New current–mode special function continuous-time active filters employing only OTAs and OPAMPs

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Active-Only Filters

- Active filters utilizing an operational amplifier (OPAMP) pole and the transconductance control property of the operational transconductance amplifier (OTA) have received considerable attention recently.

These filters do not need to employ additional passive elements, and are therefore sometimes called active-only filters.

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- The major advantage of these circuits is the elimination of passive elements that may result in a reduction of chip area for integrated circuit implementations.
- A growing number of publications exists in the literature on OPAMP and OTA-only filters

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- This study offers new topologies in current-mode active-only multifunction filter implementation.
- Three new current mode active-only filters are proposed.
- By cascading the proposed filters, which implement LPN and HPN functions, higher order band-pass and band-stop filter functions can be obtained.

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- OTA is assumed as an ideal voltage-controlled current source.
- The gm (transconductance gain), which is used to relate output current to input voltage, is
- a function of the bias current, IA.
- For the case of OTAs using MOS transistors in the saturation region, the gms are proportional to $\sqrt{I_A}$

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- The OPAMP, can be modelled by a single pole model, which can be written as B/s for the operating range of frequencies,
- This model of the OPAMP is valid between the first and second poles in the frequency domain.
- valid from a few kilohertz to a few megahertz.

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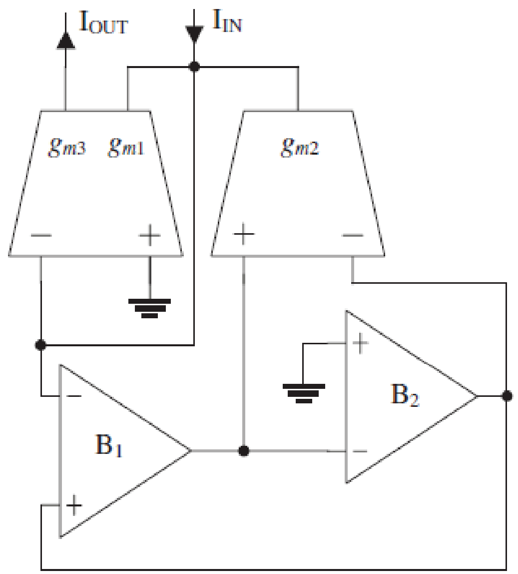

Figure 1. Circuit 1, high-pass notch.

Figure 1 (high-pass notch function, circuit 1):

$$T_{HPN}(s) = \frac{I_{out}}{I_{in}} = \frac{A_{HPN}(s^2 + \omega_o^2)}{s^2 + (\omega_p/Q)s + \omega_p^2} = -\frac{g_{m3}(s^2 + B_1 B_2)}{g_{m1}s^2 + g_{m2}B_1 s + B_1 B_2(g_{m1} + g_{m2})} \quad (1a)$$

The angular resonant frequency, quality factor and pass-band gain, denoted by A_{HPN}, are given by

$$\omega_p = \sqrt{\frac{(g_{m1} + g_{m2})B_1 B_2}{g_{m1}}} \qquad \omega_0 = \sqrt{B_1 B_2} \quad (1b)$$

$$Q = \frac{1}{g_{m2}}\sqrt{\frac{g_{m1}(g_{m1} + g_{m2})B_2}{B_1}} \qquad A_{HPN} = -\frac{g_{m3}}{g_{m1}} \quad (1c)$$

The active sensitivities of the circuit are expressed as

$$S_{B_1}^{\omega_p} = S_{B_2}^{\omega_p} = S_{B_1}^{\omega_0} = S_{B_2}^{\omega_0} = -S_{B_1}^{Q} = S_{B_2}^{Q} = \frac{1}{2} \quad (1d)$$

$$S_{g_{m1}}^{\omega_p} = -S_{g_{m2}}^{\omega_p} = \frac{-g_{m2}}{2(g_{m1} + g_{m2})} \quad (1e)$$

$$S_{g_{m1}}^{Q} = -S_{g_{m2}}^{Q} = \frac{2g_{m1} + g_{m2}}{2(g_{m1} + g_{m2})} \quad (1f)$$

