1) Connect directly - what is \( V_{out} \)?

\[
V_{out} = \frac{1 \text{ k}\Omega}{1 \text{ k}\Omega + 1 \text{ M}\Omega} (1V) = 1 \text{ mV}
\]

2) Alternative: add voltage buffer

\[
V_0 = 0.9 V_i = \left( \frac{1000}{1000 + 100} \right) 1V
\]

**Fig 7.42**

How it works?

- \( V_{gate} \)
- \( i_D \) cannot change
- \( V_{source} \) source follower
Small Signal model

\[ i_g = 0 \]

\[ \text{in} = \infty \quad \text{because} \quad i_g = 0 \]

\[ A_v = \frac{V_o}{V_i} \quad (\text{ignore} \ R_o) : \quad \frac{R_L}{R_L + 1/g_m} \quad (\text{Voltage divider} \quad T \text{ model}) \]

If \[ R_L = \infty \Rightarrow A_v = 1 \]

\[ R_o : \text{assuming neglect} \; R_o \]

\[ R_o = \frac{\text{in} \cdot i_v}{i_x} \quad |v_i = 0 \quad v_i = 0 \; \text{shorts out} \; \Delta i \]
\[ R_0 = \frac{1}{\text{gm}} \quad R_L = (\text{gm} + 1/R_L)^{-1} \quad \text{(see inset if needed)} \]

\[ R_0 = \frac{1}{9m + 1/R_L} \approx \frac{1}{9m} \quad \text{for large } R_L \]

\[ G_v = A_v = \frac{R_L}{R_L + 1/9m} \quad \left( G_v = \frac{R_{in} A_v}{R_{in} + R_{sig}} \quad \begin{cases} \text{since } R_{in} = \infty \\ G_v = A_v \end{cases} \right) \]

> used as last stage in multistage amplifier (low output resistance)
> enable large load currents

### 7.4 Biasing in MOSFET circuits

**Biasing by fixing \( V_{GS} \)**

> DC bias point: must provide stable \( I_D \) and \( V_{DS} \) to ensure saturation for all signal levels (amplifiers)
> Simplest scheme: fix \( V_{GS} \) to achieve this

- Not a good solution
  - \( I \propto V_{GS}, L, W, T, V_{GS} \)
  - Biasing will vary from batch to batch of transistors

\[ I_D = \frac{1}{2} \mu_n C_w \cdot (V_{GS} - V_t)^2 \quad \text{Sat} \]
Biasing with $V_G$ and $R_s$

Excellent option: fixed voltage $V_G$ to gate and connect $R_s$ to source

Fig 7.48(a)

$V_G = V_{GS} + I_D R_s$

If $V_G \gg V_{GS}$, $I_D$ determined mainly by $V_G$

If $I_D$ changes, $R_s$ provides negative feedback

When $\uparrow I_D$, $\downarrow V_{GS}$ since $V_G$ is fixed, then $\downarrow I_D$ ($R_s$ keeps $I_D$ as constant as possible)

$R_s$ negative feedback action $\Rightarrow$ degeneration resistance

Fig 7.48(b)

Device 2

Device 1

slope $= 1/R_s$

Even with 2 different MOSFETS, $I_D$ is nearly constant

Compared with fixed $V_{GS}$ schemes, $I_D$ much more stable

$ID$ more stable when $V_G$ & $R_s$ are large
Insert (if needed)

Output resistance of source follower (common drain)

\[ V_i = 0 \text{ for } R_o \]

\[ V_x - i_x \left( \frac{1}{g_m} || R_L \right) = 0 \]

\[ \frac{V_x}{i_x} = \frac{1}{g_m || R_L} \]
Hybrid TT model

\[ i_x + g_m V_{gs} - \frac{V_x}{R_L} = 0 \]

\[ i_x + g_m (0 - V_x) - \frac{V_x}{R_L} = 0 \]

\[ \frac{V_x}{i_x} = \frac{1}{\frac{1}{g_m} + \frac{1}{R_L}} \]