Chapter 8
Feedback

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教材:模拟CMOS集成电路设计

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8.1 General considerations

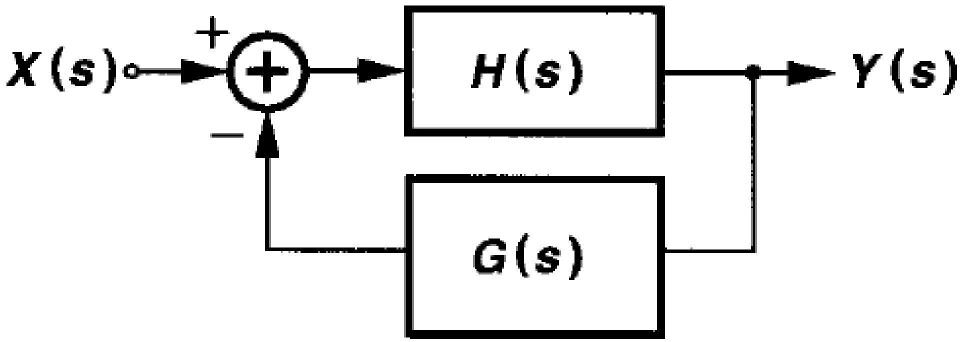


Figure 8.1 General feedback system.

$$Y(s) = H(s)[X(s) - G(s)Y(s)].$$

$$\frac{Y(s)}{X(s)} = \frac{H(s)}{1 + G(s)H(s)}$$

1.任何反馈电路首先确定是正/负反馈

2.环路增益无量纲!

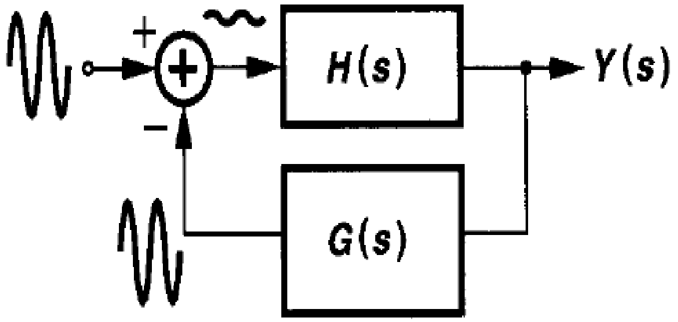
We call $H(s)$ the "open-loop" transfer function and $Y(s)/X(s)$ the "closed-loop" transfer function. a fraction of the output signal is sensed and compared with the input, generating an error term.

In a well-designed negative feedback system, the error term is minimized, thereby making the output of $G(s)$ an accurate "copy" of the input and hence the output of the system a faithful replica of the input

反馈系统的4个部分

the input of $H(s)$ is a "virtual ground" because the signal amplitude at this point is very small.

负反馈信号与输入信号加在H(s)同一端，则电流相减（减小闭环输入阻抗）；
负反馈信号与输入信号加在H(s)的2输入端，则电压相减（增大闭环输入阻抗）。



负反馈支路采样输出电压（目的是稳定电压、减小输出阻抗）或输出电流（目的是稳定电流、增大输出阻抗）

four elements in the feedback system

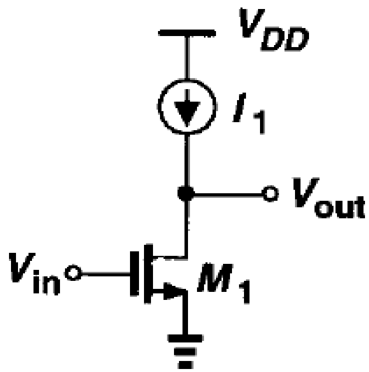
(1) the feedforward amplifier,

(2) a means of sensing the output,

(3) the feedback network,

(4) a means of generating the feedback error.

Gain Desensitization (增益灵敏度降低)



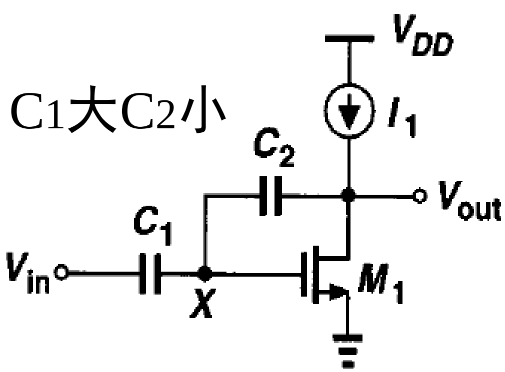
(a)

the voltage gain is equal to $g_{m1}r_{O1}$.

A critical drawback of this circuit is the poor definition of the gain: both g_{m1} and r_{O1} vary with process and temperature.

Figure 8.3 (a) Simple common-source stage.

C1大C2小



(b)

at relatively low frequencies such that C_2 does not load the output node,

$$V_{out}/V_X = -g_{m1}r_{O1}$$

Since $(V_{out} - V_X)C_2s = (V_X - V_{in})C_1s$

we have
$$\frac{V_{out}}{V_{in}} = -\frac{1}{\left(1 + \frac{1}{g_{m1}r_{O1}}\right)\frac{C_2}{C_1} + \frac{1}{g_{m1}r_{O1}}} \approx -\frac{C_1}{C_2}$$

(b) circuit of (a) with feedback.

the closed-loop gain is much less sensitive to device parameters than the open-loop gain is.

环路增益

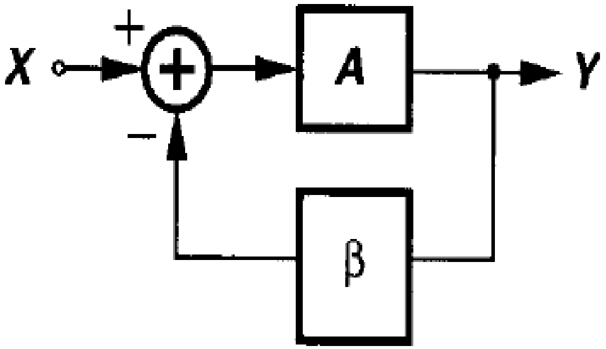


Figure 8.4 Simple feedback system.

replace $G(s)$ by a frequency-independent quantity β and call it the "feedback factor."

$$\frac{Y}{X} = \frac{A}{1+\beta A} \tag{8.5}$$

$$\approx \frac{1}{\beta}\left(1 - \frac{1}{\beta A}\right) \tag{8.6}$$

where we have assumed $\beta A \gg 1$.

βA Called the "loop gain,"

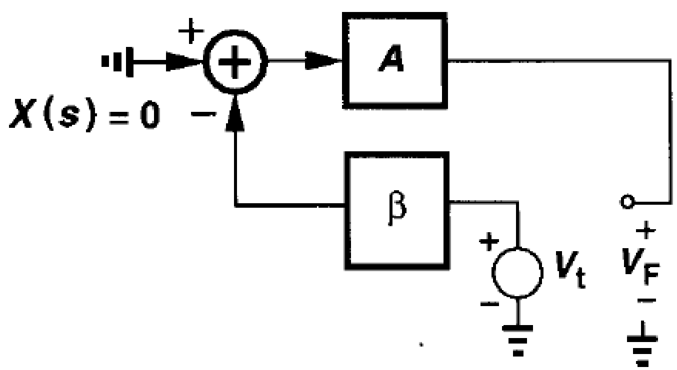


Figure 8.5 Computation of loop gain.

The calculation of the loop gain usually proceeds as follows.

set the main input to zero,
break the loop at some point,
inject a test signal in the "right direction," follow the signal around the loop, and obtain the value that returns to the break point.

The negative of the transfer function thus derived is the loop gain.

一个简单反馈电路中环路增益的计算

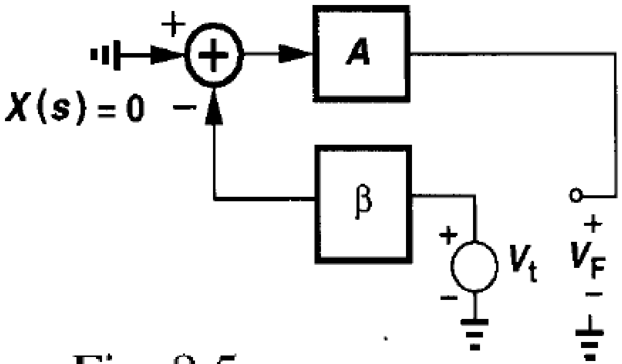


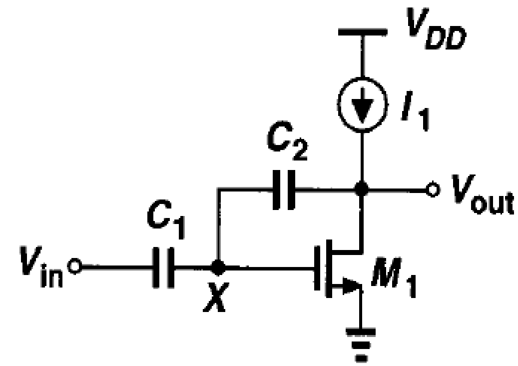
Fig. 8.5

$$V_t \beta(-1)A = V_F$$

$$\rightarrow V_F / V_t = -\beta A$$

Note that the loop gain is a dimensionless quantity.

无量纲



(b)

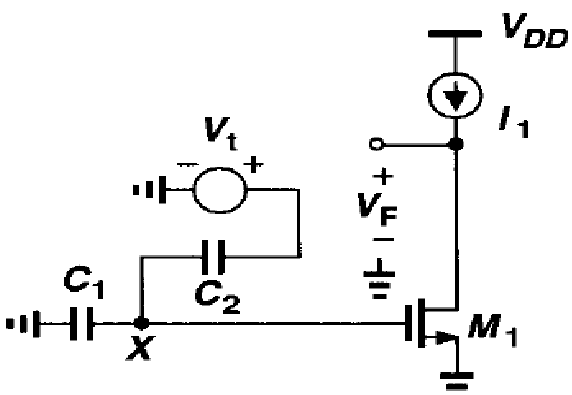


Figure 8.6 Computation of loop gain in a simple feedback circuit.

$$V_t \frac{C_2}{C_1 + C_2}(-g_{m1} r_{O1}) = V_F$$

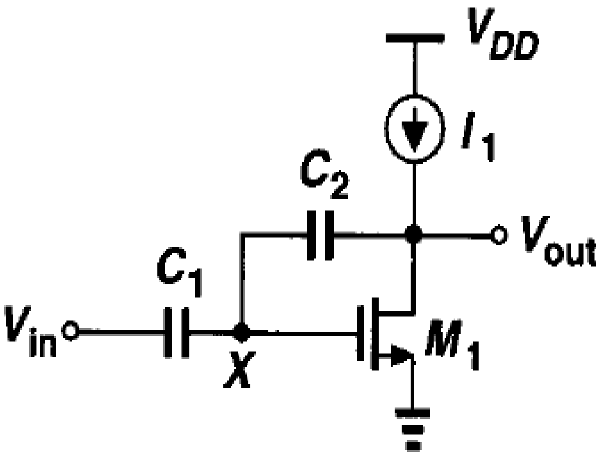
$$\frac{V_F}{V_t} = -\frac{C_2}{C_1 + C_2} g_{m1} r_{O1} = -\beta A$$

Note that the loading of C_2 on the output is neglected here.

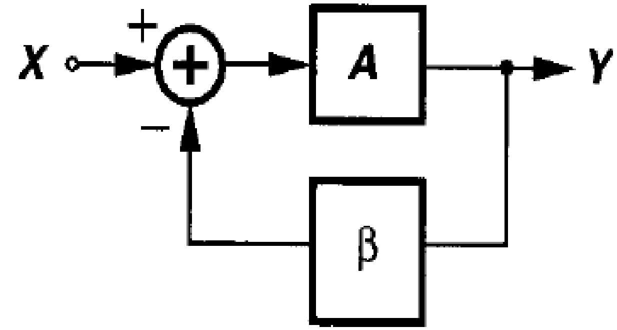
一般C1>>C2, $\beta = -\frac{C_2}{C_1 + C_2} \approx -\frac{C_2}{C_1}$

反馈系统的闭环增益：$A_f \approx \frac{1}{\beta} \approx -\frac{C_1}{C_2}$

识别反馈系统的4个部分



反馈与输入接到前馈放大器同一个端口：输入为电流反馈



Transistor M_1 and current source I_1 constitute the feedforward amplifier.

Capacitor C_2 senses the output voltage and converts it to a current feedback signal, which is then added to the current produced by V_{in} through C_1.

Note that the feedback is negative even though the currents through C_1 and C_2 are *added* because the feedforward amplifier itself provides a negative gain.

large variations in A affect Y/X negligibly if βA is large. Such variations can arise from different sources: process, temperature, frequency, and loading.

Properties of Feedback circuits (cont.)

Terminal Impedance Modification

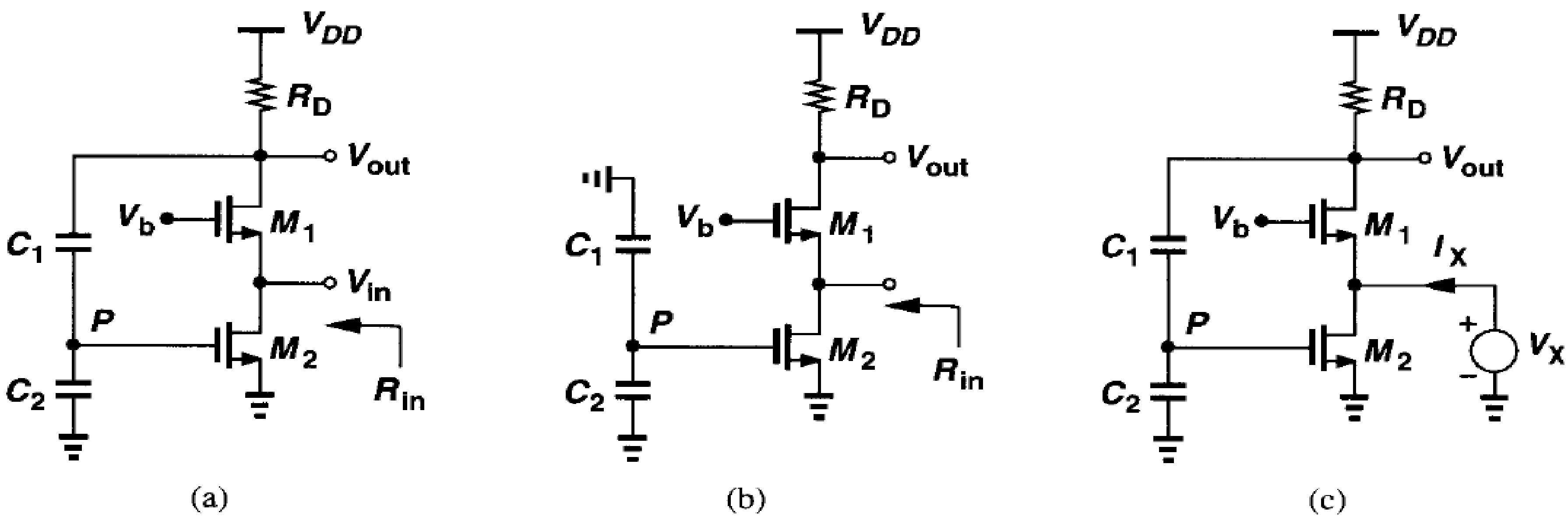


Figure 8.7 (a) Common-gate circuit with feedback, (b) open-loop circuit, (c) calculation of input resistance.

capacitive voltage divider senses the output voltage

a current feedback signal to the input.

Fig. 8.7(b)

$$R_{in,open} = \frac{1}{g_{m1} + g_{mb1}} \tag{8.9}$$

Terminal impedance modification (cont.)

低频CG 。求M2漏极电流：先得到VP

$$V_{out} = (g_{m1} + g_{mb1})V_X R_D$$

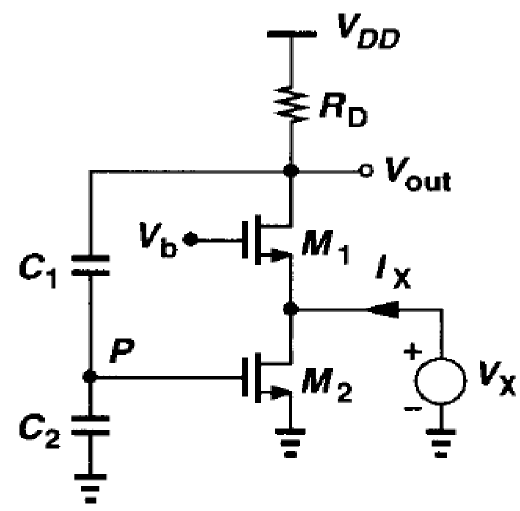
$$V_P = V_{out}\frac{C_1}{C_1 + C_2} = (g_{m1} + g_{mb1})V_X R_D \frac{C_1}{C_1 + C_2}$$

Thus, the small-signal drain current of M_2 equals

$$g_{m2}(g_{m1} + g_{mb1})V_X R_D C_1/(C_1 + C_2).$$

$$I_X = (g_{m1} + g_{mb1})V_X + g_{m2}(g_{m1} + g_{mb1})\frac{C_1}{C_1 + C_2}R_D V_X$$

$$= (g_{m1} + g_{mb1})\left(1 + g_{m2}R_D\frac{C_1}{C_1 + C_2}\right)V_X.$$



(c)

(c) calculation of input resistance

The bias network for M_2 is not shown.

