Fig. 7.24  High-frequency analysis of the cascode amplifier in Fig. 7.23. Note that to simplify the analysis, \( r_{x2} \) and \( r_{o2} \) are not included.
The Method of Open Circuit Time Constants Approximate Transfer Function at High Frequencies

Any multistage amplifier will have many high frequency poles and zeroes.

\[
\frac{V_o(s)}{V_i(s)} = K \frac{(s-s_1)(s-s_3)\cdots}{(s-s_2)(s-s_4)\cdots(s-s_{2n})}
\]

\[
\frac{V_o(s)}{V_i(s)} \approx K \frac{(-s_1)(-s_3)\cdots}{(s-s_2)(s-s_4)\cdots(s-s_{2n})} \quad \text{if all the zeroes are large in magnitude as often is}
\]
the case.

\[
\frac{V_o(s)}{V_i(s)} \approx \frac{K'}{s^n + a_{n-1}s^{n-1} + \cdots + a_1s + a_0}
\]

\[
\frac{V_o(s)}{V_i(s)} = \frac{K'}{a_0} \text{ all frequency dependent midband terms are small.}
\]

\[
s = j\omega
\]

\[
\omega \text{ small}
\]

As the frequency increases from midband, the term \( a_1s = a_1(j\omega) \) becomes important. The other terms in \( s \) are assumed small.
\[
\frac{V_o(s)}{V_i(s)}|_{s=j\omega} = \frac{K'}{1 + \frac{sa_i}{a_0}} = \frac{K/a_0}{1 + s/\omega_n}
\]

midband and just above

where \(\omega_n = \frac{a_0}{a_i}\) is the upper half-power frequency

Open-Circuit Time Constants

\(\omega_n \approx a_0/a_i\)
Open-Circuit Time Constants

Finding $a_1/a_0$

Section 15.2.2

Consider a 3 Capacitor Network

![Diagram of a 3 capacitor network](image)

(a) Capacitors identified by terminal pair

Linear active network without energy storage

(b) Network with capacitors removed

![Diagram of network with capacitors removed](image)

Fig. 15.3 Linear Active Network May Include Dependent Sources But No Independent Sources
No Independent Sources But Any Dependent Sources Must Be Included

\[ I_1 = g_{11} V_1 + g_{12} V_2 + g_{13} V_3 \quad (15.23a) \]
\[ I_2 = g_{21} V_1 + g_{22} V_2 + g_{23} V_3 \quad (15.23b) \]
\[ I_3 = g_{31} V_1 + g_{32} V_2 + g_{33} V_3 \quad (15.23c) \]

Let \( \Delta g \) denote the \( g \) determinant

\[ \Delta_g = \begin{vmatrix} g_{11} & g_{12} & g_{13} \\ g_{21} & g_{22} & g_{23} \\ g_{31} & g_{32} & g_{33} \end{vmatrix} \quad (15.25) \]

Let \((\Delta g)_{jk}\) denote the cofactor of element \( g_{jk} \). For example,

\[ (\Delta g)_{11} = \begin{vmatrix} g_{22} & g_{23} \\ g_{32} & g_{33} \end{vmatrix} \quad (\Delta g)_{21} = \begin{vmatrix} g_{12} & g_{13} \\ g_{32} & g_{33} \end{vmatrix} \]
Matrix Inversion

\[ V_1 = \frac{(\Delta g)_{11}}{\Delta g} I_1 + \frac{-(\Delta g)_{21}}{\Delta g} I_2 + \frac{-(\Delta g)_{31}}{\Delta g} I_3 \]

\[ V_2 = \frac{-(\Delta g)_{12}}{\Delta g} I_1 + \frac{(\Delta g)_{22}}{\Delta g} I_2 + \frac{-(\Delta g)_{32}}{\Delta g} I_3 \]

\[ V_3 = \frac{+(\Delta g)_{13}}{\Delta g} I_1 + \frac{-(\Delta g)_{23}}{\Delta g} I_2 + \frac{(\Delta g)_{33}}{\Delta g} I_3 \]

\[ \frac{V_1}{I_1} \bigg|_{I_2=I_3=0} = \frac{(\Delta g)_{11}}{\Delta g} = R_{10} \]

\[ \frac{V_2}{I_2} \bigg|_{I_1=I_3=0} = \frac{(\Delta g)_{22}}{\Delta g} = R_{20} \]

\[ \frac{V_3}{I_3} \bigg|_{I_1=I_2=0} = \frac{(\Delta g)_{33}}{\Delta g} = R_{30} \]

