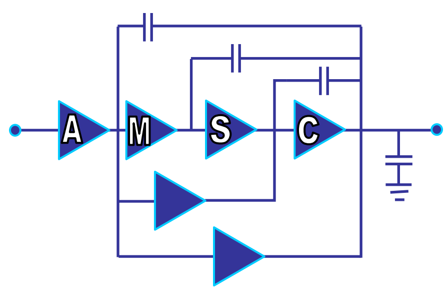
MACROMODELS OF AMPLIFIERS

- **Why do we need a macromodel?**
- **What properties of the real model can be included in the macromodel?**
- **What are the trade-offs of simplicity versus completeness?**

i.e., how many poles and zeros should be included in the linear model?



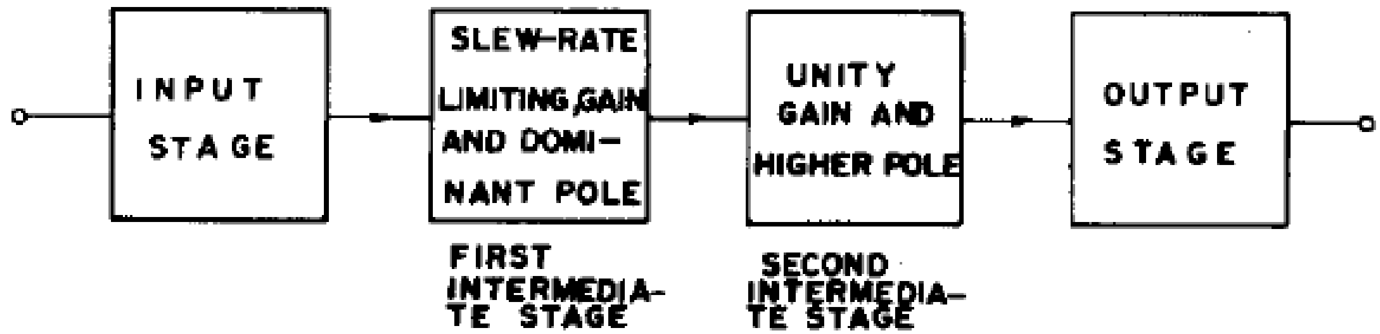


Fig. 1. Block diagram of the OA macromodel.

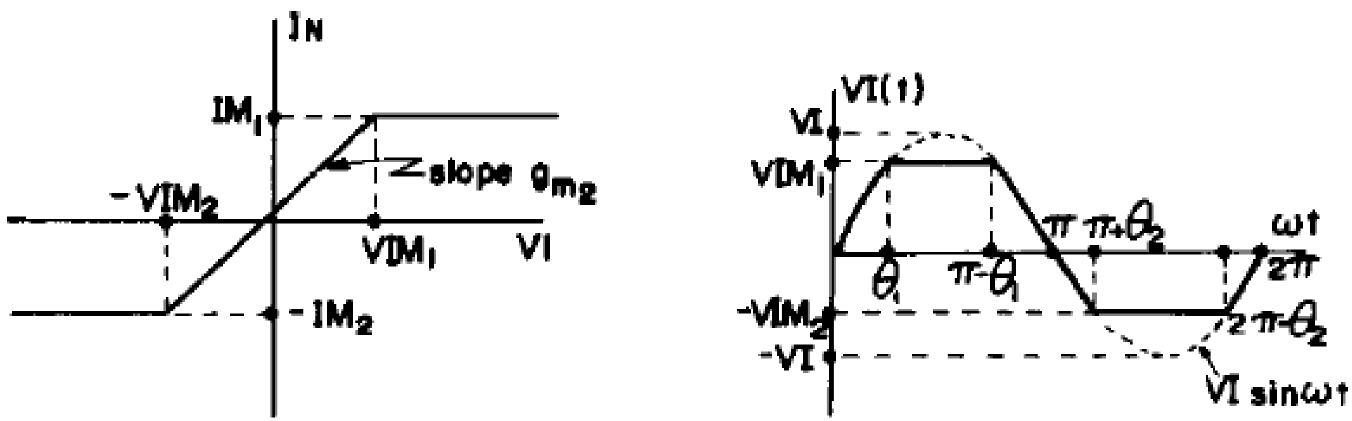


Fig. 2. Transfer characteristics including saturation characteristics of the VCCS, I_N of Fig. 3.