It follows that

$$R_{in,closed} = V_X/I_X = \frac{1}{g_{m1} + g_{mb1}}\frac{1}{1 + g_{m2}R_D\dfrac{C_1}{C_1 + C_2}} \quad (8.15)$$

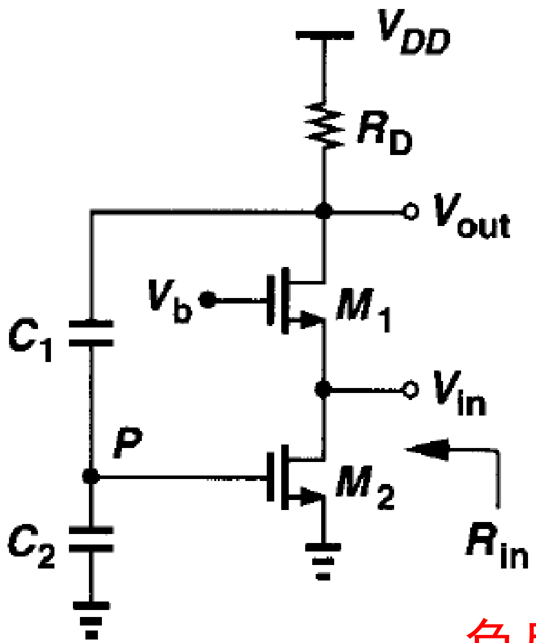
小了！

输入为电流反馈，求环路增益时令IX=0

the loop gain **Of CASCODE=** $g_{m2}R_D C_1/(C_1 + C_2)$

减小多少倍？环路增益

Identify(识别) four elements of feedback



The feedforward amplifier consists of M_1 and R_D,
the output voltage is sensed by C_1 and C_2,
the feedback network comprises C_1, C_2, and M_2,
the subtraction current occurs at the input terminal.

交流小信号:

M1源极流入电流=外部输入电流-M2漏极电流

负反馈支路检测输出电压，则为稳定输出电压！输出阻抗必然减小。

C 的设计问题：

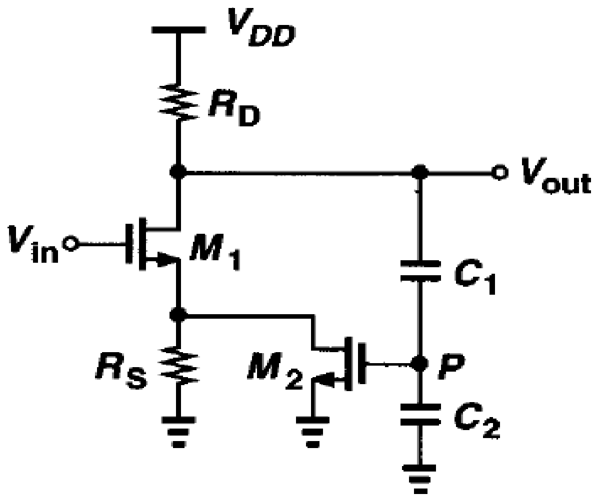
芯片内C1和C2不能太大，例如MIM电容每平方微米1fP（多种，<2fP）；

现代工艺MOM 电容与工艺有关。

外部C小的问题：MOS寄生电容的影响增大。

首先要保证M1工作点！实际电路中C2接地处为某恒定电平。

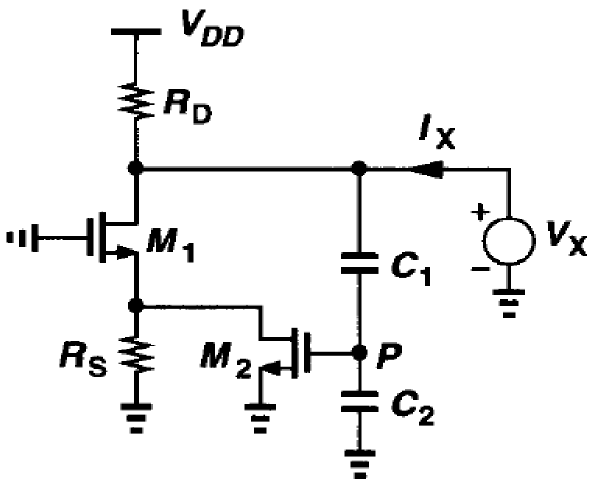
例: 反馈改变输出电阻



(a)

前馈放大器输出阻抗**RD**

C_1, C_2, and M_2 sense the output voltage, returning a current equal to $[C_1/(C_1+C_2)]V_{out}g_{m2}$



(b)

交变小信号

Figure 8.8 (a) CS stage with feedback, (b) calculation of output resistance.

Fig. 8.8(b)

$$I_{D1} = V_X \frac{C_1}{C_1+C_2} g_{m2} \frac{R_S}{R_S + \dfrac{1}{g_{m1}+g_{mb1}}}$$

设为低频，忽略反馈支路C1和C2负载电流

Since $I_X = V_X/R_D + I_{D1}$, we have
$$\frac{V_X}{I_X} = \frac{R_D}{1 + \dfrac{g_{m2}R_S(g_{m1}+g_{mb1})R_D}{(g_{m1}+g_{mb1})R_S+1}\dfrac{C_1}{C_1+C_2}}$$
小了!

feedback decreases the output resistance.

loop gain

RD可包含负载CL

Properties of Feedback circuits (cont.)

Bandwidth Modification.

Suppose the feedforward amplifier has a one-pole transfer function:

$$A(s)=\frac{A_0}{1+\frac{s}{\omega_0}}$$

Ao低频增益,
A传输函数

where A_0 denotes the low-frequency gain and ω_0 is the 3-dB bandwidth.

closed-loop

$$\frac{Y}{X}(s)=\frac{A}{1+\beta A}=\frac{\frac{A_0}{1+\frac{s}{\omega_0}}}{1+\beta\frac{A_0}{1+\frac{s}{\omega_0}}}=\frac{A_0}{1+\beta A_0+\frac{s}{\omega_0}}=\frac{\frac{A_0}{1+\beta A_0}}{1+\frac{s}{(1+\beta A_0)\omega_0}} \quad (8.21)$$

The numerator of (8.21) is simply the closed-loop gain at low frequencies.

the denominator reveals a pole at $(1+\beta A_0)\omega_0$.

Thus, the 3-dB bandwidth has in creased by a factor $1+\beta A_0$,

一阶系统组成反馈电路,
增益带宽积不变
=开环低频增益*开环带宽

带宽变化(续)

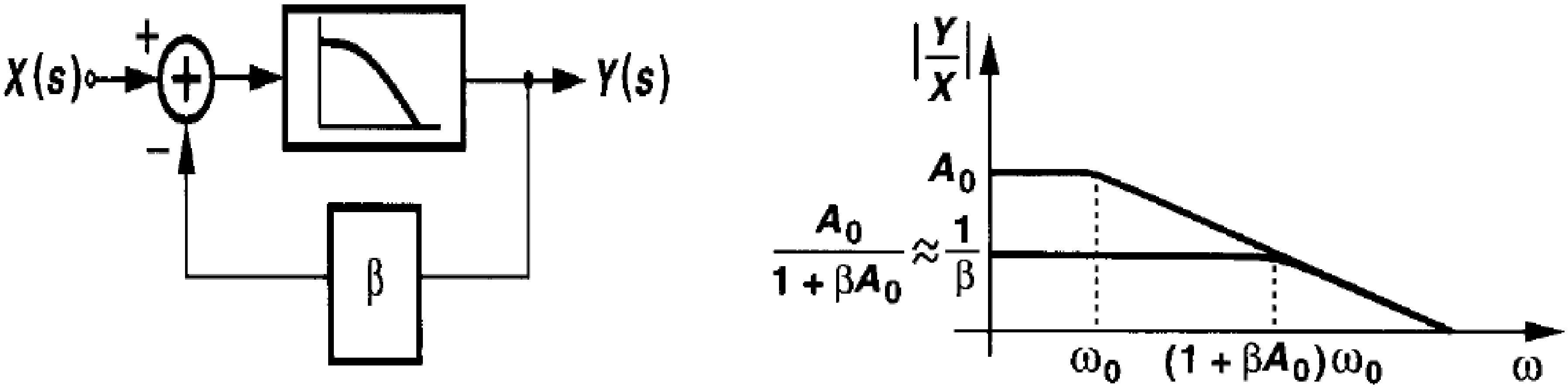


Figure 8.9 Bandwidth modification as a result of feedback.

Equation (8.21) suggests that the gain-bandwidth product of a one-pole system does not change with feedback,

带宽是表示传递函数幅频平坦性的人为界限，并不代表不能放大或通过信号。幅频不平坦表示各频率放大不一致，将导致信号失真。

Nonlinearity Reduction

A very important property of negative feedback is the suppression of nonlinearity in analog circuits.

例:负反馈增加带宽以提高信号速度

how feedback improves the speed if a high gain is required.

20MHz半周期时间=25ns

经过4倍时间常数的时间达到终值98%

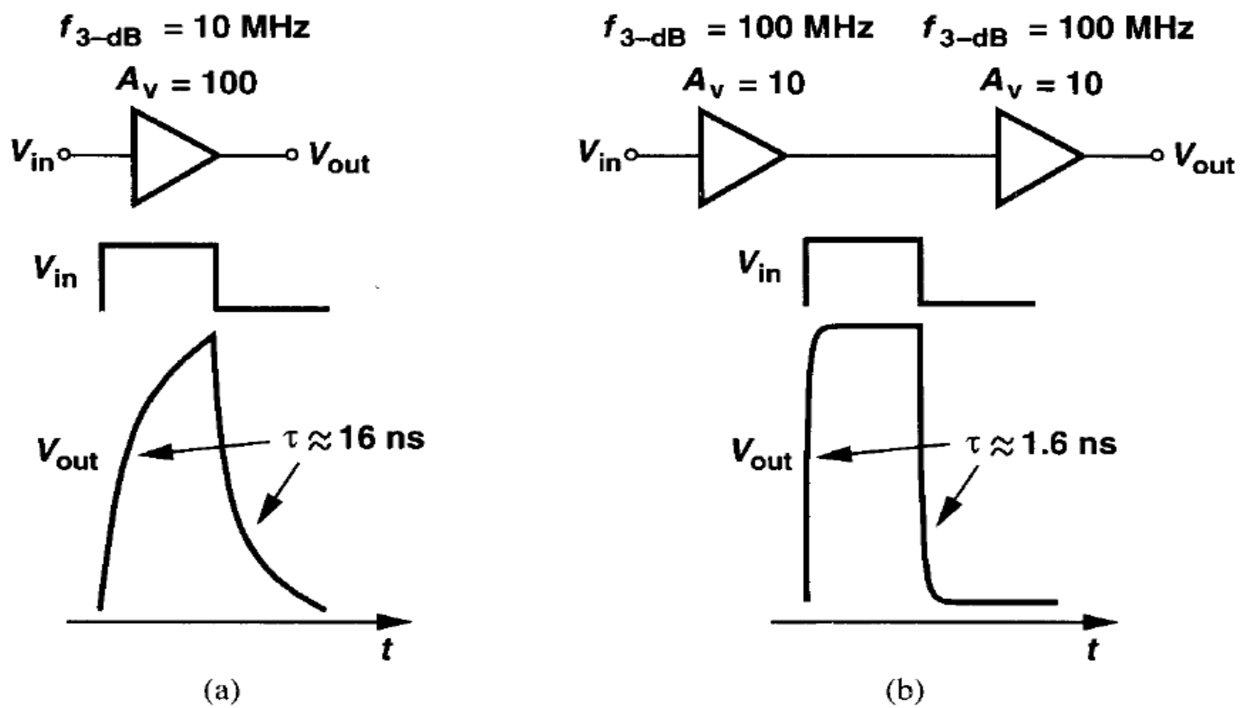


Figure 8.10 Amplification of a 20-MHz squarewave by (a) 20-MHz amplifier and (b) cascade of two 100-MHz feedback amplifiers.

the time constant is equal to $1/(2\pi f_{3-dB}) \approx 16$ ns.

8.1.2 types of Amplifiers

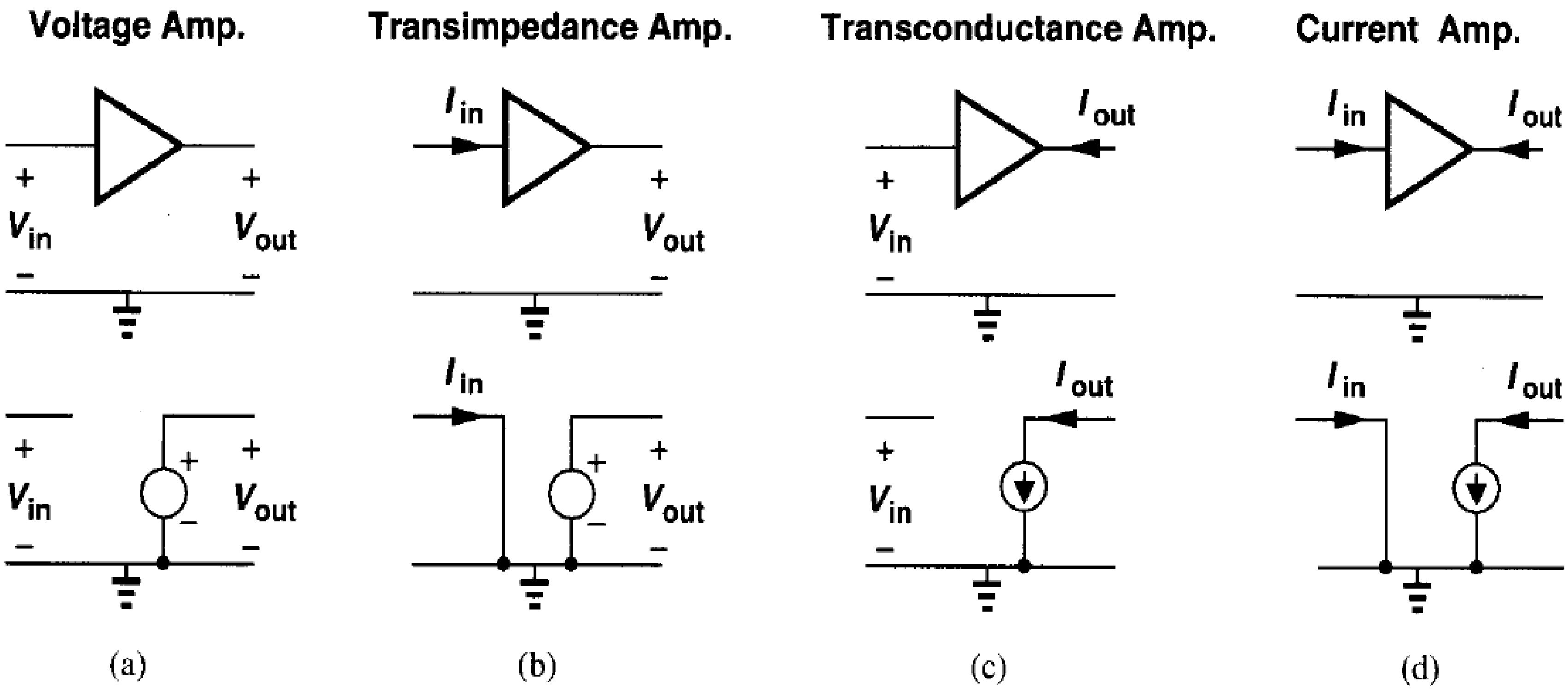


Figure 8.11 Types of amplifiers along with their idealized models.

