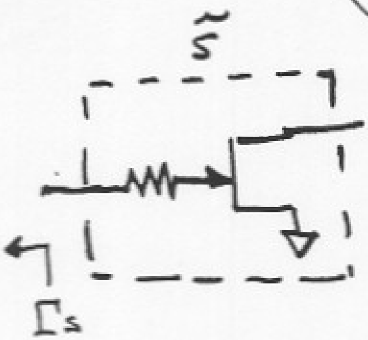
is like decreasing r_{ce} or r_{ds}

... think of effect of this on the f_{max} of the composite device (goes down)





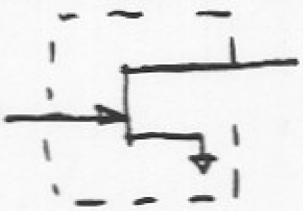




so stability factor $\underline{\underline{\tilde{k}}}$ must now $= 1$!

where k now refers to a new "device", the combined resistor & transistor.

Before stabilization:



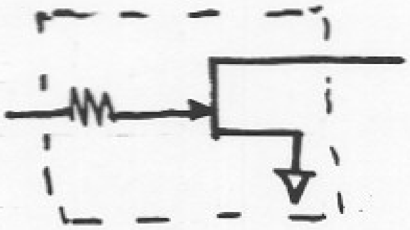
S

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

$= $ undefined (unstable)

After stabilization:

$\tilde{S}$



$$G_{max} = \frac{|\tilde{S}_{21}|}{|\tilde{S}_{12}|}\left(\underbrace{\tilde{K}}_{=1} - \sqrt{\tilde{K}^2-1}\right)$$

$$= |\tilde{S}_{21}| / |\tilde{S}_{12}|$$

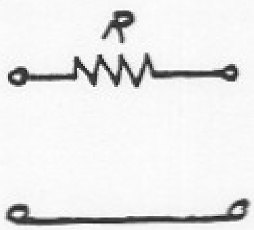
note that $\tilde{S}_{21} \neq S_{21}$ and $\tilde{S}_{12} \neq S_{12}$. But if the series stabilization element is $\ll Z_0$ (or if the shunt stabilization element is $\gg Z_0$) then S_{12} & S_{21} won't have changed much. then G_{max} after adding just enough stabilization so that it is just impossible to find any (Γ_s & Γ_L) which cause oscillation is $\approx |S_{21}| / |S_{12}|$.

"Maximum stable gain" $= MSG = |S_{21}| / |S_{12}|$
if the device is potentially unstable.

Now wait... the texts state $MSG = |S_{21}|/|S_{12}|$, not approximately.

Clearly, adding stabilization changes the 4 S-parameters; maybe it doesn't change the S_{21}/S_{12} ratio:

Check this:

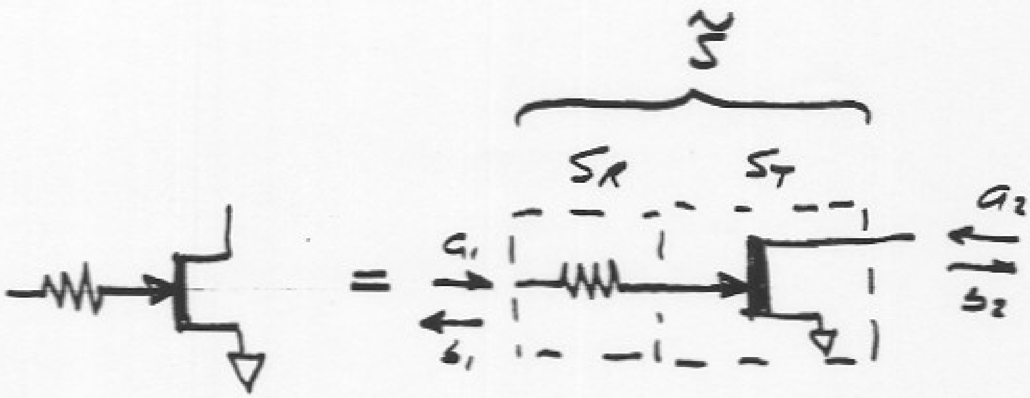


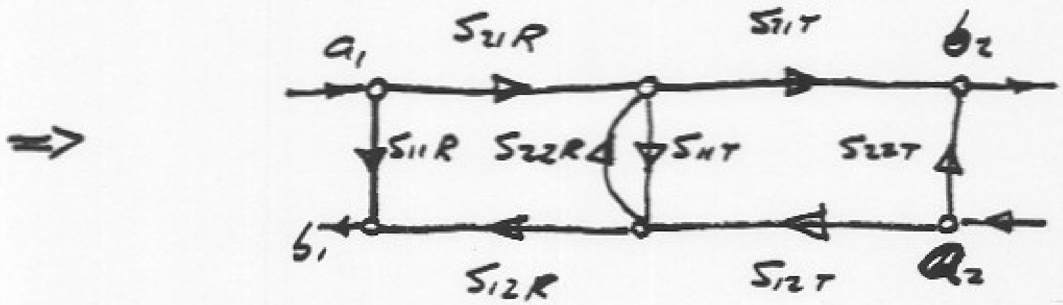
$S_R = ?$

use properties of S-parameters =>

$$S_R = \begin{bmatrix} S_{11R} & S_{12R} \\ S_{21R} & S_{22R} \end{bmatrix}$$

$$S_{22R} = S_{11R} = \frac{R/2Z_0}{1 + R/2Z_0} \quad ; \quad S_{12R} = S_{21R} = 1 - S_{11R}$$





$$\frac{b_2}{a_2} = \tilde{S}_{21} = \frac{S_{21R}\, S_{21T}}{1 - S_{22R}\, S_{11T}}$$

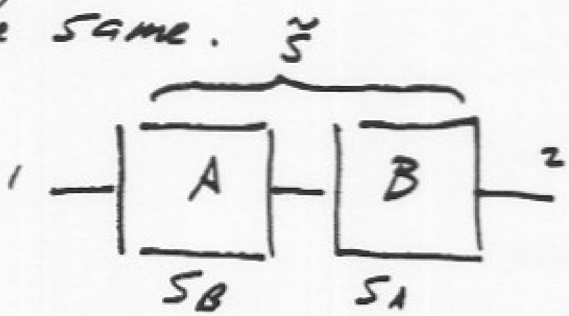
$$\frac{b_1}{a_2} = \tilde{S}_{12} = \frac{S_{12T}\, S_{12R}}{1 - S_{22R}\, S_{11T}}$$

so: $$\frac{\tilde{S}_{21}}{\tilde{S}_{12}} = \frac{S_{21R}\, S_{21T}}{S_{12T}\, S_{12R}}$$ but resistor has $S_{12} = S_{21}$

so $$\frac{|\tilde{S}_{21}|}{|\tilde{S}_{12}|} = \frac{|S_{21}|}{|S_{12}|}$$

How about the other 3 cases?

Well note that the denominator in $\tilde{S}_{12}$ & $\tilde{S}_{21}$ are <u>always</u> the same.



In general: $\tilde{S}_{21} = \dfrac{S_{21A}\, S_{21B}}{\text{denominator}}$

$$\tilde{S}_{12} = \frac{S_{12A}\, S_{12B}}{\text{denominator}}$$

also, a general property of two-ports containing <u>only</u> passive <u>reciprocal</u> elements (L's, C's, R's, trx lines...) is that $S_{21} = S_{12}$.

So adding a "black box" to the transistor input or the output won't change ratio of S_{12}/S_{21}.

So, always:

Maximum stable gain $= \dfrac{|S_{21}|}{|S_{12}|}$ (if was unstable)

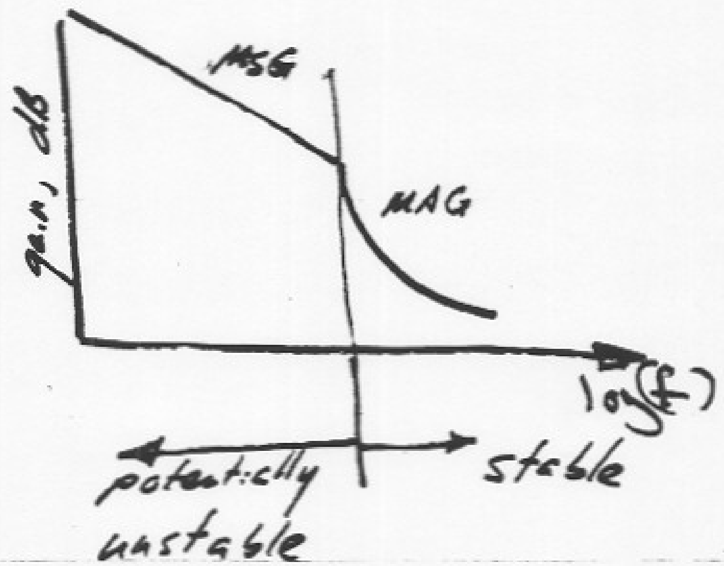
this means that:

- Given that you have an unstable transistor
- You add stabilization resistance so you can <u>just</u> guarantee unconditional (overall) stability.
- You then provide matching on input & output

$\Rightarrow$ You will then attain a power gain of $\dfrac{|S_{21}|}{|S_{12}|}$

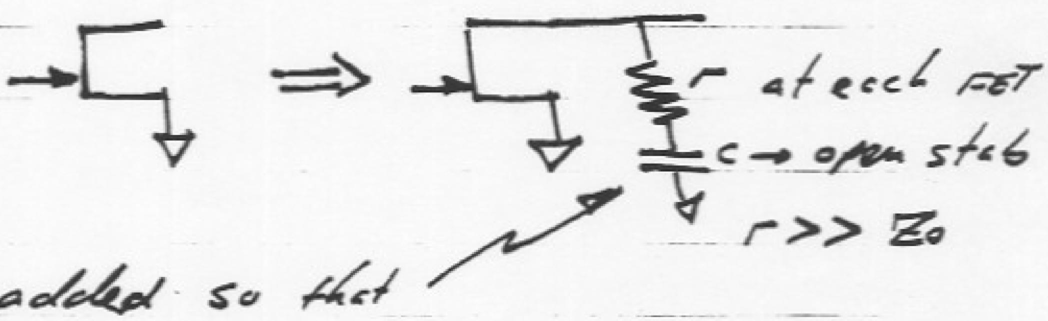
Trick Question: suppose ~~an~~ $K>1$, $|S_{21}| = 40\,dB$ & $|S_{12}| =$ ~~[illegible]~~ $-10\,dB$.
What is MSG?

<u>Touchstone</u> plots MAG (when called for) at all frequencies where the device is ~~un~~stable. It then defaults to MSG.



Practical Hint: In the TWA, terrible danger of oscillation at or near the lines' bragg frequencies.

solution:



capacitor is added so that $1/2\pi rc \approx f_{bragg}$, so that ~~cap~~ the network only has effect at the high end of the amplifier band

Cost of increased drainline loading and danger of

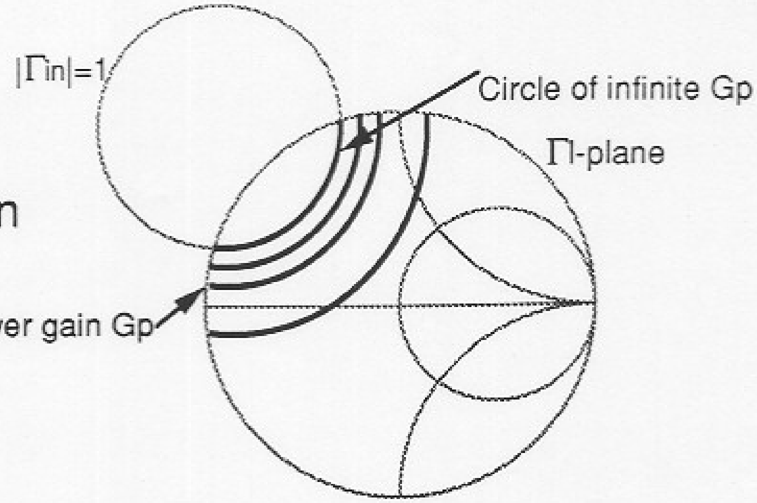
Ok so we have just stabilized the transistor.

Is this enough? Not really. We will find that the amplifier is matched at one port with a reflection coefficient of exactly one.