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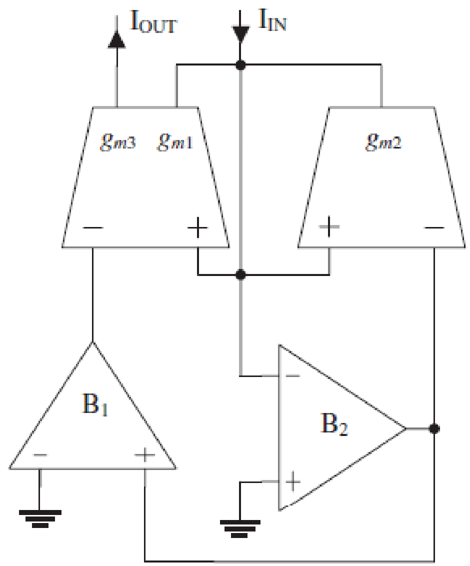

Figure 2. Circuit 2, low-pass notch.

Figure 2 (low-pass notch function, circuit 2):

$$T_{LPN}(s) = \frac{I_{out}}{I_{in}} = \frac{A_{LPN}(s^2+\omega_o^2)}{s^2+(\omega_p/Q)s+\omega_p^2} = -\frac{g_{m3}(s^2+B_1B_2)}{(g_{m1}+g_{m2})s^2+g_{m2}B_2s+B_1B_2g_{m1}} \quad (2a)$$

The angular resonant frequency, quality factor and pass-band gain, denoted by A_{LPN}, are given by

$$\omega_p = \sqrt{\frac{g_{m1}B_1B_2}{(g_{m1}+g_{m2})}} \qquad \omega_0 = \sqrt{B_1B_2} \quad (2b)$$

$$Q = \frac{1}{g_{m2}}\sqrt{\frac{g_{m1}(g_{m1}+g_{m2})B_1}{B_2}} \qquad A_{LPN} = -\frac{g_{m3}}{g_{m1}+g_{m2}} \quad (2c)$$

The active sensitivities of the circuit are expressed as

$$S_{B_1}^{\omega_p} = S_{B_2}^{\omega_p} = S_{B_1}^{\omega_0} = S_{B_2}^{\omega_0} = S_{B_1}^{Q} = -S_{B_2}^{Q} = \frac{1}{2} \quad (2d)$$

$$S_{g_{m1}}^{\omega_p} = -S_{g_{m2}}^{\omega_p} = \frac{g_{m2}}{2(g_{m1}+g_{m2})} \quad (2e)$$

$$S_{g_{m1}}^{Q} = -S_{g_{m2}}^{Q} = \frac{2g_{m1}+g_{m2}}{2(g_{m1}+g_{m2})} \quad (2f)$$

$$S_{g_{m3}}^{A_{LPN}} = 1 \qquad S_{g_{m1}}^{A_{LPN}} = -\frac{g_{m1}}{g_{m1}+g_{m2}} \qquad S_{g_{m2}}^{A_{LPN}} = -\frac{g_{m2}}{g_{m1}+g_{m2}} \quad (2g)$$

Thus, all sensitivities are no more than unity or can be made smaller than unity.

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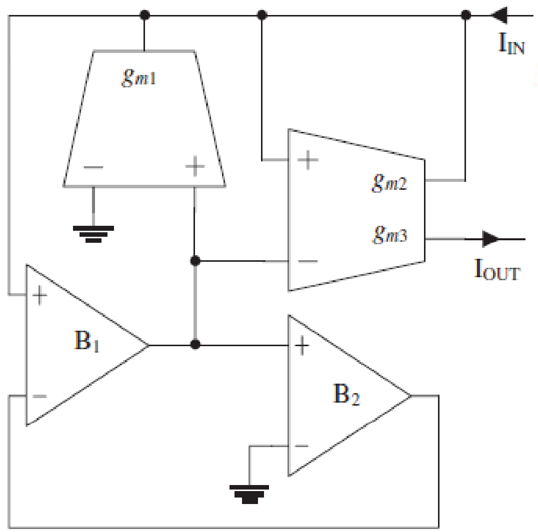

Figure 3. Circuit 3, AP function.

