EECS 242:
Amplifier Design Examples

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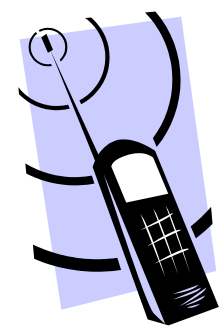
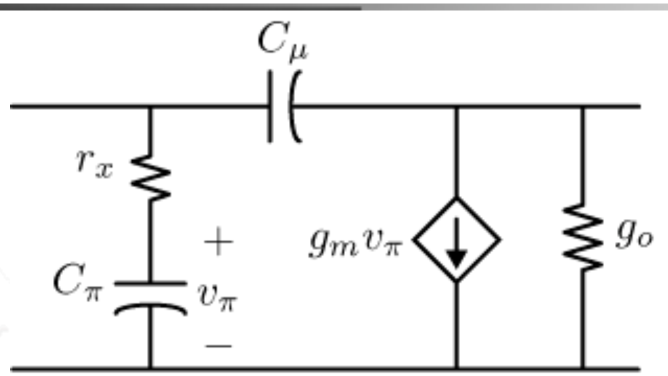


Small-Signal Transistor Model

$$\omega_T = \frac{g_m}{C_{gs}} \qquad g_m = \frac{2I_{ds}}{V_{dsat}}$$

$$C_{gd} = \mu C_{gs} \qquad A_{v,0} = g_m r_o$$

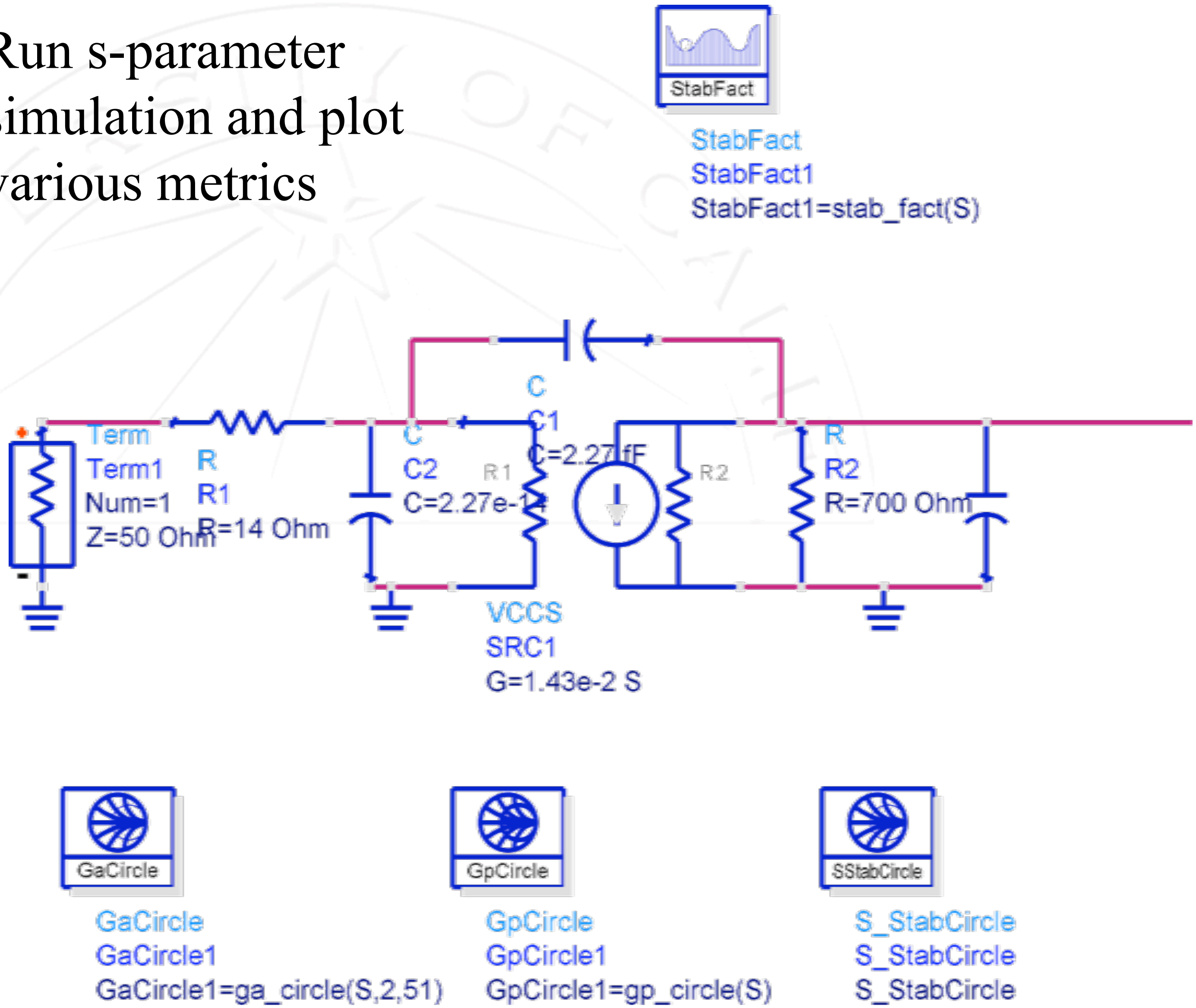
$$r_x = \frac{1}{5g_m}$$



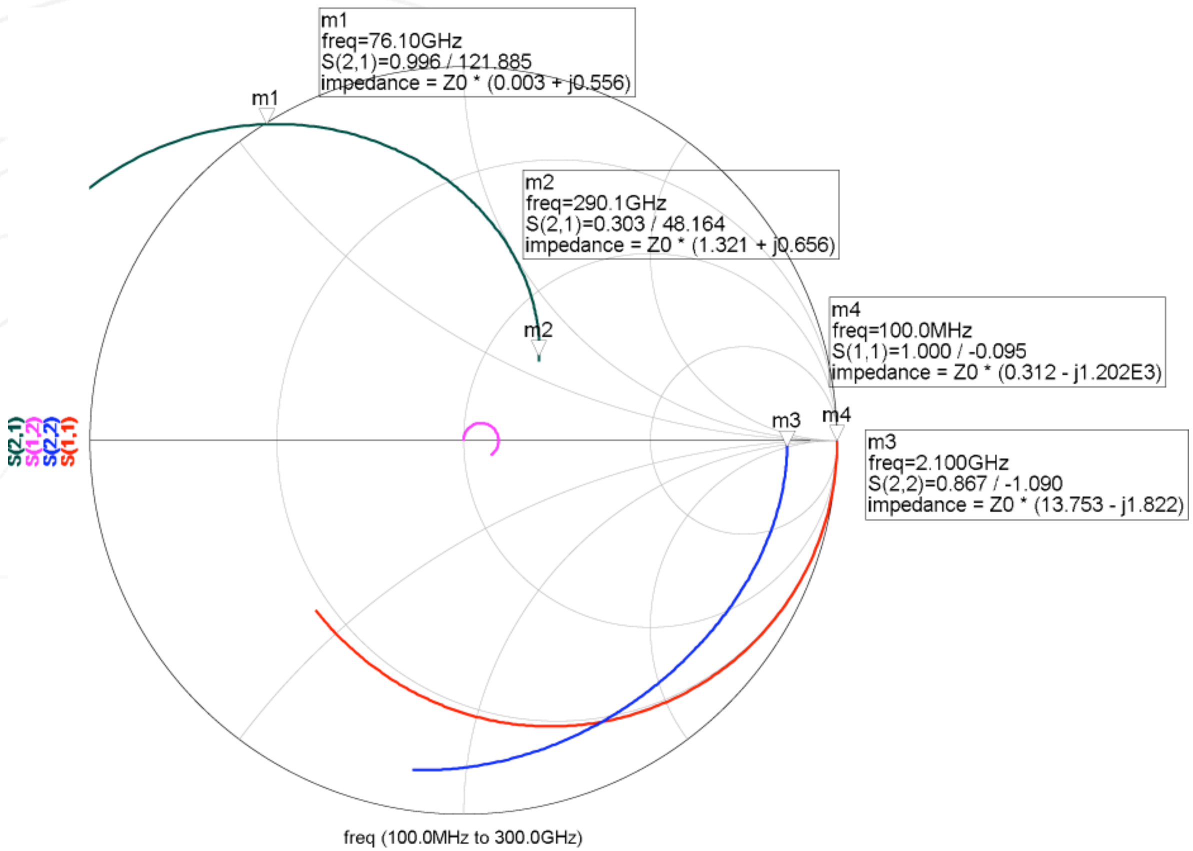
- Intrinsic transistor model
- Using basic equations, let's assume we have the following process:
  - f_T = 100 GHz
  - A_{v0} = 10, V_t = 0.3V, V_{gs} = Vdd = 1V, V_{dsat} = 0.7V, I_{ds} = 5mA
  - g_m = 14.3mA/V, r_o = 700Ω, C_{gs} = 22.7 fF
  - C_{gd} = 0.1 C_{gs} = 2.27 fF
  - C_{db} = 10fF (arbitrary)

Simulation Setup (ADS)