不同类型放大器（包括反馈）的输入、输出电阻的串并联方式不同。
输入端：若为电压，则输入阻抗与端口并联；若电流，则输入阻抗与端口串联。
输出端：若为电压，则输出阻抗与端口串联；若电流，则输出阻抗与端口并联。
提示：参考理想放大器。

Four types of Amp

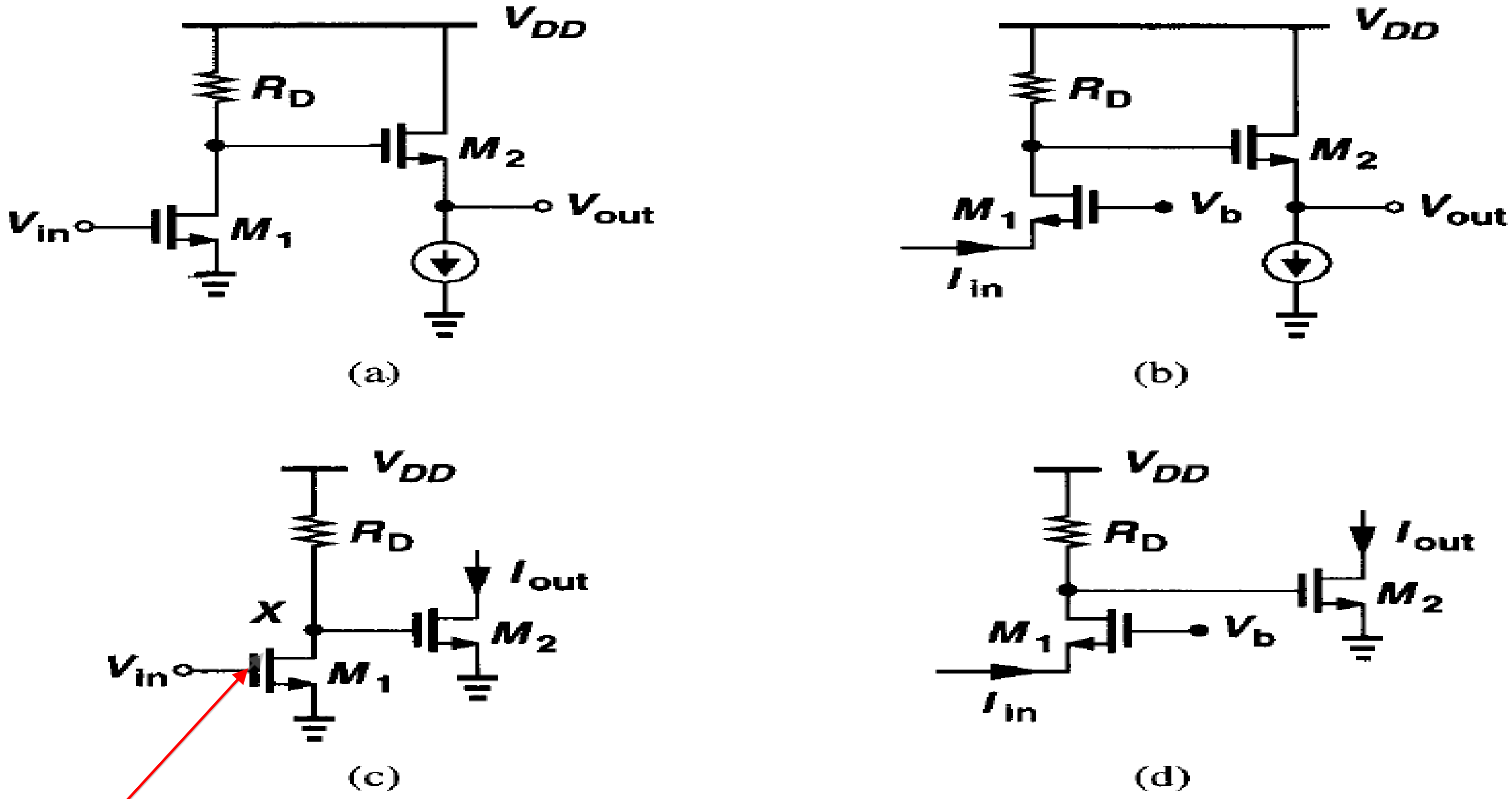


Figure 8.13 Four types of amplifiers with improved performance.

$$G_m = \frac{V_X}{V_{in}} \cdot \frac{I_{out}}{V_X}$$

$$= -g_{m1}(r_{O1} \| R_D) \cdot g_{m2}$$

放大器类型由反馈支路特性确定

8.2.1 Voltage-Voltage Feedback

输出端检测的信号类型。
并联！

反馈到输入端的信号类型。
串联！

V-V反馈也称为电压串联反馈

(1) circuits sensing a voltage must exhibit a high input impedance whereas those sensing a current must provide a low input impedance

(2) circuits generating a voltage must exhibit a low output impedance while those generating a current must provide a high output impedance

$$V_{out} = A_0(V_{in} - \beta V_{out})$$

$$\frac{V_{out}}{V_{in}} = \frac{A_0}{1 + \beta A_0}.$$

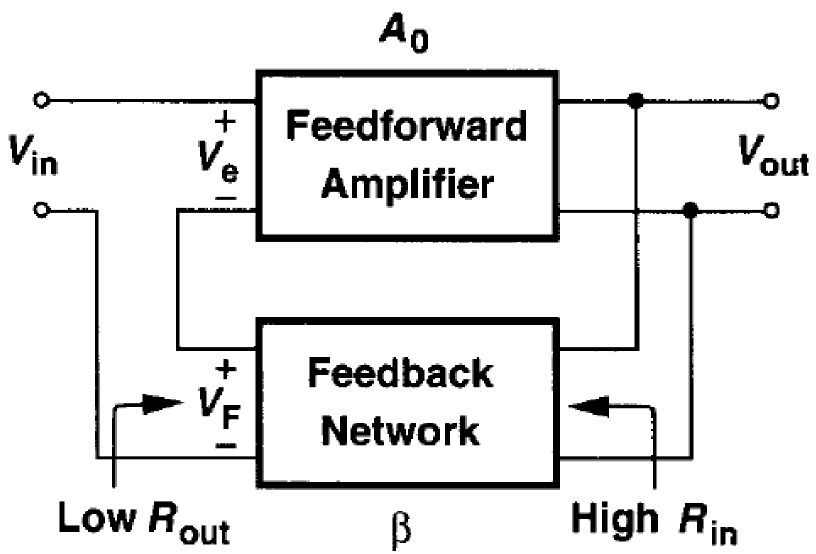


Figure 8.17 Voltage-voltage feedback.

$$V_F = \beta V_{out}$$

$$V_e = V_{in} - V_F$$

both A_0 and β are dimensionless quantities.

环路概念有助于简化解题和设计。
也可直接列节点或回路方程求解

An example of V-V feedback

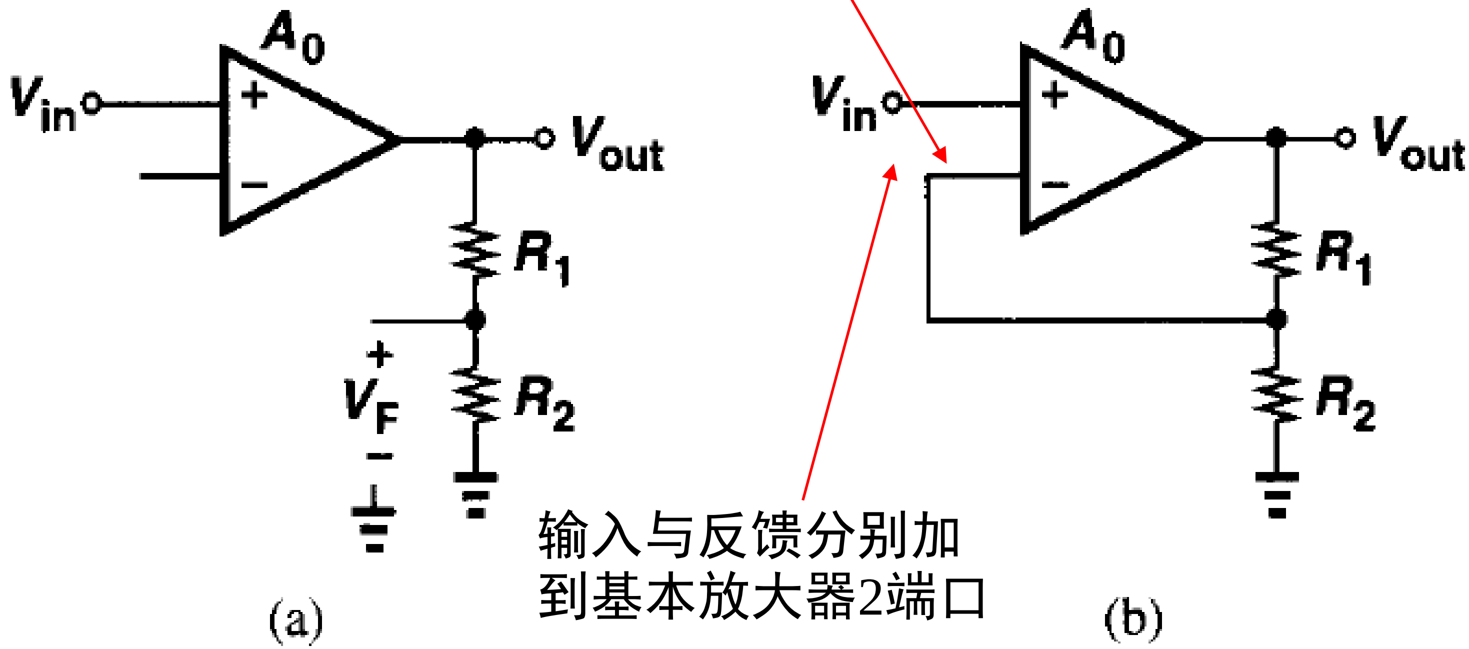


Figure 8.18 (a) Amplifier with output sensed by a resistive divider, (b) voltage-voltage feedback amplifier.

Note that for voltage subtraction the input and feedback signals are applied to *two* distinct nodes whereas for current subtraction they are applied to a single node.

Output impedance of V-V feedback

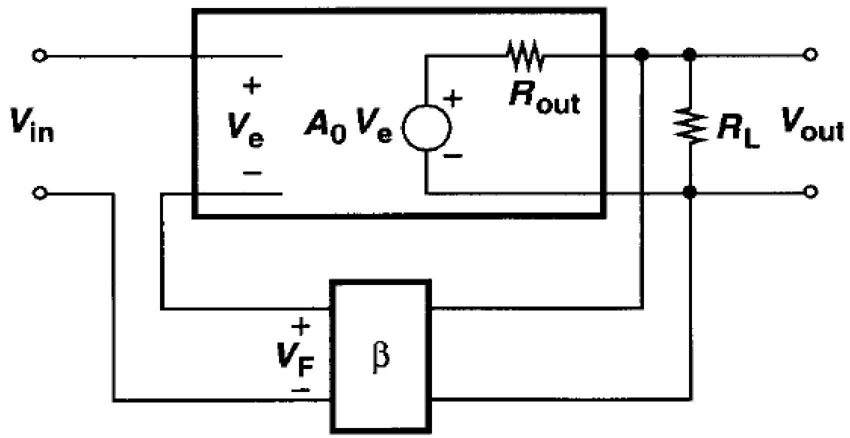


Figure 8.19 Effect of voltage-voltage feedback on output resistance.

so long as the loop gain remains much greater than unity, $V_{out}/V_{in} \approx 1/\beta$, regardless of the value of R_L.

输出电压反馈有稳定电压的作用，因此输出阻抗变小。

不包括RL

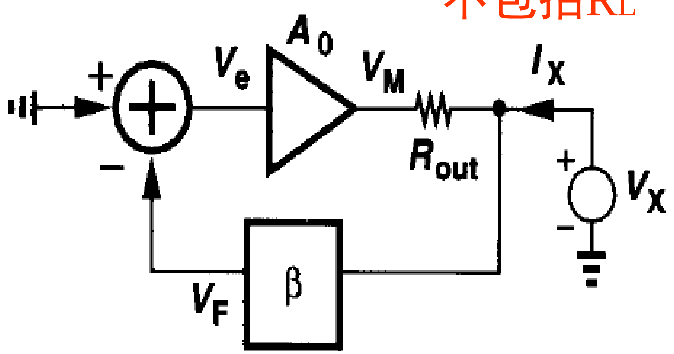


Figure 8.20 Calculation of output resistance of a voltage-voltage feedback circuit.

$$V_F = \beta V_X, V_e = -\beta V_X, V_M = -\beta A_0 V_X,$$

hence $I_X = [V_X - (-\beta A_0 V_X)]/R_{out}$

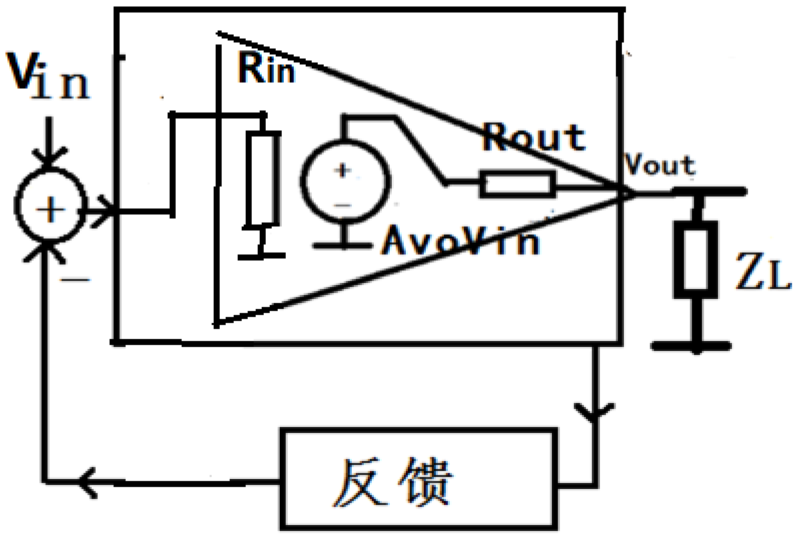
It follows that

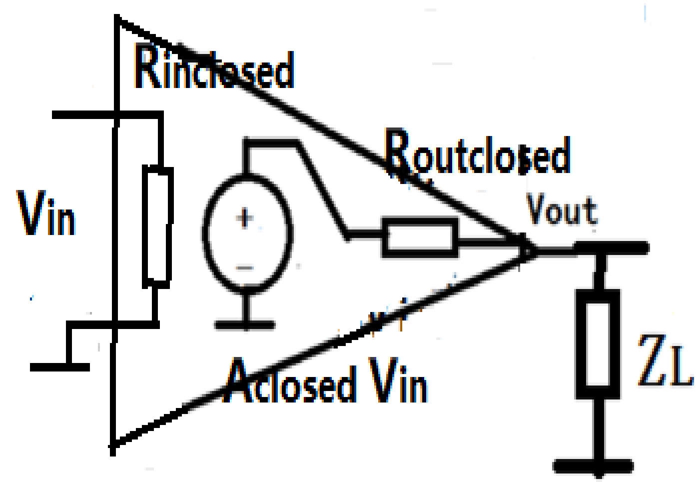
忽略输出端反馈支路电流作用

$$\frac{V_X}{I_X} = \frac{R_{out}}{1+\beta A_0}.$$

计算Vout时应计入RL

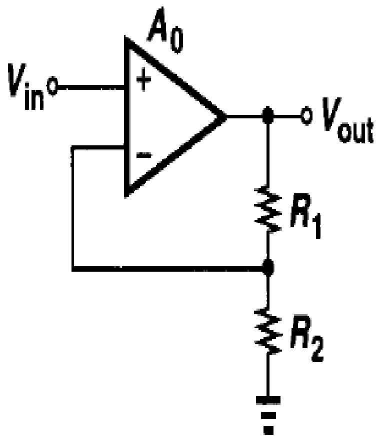
R_L放在反馈环路之外计算时



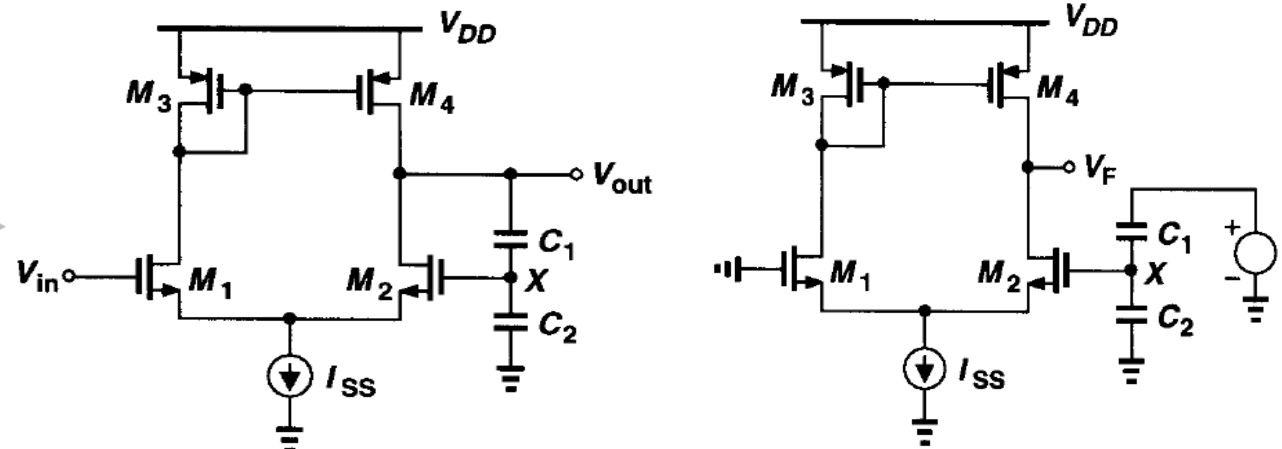


小信号等效电路

Calculate the closed-loop gain and output resistanceof the amplifier at relatively low frequencies.



交流地



(a) (c)

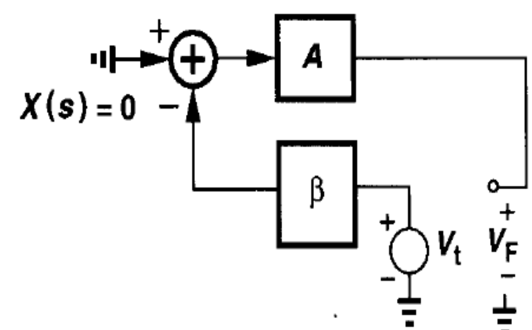
Figure 8.21

Solution

The open-loop gain is equal to $g_{m1}(r_{O2}\|r_{O4})$.

compute the loop gain.

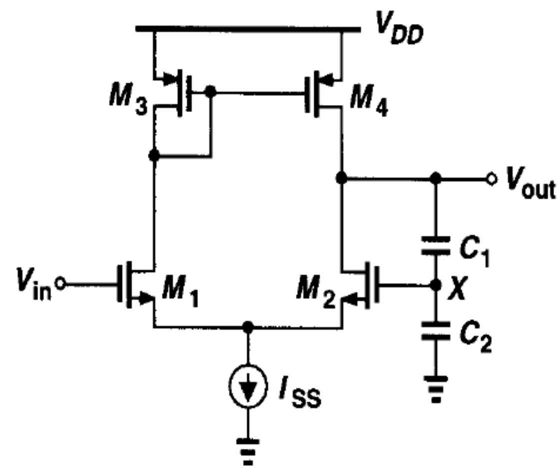
$$V_F = -V_t \frac{C_1}{C_1 + C_2} g_{m1}(r_{O2}\|r_{O4})$$



$$V_F/V_t = -\beta A \rightarrow \beta A_0 = \frac{C_1}{C_1 + C_2} g_{m1}(r_{O2}\|r_{O4})$$

Example 8.2 (cont.)

$$A_{closed} = \frac{g_{m1}(r_{O2}\|r_{O4})}{1 + \frac{C_1}{C_1 + C_2} g_{m1}(r_{O2}\|r_{O4})}.$$



(a)

As expected, if $\beta A_0 \gg 1$, then $A_{closed} \approx 1 + C_2/C_1$.