Where \( R_{10} \), \( R_{20} \), and \( R_{30} \) are called open-circuit resistances.
\[ A_y = 0 \] yields the natural freq.
of the network = poles

\[ A_y = \frac{1}{R_{21}} s C_1 + R_{11} + s C_2 + R_{12} \]

\[ 8C_1 \]

\[ -s C_2 \]

\[ 8C_3 \]

\[ -s C_3 \]

(15.28)

(15.29)

With the Capacitors Present

\[ q \]

\[ -q \]
\[ a_1 = C_1(\Delta_\delta)_{11} + C_2(\Delta_\delta)_{22} + C_3(\Delta_\delta)_{33} \quad (15.31) \]

\[ \frac{a_1}{a_0} = C_1 \frac{(\Delta_\delta)_{11}}{\Delta_\delta} + C_2 \frac{(\Delta_\delta)_{22}}{\Delta_\delta} + C_3 \frac{(\Delta_\delta)_{33}}{\Delta_\delta} \quad (15.32) \]

\[ \frac{a_1}{a_0} = R_{10}C_1 + R_{20}C_2 + R_{30}C_3 = \sum_j \tau_{j0} \quad (15.33) \]

\[ \frac{a_1}{a_0} = R_{10}C_1 + R_{20}C_2 + \cdots + R_{n0}C_n = \sum_j \tau_{j0} \]

\[ \omega_n \approx \frac{1}{\frac{a_1}{a_0}} = \frac{1}{\sum \tau_{j0}} \]

We must use the high frequency network if \( C_{\Pi} \), \( C_4 \), \( C_{95} \), and \( C_{gd} \) are present. Coupling capacitors & Bypass capacitors are AC shunts.

15-15E
Each open-circuit time constant is the product of a capacitance $C_j$ and a resistance $R_{jo}$ where $C_j$ is a capacitor in the high frequency small-signal equivalent circuit and $R_{jo}$ is the resistance facing that capacitor when all other capacitors are open-circuits.

$C_j$: capacitor in high frequency eq. circuit

$R_{jo}$: open-circuit resistance facing $C_j$
\[ \omega_n \approx \frac{a_0}{a_1} = \frac{1}{\frac{a_1}{a_0}} = \frac{1}{\sum_{j=1}^{k} T_{j0}} = \frac{1}{R_{10}C_1 + R_{20}C_2 + \cdots + R_{k0}C_k} \]

We see that each capacitor contributes to the sum \( \sum T_{j0} \) and makes the sum larger and \( \omega_n \) smaller. Those capacitors with the largest open-circuit time constant values reduce the amplifier high frequency response the most.
Stress that

\( \omega_c = \frac{1}{R_{1s}C_1} + \frac{1}{R_{2s}C_2} + \cdots + \frac{1}{R_{js}C_j} \)

for the low frequency response and that

\( \omega_h = \frac{1}{R_{1o}C_1 + R_{2o}C_2 + \cdots + R_{ko}C_k} \)

for the high frequency response

(3) illustrate the difference with these two examples

\( j = 3 \quad R_{1s}C_1 = R_{2s}C_2 = R_{3s}C_3 = 1 \text{ msec} \)
\[ \omega_e = \frac{1}{1\text{msec}} + \frac{1}{1\text{msec}} + \frac{1}{1\text{msec}} \]
\[ = 1000 + 1000 + 1000 = 3000 \text{ rad/sec} \]
\[ \omega_e \neq \frac{1}{1\text{msec} + 1\text{msec} + 1\text{msec}} = \frac{1}{3\text{msec}} \]
\[ = 333 \text{ rad/sec} \quad \text{Wrong Result!} \]
\[ k = 4 \quad R_{10} C_1 = R_{20} C_2 = R_{30} C_3 = R_{40} C_4 = 1\text{nsec} \]
\[ \omega_h = \frac{1}{1\text{nsec} + 1\text{nsec} + 1\text{nsec} + 1\text{nsec}} = \frac{1}{4\text{nsec}} \]
\[ = 0.25 \times 10^9 \text{ rad/sec} \]
\[ \omega_{h'} = \frac{1}{1\text{nsec} + 1\text{nsec} + 1\text{nsec} + 1\text{nsec} + 1\text{nsec}} = \frac{4}{\text{nsec}} = 4 \times 10^9 \text{ rad/sec} \quad \text{Wrong Result!} \]
Calculation of $R_{10}$ and $R_{20}$ for Bipolar Stages