Figure 3 (all-pass function, circuit 3):

$$T_{AP}(s) = \frac{I_{out}}{I_{in}} = \frac{A_{AP}(s^2 - (\omega_p/Q)s + \omega_p^2)}{s^2 + (\omega_p/Q)s + \omega_p^2}$$
$$= -\frac{g_{m3}(s^2 - B_1 s + B_1 B_2)}{g_{m2}s^2 + (g_{m1}B_1 - g_{m2}B_1)s + B_1 B_2 g_{m2}} \quad (3a)$$

The delay is given by

$$\tau_{AP}(\omega) = \frac{2(\omega_p^2 + \omega^2)}{Q\omega_p((\omega_p^2 - \omega^2)^2/\omega_p^2 + \omega^2/Q^2)}$$
$$= \frac{2B_1 g_{m2}(g_{m1} - g_{m2})(\omega^2 + B_1 B_2)}{(g_{m2}^2\omega^2(\omega^2 - 2B_1 B_2) + B_1^2(B_2^2 g_{m2}^2 + (g_{m1} - g_{m2})^2\omega^2))} \quad (3b)$$

The angular resonant frequency, quality factor and pass-band gain, denoted by A_{AP}, are given by

$$\omega_p = \sqrt{B_1 B_2} \quad (3c)$$

$$Q = \frac{g_{m2}}{(g_{m1} - g_{m2})}\sqrt{\frac{B_2}{B_1}} \qquad A_{AP} = -\frac{g_{m3}}{g_{m2}} \quad (3d)$$

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The active sensitivities of the circuit are expressed as

$$S_{B_1}^{\omega_p} = S_{B_2}^{\omega_p} = S_{B_2}^{Q} = -S_{B_1}^{Q} = \frac{1}{2} \tag{3e}$$

$$-S_{g_{m1}}^{Q} = S_{g_{m2}}^{Q} = \frac{g_{m1}}{(g_{m1} - g_{m2})} \tag{3f}$$

$$S_{g_{m3}}^{A_{\mathrm{AP}}} = -S_{g_{m2}}^{A_{\mathrm{AP}}} = 1 \tag{3g}$$

Thus, all sensitivities except the sensitivities of Q on g_{m1} and g_{m2} are no more than unity. However, this drawback can be tolerated for particular phase responses and g_m values. g_{m3} should be chosen equal to $(g_{m1} - g_{m2})$ for proper operation.

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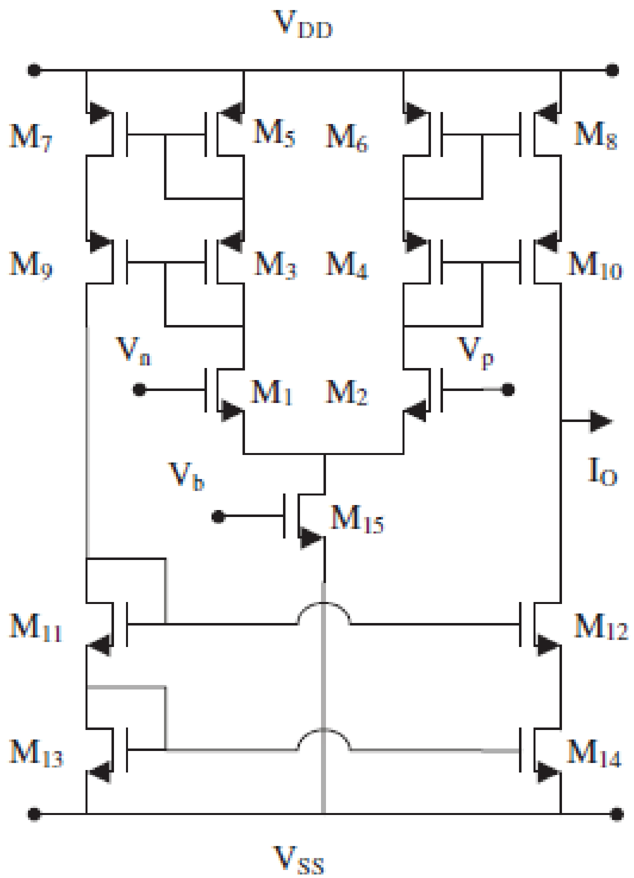

Figure 4. CMOS OTA circuit.