- Run s-parameter simulation and plot various metrics

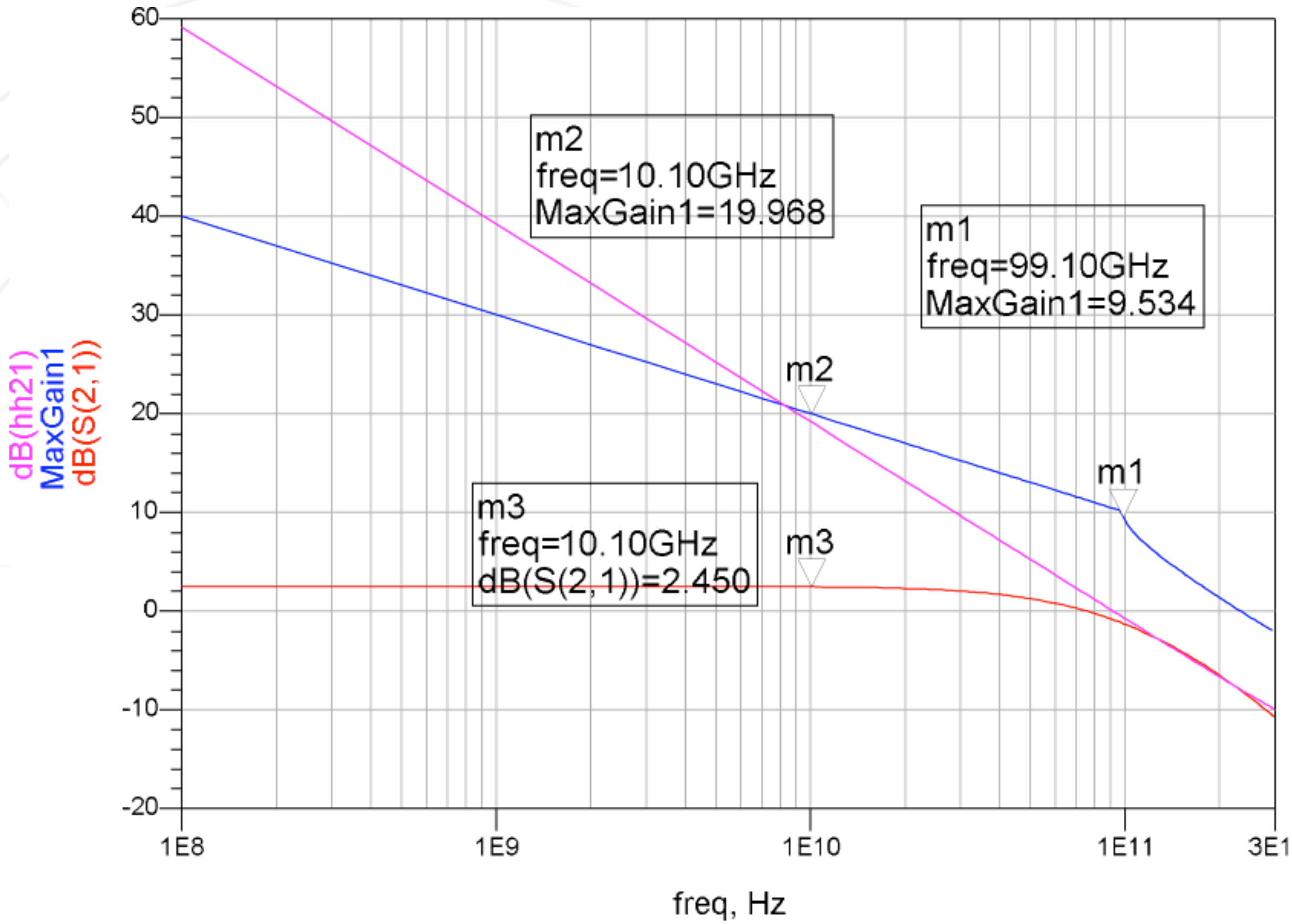


S-Parameter Simulations



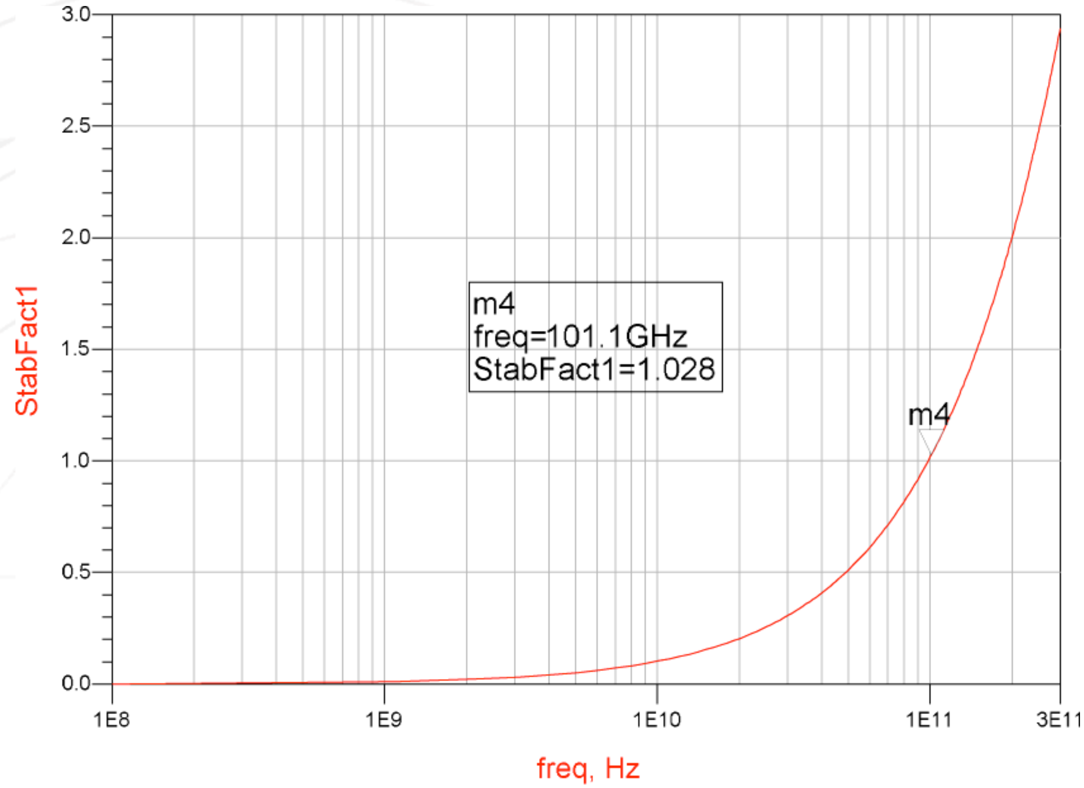
- Note |S21| < 1 above 76 GHz, |S12| is relatively small
- At low frequency, S11 and S22 dominated by capacitance

Maximum Gain Plots