$$I_N(\omega t)=\begin{cases} IM, & \text{for } (\theta,\pi-\theta) \text{ and } (\pi+\theta,2\pi-\theta) \\ g_{m2}VI\sin(\omega t), & \text{otherwise.} \end{cases}$$

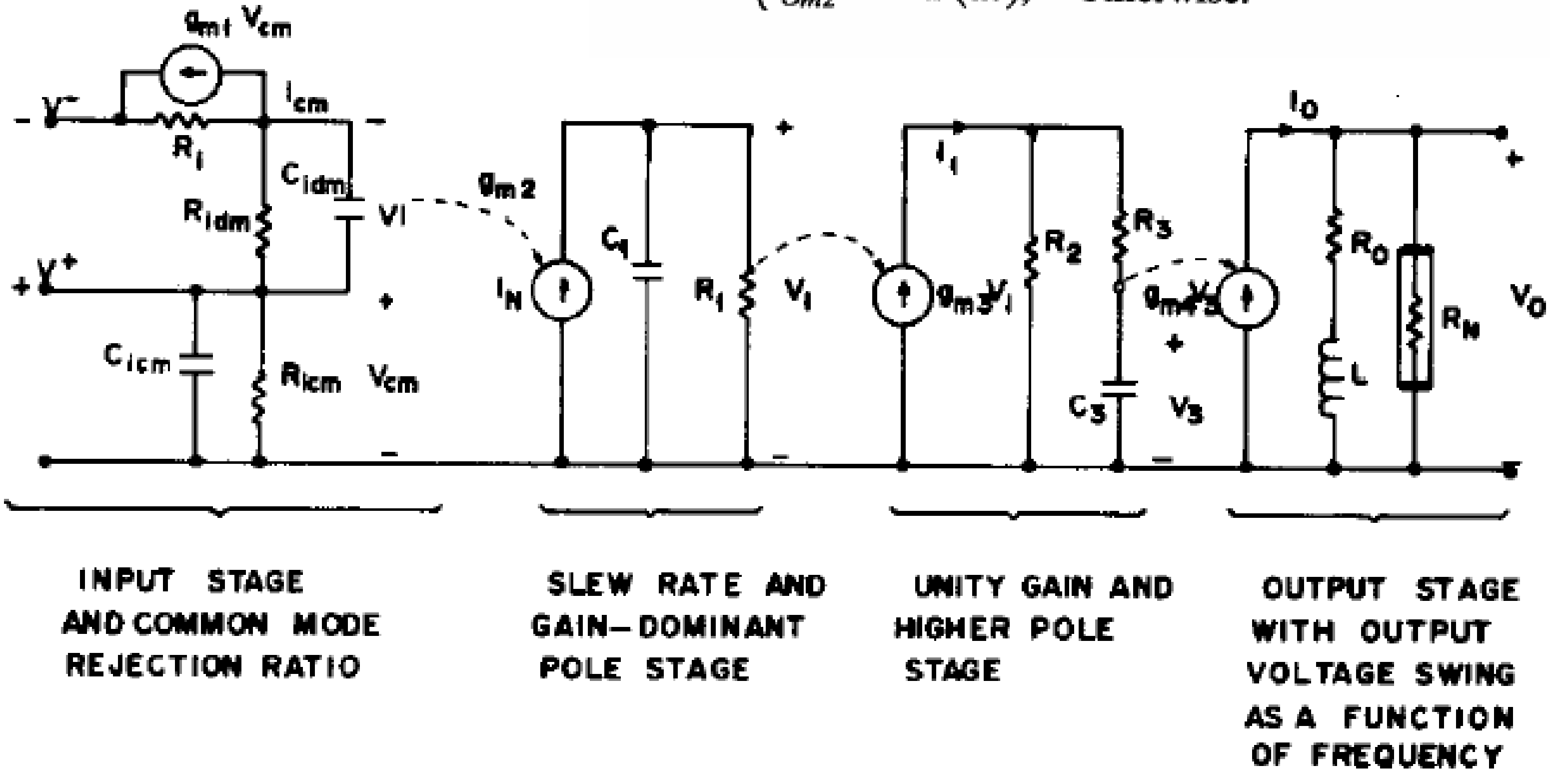


Fig. 3. Macromodel equivalent circuit.