The open-loop output resistance of the circuit is equal to $r_{O2}\|r_{O4}$

It follows that

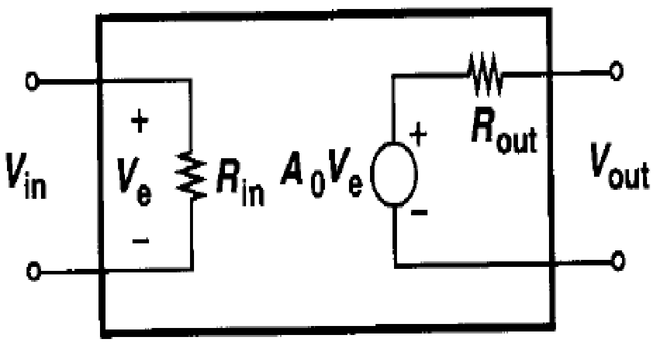
$$R_{out,closed} = \frac{r_{O2}\|r_{O4}}{1 + \frac{C_1}{C_1 + C_2} g_{m1}(r_{O2}\|r_{O4})}.$$

if $\beta A_0 \gg 1$, then

$$R_{out,closed} \approx \left(1 + \frac{C_2}{C_1}\right)\frac{1}{g_{m1}}$$

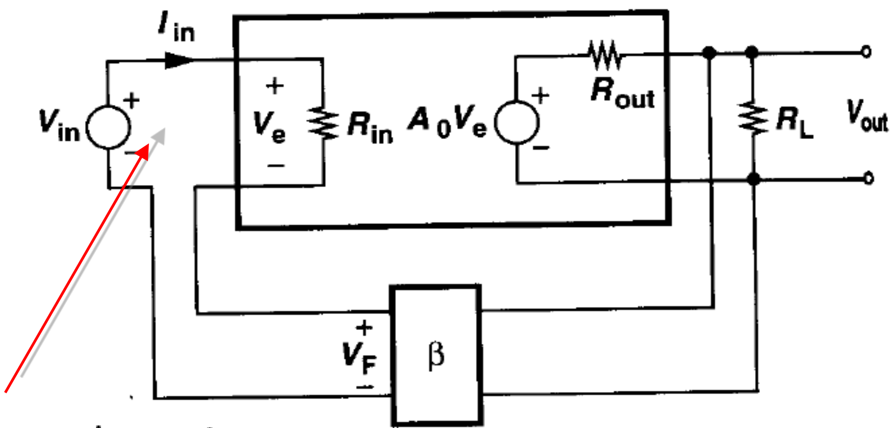
低频，忽略输出端反馈支路的负载（电流）作用

Input impedance of V-V feedback



(a)

increases the input impedance.



(b)

Figure 8.22 Effect of voltage-voltage feedback on input resistance.

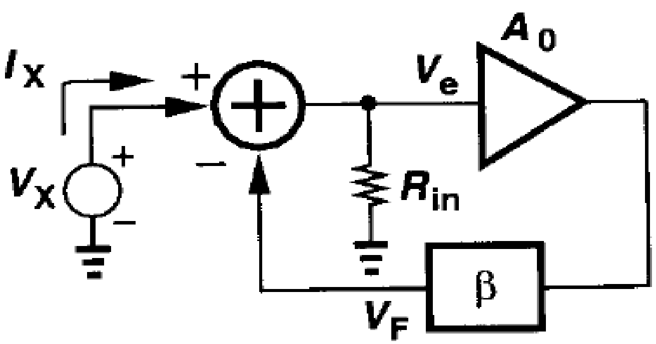


Figure 8.23 Calculation of input impedance of a voltage-voltage feedback circuit.

$$V_e = I_X R_{in} \qquad V_F = \beta A_0 I_X R_{in}$$

$$V_e = V_X - V_F = V_X - \beta A_0 I_X R_{in}.$$

Thus, $I_X R_{in} = V_X - \beta A_0 I_X R_{in},$

$$\frac{V_X}{I_X} = R_{in}(1 + \beta A_0). \tag{8.31}$$

注意：这里Ao（新）包括了Rout与RL分压

增大输入阻抗！

Example 8.3

Calculate the input resistance

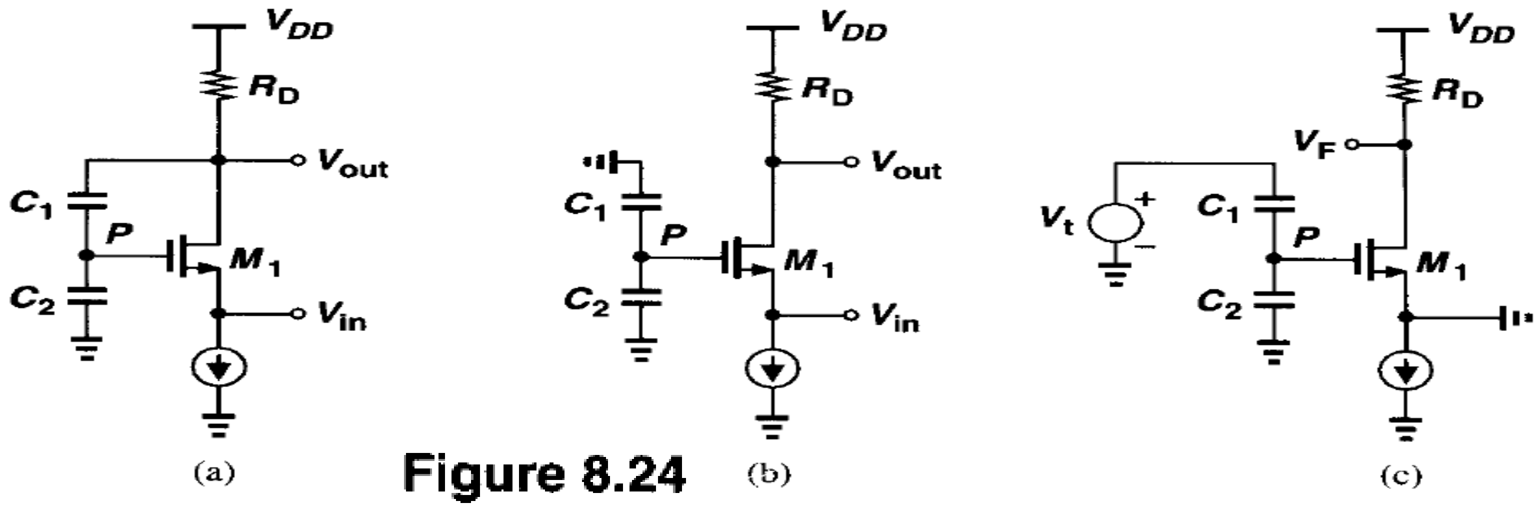


Figure 8.24

channel-length modulation is negligible.

Solution

$$V_F/V_t = -g_{m1}R_DC_1/(C_1+C_2). = -\beta A$$

$$R_{in,closed} = \frac{1}{g_{m1}+g_{mb1}}\left(1+\frac{C_1}{C_1+C_2}g_{m1}R_D\right).$$

In summary, voltage-voltage feedback decreases the output impedance and increases the input impedance, thereby proving useful as a "buffer" stage that can be interposed between a high-impedance source and a low-impedance load.

Current-Voltage Feedback

输出端检测的信号类型。串联！

反馈到输入端的信号类型。串联！

feedback factor (β) has the dimension 量纲 of resistance and is denoted by R_F.

$$V_F = R_F I_{out},$$

$$V_e = V_{in} - R_F I_{out},$$

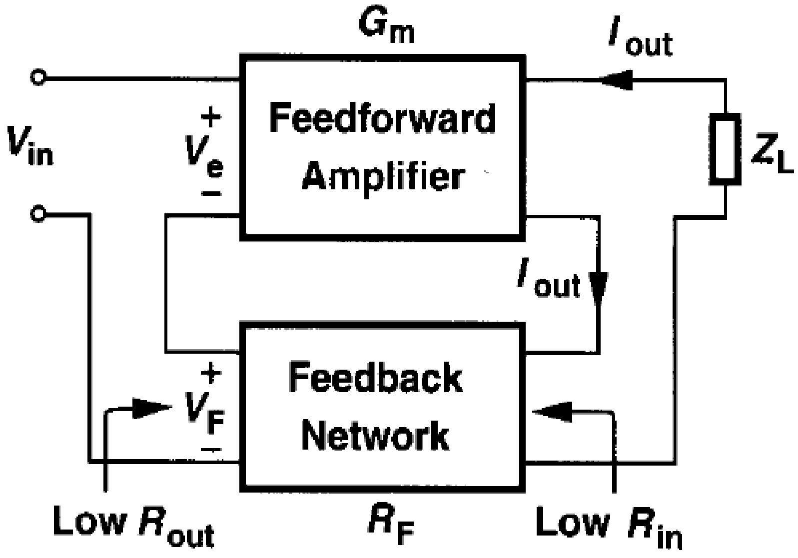


Figure 8.25 Current-voltage feedback.

环路增益VF/Vt的大小与反馈模式无关！

前馈放大器输出端等效为电流源（方向为流入！）并联一个输出阻抗。

C-V反馈也称为电流串联反馈

C-V feedback increases output impedance

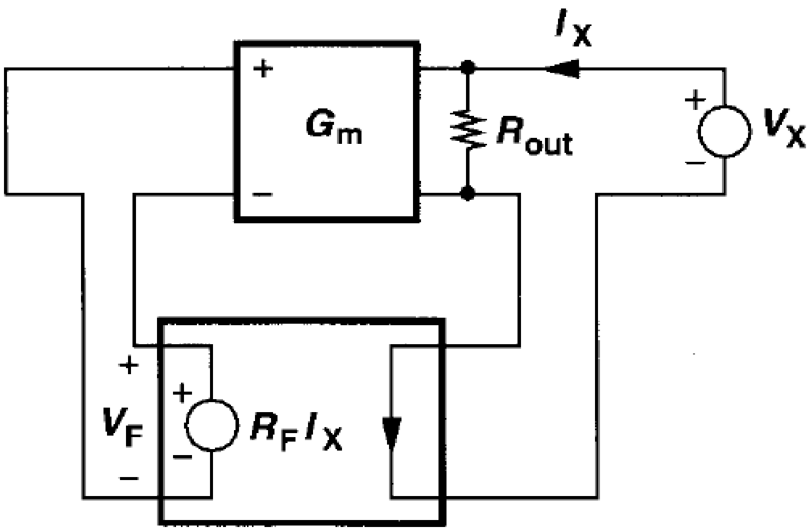


Figure 8.27 Calculation of output resistance of a current-voltage feedback amplifier.

where R_{out} represents the finite output impedance of the feedforward ampli fier.

Note that R_{out} is placed in *parallel* with the output because the ideal transimpedance amplifier is modeled by a voltage-dependent current source.

$$V_F = R_F I_X,$$

$$-R_F I_X G_m = I_X - V_X / R_{out},$$

理想反馈网络

双口网络Gm电流流进为正！

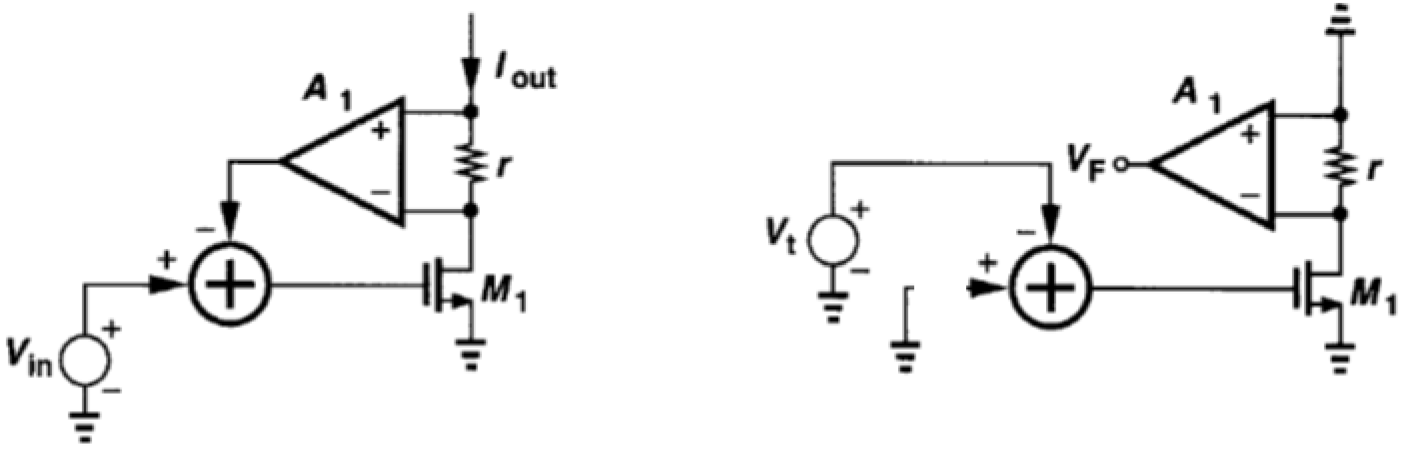
yielding

$$\frac{V_X}{I_X} = R_{out}(1 + G_m R_F). \qquad (8.34)$$

Example 8.4

Suppose we need to increase the output impedance of a common-source stage by current feedback. As shown in Fig. 8.28(a), we insert a small resistor r in the output current path, apply the voltage across r to an amplifier A_1, and subtract the output of A_1 from the input voltage. Calculate the output impedance of this circuit.

C-C负反馈



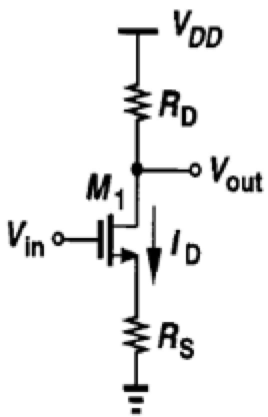
(a) (b)

Solution

Using the circuit of Fig. 8.28(b) to determine the loop gain, $\frac{V_F}{V_t} = -g_m r A_1.$

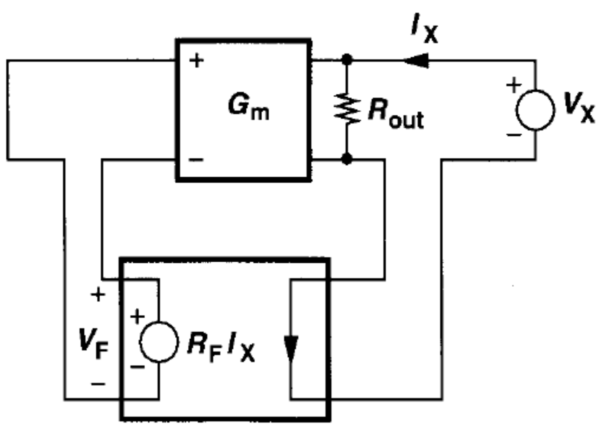
$$R_{out,closed} = (1 + g_m r A_1) r_{O1}. \qquad (8.36)$$

例：C-V负反馈



- 前馈放大器为跨导放大器$G_m=g_m$,
- 反馈信号电压加在-输入端，
  反馈网络为R_F=Rs
- 环路增益为g_mRs

$$闭环G_{mclosed} = \frac{G_m}{1+G_m R_F} = \frac{g_m}{1+g_m R_S}$$



$$电压增益A_v = G_{mclosed} R_D = \frac{g_m R_D}{1+g_m R_S} == \frac{R_D}{\frac{1}{g_m}+R_S}$$

第三章，输出阻抗（向*MOS*看）

$$R_{out} \approx r_o + g_m r_o R_S = r_o(1+g_m R_S)$$

C-V feedback increases Input impedance

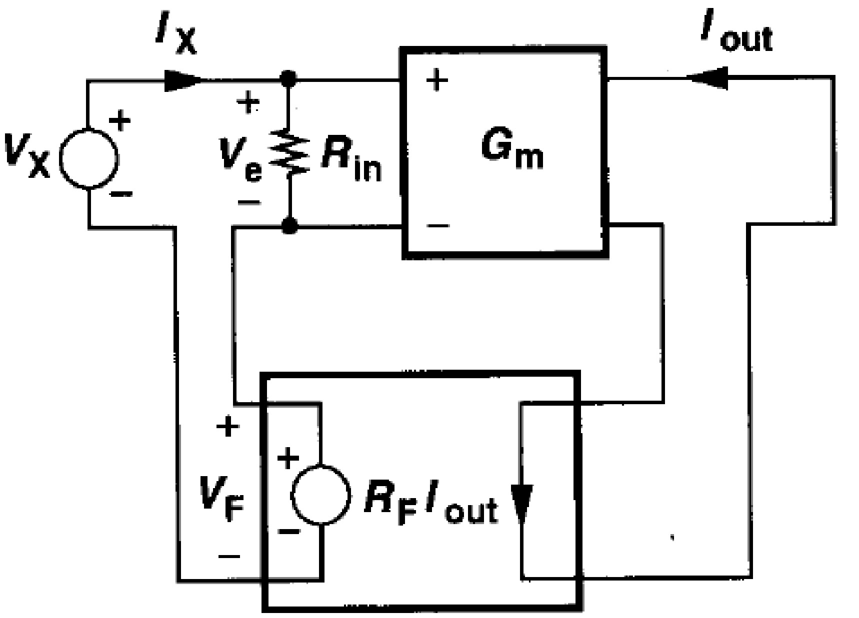


Figure 8.29 Calculation of input resistance of a current-voltage feedback amplifier.

$$I_X R_{in} G_m = I_{out}.$$ 理想反馈网络

$$V_e = V_X - G_m R_F I_X R_{in}$$

$$V_e = I_X R_{in}$$

$$\frac{V_X}{I_X} = R_{in}(1 + G_m R_F). \qquad (8.37)$$

In summary, current-voltage feedback increases both the input and the output impedances while decreasing the feedforward transconductance.