The shape of either the operating (G_P) or available (G_A) power gain will change as we add stabilization. If we have just added a critical level of stabilization, the gain is very sensitive to the match

$\Rightarrow$ "lossy" Match

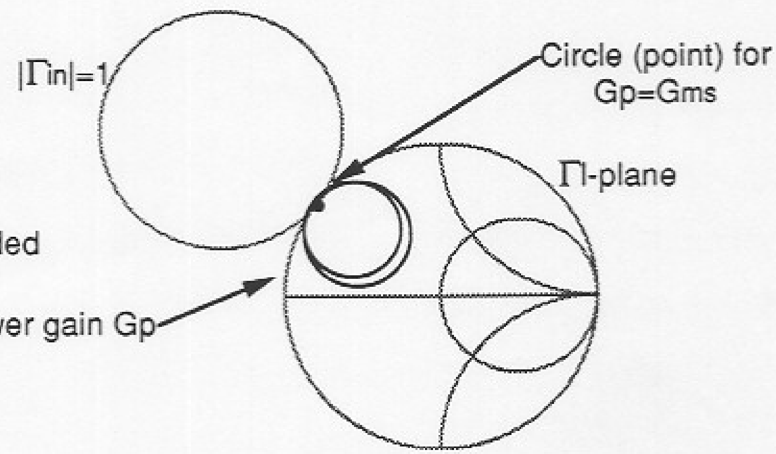
Before Stabilization



Circles of Constant operating power gain Gp

After Stabilization-

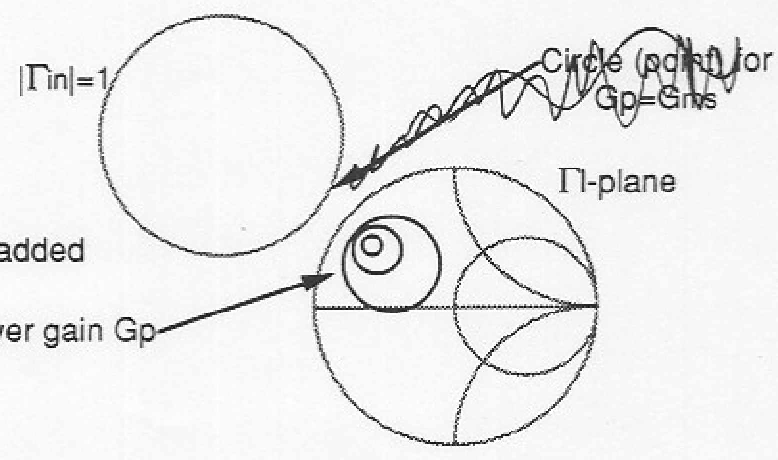
with just the critical stabilization added



Circles of Constant operating power gain Gp

After Stabilization-

with more than critical stabilization added



Circles of Constant operating power gain Gp

similar construction on input (Γ_s plane, G_A circles)

So to design a narrowband matched amplifier: first decide what gain, bandwidth, (noise, power) required?

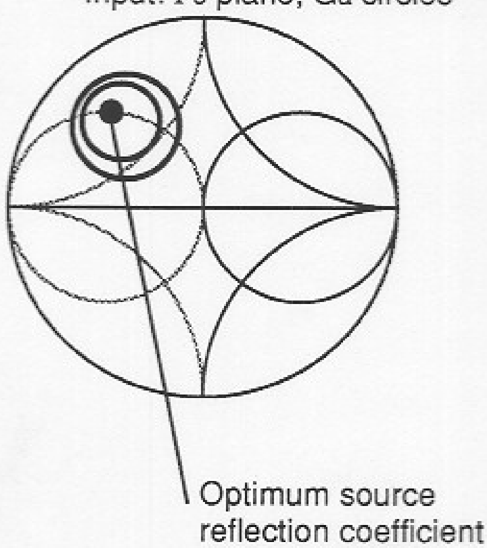
Is the device stable or unstable at the design frequency?

If the device is stable, determine the source and load reflection coefficients required for simultaneous input/output matching. To do this, solve the simultaneous equations (Gonzales page 113) or use Touchstone to look at the required matches conditions

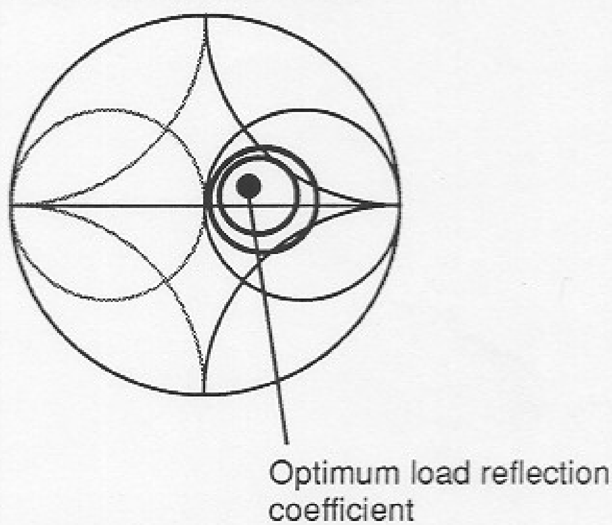
Ga circles show how the gain varies with input (mis)match assuming that the output is matched