First stage.-

$$I_{cm} = g_{m1} V_{cm} \qquad (1)$$

$$g_{m1} = \frac{1}{CMRR(\omega) \cdot R_i}. \qquad (2)$$

$$CMRR(\omega) = \frac{CMRR_o}{\left(1 + j\frac{f}{f_{CMRR}}\right)}. \qquad (3)$$

$$C_{icm} = \frac{1}{2\pi R_{icm} \cdot f_{CMRR}}. \qquad (4)$$

$$\frac{V_{cm}}{CMRR} = I_{cm} R_i \qquad (5)$$

$$R_i \ll R_{idm}.$$

$$VI = \frac{V^+ - V^- + g_{m1} V^+ R_i}{R_i + Z_{idm}} Z_{idm}. \qquad (6)$$

Second Stage.-

$$g_{m2} = \frac{I_N}{VI} \qquad (7)$$

$$I_N = \begin{cases} g_{m2} VI, & \text{for } |VI| \leqslant VIM \\ IM, & \text{for } |VI| > VIM. \end{cases} \qquad (8)$$

$$I_{o,\text{swing}} = IM = S_r C_1 \qquad (9)$$

$$C_1 = \frac{IM}{S_-}. \quad (9a)$$

$$R_1 = \frac{1}{\omega_1 C_1}. \quad (10)$$

$$g_{m2} = \frac{A_{dm}}{R_1}. \quad (11)$$

$$VIM = \frac{S_r}{A_{dm}\omega_1} = \frac{S_r C_1}{g_{m2}}. \quad (12)$$

$$I_{Ni} = \frac{1}{2\pi}\int_0^{2\pi} I_N(\omega t)\sin(n\omega t)\, d(\omega t), \qquad i, n = 0, 1, 2, \cdots. \quad (13)$$

$$I_{Ni} = g_{m2} VI \cdot N_i\left(\frac{VIM}{VI}\right), \qquad i = 1, 3, 5, \cdots. \quad (14)$$

$$VI^i = VI \cdot N_i\left(\frac{VIM}{VI}\right), \qquad i = 1, 3, 5, \cdots. \quad (15)$$

$$V_{\text{out}} = A_{dm1}(VI' \sin \omega t) + A_{dm3}(VI''' \sin 3\omega t) + A_{dm_5}(VI^v \sin 5\omega t) + \cdots. \quad (16)$$

$$g_{m_2}^{\text{non}} = g_{m2}\left[N_1\left(\frac{VIM}{VI}\right) + N_3\left(\frac{VIM}{VI}\right) + N_5\left(\frac{VIM}{VI}\right) + \cdots\right] \quad (17)$$

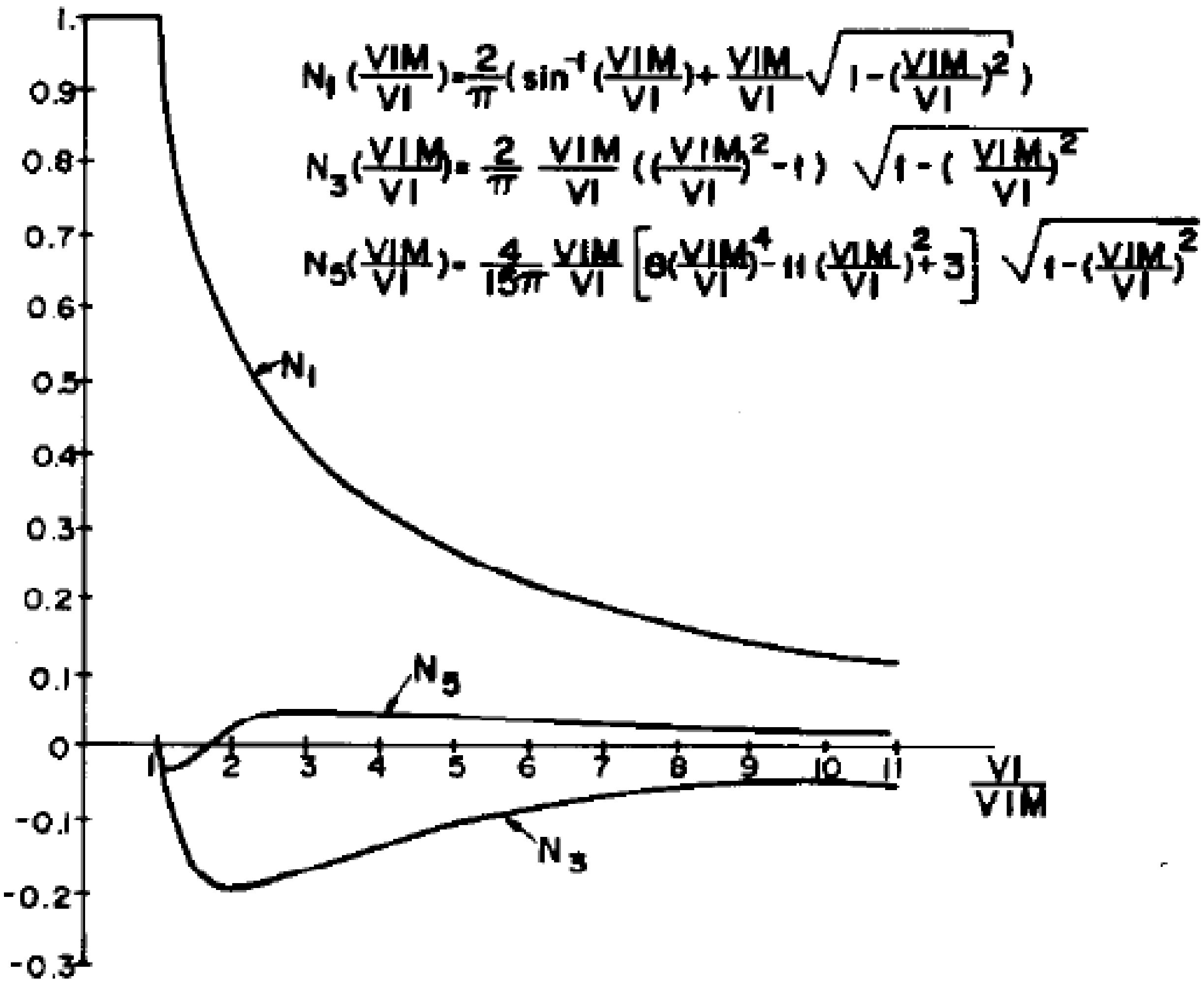
$$C_3 = \frac{1}{\omega_2 R_3} \quad (20)$$