8.2.3 Voltage-Current feedback

Voltage-Current Feedback

输出端检测电压。并联！

电流信号反馈到输入端. 并联！

This topology is also called "shunt-shunt" feedback.

the feedback network is characterized by a transconductance g_{mF},

$$V_{out} = R_0 I_e = R_0(I_{in} - g_{mF} V_{out}).$$

$$\rightarrow \frac{V_{out}}{I_{in}} = \frac{R_0}{1 + g_{mF} R_0}.$$

$g_{mF} R_0$ is the loop gain,

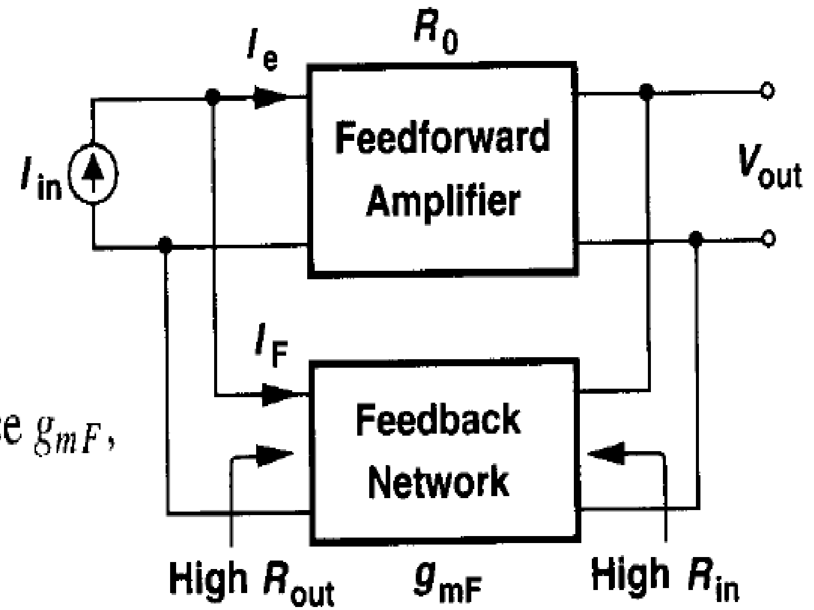


Figure 8.30 Voltage-current feedback.

跨阻放大器TIA

V-C反馈也称为电压并联反馈

环路增益V_F/V_t的大小与反馈模式无关！

Example 8.5

Calculate the transimpedance, V_{out}/I_{in}, of the circuit at relatively low frequencies.

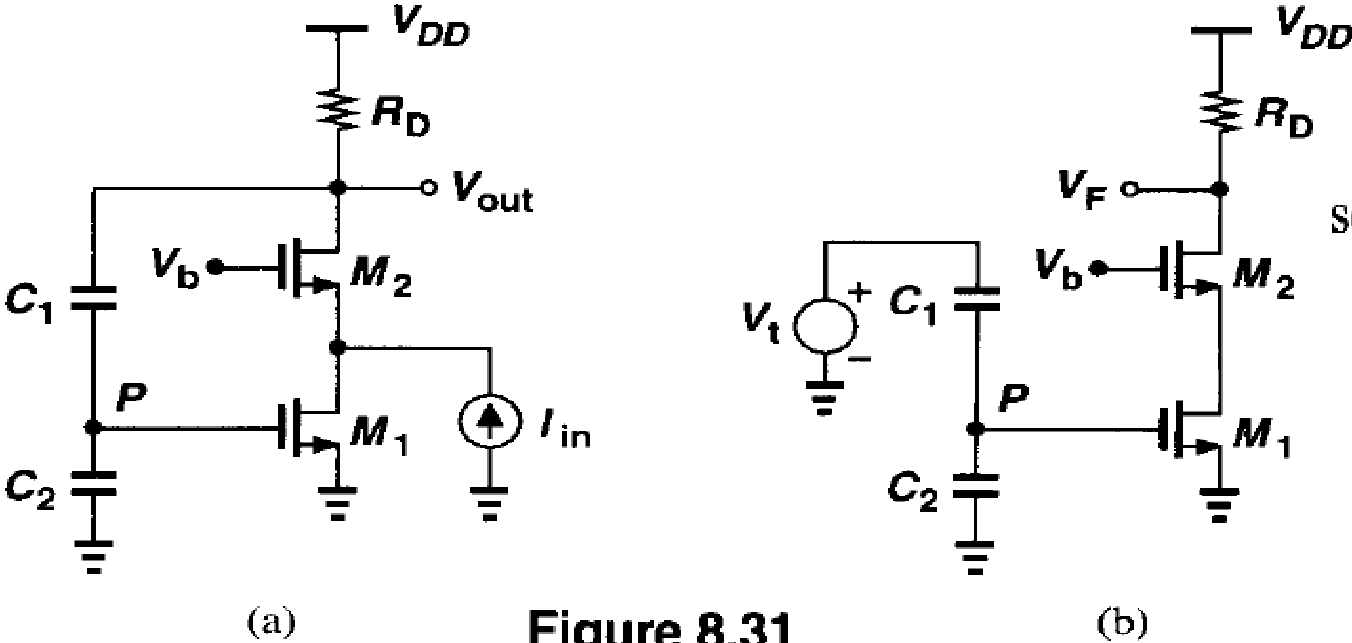


Figure 8.31

setting I_{in} to zero

loop gain

Solution

The open-loop transimpedance equals that of the core common-gate stage, R_D.

$$-V_t \frac{C_1}{C_1 + C_2} g_{m1} R_D = V_F$$

$$R_{tot} = \frac{R_D}{1 + \dfrac{C_1}{C_1 + C_2} g_{m1} R_D}. \tag{8.40}$$

计算**输入**阻抗:

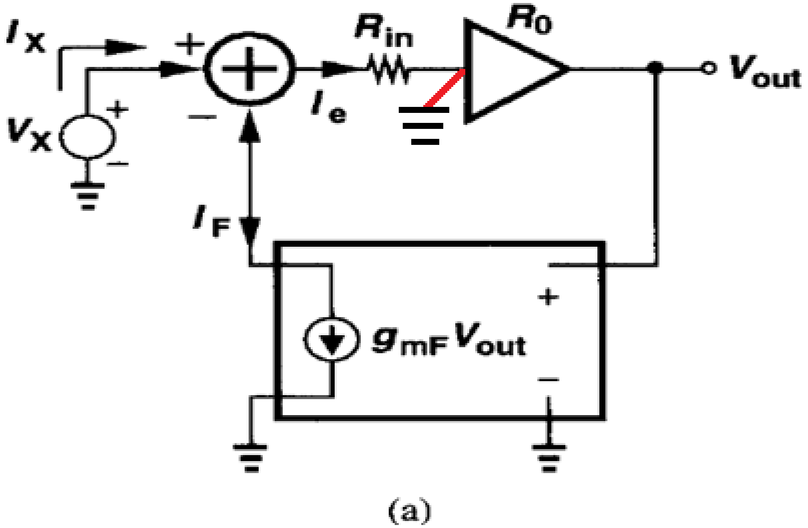


Figure 8.32 Calculation of (a) input impedance of a voltage-current feedback amplifier.

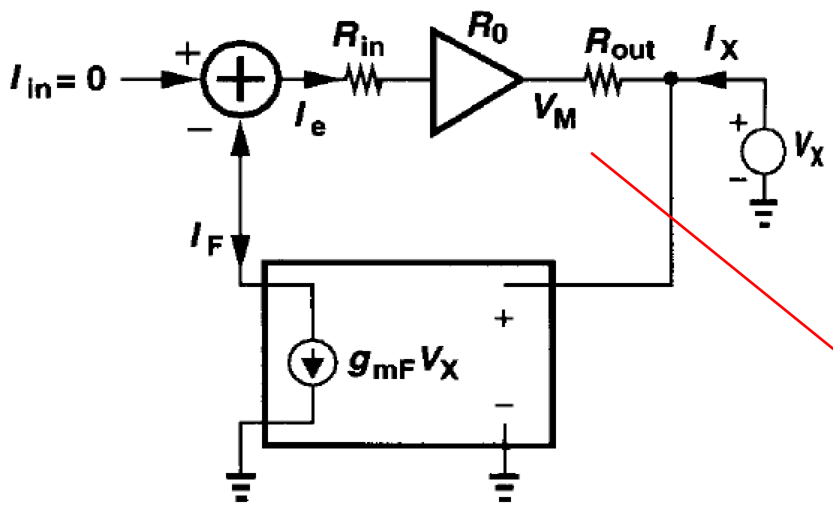
the input resistance of R_0 is placed in *series* because an ideal transimpedance amplifier exhibits a zero input impedance.

$$I_F = I_X - V_X/R_{in} \qquad (V_X/R_{in})R_0 g_{mF} = I_F.$$

$$\frac{V_X}{I_X} = \frac{R_{in}}{1 + g_{mF}R_0} \qquad (8.41)$$

计算**输出**阻抗:

假设反馈支路无负载电流。



(b)

$$I_F = V_X g_{mF},$$

$$I_e = -I_F,$$

$$V_M = -R_0 g_{mF} V_X.$$

Figure 8.32 Calculation of

(b) output impedance of a voltage-current feedback amplifier.

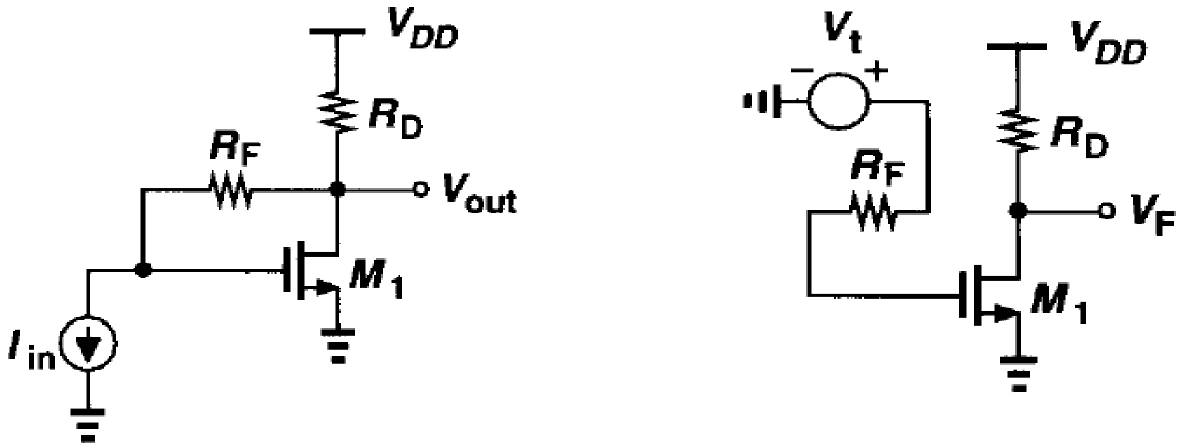
Neglecting the input current of the feedback network,

$$I_X = (V_X - V_M)/R_{out} = (V_X + g_{mF} R_0 V_X)/R_{out}$$

That is, $$\frac{V_X}{I_X} = \frac{R_{out}}{1 + g_{mF} R_0} \qquad (8.42)$$

Example 8.6

Calculate the input and output impedances of the circuit shown in Fig. 8.33(a). For simplicity, assume $R_F \gg R_D$.



loop gain

$g_m R_D$

(a) **Figure 8.33** (b)

Solution

$$R_{in,closed} = \frac{R_F}{1 + g_m R_D}$$

$$R_{out,closed} = \frac{R_D}{1 + g_m R_D},$$

参考后一节的反馈支路负载作用。这里RF是包含反馈支路负载的开环跨阻放大器的输入阻抗。

Note $R_{out,closed}$ is in fact the parallel combination of a diode-connected transistor and R_D.

应用例

An important application of amplifiers with *low* input impedance is in fiber optic receivers, where light received through a fiber is converted to a *current* by a reverse-biased photodiode. This current is typically converted to a voltage for further amplification and processing. Shown in Fig. 8.34(a), such conversion can be accomplished by a simple resistor but at the cost of bandwidth because the diode suffers from a relatively large junction capacitance. For this reason, the feedback topology of Fig. 8.34(b) is usually employed, where R_1 is placed around the voltage amplifier A to form a transimpedance circuit. The input impedance is $R_1/(1+A)$ and the output voltage is approximately $R_1 I_{D1}$.

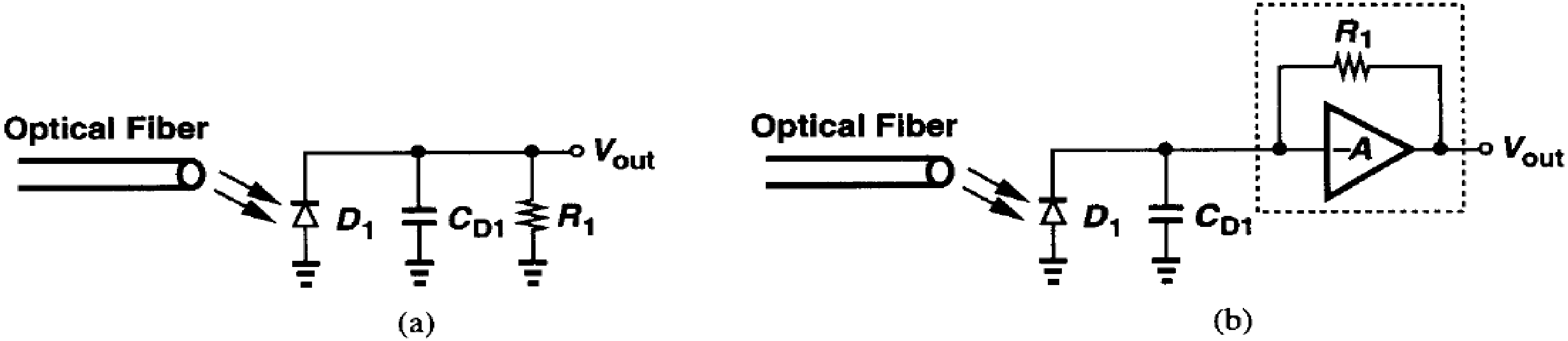
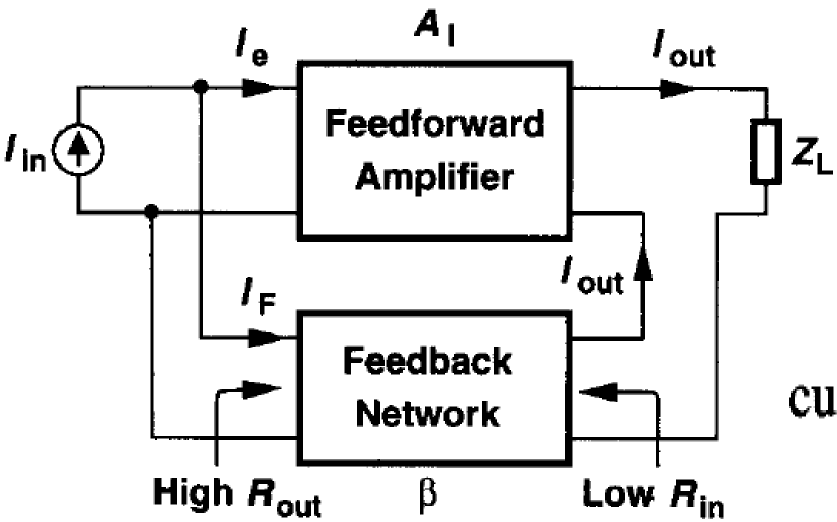


Figure 8.34 Detection of current produced by a photodiode by (a) resistor R_1 and (b) a transimpedance amplifier.

8.2.4 Current-Current feedback



current gain, A_I

current ratio, β.

Figure 8.35 Current-current feedback.

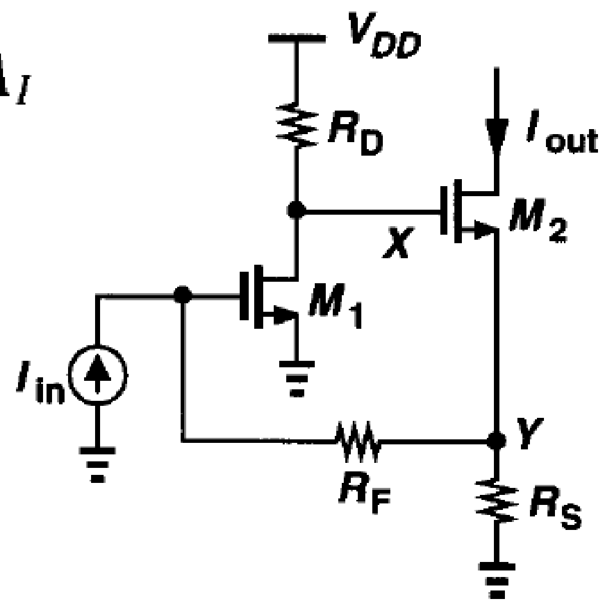


Figure 8.36

the closed-loop current gain is equal to $A_I/(1+\beta A_I)$

the input impedance is divided by $1+\beta A_I$

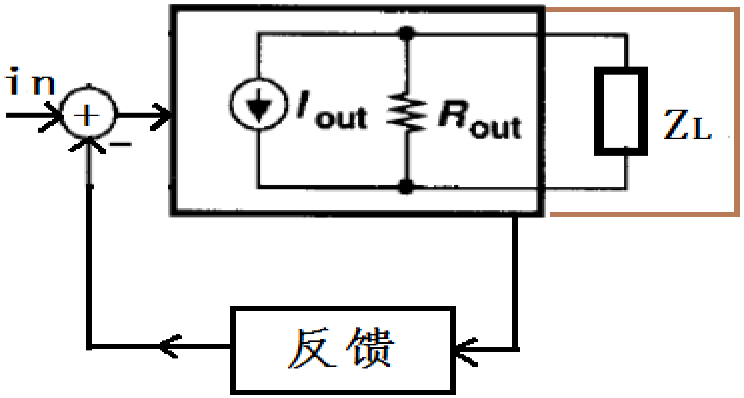
the output impedance is multiplied by $1+\beta A_I$.