- Fmax > Ft (Fmax ~ 237 GHz)

Stability Factor



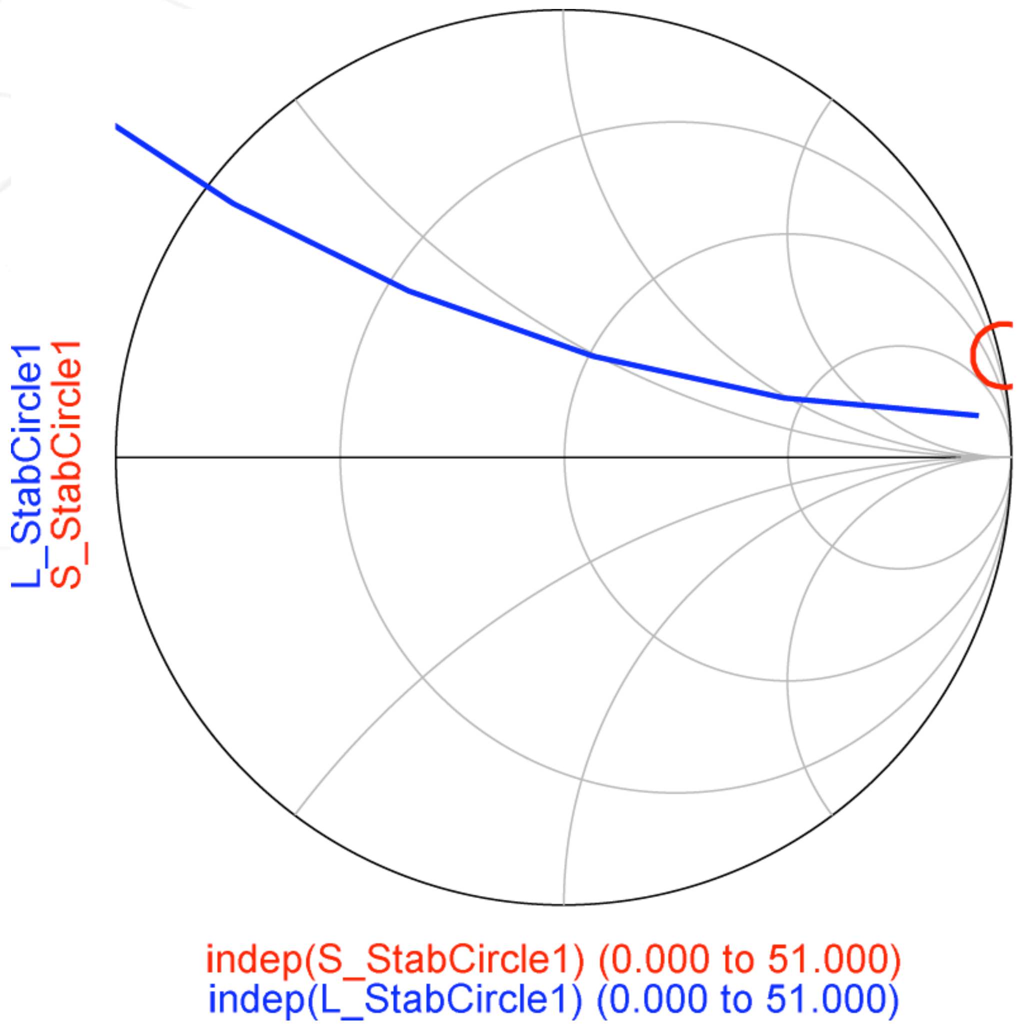
- Device is unconditionally stable only after 100 GHz!
- For a stable amplifier, need to add loss to input/output to make K > 1. The larger K, the more "safe" the design, but the less gain we can extract.