$$g_{m_3} = \frac{1}{R_2}. \quad (21)$$

$$L = \frac{R_o}{\omega_o}. \quad (22)$$

$$g_{m_4} = \frac{1}{R_o + j\omega L}. \quad (23)$$

$$R_N = \begin{cases} \infty, & \text{if } |V_{\text{out}}| \leqslant \max|V_{o,\text{swing}}| \\ 0, & \text{if } |V_{\text{out}}| > \max|V_{o,\text{swing}}| \end{cases}$$



Nonlinear characteristics of N_1, N_3, N_5 versus $|VI/VIM|$ for the symmetric case.

$$VI^{i} = VI \cdot N_{i}\left(\frac{VIM}{VI}\right), \qquad i = 1, 3, 5, \cdots . \tag{15}$$

Therefore, the output voltage of this second stage becomes

$$V_{\text{out}} = A_{dm1}(VI' \sin \omega t) + A_{dm3}(VI''' \sin 3\omega t) + A_{dm_5}(VI^{v} \sin 5\omega t) + \cdots . \tag{16}$$

$$VI^i = VI \cdot N_i\left(\frac{VIM}{VI}\right), \qquad i=1,3,5,\cdots. \tag{15}$$

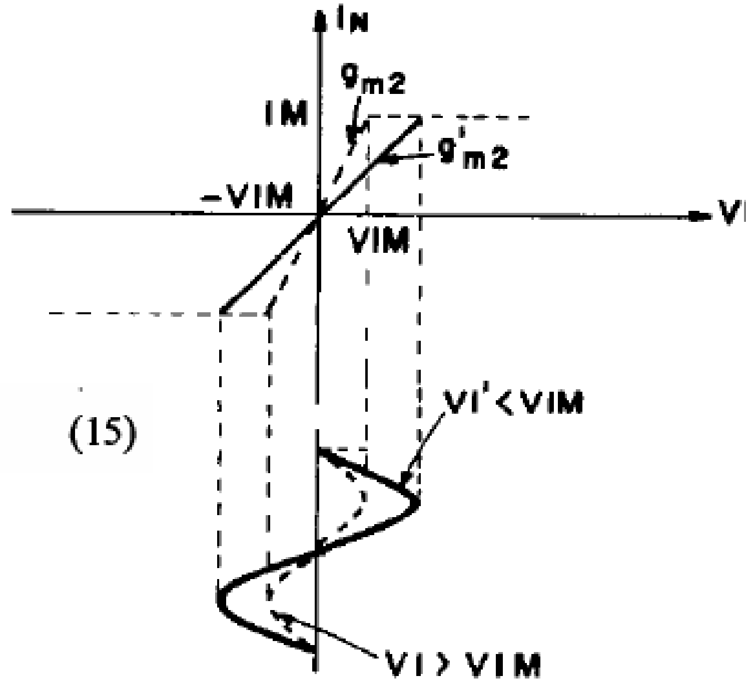


Fig. 5. Saturation characteristics of I_N when an OA is overdriven by a large input signal.