Gp circles show how the gain varies with output (mis)match assuming that the input is matched

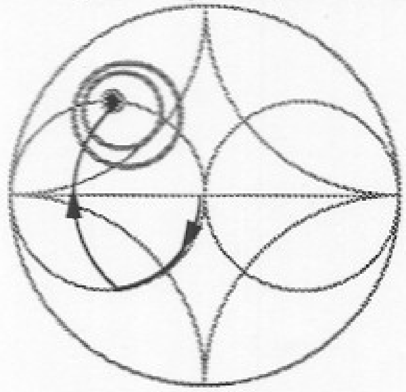
Input: Γ_s plane, G_a circles

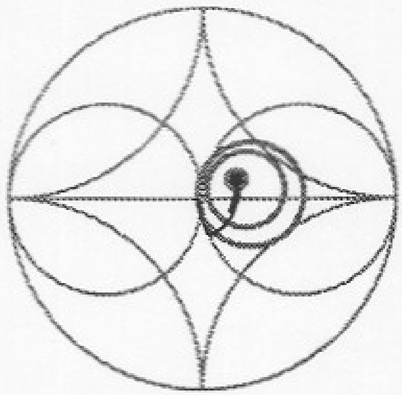


Output: Γ_l plane, G_p circles

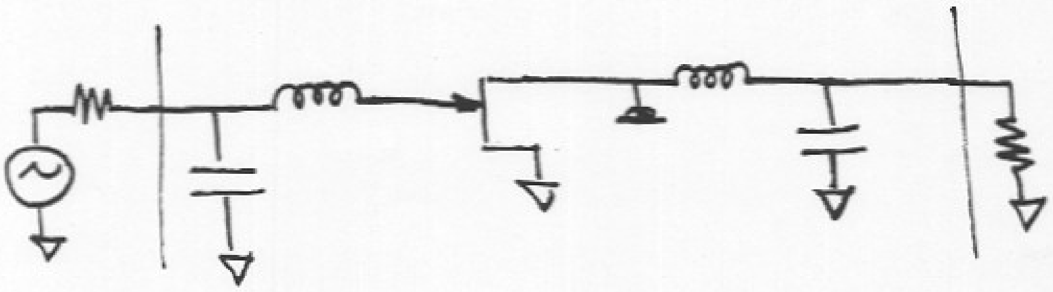


Then design input and ouput matching networks: (here I am assuming 50Ω source and load)





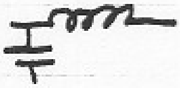
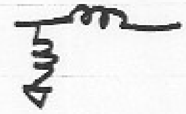
So, implementation looks like:



⇒ Then replace with microstrip elements.

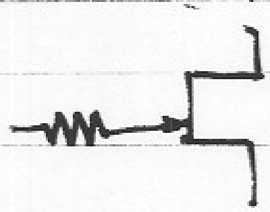
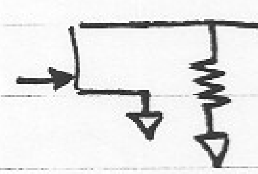
Now simulate over frequency: is the desired bandwidth attained?

How much does performance change with small changes in parameters? Look at g_A and G_p circles of the overall amplifier.

If either the bandwidth is too small, or the design too parameter-sensitive (amplifier G_A G_P circles), need to either use alternative matching networks ( vs  vs ...), use broadband matching networks (next time) or use a <u>lossy match</u>.

If transistor is unstable at the match frequency:

1) add series or shunt stabilization resistance at input or output

 or  or ...