Fig. 16.9

$R_{10}$ Calculation

$\beta$, $R_e$, and $R_c$ are the equivalent resistances, external to the transistors, between base and ground, between emitter and ground, and between collector and ground respectively. Note that $\beta$, $R_e$, and $R_c$ include the loading effects of adjacent stages. Furthermore, each is the resistance looking out of a terminal between that terminal and ground.
$R_{10}$ calculation

(a) remove $C_{m}$ and calculate the resistance $R_{10}$ facing $C_{n}$. Replace $C_{n}$
by a voltage source $V_{t}$ and calculate $I_{t}$
(b) $R_{10} = V_{t} / I_{t}$

Use of the principle of superposition

Note that by placing a known voltage
source $V_{t}$ across $G_{n}$ that the dependent current
generator $g_{m}V$ is now determined and
$g_{m}V = g_{m}V_{t}$ because $V = V_{t}$. We can now
treat $g_{m}V_{t}$ as an independent source. Thus
we may treat the problem as one having two
independent sources $V_{t}$ and $g_{m}V_{t}$. We can
use the principle of superposition to calculate
$I_{t}$. Let $I_{t1}$ be the current $I_{t}$ when $g_{m}V_{t}$
is made dead. Let $I_{t2}$ be the current when
$V_{t}$ is made dead. Then $I_{t} = I_{t1} + I_{t2}$ and

(2)
\[ \frac{1}{R_{10}} = \frac{I_t}{V_t} = \frac{I_t}{V_t} + \frac{I_{t2}}{V_t} \]

Calculation of \( I_{t1} \) (Set \( g_m V_t = 0 \).)

We set \( g_m V_t = 0 \) to make a current source dead; i.e. \( g_m V_t \) is an open-circuit.

\[ I_{t1} = \frac{V_t}{r_{\Pi}} + \frac{V_t}{(r_X + R_b + R_e)} \]  \hspace{1cm} (3)
Calculation of \( I_{t2} \) (Set \( V_t = 0 \))

We set \( V_t = 0 \) to make a voltage source dead, i.e. \( V_t \) is replaced by a short-circuit.

\[
I_{t2} = g_m V_t \left( \frac{1}{r_x + R_b} + \frac{1}{R_e} \right) = \frac{g_m R_e V_t}{r_x + R_b + R_e}
\]

\( (4) \)
\[ I_t = I_{t1} + I_{t2} = \frac{V_t}{R_i} + \frac{1 + 9m \text{Re}}{\Gamma_x + R_b + \text{Re}} V_t \]

\[ \frac{1}{R_{10}} = \frac{I_t}{V_t} = \frac{1}{R_i} + \frac{1 + 9m \text{Re}}{\Gamma_x + R_b + \text{Re}} \]

\[ R_{10} = R_i \frac{\Gamma_x + R_b + \text{Re}}{1 + 9m \text{Re}} \]

(4)

**Calculation of \( R_{20} \)**

(a) Remove \( C_i \) and calculate the resistance \( R_{20} \) facing \( C_m \). Replace \( C_m \) by a voltage source \( V_t \) and calculate \( I_t \).

(b) \( R_{20} \equiv V_t / I_t \)

(5)
\[ V = I_1 r_{\pi} \quad \text{so} \quad g_m V = g_m r_{\pi} I_1 = \beta I_1 \]

The current thru \( R_e \) is \( (\beta+1) I_1 \)

\[ V_e = (\beta+1) I_1 R_e \]

\[ V_b' = I_2 (r_x + R_b) \]

\[ V_b = I_1 (r_{\pi}) + (\beta+1) I_1 R_e = I_1 \left[ r_{\pi} + R_e (\beta+1) \right] \]

\( (6) \)
Thus $I_2 = I_1 \left[ \frac{r_{\Pi} + (\beta+1) R_e}{r_x + R_b} \right] / [r_x + R_b]$

$I_C = I_2 + (\beta+1) I_1 = I_1 \left[ \frac{r_{\Pi} + (\beta+1) R_e}{r_x + R_b} \right] + (\beta+1) I_1$