$$g_{m_2}^{\text{non}} = g_{m2}\left[N_1\left(\frac{VIM}{VI}\right) + N_3\left(\frac{VIM}{VI}\right) + N_5\left(\frac{VIM}{VI}\right) + \cdots\right] \tag{17}$$

and so

$$I_N = g_{m_2}^{\text{non}} \cdot VI. \tag{18}$$

Stage 3

$$C_3 = \frac{1}{\omega_2 R_3} \tag{20}$$

$$g_{m_3} = \frac{1}{R_2}\,. \tag{21}$$

$$L = \frac{R_o}{\omega_o}\,. \tag{22}$$

$$g_{m_4} = \frac{1}{R_o + j\omega L}\,. \tag{23}$$

$$R_N = \begin{cases} \infty, & \text{if } |V_{\text{out}}| \leqslant \max|V_{o,\,\text{swing}}| \\ 0, & \text{if } |V_{\text{out}}| > \max|V_{o,\,\text{swing}}| \end{cases}$$

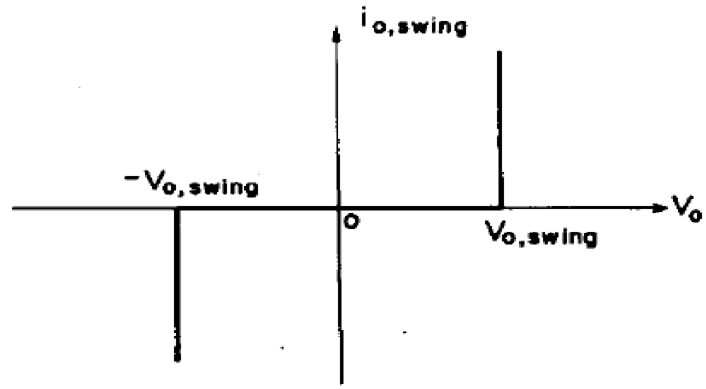


Fig. 6. V–I characteristic of the output nonlinear resistor R_N.

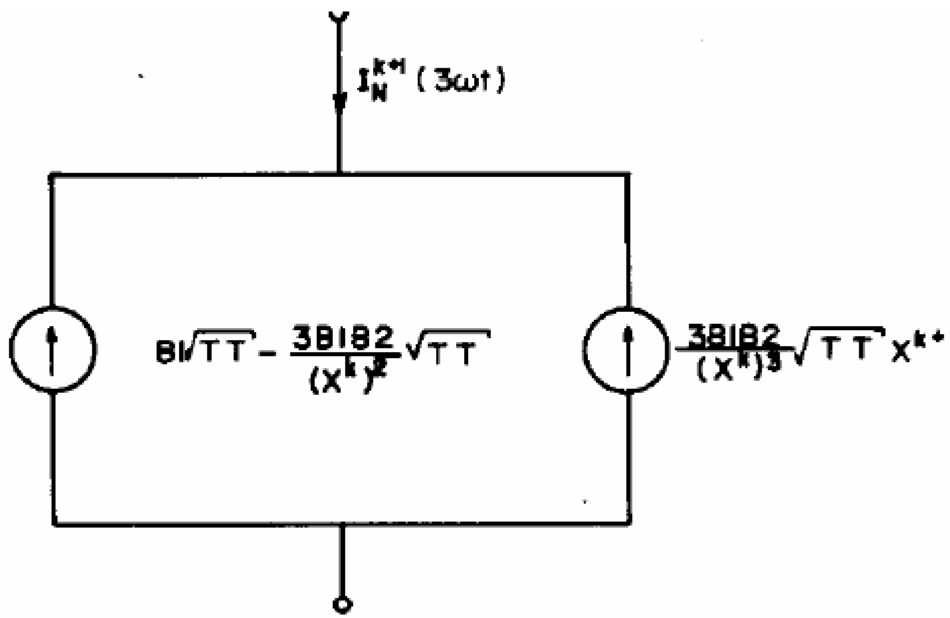


Fig. 7. Companion model of the third-harmonic component of $I_N(3\omega t)$. k is the iteration counter.