Example: 10 GHz Design

- Using this transistor, let’s design an amplifier.
- Since it’s bilateral, it’s easier to work with the operating power gain, which is only a function of the load impedance.
- We’ll notice that the source instability circle only crosses the unity Smith chart over a small region. So it’s safe to assume that we can pick the optimum load and then conjugate match the input (without stability issues).
- We can always check to make sure this is true in the design.

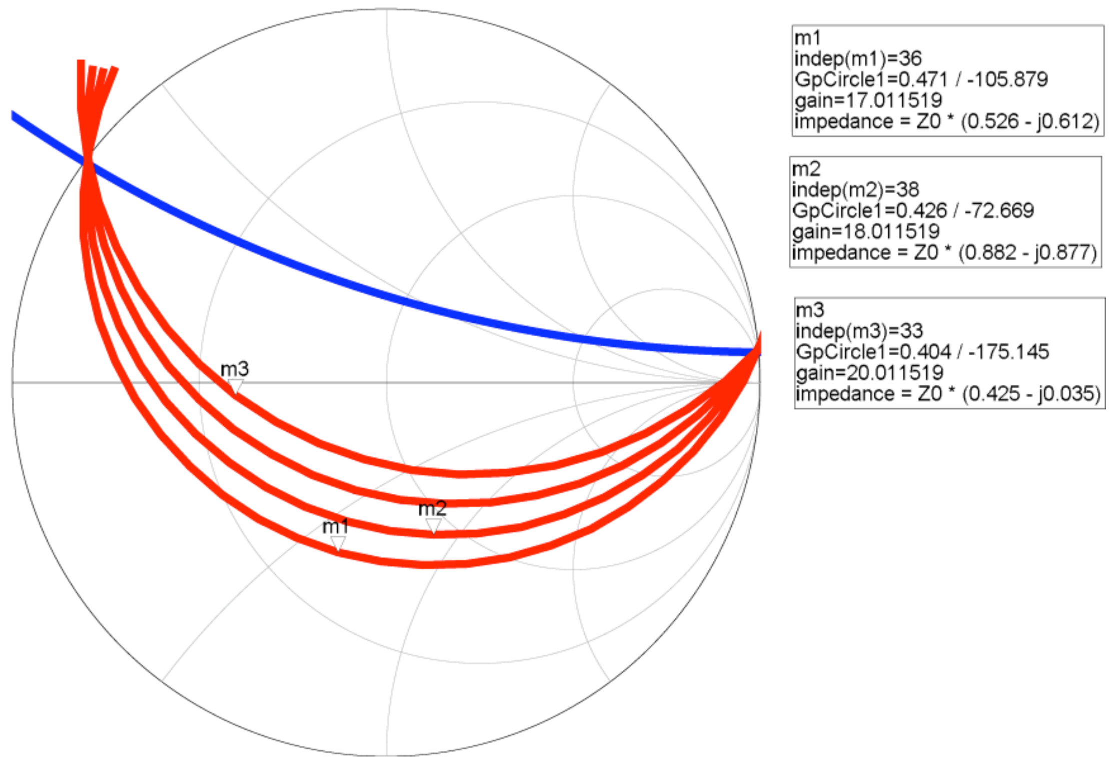
Source/Load Stability Circles

- Since |S11|<1 and |S22| <1, the origin is stable
- The source instability region is very small.
- The load requires careful design.

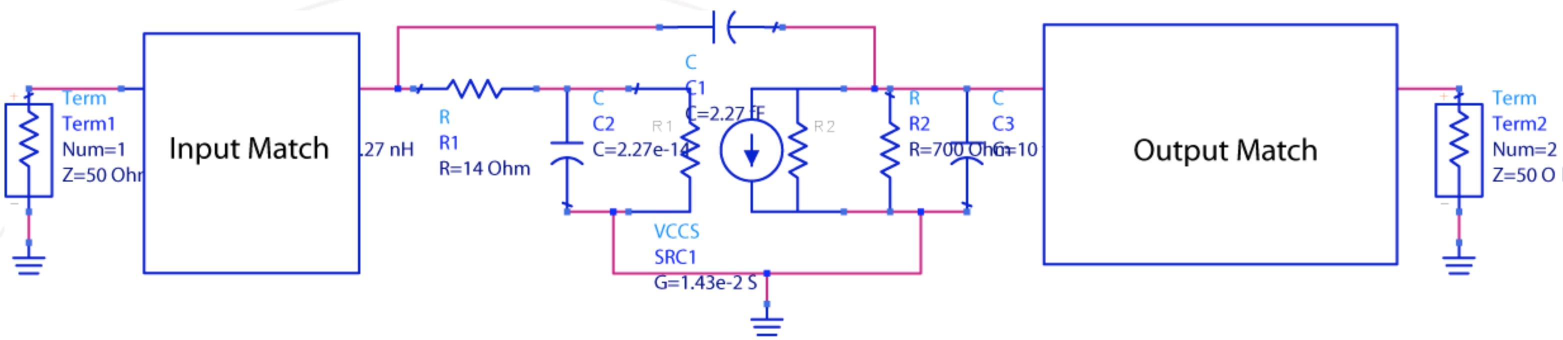


Power Gain Circles

- Any point on a constant power gain circle that does not lie in the instability region is a potential load.
- Must double check that the source stability is also satisfied for conjugate match.