基本（开环）放大器输入和输出阻抗应计入反馈支路的负载

电路负载Z_L的处理

2种处理方式：

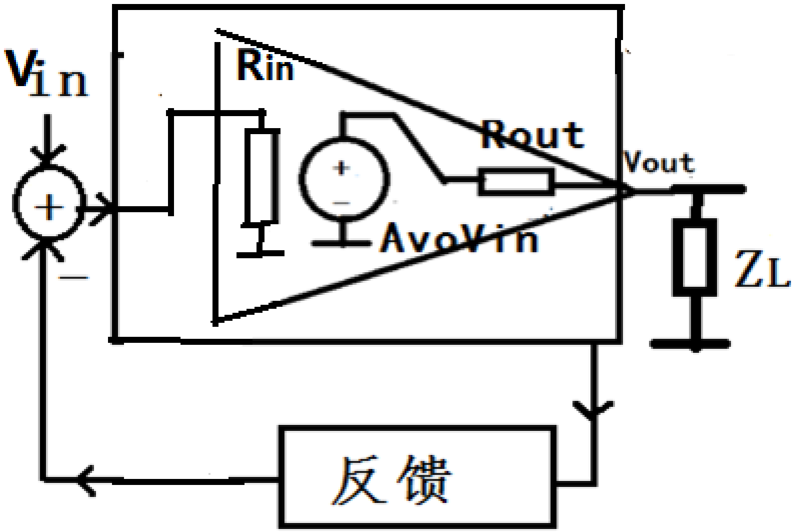
（1）与前馈放大器输出阻抗R_{out}合并



反馈改变输出阻抗与Z_L有关，即前馈放大器增益与Z_L有关

（2）单独作为闭环放大器的负载Z_L（串并均可）

反馈改变输出阻抗与Z_L无关

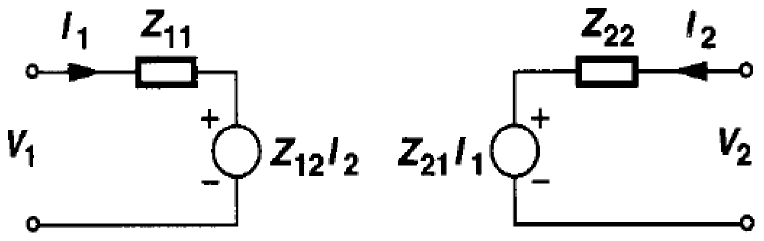


8.3 effect of loads

the loading due to the feedback network may not be negligible.

8.3.1 Two-Port Network Models

Figure 8.37 Linear two-port network models.



(a)

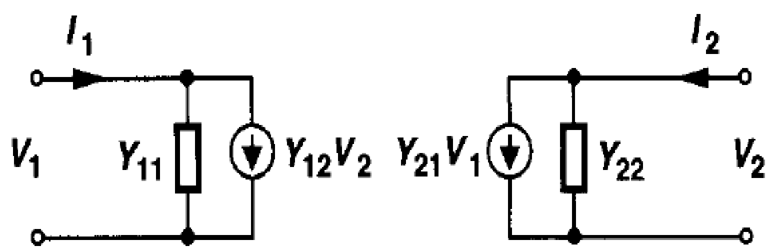
"Z model" current-voltage

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$

$$V_2 = Z_{21}I_1 + Z_{22}I_2.$$

反馈网络信号传输方向与闭环（或前馈）放大器相反

下标1表示反馈网络输入端，实际是在闭环放大器输出端



(b)

"Y model" voltage-current

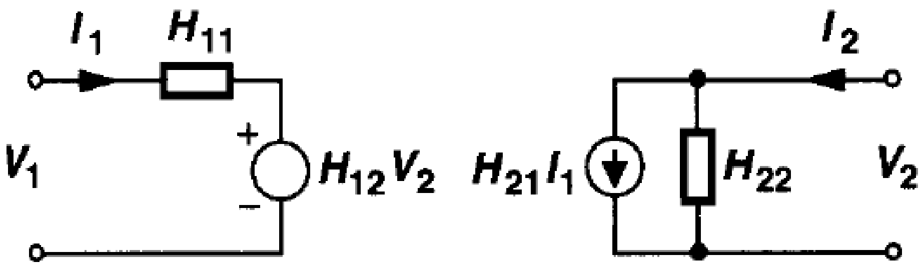
$$I_1 = Y_{11}V_1 + Y_{12}V_2$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2,$$

admittances 导纳

第21项表示反馈，其它是非理想参数

Linear two-port network models.



(c)

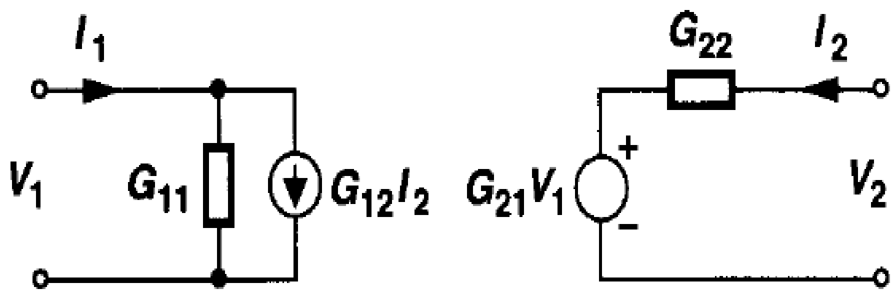
"hybrid models" H model

$$V_1 = H_{11}I_1 + H_{12}V_2$$

$$I_2 = H_{21}I_1 + H_{22}V_2,$$

current-current

第12项表示反馈网络的前通作用，
第11和22项表示输入和输出端反馈支路的电阻或电导，此3项理想值=0



(d)

"hybrid models" G model

$$I_1 = G_{11}V_1 + G_{12}I_2$$

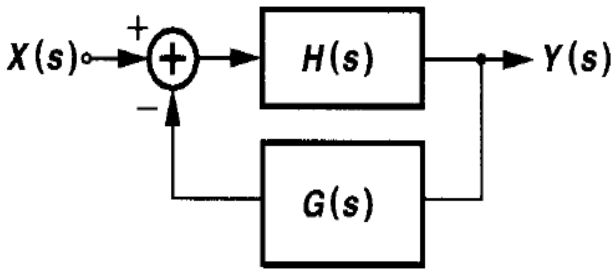
$$V_2 = G_{21}V_1 + G_{22}I_2.$$

voltage-voltage

the G model is the most suitable one for voltage-voltage feedback; $G_{11} = 0, G_{22} = 0,$

反馈网络应该用哪种双端口模型？总结

依据采样信号和对于前馈放大器的输入形式决定。

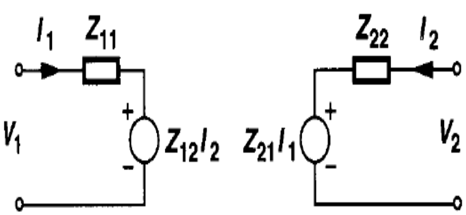


反馈网络模型判断:

- 反馈网络输入（端口下标1）接前馈放大器输出，检测电压（并联）或电流（串联）；
- 反馈网络输出（端口下标2）接前馈放大器输入，双端是电压或单端是电流；
- 简单方法：根据第21项（反馈信号）量纲确定。

current-voltage:

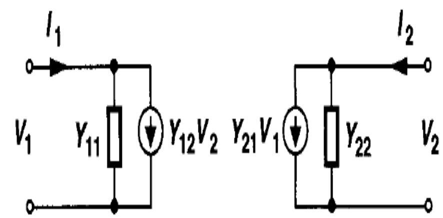
$$V_1 = Z_{11}I_1 + Z_{12}I_2$$
$$V_2 = Z_{21}I_1 + Z_{22}I_2.$$



(a)

voltage-current

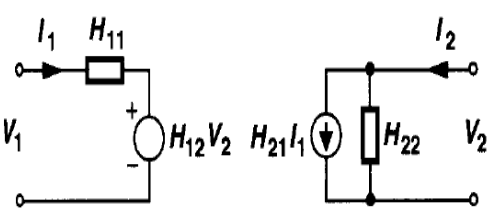
$$I_1 = Y_{11}V_1 + Y_{12}V_2$$
$$I_2 = Y_{21}V_1 + Y_{22}V_2,$$



(b)

current-current

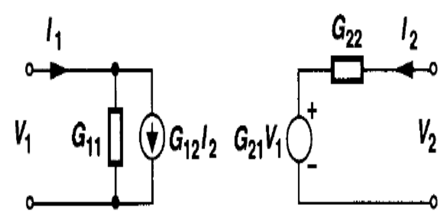
$$V_1 = H_{11}I_1 + H_{12}V_2$$
$$I_2 = H_{21}I_1 + H_{22}V_2,$$



(c)

voltage-voltage

$$I_1 = G_{11}V_1 + G_{12}I_2$$
$$V_2 = G_{21}V_1 + G_{22}I_2.$$



(d)

Loading in Voltage-Voltage Feedback

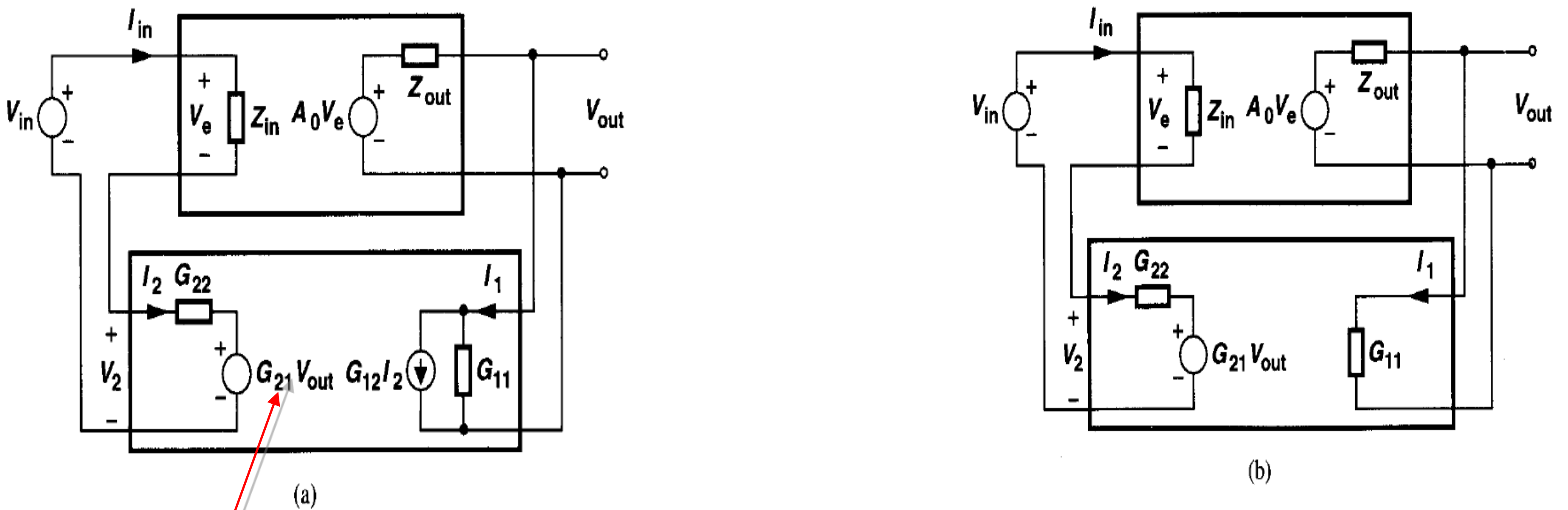


Figure 8.38 Voltage-voltage feedback circuit with (a) feedback network represented by a G model and (b) simplified G model.

compute the closed-loop gain of the circuit shown in Fig. 8.38(b).

$$I_1 = G_{11}V_1 + G_{12}I_2$$

$$V_2 = G_{21}V_1 + G_{22}I_2.$$

$$V_e = (V_{in} - G_{21}V_{out})\frac{Z_{in}}{Z_{in} + G_{22}}$$

令I2=0得反馈G21

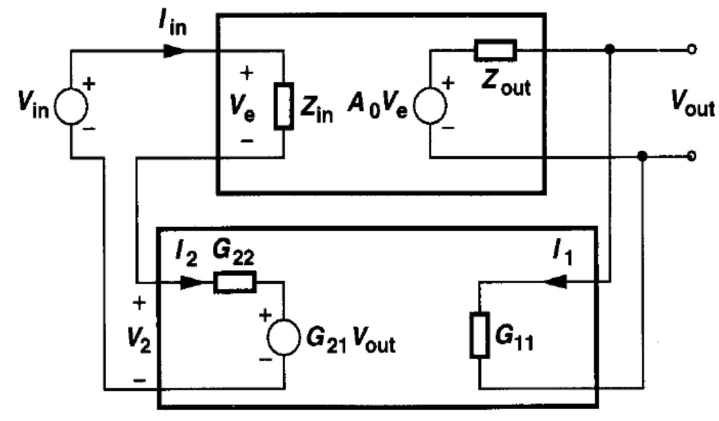
计入反馈支路负载作用的开环增益

and hence

$$(V_{in} - G_{21}V_{out})\frac{Z_{in}}{Z_{in}+G_{22}}A_0\frac{G_{11}^{-1}}{G_{11}^{-1}+Z_{out}} = V_{out}.$$

It follows that

$$\frac{V_{out}}{V_{in}} = \frac{A_0\dfrac{Z_{in}}{Z_{in}+G_{22}}\dfrac{G_{11}^{-1}}{G_{11}^{-1}+Z_{out}}}{1+\dfrac{Z_{in}}{Z_{in}+G_{22}}\dfrac{G_{11}^{-1}}{G_{11}^{-1}+Z_{out}}G_{21}A_0}. \qquad (8.55)$$



(b)

Note that if the feedback network is ideal, i.e., if $G_{11}^{-1} = \infty$ and $G_{22} = 0$, then $V_{out}/V_{in} = A_0/(1+G_{21}A_0)$, as expected.

Equation 8.55 assumes the standard form of a feedback transfer function if we define the open-loop gain in the presence of loading as

$$A_{v,open} = \frac{Z_{in}}{Z_{in}+G_{22}}\frac{G_{11}^{-1}}{G_{11}^{-1}+Z_{out}}A_0. \qquad (8.56)$$

G11、G22体现了反馈网络对基本放大器的负载作用.

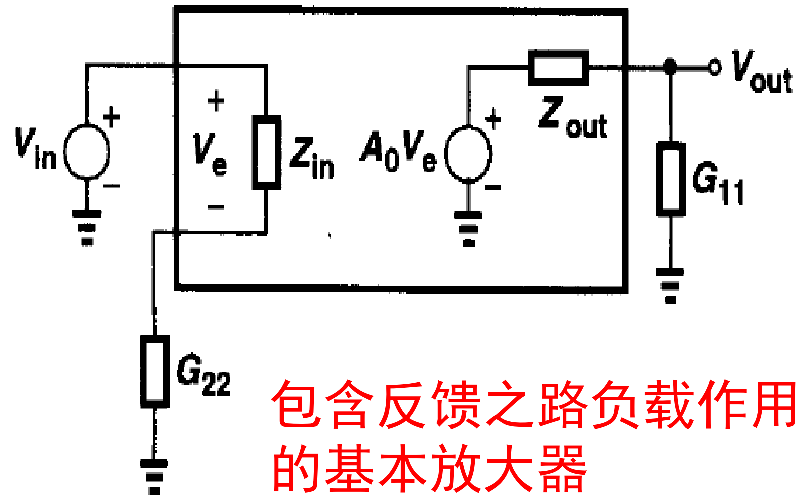
计入反馈支路负载作用的开环增益(续)

The loaded open-loop gain can be obtained from the circuit depicted in Fig. 8.39.

反馈网络:

$$I_1 = G_{11}V_1 + G_{12}I_2$$

$$V_2 = G_{21}V_1 + G_{22}I_2.$$



包含反馈之路负载作用的基本放大器

Figure 8.39 Proper method of including loading in a voltage-voltage feedback circuit.