TABLE II
MODEL COMPONENTS AND AMPLIFIER PARAMETERS

Amplifier Parameters		
$A_{dm} = 2\times10^{5}$	$R_{idm} = 2\times10^{6}\Omega$	$\omega_o = 2\pi\times150\times10^{3}\ \frac{rad}{s}$
$\omega_1 = 2\pi\times5\ \frac{rad}{s}$	$R_{icm} = 2\times10^{9}\Omega$	$R_o = 75\Omega$
$\omega_2 = 2\pi\times2\times10^{6}\ \frac{rad}{s}$	$C_{idm} = 1.4pF$	$S_r = 0.5V/\mu s$
$f_{CMRR} = 300$ Hz	$CMMRR_o = 31622.77$	$TM = 133.3\times10^{-3}$ A
		$V_{omax} = \pm\ 10V$
Model Components		
$R_i = 10\Omega$	$g_{m2} = 1.67551$ mhos	$L = 79.5\ \mu H$
$C_{icm} = 0.265pF$	$R_2 = 10\Omega$	$VIM = 79.5mV$
$R_1 = .11936M\Omega$	$R_3 = 1K\Omega$	$g_{m1} = 3.162\times10^{-6}$ mhos
$C_1 = 0.266\mu F$	$C_3 = 79.6pF$	$g_{m3} = 0.1$ mhos
	g_{m4} given by Eqn. (23)	