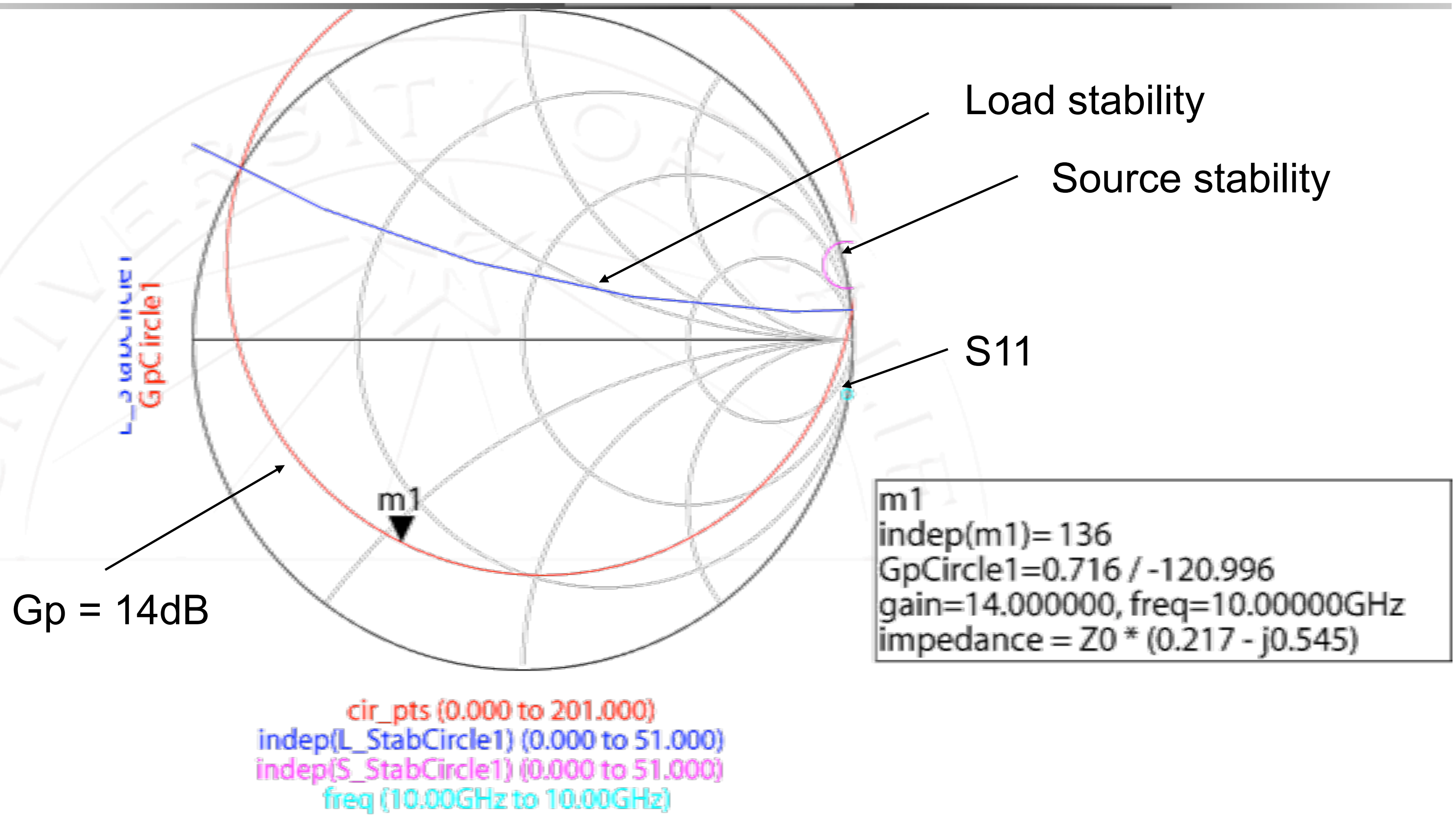
Example Amplifier Design



freq	S(1,1)	S(1,2)	S(2,1)	S(2,2)	MaxGain1
10.00 GHz	0.997 / -9.508	0.013 / 83.194	1.327 / 171.4...	0.866 / -5.018	20.012

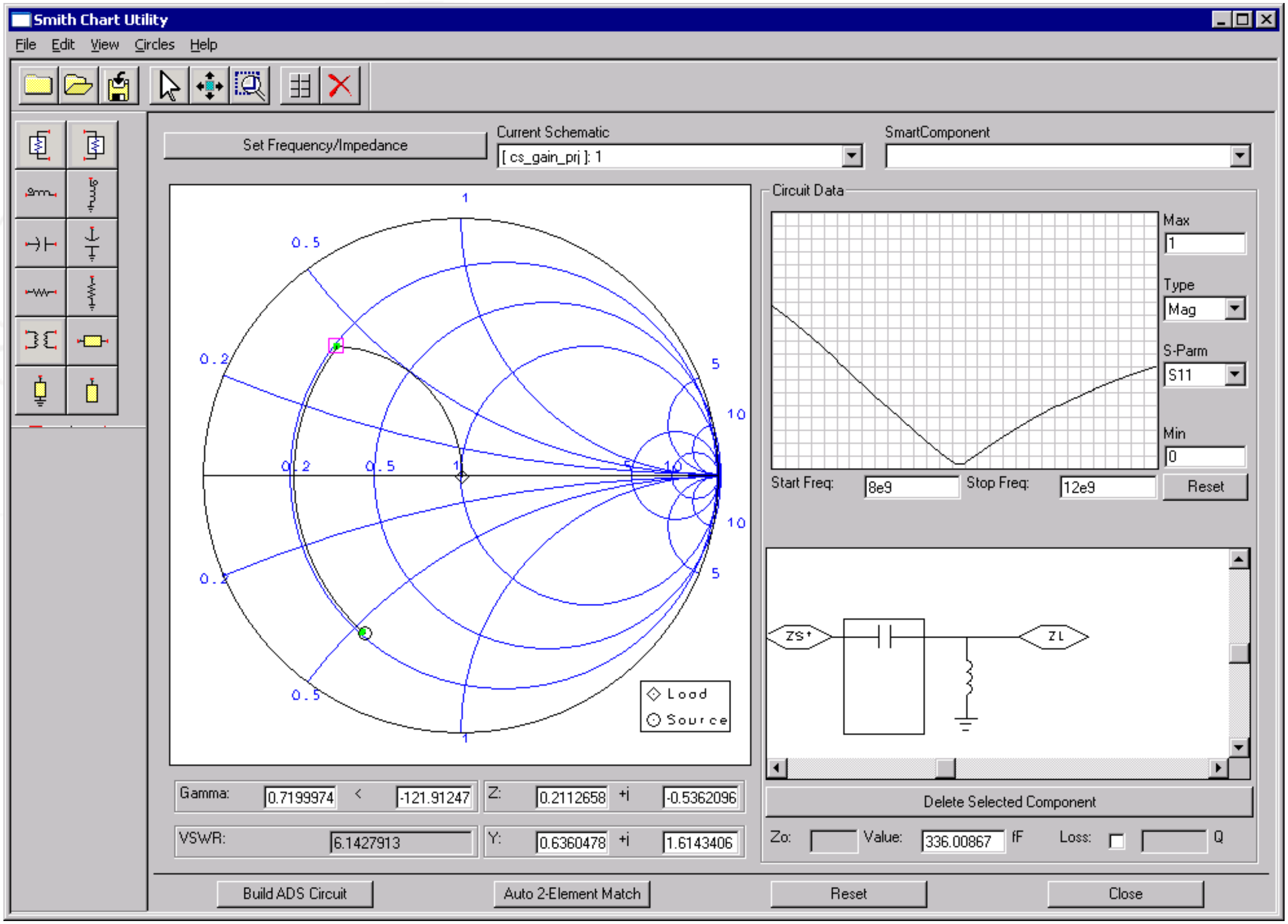
- Design a single stage amplifier with G = 14 dB and input match.
- Since input must be matched, let's select the load for gain/stability.
- MSG = 20 dB; back-off by 6 dB and plot Gp = 14 dB circles. Also plot load stability.
- Select load far away from instability region.