$I_C = I_1 \frac{r_{\Pi} + (\beta+1) (R_e + r_x + R_b)}{r_x + R_b}$

$V_t = I_1 \left( r_{\Pi} + (\beta+1) I_1 R_e + R_c I_C \right)$

$\frac{V_t}{I_1} = r_{\Pi} + (\beta+1) R_e + R_c \frac{r_{\Pi} + (\beta+1) (R_e + r_x + R_b)}{r_x + R_b}$

$R_{20} = \frac{V_t}{I_t} = \frac{V_t}{I_1 + I_2} = \frac{V_t}{I_1} \frac{1}{1 + \frac{I_2}{I_1}}$

$\frac{1}{1 + \frac{I_2}{I_1}} = \frac{1}{1 + \frac{r_{\Pi} + (\beta+1) R_e}{r_x + R_b}} = \frac{r_x + R_b}{r_x + R_b + r_{\Pi} + (\beta+1) R_e}$

(7)
\[ R_{20} = \frac{[r_{\pi} + (\beta+1)R_e][r_x + R_b]}{r_x + R_b + r_{\pi} + (\beta+1)R_e} + R_c \frac{r_{\pi} + (\beta+1)(R_e + r_x + R_b)}{r_x + R_b + r_{\pi} + (\beta+1)R_e} \]

\[ R_{20} = \frac{[r_x + R_b]}{[r_{\pi} + (\beta+1)R_e]} + R_c \frac{r_{\pi} + (\beta+1)(R_e + r_x + R_b)}{r_x + R_b + r_{\pi} + (\beta+1)R_e} \]

---

For FET's let \( r_x \to 0 \), \( r_{\pi} \to \infty \), \( \beta \to \infty \)

and let \( R_b \to R_g \), \( R_e \to R_s \) and \( R_c \to R_d \)

\[ C_{gs} \leftrightarrow C_{\pi} \quad C_{gd} \leftrightarrow C_{\alpha} \]

\[ (8) \]
Summary of Open-Circuit Time Constants - BJT

1) General Case  \( T_{10} = R_{10} C_{\pi} \quad T_{20} = R_{20} C_{\mu} \)

\[
R_{10} = \frac{g_{m} R_{b} + R_{e}}{1 + g_{m} R_{e}} \quad R_{10} || (R_{b} + R_{x})
\]

\[
R_{20} = \frac{g_{m} R_{b} + R_{x}}{(g_{m} + R_{b})(R_{b} + R_{x} + R_{e})} + R_{c} \quad R_{20} = R_{10} + R_{c}(1 + g_{m} R_{10})
\]

\( R_{b}, R_{e} \) and \( R_{c} \) are equivalent resistances which take into account input and/or output resistances of adjacent stages.

2) Special Case  \( CE \quad R_{e} = 0 \)

\[
R_{10} = \frac{g_{m}}{(R_{b} + R_{x})} \quad R_{20} = R_{10} + R_{c}(1 + g_{m} R_{10})
\]

(9)
(3) Special Case CC \( R_c = 0 \)
\[
R_{10} = r_\Pi \left\| \frac{r_x + R_b + Re}{1 + 9m Re} \right\|
\]
\[
R_{20} = (R_b + r_x) \left\| (r_\Pi + [\beta + 1] Re) \right\|
\]

(4) Special Case CB \( R_b = 0 \)
\[
R_{10} = r_\Pi \left\| \frac{r_x + Re}{1 + 9m Re} \right\|
\]
\[
R_{20} = r_x \left\| (r_\Pi + [\beta + 1] Re) + R_c \frac{r_\Pi + (\beta + 1)(r_x + Re)}{r_x + r_\Pi + (\beta + 1) Re} \right\|
\]
\[
(10)
\]
<table>
<thead>
<tr>
<th>Case</th>
<th>τ_{10} = R_{10} C_{gs}</th>
<th>τ_{20} = R_{20} C_{gd}</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td>\frac{R_g + R_s}{1 + 9mR_s}</td>
<td>R_g + R_d \cdot \frac{1 + 9m(R_g + R_s)}{1 + 9mR_s}</td>
</tr>
<tr>
<td></td>
<td>CS</td>
<td>$R_{10}$</td>
</tr>
<tr>
<td>---</td>
<td>-------------</td>
<td>-------------------</td>
</tr>
<tr>
<td>2</td>
<td>$R_s = 0$</td>
<td>$R_g$</td>
</tr>
<tr>
<td>3</td>
<td>CD</td>
<td>$\frac{R_g + R_s}{1 + 9mR_s}$</td>
</tr>
<tr>
<td>4</td>
<td>CD</td>
<td>$\frac{1}{9m}$</td>
</tr>
<tr>
<td></td>
<td>$R_d = 0$</td>
<td></td>
</tr>
<tr>
<td></td>
<td>$9mR_s \gg 1$ $Rs \gg R_g$</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>CG</td>
<td>$\frac{R_g}{1 + 9mR_s}$</td>
</tr>
<tr>
<td></td>
<td>$R_g = 0$</td>
<td></td>
</tr>
</tbody>
</table>