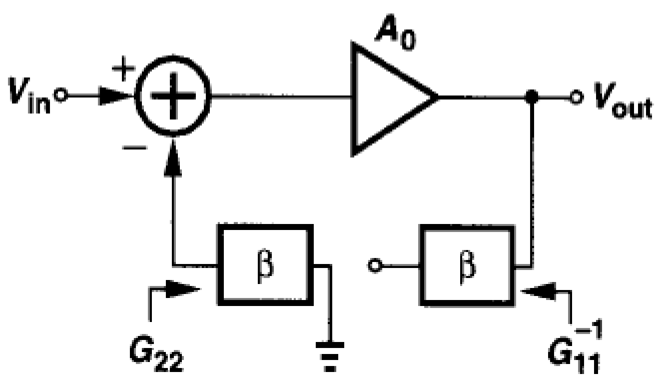


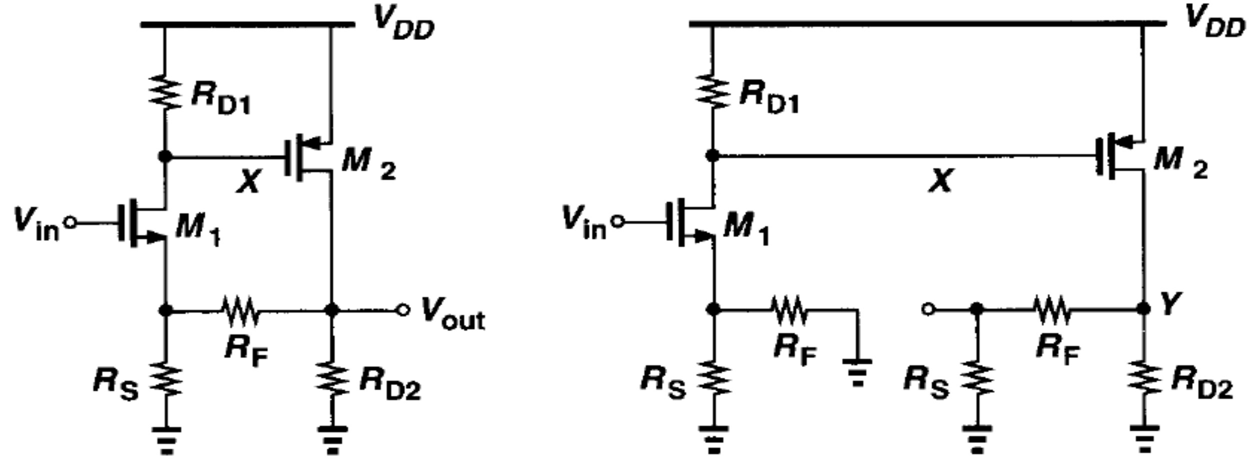
Figure 8.40 Conceptual view of opening a voltage-voltage feedback loop with proper loading.

$$G_{11} = \left.\frac{I_1}{V_1}\right|_{I2=0}$$

$$G_{22} = \left.\frac{V_2}{I_2}\right|_{V1=0}.$$

G11、G22体现了反馈网络对基本放大器的负载作用.

For the circuit shown in Fig. 8.41(a), calculate the open-loop and closed-loop gains.



(a) (b)

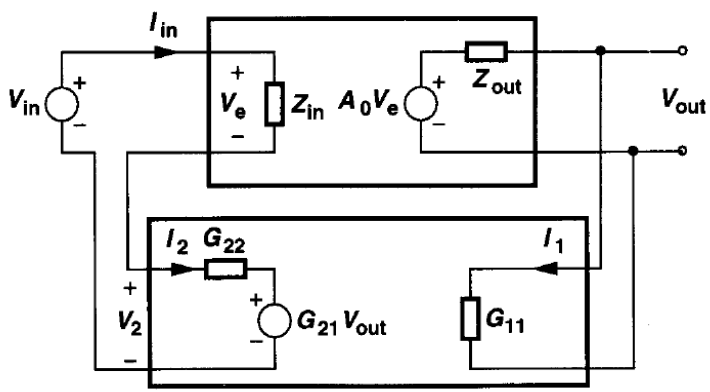
Figure 8.41

$$I_1 = G_{11}V_1 + G_{12}I_2$$

$$V_2 = G_{21}V_1 + G_{22}I_2.$$

$$G_{11} = \frac{I_1}{V_1}\bigg|_{I2=0}$$

$$G_{22} = \frac{V_2}{I_2}\bigg|_{V1=0}.$$



(b)

$$\beta = \frac{V_f}{V_o} = G_{21} = \frac{V_2}{V_1}\bigg|_{I2=0} = R_S/(R_F + R_S)$$

$$A_{v,open} = \frac{V_Y}{V_{in}}$$

$$= \frac{-R_{D1}}{R_F \| R_S + 1/g_{m1}}\{-g_{m2}[R_{D2}\|(R_F + R_S)]\}$$

The closed-loop gain is simply equal to $A_{v,closed} = A_{v,open}/(1 + G_{21}A_{v,open})$.

闭环输入和输出阻抗

（1）计算带反馈支路负载的开环放大器输入或输出阻抗；

（2）根据反馈组态，乘或除以

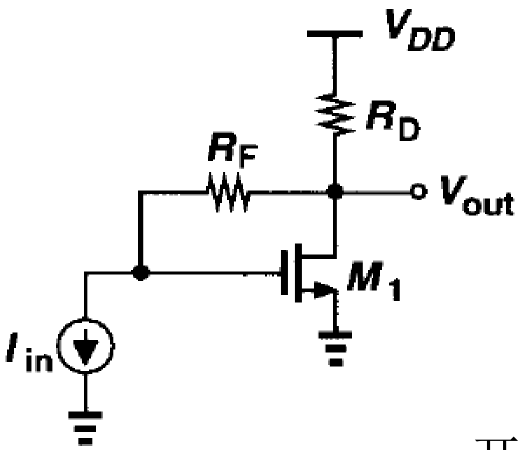
（1+带反馈支路负载的开环放大器增益*反馈因子），

增益为电压比/跨阻/跨导/电流比。

例：V-C负反馈

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2,$$



(a)

反馈因子$Y_{21}=1/R_F$

开环放大器输入阻抗$=Y_{22}^{-1}=R_F$

开环跨阻(输入电流变换成输出电压）$=-R_F*g_m$（$R_D||R_F$)

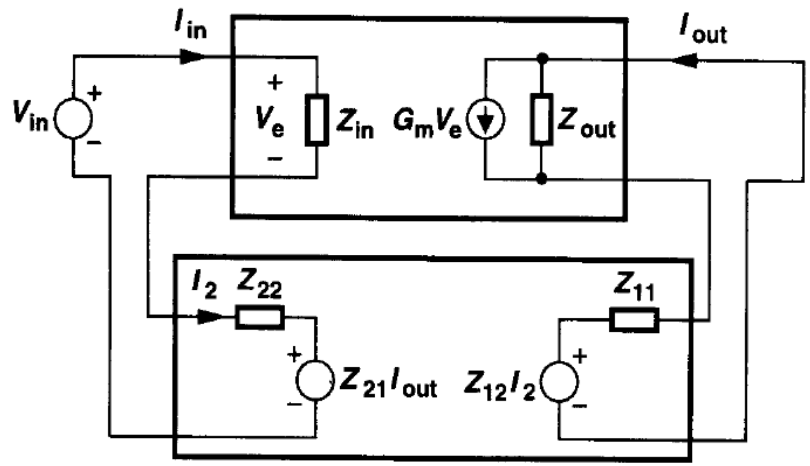
$$R_{in,closed} = \frac{R_F}{1+g_mR_D}$$

开环放大器输出阻抗$=Y_{11}||R_D=R_D$

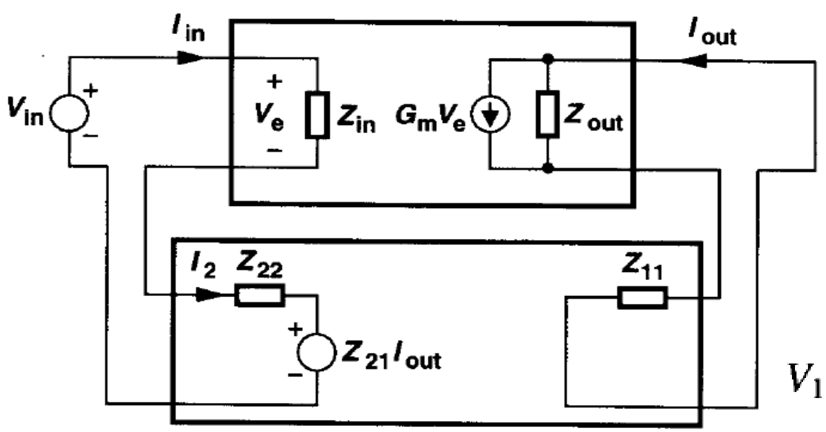
$$R_{out,closed} = \frac{R_D}{1+g_mR_D}$$

精确值表达式？

8.3.3 Load in current-voltage feedback



(a)



(b)

Figure 8.42 Current-voltage feedback circuit with (a) feedback network represented by a Z model and (b) simplified Z model.

neglect the source $Z_{12}I_2$,

$$(V_{in} - Z_{21}I_{out})\frac{Z_{in}}{Z_{in}+Z_{22}}G_m\frac{Z_{out}}{Z_{out}+Z_{11}} = I_{out}$$

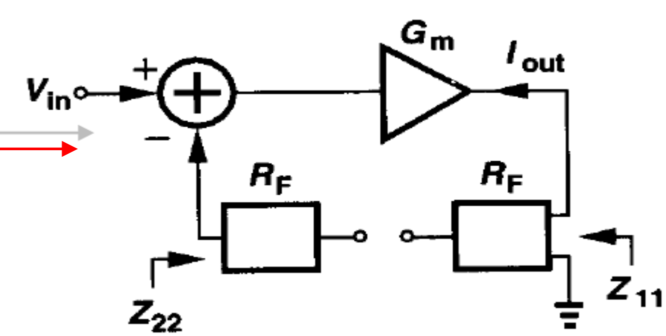
That is,

$$\frac{I_{out}}{V_{in}} = \frac{\frac{Z_{in}}{Z_{in}+Z_{22}}\frac{Z_{out}}{Z_{out}+Z_{11}}G_m}{1+\frac{Z_{in}}{Z_{in}+Z_{22}}\frac{Z_{out}}{Z_{out}+Z_{11}}G_mZ_{21}}$$

$$G_{m,open} = \frac{Z_{in}}{Z_{in}+Z_{22}}\frac{Z_{out}}{Z_{out}+Z_{11}}G_m$$

$$V_1 = Z_{11}I_1 + Z_{12}I_2$$

$$V_2 = Z_{21}I_1 + Z_{22}I_2.$$



Example 8.8

Calculate the open-loop and closed-loop gain of the circuit shown in Fig. 8.45(a).

Current-Voltage Feedback

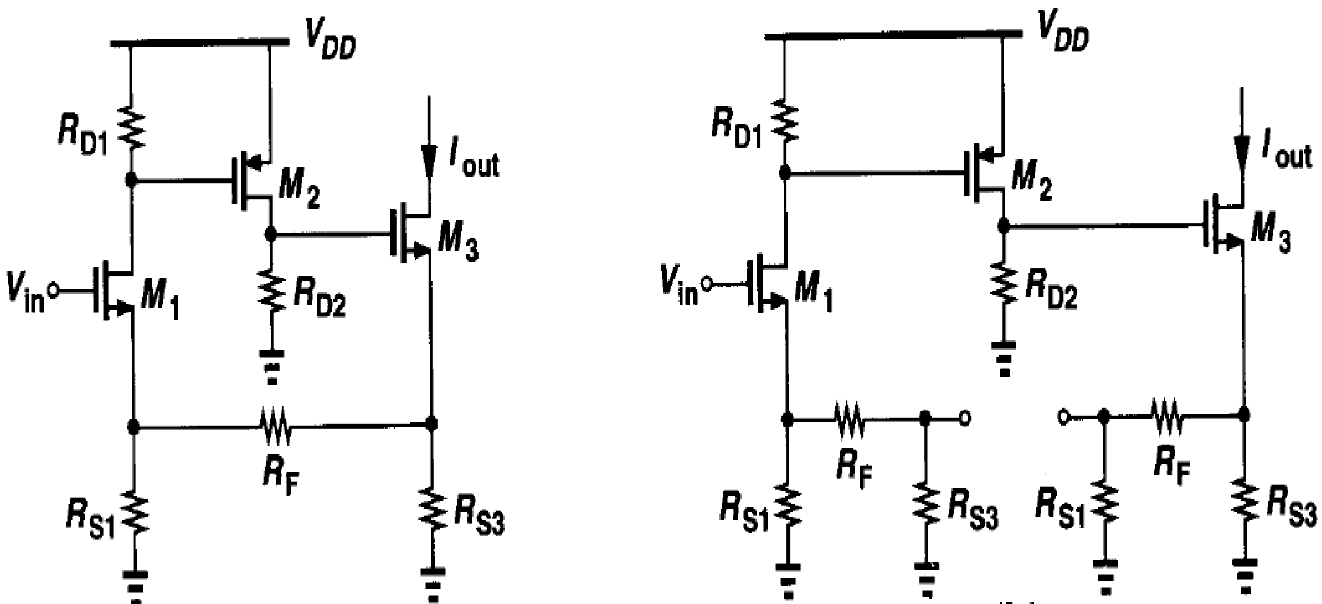
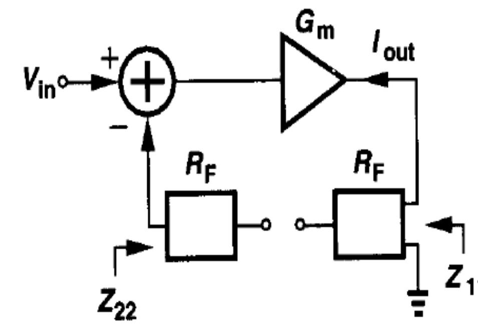


Figure 8.45



$$V_f = V_{RS1} = V_{M3S}\frac{R_{S1}}{R_{S1}+R_F}$$

If $\lambda = \gamma = 0$, the open-loop gain is equal to

由(3.56)：

$$G_{m,open} = \frac{-R_{D1}}{R_{S1}\|(R_F+R_{S3})+1/g_{m1}} \cdot \frac{-g_{m2}R_{D2}}{R_{S3}\|(R_F+R_{S1})+1/g_{m3}} \quad (8.63)$$

$$Z_{21} = \frac{R_{S3}}{R_{S3}+R_{S1}+R_F}R_{S1}$$

The closed-loop gain equals $G_{m,open}/(1+Z_{21}G_{m,open})$.

8.3.4 Loading in voltage-current feedback

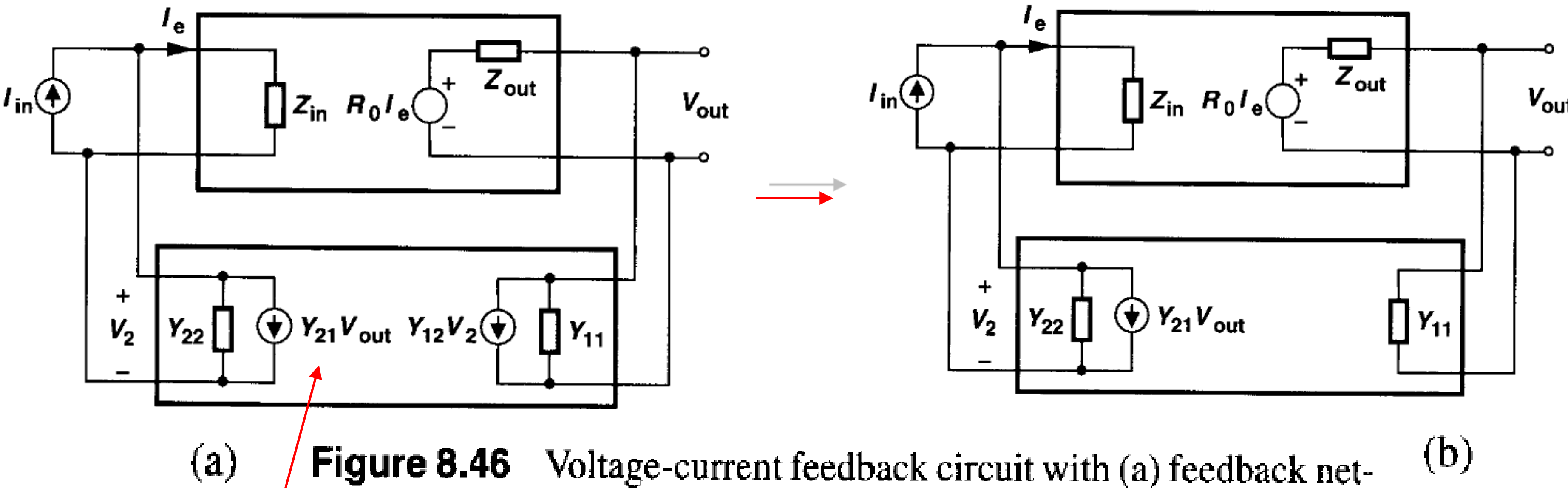


Figure 8.46 Voltage-current feedback circuit with (a) feedback network represented by a Y model and (b) simplified Y model.

$$(I_{in} - Y_{21}V_{out})\frac{Y_{22}^{-1}}{Y_{22}^{-1} + Z_{in}} R_0 \frac{Y_{11}^{-1}}{Y_{11}^{-1} + Z_{out}} = V_{out}$$

$$\frac{V_{out}}{I_{in}} = \frac{\frac{Y_{22}^{-1}}{Y_{22}^{-1} + Z_{in}} R_0 \frac{Y_{11}^{-1}}{Y_{11}^{-1} + Z_{out}}}{1 + \frac{Y_{22}^{-1}}{Y_{22}^{-1} + Z_{in}} R_0 \frac{Y_{11}^{-1}}{Y_{11}^{-1} + Z_{out}} Y_{21}}$$

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2,$$

$$R_{0,open} = \frac{Y_{22}^{-1}}{Y_{22}^{-1} + Z_{in}} \frac{Y_{11}^{-1}}{Y_{11}^{-1} + Z_{out}} R_0$$

The loop gain is given by $Y_{21}R_{0,open}$.