Output Load Circles

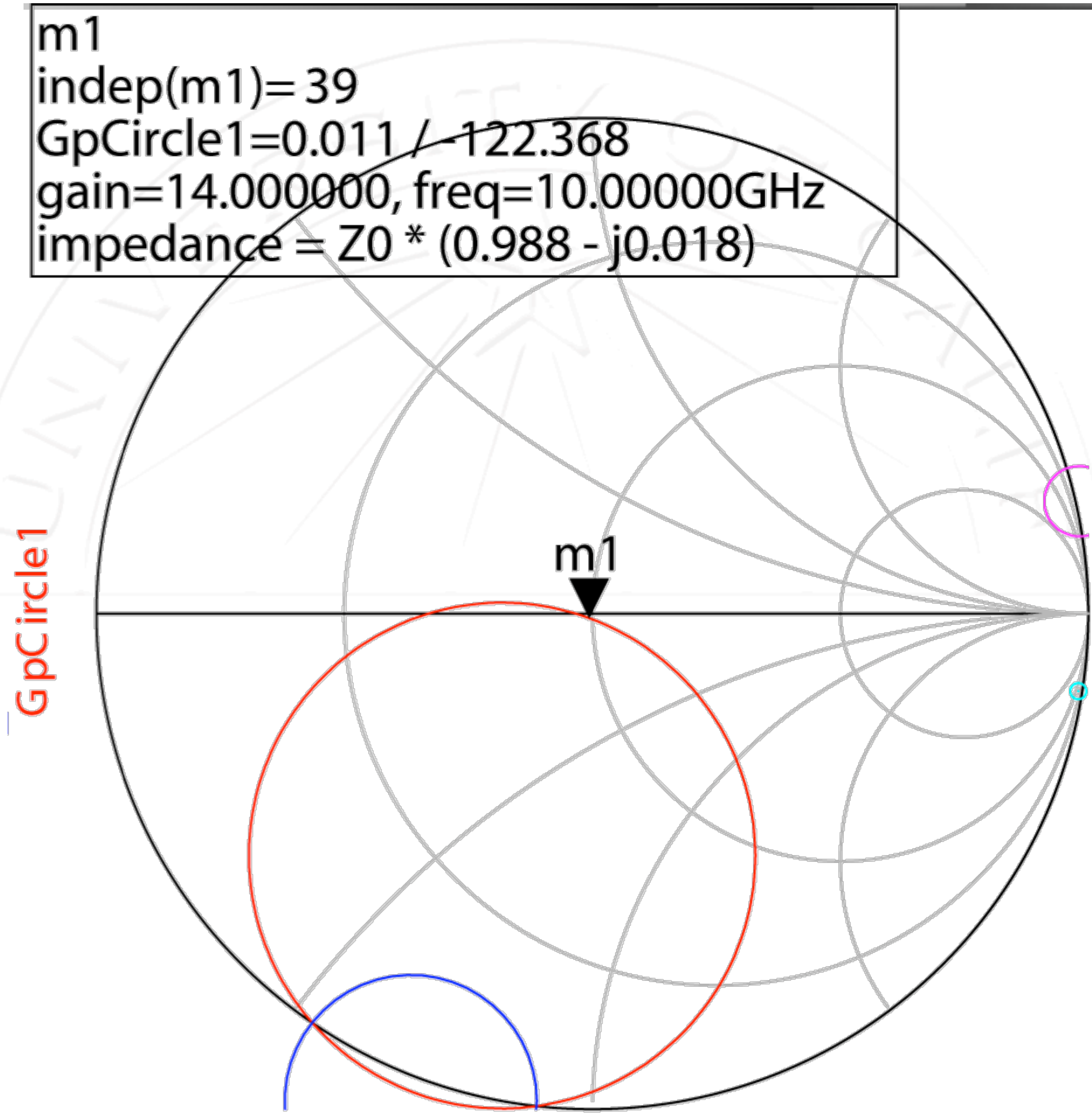


- Point m1 is far away from instability region for load.