$R_g, R_s, R_d$ are the equivalent resistances from gate to ground, source to ground, and drain to ground respectively. The loading of adjacent stages must be included in $R_g, R_s, R_d$. 

(12)
The Cascode Amplifier

Fig. 15.1a

Parameters:
\[ \beta = 60 \quad I_c = 10 \text{mA} \]
\[ f_T = \frac{1000}{\pi} \text{MHz} \quad \omega_T = 2 \frac{\text{Grad}}{\text{sec}} \]
\[ r_x = 50 \Omega \quad C_m = 5 \text{pF} \]
\[ g_m = 40 \quad I_c = 400 \text{mmho} \]
\[ r_{\pi} = \frac{\beta}{g_m} = 60/4 = 150 \Omega \]
\[ C_{\pi} = g_m / \omega_T = 400/2 = 200 \text{pF} \]
Small-Signal Equivalent Circuit

\[ \begin{align*}
V_o &= \frac{V_o}{V_{e2}} \times \frac{V_{cl}}{V_s} \\
\end{align*} \]
\[
\frac{V_0}{V_{e2}} = \frac{V_0}{V_{e2}} = \frac{9mV_2R_L}{V_2} \times \frac{r_\Pi}{r_\pi + r_x} = \beta \frac{R_L}{r_\pi + r_x}
\]
which is the midband gain of a CB stage with \( R_s = 0 \)

\[
\left. \frac{V_{e1}}{Vs} \right|_{CE} = -\beta R_L
\]

midband gain of a CE stage

\( R_L^{(1)} = R_{IN}^{(2)} \) where \( R_{IN}^{(2)} \) is the input resistance of a CB stage

\[
R_{IN}^{(2)} = \frac{r_x + r_\Pi}{\beta + 1}
\]
\[
\frac{V_{o1}}{V_s} = \frac{-\beta}{R_s + r_x + r_{\pi}} \times \frac{(r_x + r_{\pi})}{(\beta + 1)}
\]

\[
\frac{V_o}{V_s} = -\frac{\beta}{R_s + r_x + r_{\pi}} \times \frac{r_x + r_{\pi}}{\beta + 1} \times \frac{\beta R_L}{r_{\pi} + r_x} \approx -\frac{\beta R_L}{R_s + r_x + r_{\pi}}
\]

We see that the midband gain of a cascode is the same as that of a single CE stage with a load resister \(R_L = 1K\)

\[
\frac{V_o}{V_s} = -60 \times \frac{1000}{50+150+50} = -240
\]
CE Stage Comparison.
For a single CE stage to have a gain of 
-240, a load resistor $R_L = 1000 \Omega$
is required.

High Frequency Response
The upper half-power frequency $\omega_n$
can be calculated using the method
of open-circuit time constants.
$$\omega_n \approx 1 / \sum_{j=1}^{4} T_{j0} = 1 / \sum_{j=1}^{4} R_{j0} C_j$$

CE stage $T_{10}$ and $T_{20}$

$R_e = 0 \quad R_b = R_s = 50 \quad R_c = R_{IN,2}$

$R_c = R_{IN,2} = (r_x + r_{\pi})/\beta + 1 = (50 + 150)/60 = 3.3 \Omega$

$T_{10} = R_{10} C_{\pi} \quad C_{\pi} = 200 \text{ pF}$

$R_{10} = r_{\pi} || (r_x + R_s) = 150 || 100 = 60 \Omega$

$T_{10} = 60 \Omega \times 200 \text{ pF} = 12000 \text{ psec} = 12 \text{ nsec}$

$T_{20} = R_{20} C_m \quad C_m = 5 \text{ pF}$
\[ R_{20} = R_{10} + R_c (1 + g_m R_{10}) = 60 + \frac{3.3 (1 + 0.4 \times 60)}{24} \]
\[ = 142 \ \Omega \]
\[ T_{20} = 142 \ \Omega \times 5 \text{pF} = 710 \text{psec} = 0.7 \text{nsec} \]

