1) The small-signal model for this circuit is:

\[ \text{Vin} \quad \begin{array}{c} \text{Vgs1} \\
\text{gm} \end{array} \quad \begin{array}{c} \text{Vgs2} \\
\text{gm} \end{array} \quad \begin{array}{c} \text{Ro1} \\
\text{Ro2} \end{array} \quad \text{Vout} \]

Redrawing this gives:

Thus, the feedback is \[ \text{series-shunt} \].

b) The feedback factor is:

\[ f = \frac{V_{in}}{V_{out}} = 1 \]

c) \[ a_{v}' = g_m \left( r_{o1} \parallel r_{o2} \right) \]

\[ T' = a_{v}' \cdot f = \frac{g_m \left( r_{o1} \parallel r_{o2} \right)}{g_m \left( r_{o1} \parallel r_{o2} \right) + 1} \]

\[ g_m = \sqrt{2} \left( 14 \text{mS} \times \frac{100 \text{mS}}{0.1 \times 100 \text{mS}} \right) = 966 \text{mS} \]

\[ r_{o1} = r_{o2} = \frac{1}{(0.1 \times 100 \text{mS})} = 100 \text{ kS} \]

\[ r_{out}' = r_{o1} \parallel r_{o2} \]
\[ V_{\text{out}} = \frac{1}{f} \cdot \frac{T}{1 + T} = \frac{g_m (R_{\text{off}} R_{\text{ox}})}{1 + g_m (R_{\text{off}} R_{\text{ox}})} = 0.98 \]

\[ R_{\text{out}} = \frac{R_{\text{out}}'}{1 + T} = \frac{R_{\text{off}} R_{\text{ox}}}{1 + g_m (R_{\text{off}} R_{\text{ox}})} = 1.014 \, \text{k}\Omega \]

The exact expression for \( R_{\text{out}} \) is:

\[ R_{\text{out}} = \frac{R_{\text{off}} R_{\text{ox}}}{\frac{1}{g_m} + (R_{\text{off}} R_{\text{ox}})} \]

The exact expression for \( \frac{V_{\text{out}}}{V_{\text{in}}} \) is:

\[ \frac{V_{\text{out}}}{V_{\text{in}}} = g_m R_{\text{out}} = \frac{g_m (R_{\text{off}} R_{\text{ox}})}{1 + g_m (R_{\text{off}} R_{\text{ox}})} \]

Therefore, the feedback equations with loading are identical to the exact expressions calculated before.
2) a) The feedback is **shunt-series**.

b) We should use a Norton equivalent source:

The feedback factor is: \[ f = \frac{\text{Vs}}{\text{Vo}} = 1 \]

c) When considering loading effects, it is important to realize that the 100 kΩ load should not be included when analyzing the feedback circuit, only at the very end. This is because it is not a part of either the main amplifier or the feedback amp.

The main amplifier with loading is:

Thus, with loading, the main amplifier becomes:

\[
\begin{align*}
\text{Vin'} & = \text{Vin} = 1 \text{ kΩ} \\
\text{Vin' + Vo' = 1 HΩ + 10 kΩ} & = 1.01 \text{ HΩ} \\
\frac{Vo'}{\text{Vin'}} & = \frac{1.01}{1.01} = 1
\end{align*}
\]
2) c) (cont.)

Therefore \( T' = q_i' f = \frac{1}{1.01} \)

So, the closed-loop circuit can be modeled as:

![Circuit Diagram]

Where \( R_{in}' = \frac{R_{in}}{1+T'} = \frac{1.0k\Omega}{1+\frac{1}{1.01}} = 502.5\Omega \)

\( R_{out}' = (1+T') = (1.01M\Omega)\left(1+\frac{1}{1.01}\right) = 2.01M\Omega \)

\( A_{i}' = \frac{q_i'}{1+T'} = \frac{1}{1+\frac{1}{1.01}} = \frac{1}{2.01} \)

\[ \therefore R_{out} = 100\ k\Omega \parallel R_{out}' = 45.3\ k\Omega \]

\[ d) \frac{V_{out}}{V_{in}} = \left(\frac{V_{out}}{V_{in}}\right) = A_{i}' \left(\frac{R_{out}'}{R_{out}'+100k}\right) \left(\frac{1}{1k}\right) \]

\[ = \frac{1}{2.01} \left(\frac{2.01}{2.01+0.1}\right) \left(\frac{1}{1k}\right) \]

\[ = \frac{100}{2.11} \]

\[ = 47.4 \]

e) From SPICE:

\[ R_{out} = 95.3\ k\Omega \]

\[ \frac{V_{out}}{V_{in}} = 47.4 \]
* hw9, 2: shunt-series feedback amplifier

vin  in  0  0
xamp  0 in- out+ out- opamp
r1  in in- 1k
r2  in- out- 10k
rl  out+ 0 100k

.subckt opamp in+ in- out+ out-
g1  out+ out- in+ in- 0.001
ro  out+ out- 1x
.ends

.options post=2 nomod
.tf v(out+) vin
.end

****  small-signal transfer characteristics

v(out+)/vin = 47.4183
input resistance at vin = 2.1089k
output resistance at v(out+) = 95.2629k