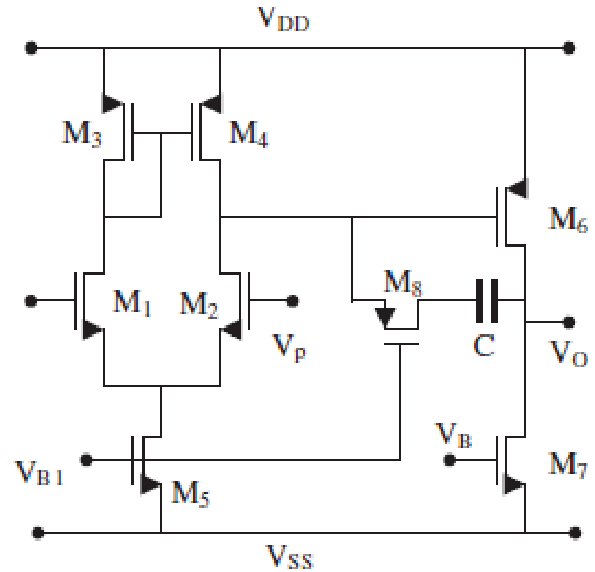

Figure 5. CMOS OPAMP circuit.

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- **Simulation results, discussion and design example**
- The filters are designed to realize a filter response with a reasonant frequency f0 of 417 kHz.
- The compensation capacitors of the OPAMPs are taken as 50 pF.
- A GBW of 417 kHz is obtained for both OPAMPs with these capacitances.

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Transistor	L (μm)	W (μm)	Transistor	L (μm)	W (μm)
M1	3	60	M8	3	12
M2	3	60	M9	3	12
M3	3	12	M10	3	12
M4	3	12	M11	3	5
M5	3	12	M12	3	5
M6	3	12	M13	3	5
M7	3	12	M14	3	5
			M15	3	25

Table 1. Dimensions of transistors used in CMOS OTA.

Transistor	L (μm)	W (μm)	Transistor	L (μm)	W (μm)
M1	10	180	M5	32	12
M2	10	180	M6	10	392
M3	10	280	M7	10	232
M4	10	280	M8	10	39

Table 2. Dimensions of transistors used in CMOS OPAMP.

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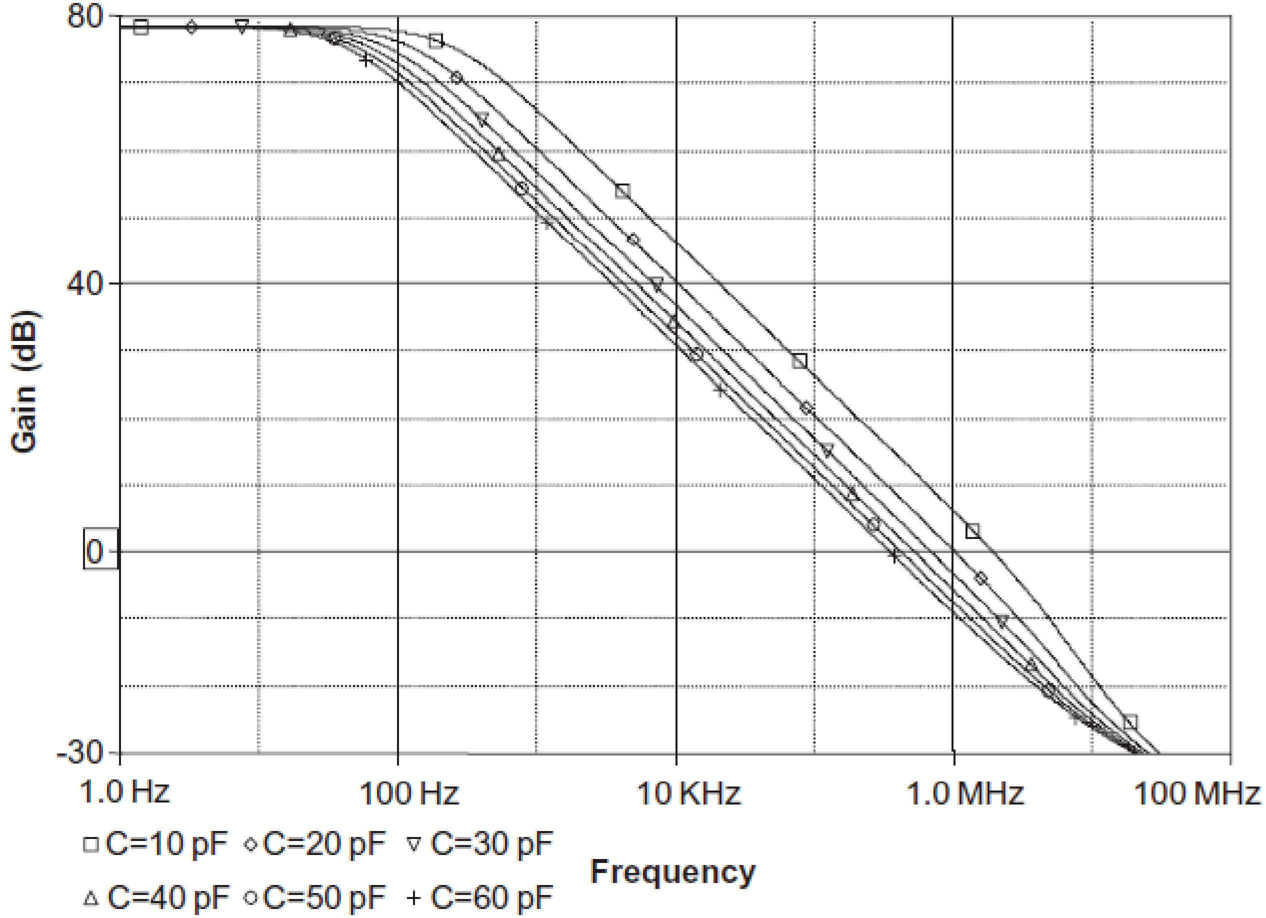