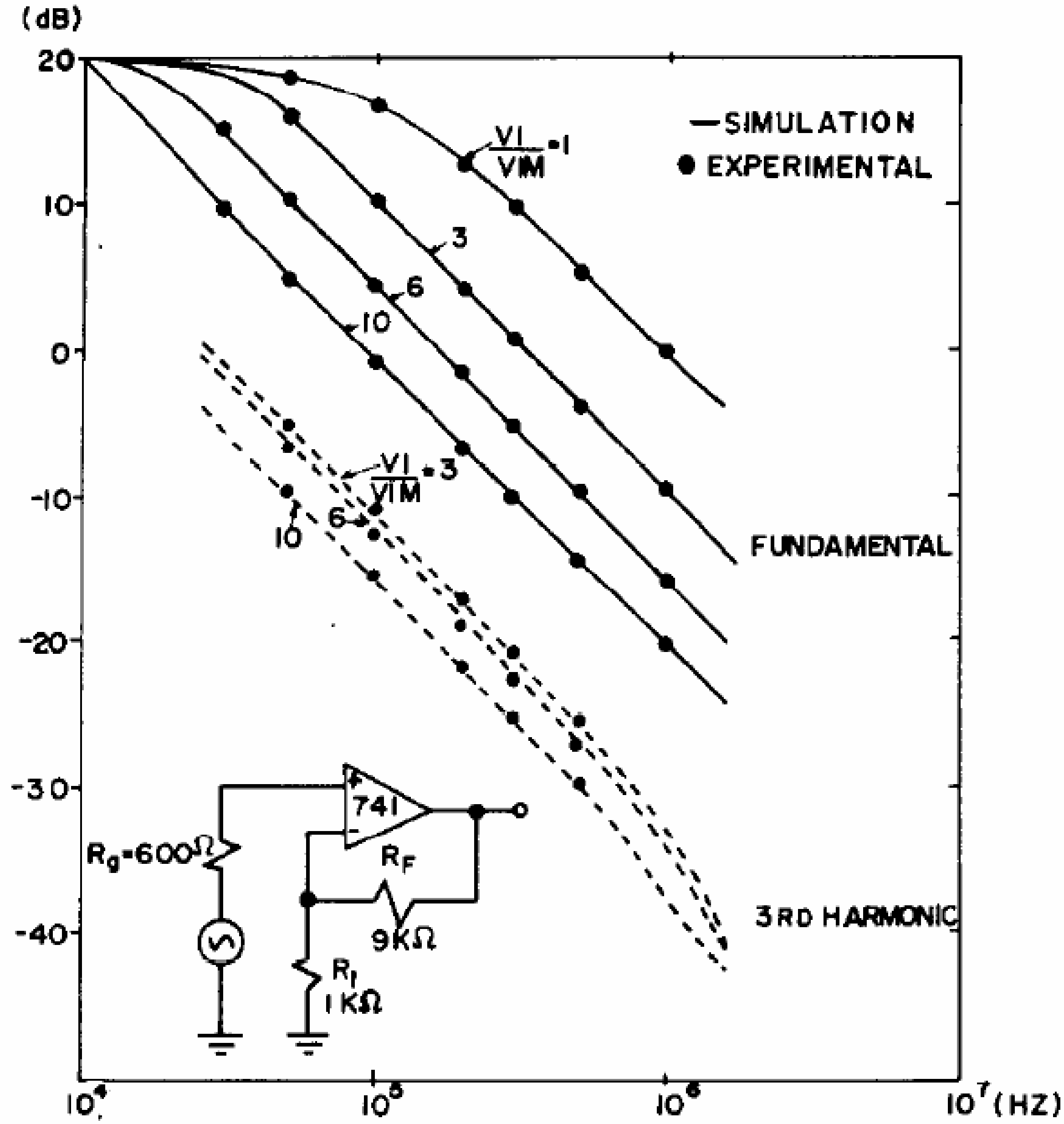


Fig. 8. Noninverting configuration. Simulation and experimental results.

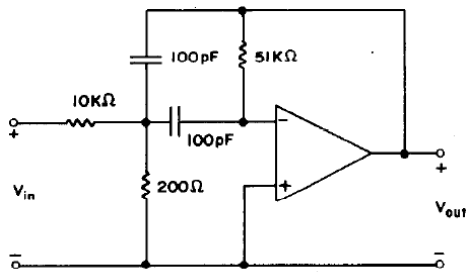


Fig. 9. *RC*-active bandpass filter.