Output Matching Network

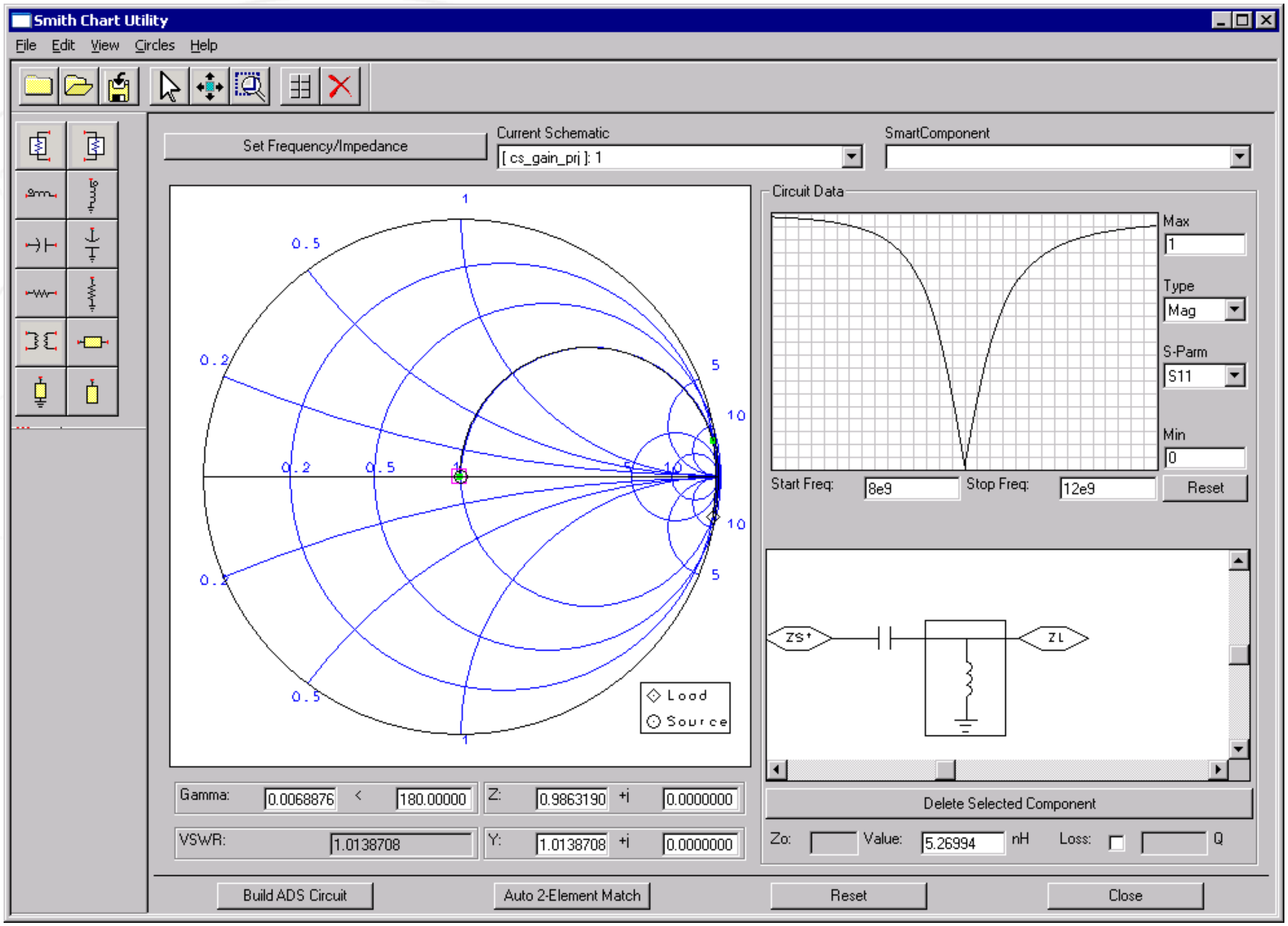


Output Load Match

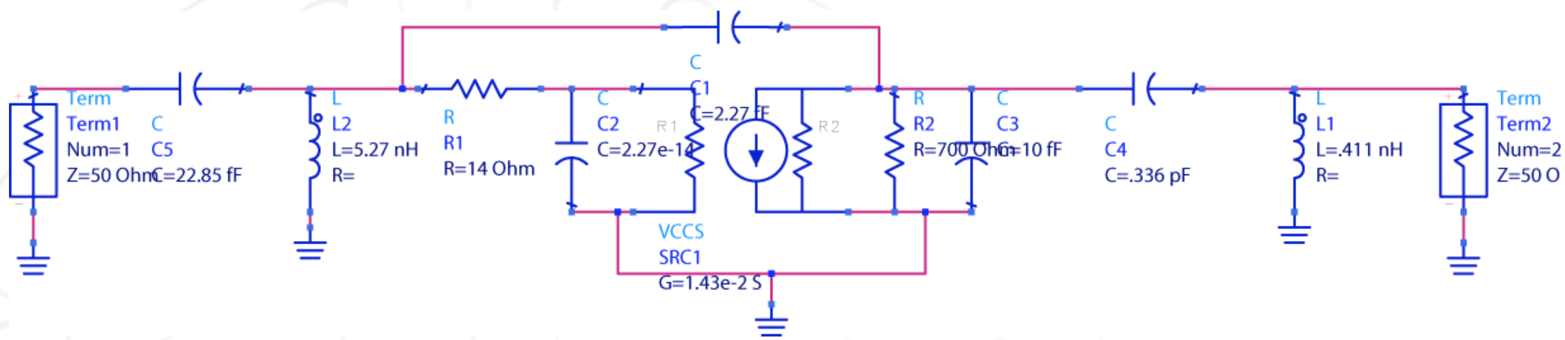


- Note that the Gp=14dB circle crosses origin
- Origin still in stable region.
- Power gain is low due to input mismatch (-4 dB)
- Since S11 is "stable", design input matching network for imp match