Figure 6. Gain–bandwidth product dependence of CMOS OPAMP on the compensation capacitor.

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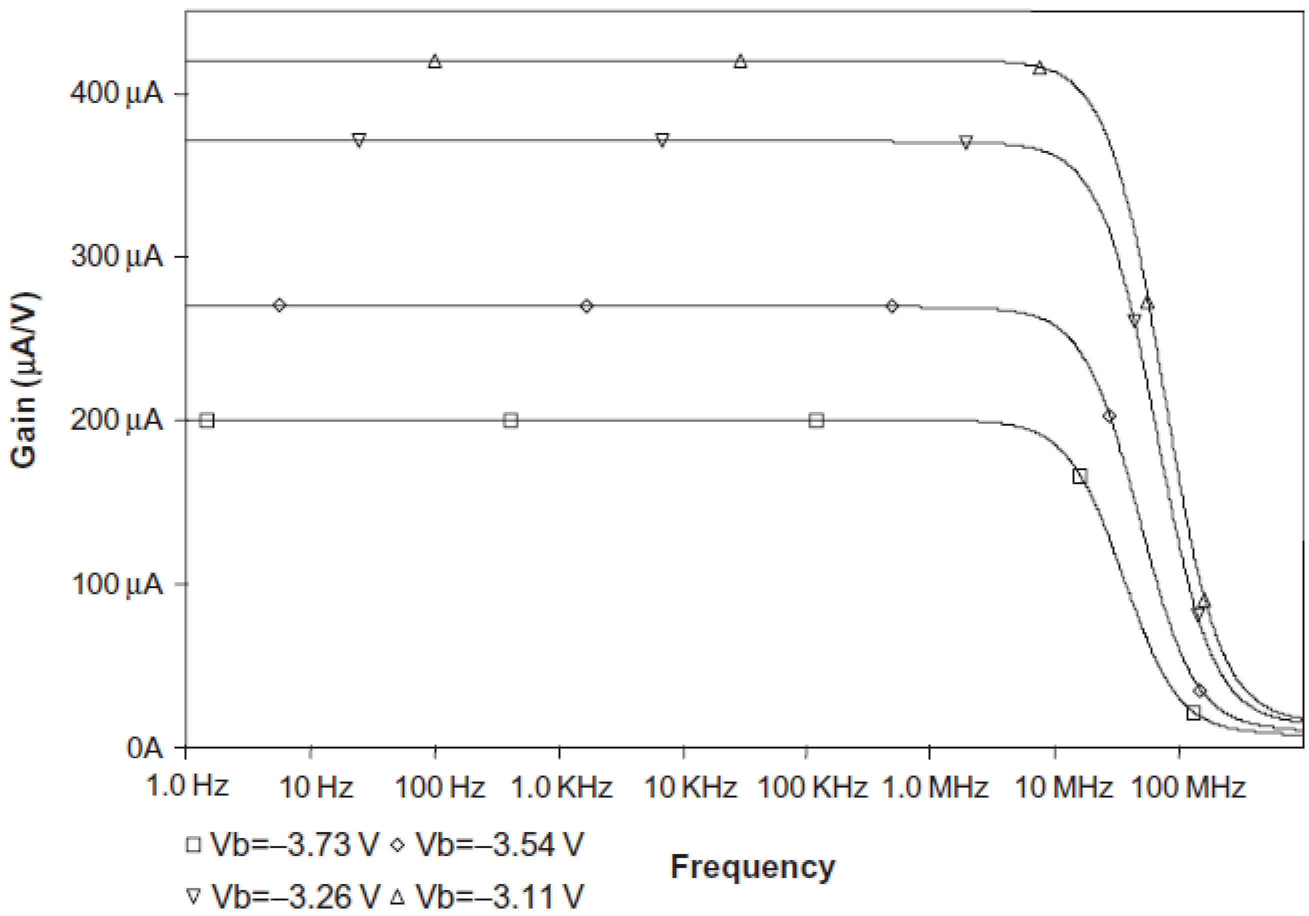