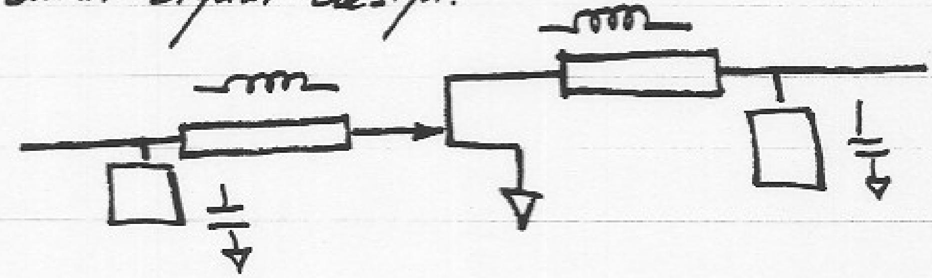
2) Look at resulting G_A, G_p circles: If gain varies very rapidly with match, or if the optimum matches are at edge of chart, add greater stabilization.

3) design input & output matching networks.

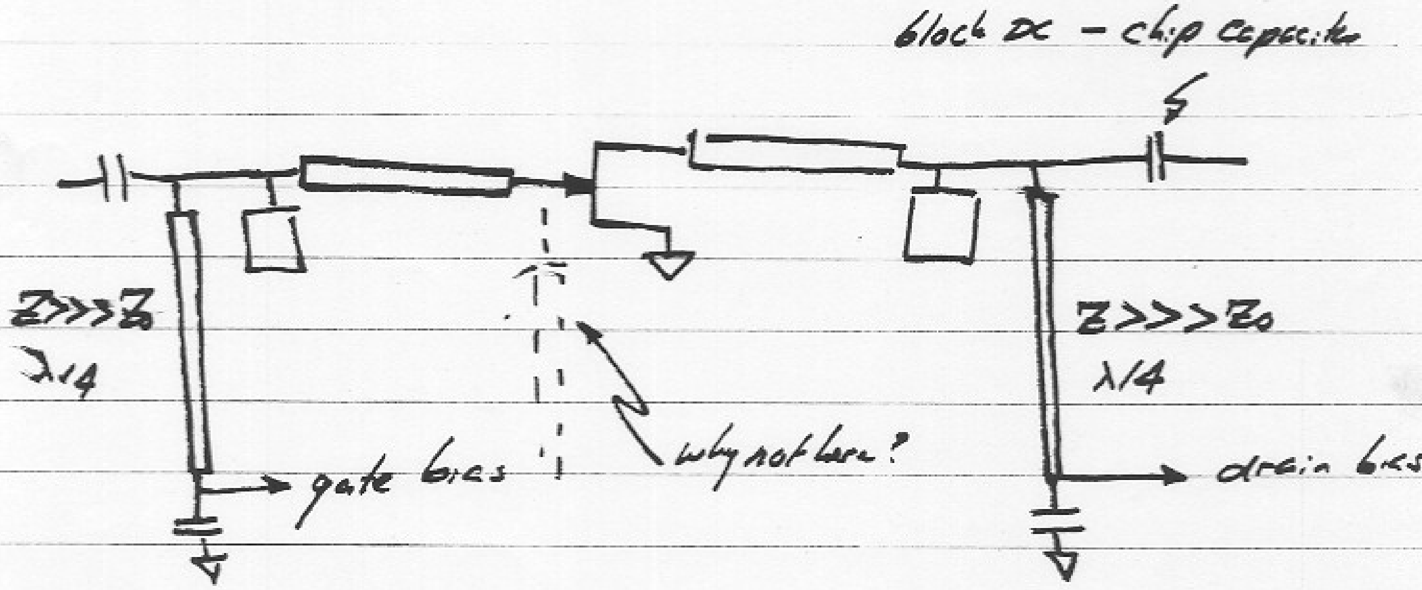
4) Again look at parameter sensitivity:
(G_A, G_p circles of overall amplifier)

Biasing: need to bring in DC:

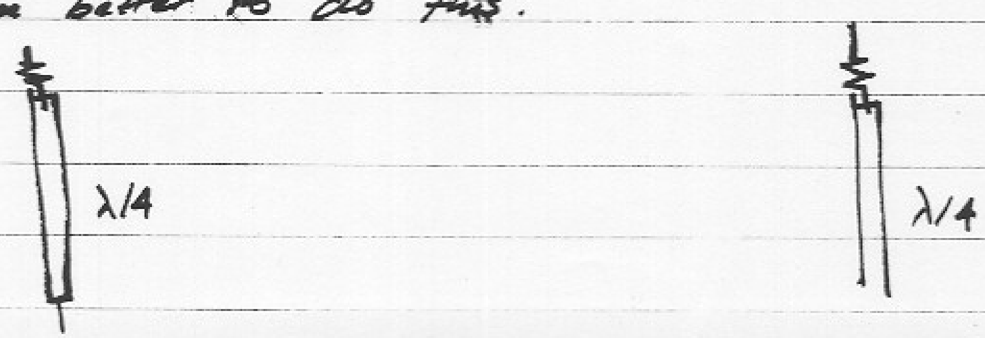
small-signal design:



adding bias:

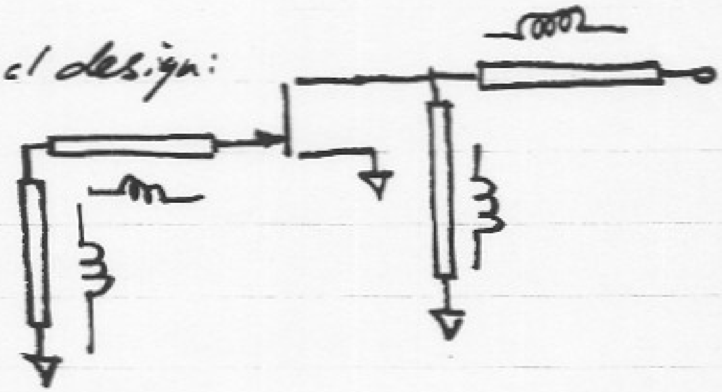


might be better to do this:

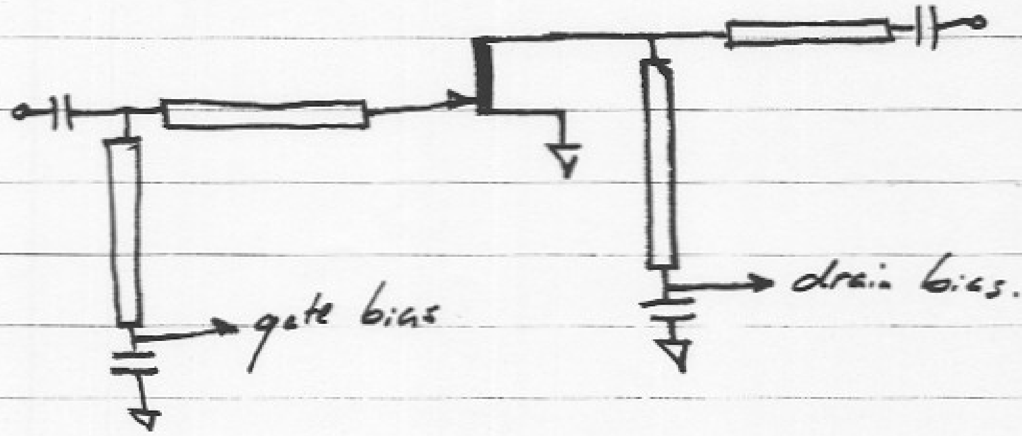


2nd example:

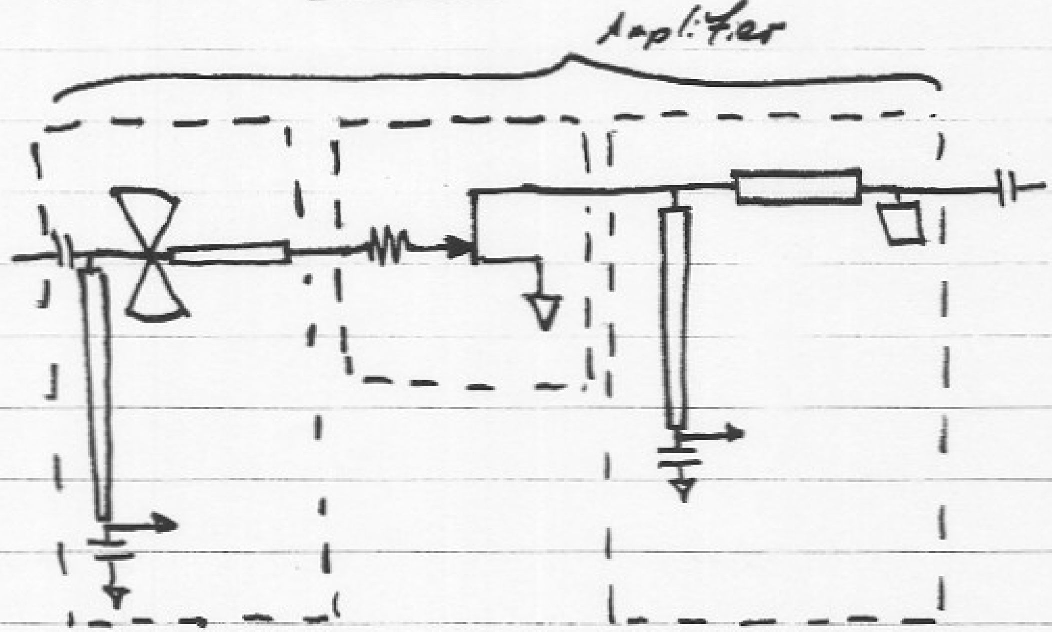
small-signal design:



adding bias:



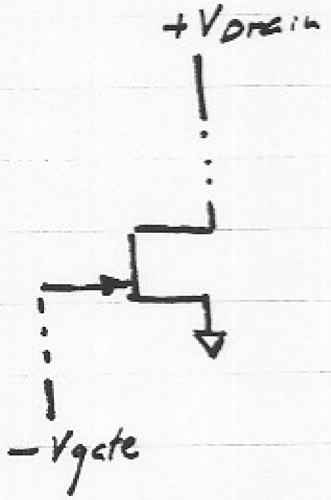
Final point: having designed amplifier + matches so that we get desired gain, bandwidth: we need to look at the stability factor from DC to f_{max}, of the overall amplifier.



Is the overall system unconditionally stable?

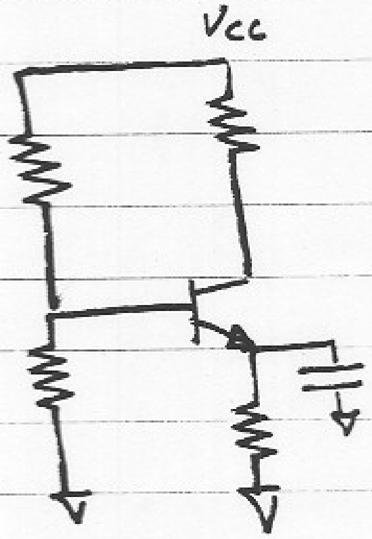
Note that stabilization resistor was picked at design frequency. It then depends upon the input & output networks whether Γ_s, Γ_L can enter the regions of potential instability.

How to actually provide bias:

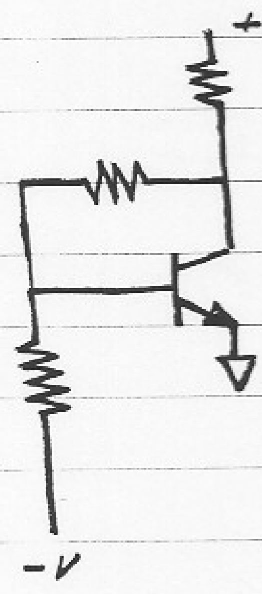


If you need to operate device at specified Vd, Vg

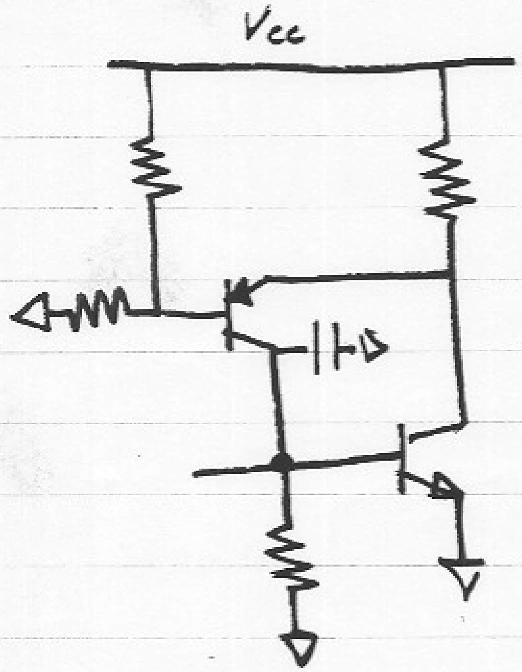
Bipolar:



or



<u>or feedback</u>:



can also be used with FET if control of drain current is desired;