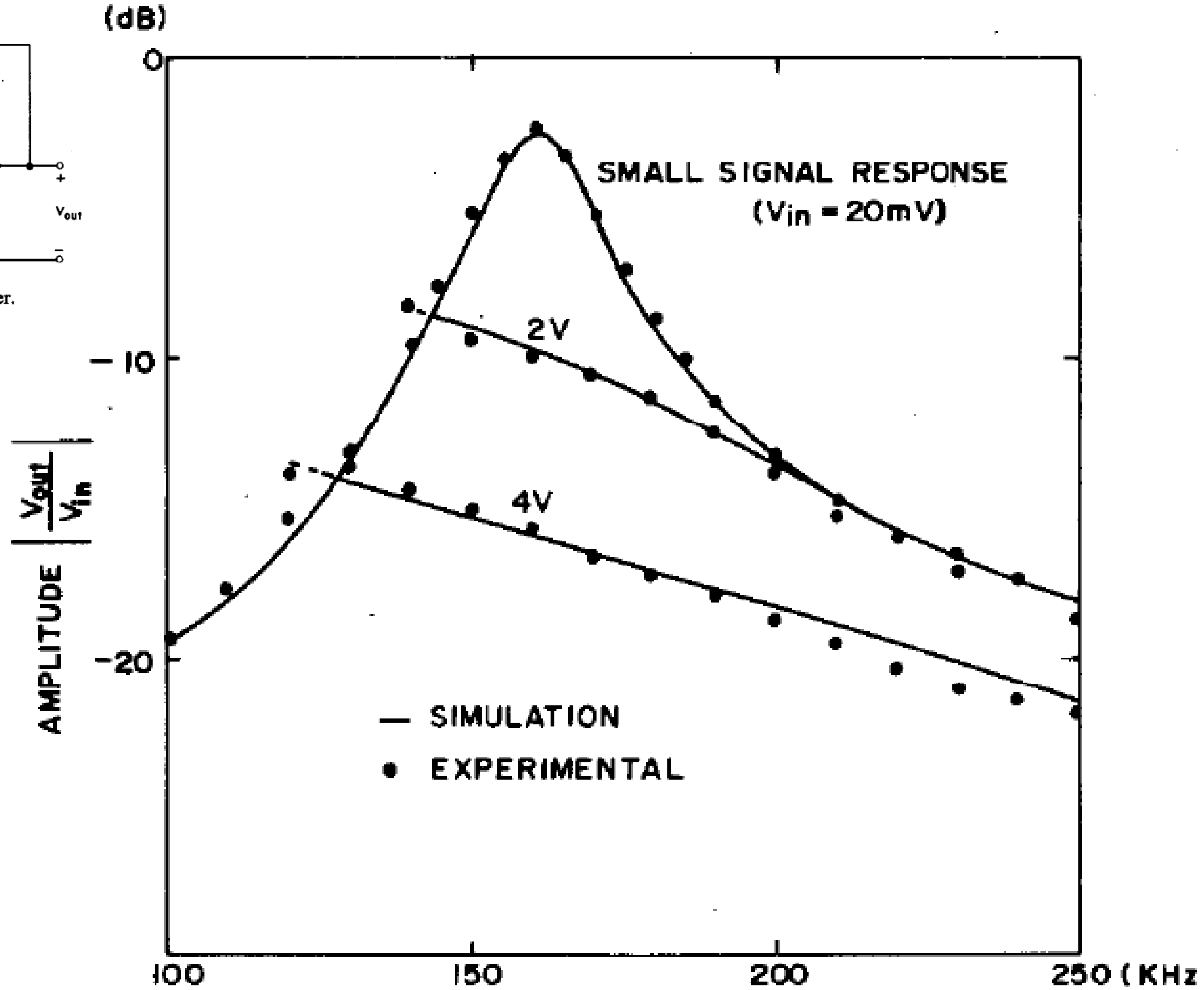


Fig. 10. Simulation and experimental results of the filter of Fig. 9.

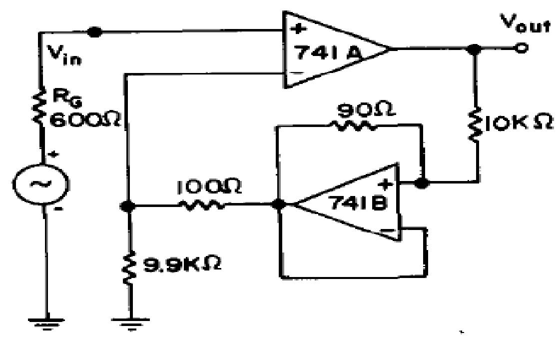


Fig. 12. A bandpass *R*-active filter.

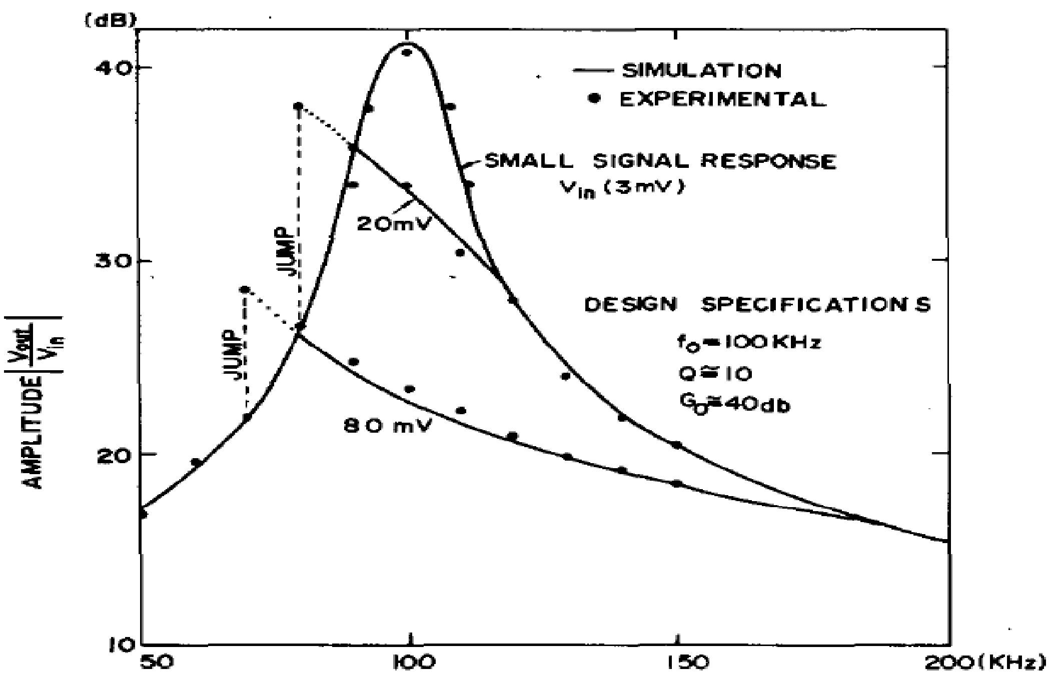


Fig. 13. Simulation and experimental results for different input signal amplitudes with the circuit of Fig. 12.