Figure 7. Frequency response dependence of CMOS OTA on bias voltage.

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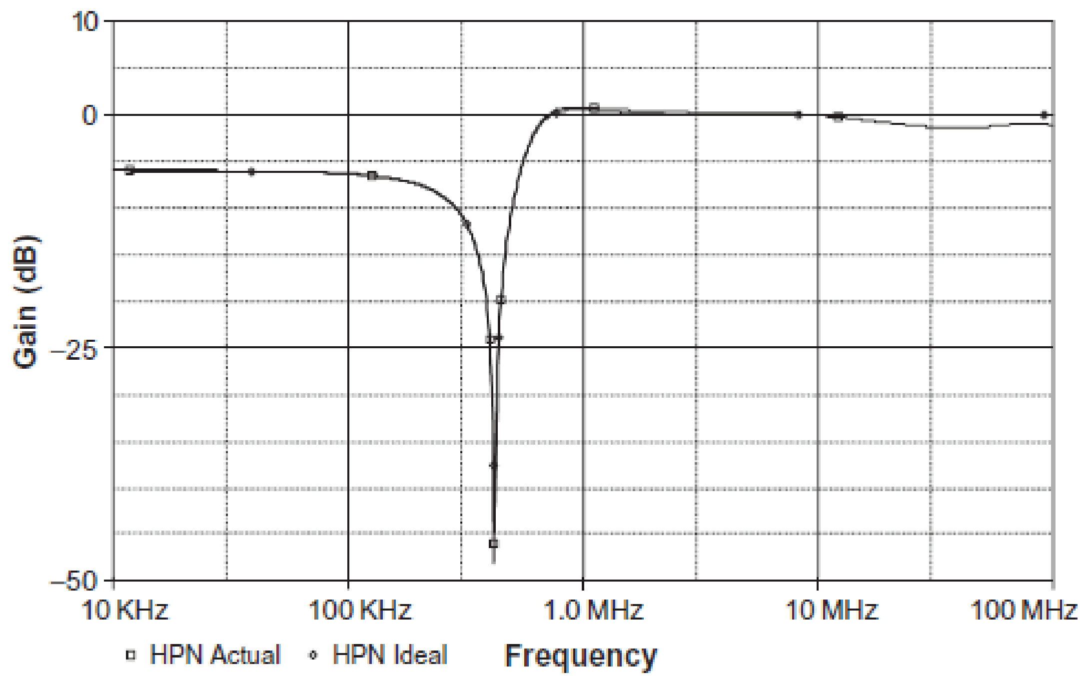

Figure 8(*a*). Frequency response of proposed HPN circuit, simulated with CMOS macro models of OPAMPs and OTAs.