Obtain Y11 & Y22

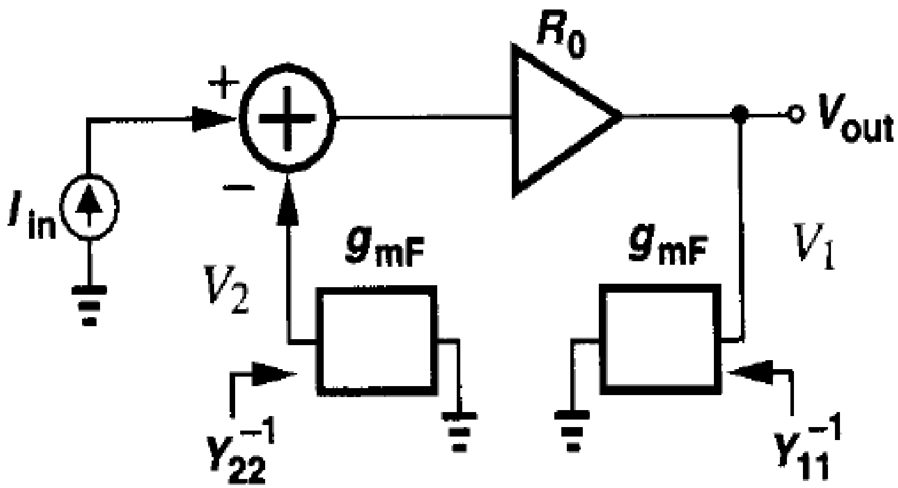
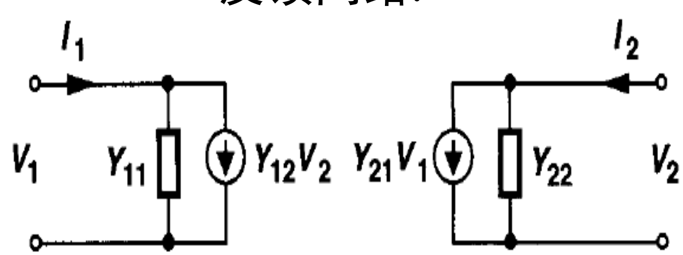


Figure 8.48 Conceptual view of opening the loop in voltage-current feedback.

反馈网络:



(b)

$$I_1 = Y_{11}V_1 + Y_{12}V_2$$

$$I_2 = Y_{21}V_1 + Y_{22}V_2,$$

$$Y_{21} = I_2/V_1 \text{ with } V_2 = 0,$$

Example 8.9

Calculate the voltage gain of the circuit shown in Fig. 8.49(a).

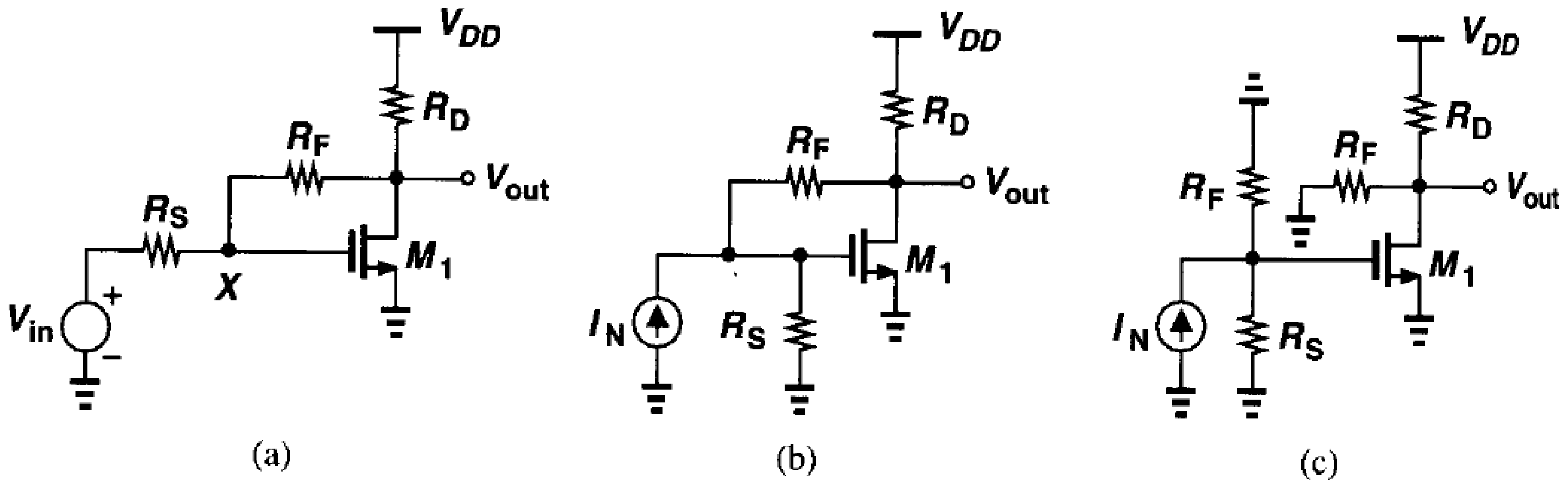


Figure 8.49

变为I_N要注意R_S的处理

Solution

$$R_{0,open} = \left.\frac{V_{out}}{I_N}\right|_{open} = -(R_S \| R_F) g_m (R_F \| R_D), \qquad \text{where } I_N = V_{in}/R_S.$$

$$Y_{21} = -1/R_F.$$

$$\frac{V_{out}}{V_{in}} = \frac{1}{R_S} \cdot \frac{-(R_S \| R_F) g_m (R_F \| R_D)}{1 + g_m (R_F \| R_D) R_S/(R_S + R_F)}.$$

输入、输出阻抗用米勒效应计算简单

8.3.5 Loading in current -current feedback

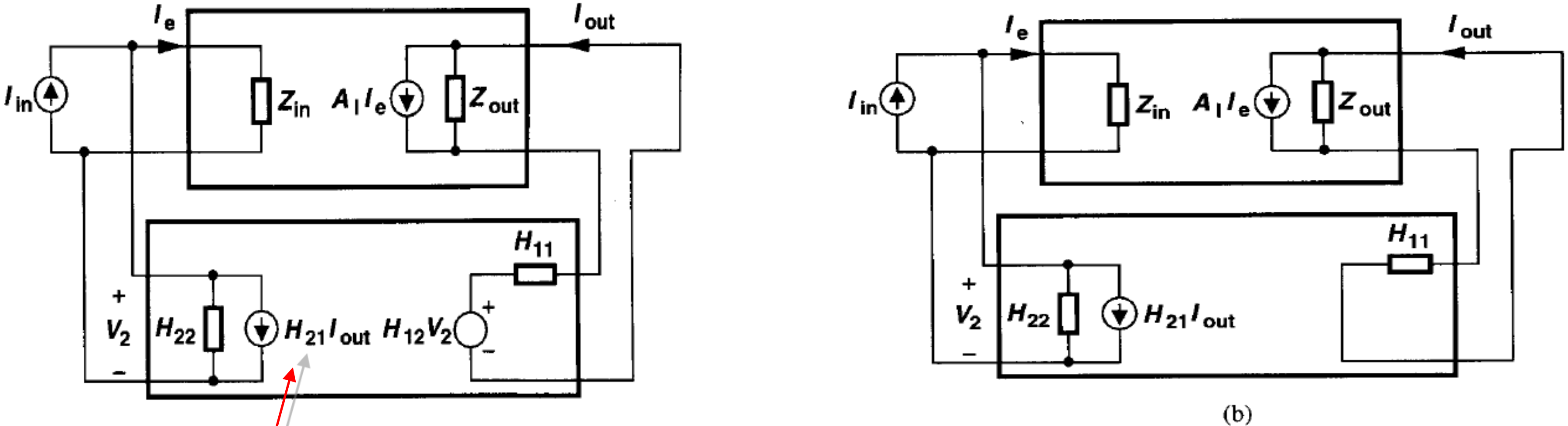


Figure 8.50 Current-current feedback circuit with (a) feedback network represented by an H model and (b) simplified H model.

$$(I_{in} - H_{21} I_{out}) \frac{H_{22}^{-1}}{H_{22}^{-1} + Z_{in}} A_I \frac{Z_{out}}{H_{11} + Z_{out}} = I_{out}$$

$$\frac{I_{out}}{I_{in}} = \frac{\dfrac{H_{22}^{-1}}{H_{22}^{-1} + Z_{in}} A_I \dfrac{Z_{out}}{H_{11} + Z_{out}}}{1 + \dfrac{H_{22}^{-1}}{H_{22}^{-1} + Z_{in}} A_I \dfrac{Z_{out}}{H_{11} + Z_{out}} H_{21}}.$$

$$V_1 = H_{11} I_1 + H_{12} V_2$$

$$I_2 = H_{21} I_1 + H_{22} V_2,$$

$$A_{I,open} = \frac{H_{22}^{-1}}{H_{22}^{-1} + Z_{in}} \frac{Z_{out}}{H_{11} + Z_{out}} A_I$$

Obtain H11 & H22

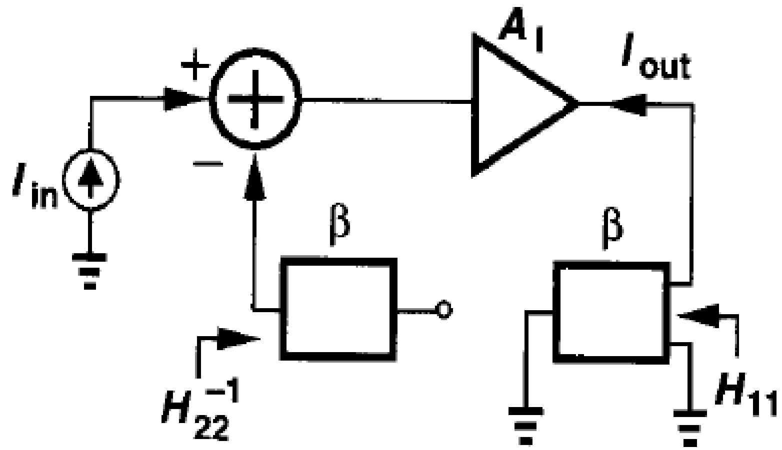
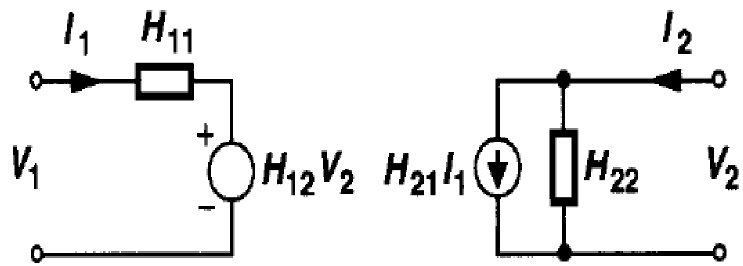


Figure 8.52 Conceptual view of including loading in current-current feedback.

反馈网络:



$$V_1 = H_{11}I_1 + H_{12}V_2$$

$$I_2 = H_{21}I_1 + H_{22}V_2,$$

Example 8.10

Calculate the open-loop and closed-loop gains of the circuit shown in Fig. 8.53(a).

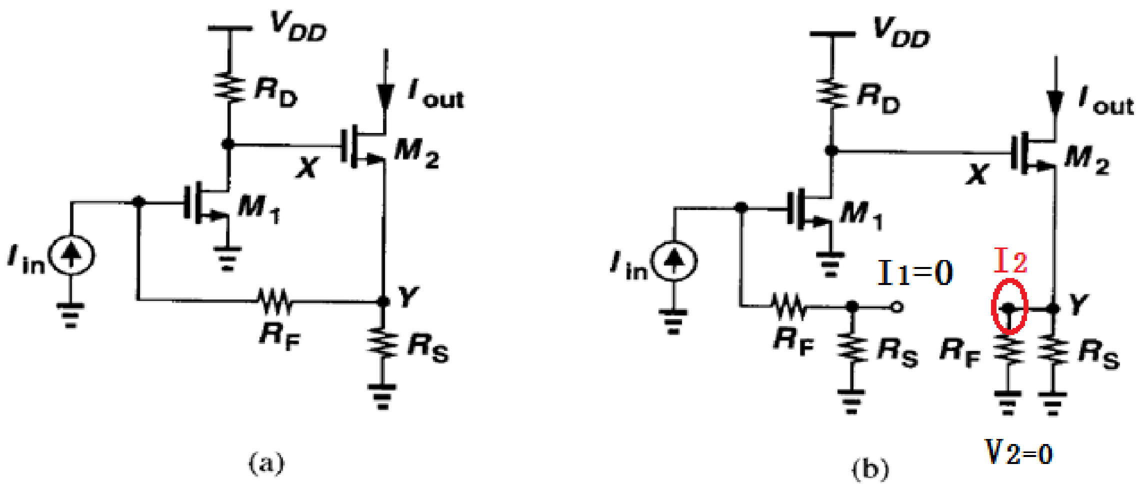


Figure 8.53

$$V_1 = H_{11} I_1 + H_{12} V_2$$

$$I_2 = H_{21} I_1 + H_{22} V_2,$$

$$H_{21} = I_2/I_1 \text{ with } V_2 = 0.$$

current-current feedback

Solution

$$A_{I,open} = -(R_F + R_S) g_{m1} R_D \frac{1}{R_S \| R_F + 1/g_{m2}} \quad (8.74)$$

$$H_{21} = -R_S/(R_S + R_F).$$

The closed-loop gain equals $A_{I,open}/(1 + H_{21} A_{I,open})$.

8.3.6 summary of loading effects

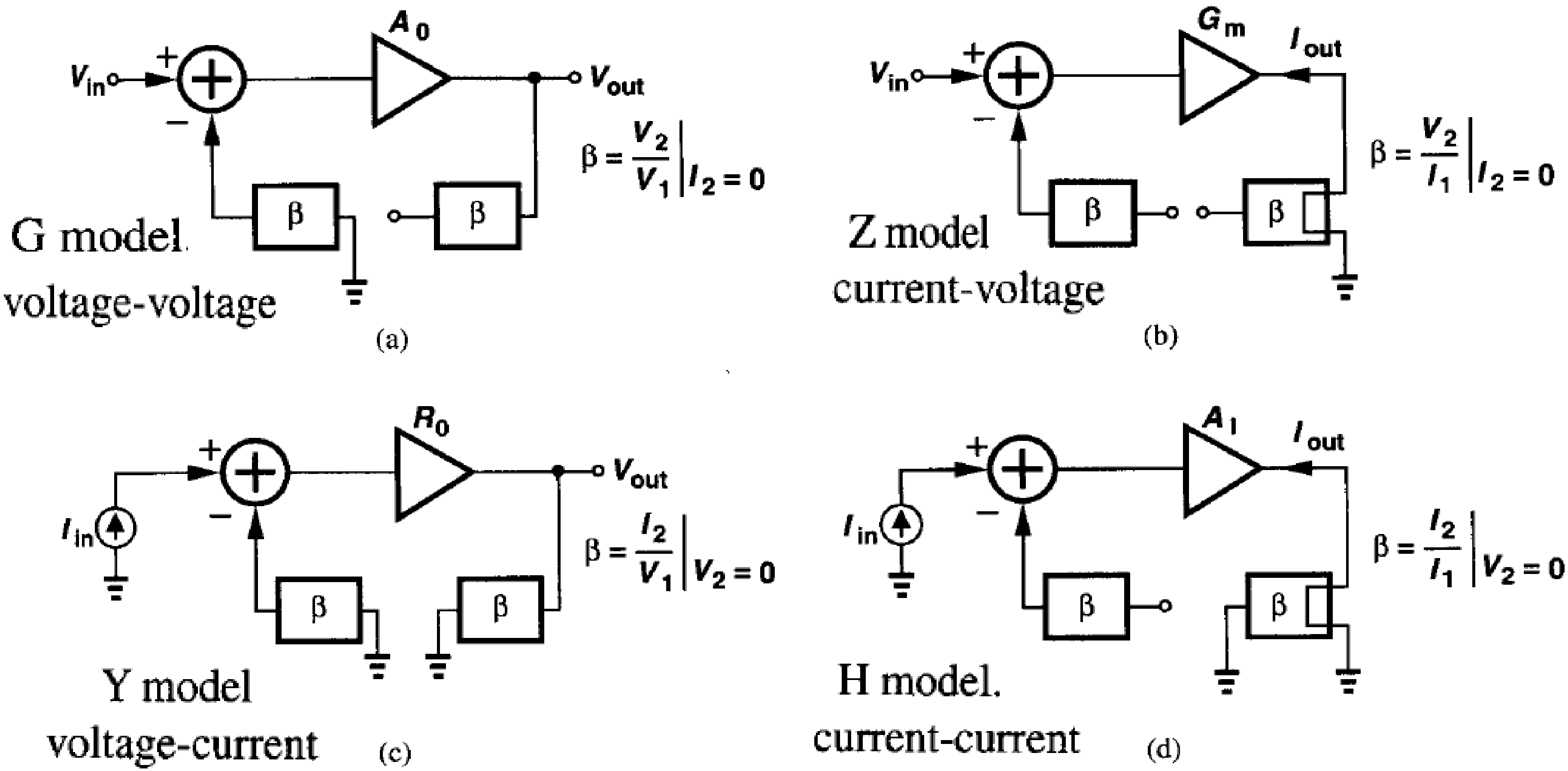


Figure 8.54 Summary of loading effects.

summary of loading effects (cont.)

The results of our study of loading are summarized in Fig. 8.54. The analysis is carried out in three steps: (1) open the loop with proper loading and calculate the open-loop gain, A_{OL}, and the open-loop input and output impedances; (2) determine the feedback ratio, β, and hence the loop gain, βA_{OL}; (3) calculate the closed-loop gain and input and output impedances by scaling the open-loop values by a factor of $1+\beta A_{OL}$. Note that in the equations defining β, the subscripts 1 and 2 refer to the input and output ports of the feedback network, respectively.

8.4 Effect of Feedback on Noise

Feedback does not improve the noise performance of circuits.

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