CB Stage

\[ R_b = 0 \quad R_e = R_{\text{out}} = \infty \quad R_c = 1 \text{K} \]

\[ T_{30} = R_{30} C_{\pi} \quad C_{\pi} = 200 \text{pF} \]

\[ R_{30} = r_{\pi} \frac{r_x + R_e}{1 + g_m R_e} = r_{\pi} \frac{1}{g_m} = r_{\pi} \frac{r_{\pi}}{\beta} = r_{\pi} / \beta = 1 / g_m \]
This is easy to see from the circuit.
If we replace $C_\pi$ by a voltage source, that source must supply the current $g_\pi V$ and $g_m V$.

$R_{30} = 150 \Omega \parallel \frac{1}{0.4} \Omega = 150 \parallel 2.5 \Omega = 2.5 \Omega$

$T_{30} = 2.5 \Omega \times 200 \text{ pF} = 500 \text{ psec} = 0.5 \text{ nsec}$

$T_{40} = R_{40} C_u \quad C_u = 5 \text{ pF}$

$R_{40} = r_x \parallel \left[r_\pi + (\beta + 1) R_e\right] + R_c \frac{r_\pi + (\beta + 1) (r_x + R_e)}{r_x + r_\pi + (\beta + 1) R_e}$

$R_e = \infty$
\[ R_{40} \bigg|_{R_e \to \infty} = \frac{r_x}{1000} + R_c \frac{(\beta+1)R_e}{(\beta+1)R_e} = r_x + R_c = 1000 \Omega \]

This is easy to see from the circuit. If we replace \( C_u \) by a voltage source, the current flows out \( r_x \) and back in thru \( R_L \).

\[ T_{40} = 1000 \Omega \times 5 \text{ pF} = 5000 \text{ psec} = 5 \text{ nsec} \]

\[ \Sigma T_{j0} = 12 + 0.7 + 0.5 + 5 = 18.2 \text{ nsec} \]

\[ \omega_n = \frac{1}{\Sigma T_{j0}} = \frac{1}{18.2 \text{ nsec}} = 0.055 \text{ Grad/sec} \]

\[ \omega_n = 55 \times 10^6 \text{ rad/sec} \]

\[ f_h = \frac{\omega_n}{2\pi} = 9 \text{ MHz} \]
Comparison to CE Stage With the Same Gain

If a single CE stage is to have the same gain, then $R_L$ must be 1 K.

There are just two time constants to calculate: $T_{10}$ and $T_{20}$.

$T_{10}$ is identical  
$T_{10} = 12 \text{ nsec}$

$T_{20} = R_{20} C_u$

$R_{20} = R_{10} + R_c (1 + g_m R_{10})$ as before
but now $R_c = R_L$ instead of $R_{\text{in},2}$

$R_{20} = 60 + 1000(25) = 25000 \Omega$

$T_{20} = 25000 \times 5 = 125000 \text{psec} = 125 \text{nsec}$

$\Sigma T_{j0} = 12 + 125 = 137 \text{nsec}$ instead of 18

$\omega_n = 1/137 \text{nsec} = 7.3 \times 10^6 \text{rad/sec}$ instead of $55 \times 10^6$

$f_n = \omega_n / 2 \pi = 1.2 \text{MHz}$ instead of 9 MHz
Summary

In the CE single stage amplifier, the load resistance $R_L^{('1')} = 1\,\text{k}\Omega$ has a large effect upon the value for $\omega_n$ by making the time constant $T_{20} = R_{20} C_u$ the largest in the circuit. Equivalently, this is the effect previously studied where the $C_u(1+g_{m}R_L^{('1')})$ contribution to $C_t$ is very large because $g_{m}R_L^{('1')}$ is very large.
In the cascode circuit the factor \( R_L^{(1)} C_u (g_m R_{10}) \) is greatly reduced because \( R_L \) is now the input resistance of a common base stage which is very low. The dominant time constant \( T_{20} \) is replaced by the time constant \( T_{40} \) which equals \( \sim R_L^{(2)} C_u \) and is much smaller.
Dual Gate FET

\[ G_1 \rightarrow G_2 \]

\[ S \rightarrow D \]

Commercially Available

\[ \text{sig} \quad \downarrow \]

\[ G_1 \rightarrow G_2 \]

\[ S \rightarrow D \rightarrow S \rightarrow D \]