Input Match

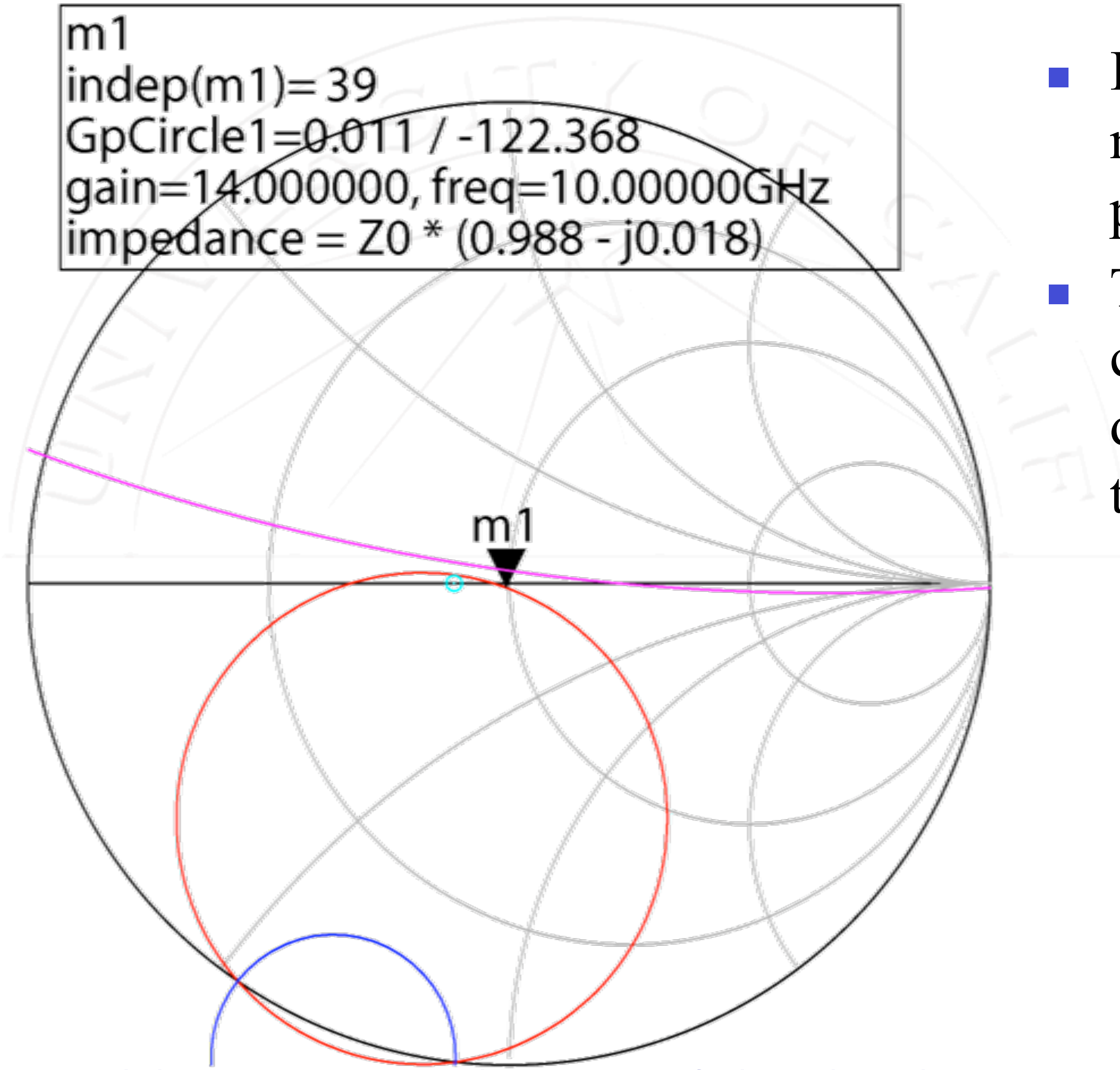

Smith Chart Utility
File Edit View Circles Help
Set Frequency/Impedance
Current Schematic
[cs_gain_prj]: 1
SmartComponent
Circuit Data
Max
1
Type
Mag
S-Parm
S11
Min
0
Start Freq:
8e9
Stop Freq:
12e9
Reset
Load
Source
ZS*
ZL
Gamma:
0.0068876
180.00000
Z:
0.9863190
+j
0.0000000
VSWR:
1.0138708
Y:
1.0138708
+j
0.0000000
Delete Selected Component
Zo:
Value:
5.26994
nH
Loss:
Q
Build ADS Circuit
Auto 2-Element Match
Reset
Close

Complete Amp Schematic



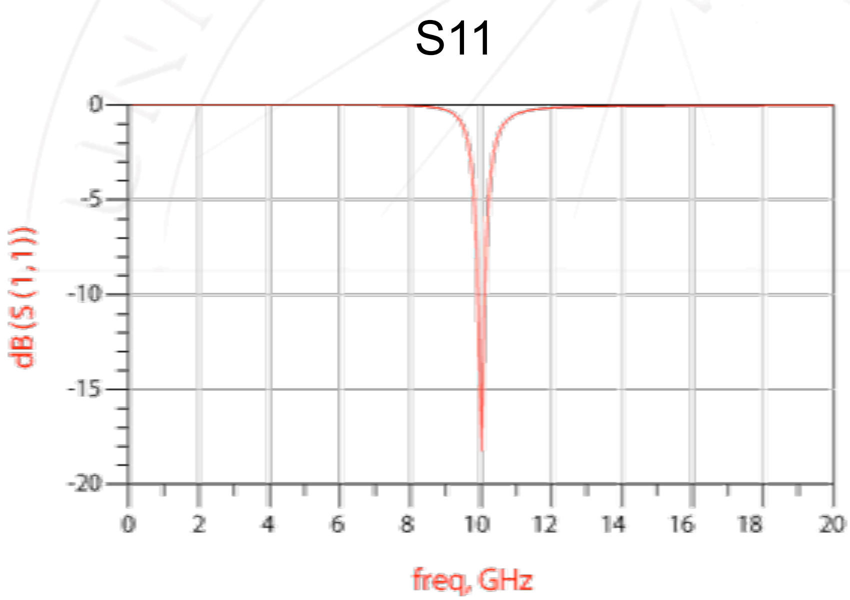
- Out match is simple L matching network; component values are reasonable.
- Other possibilities include T-line/stub matching.
- Input match component values are not very practical but okay for demonstration.

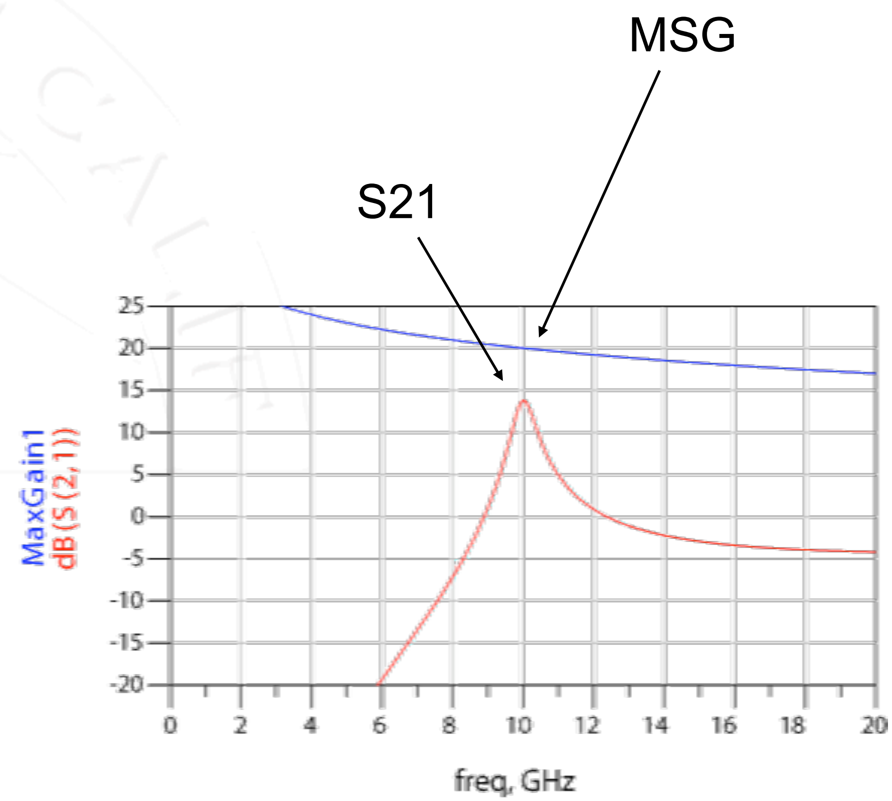
Source Matching



- Input is matched and now the realized power gain is 14 dB
- The source stability circle, though, is dangerously close to the origin.

Match/Gain Plots





Comments on Design

- Input match looks good (S11 < 0.11)
- Power gain is as desired: G = 14 dB
- Output match is terrible (S22 ~ 1) and close to instability!
- We see that this design requires some iteration to arrive at the best input/output match pair to give gain and good stability.
- In practice a lossy matching network (or added loss/ feedback to device) helps to create a good match.