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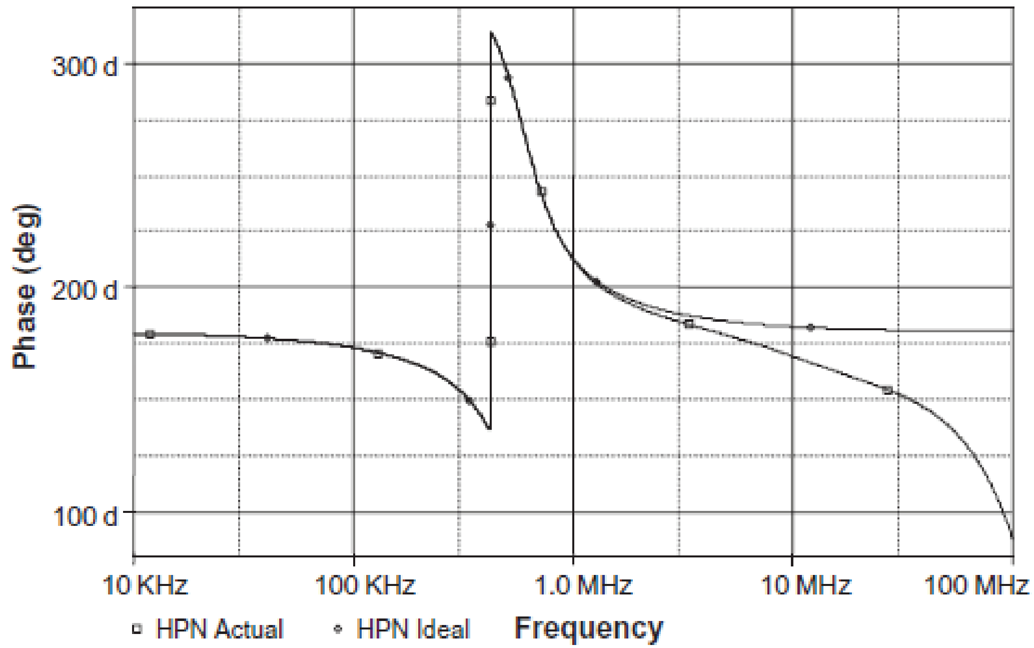

Figure 8(*b*). Phase response of proposed HPN circuit, simulated with CMOS macro models of OPAMPs and OTAs.

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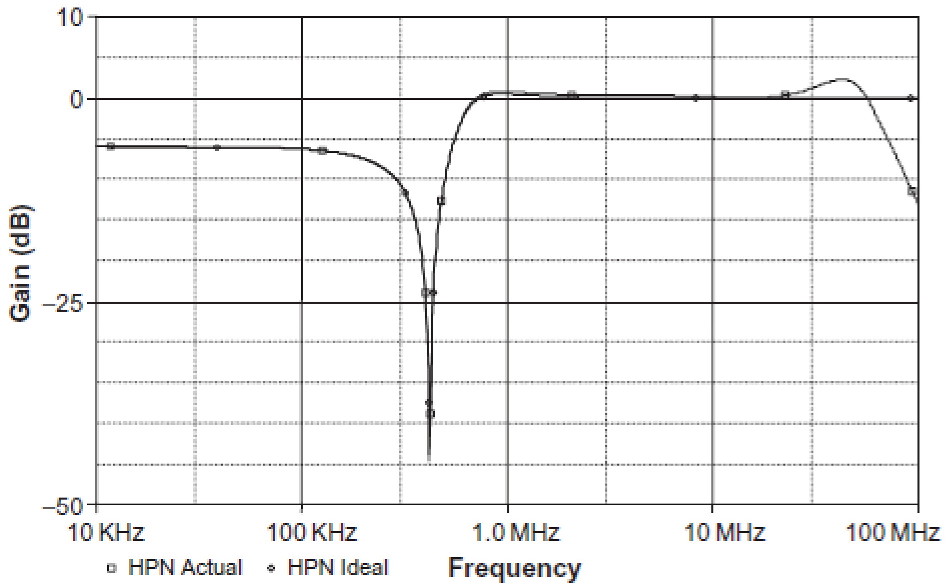

Figure 9(*a*). Frequency response of proposed HPN circuit, simulated with parasitics extracted from chip layout.

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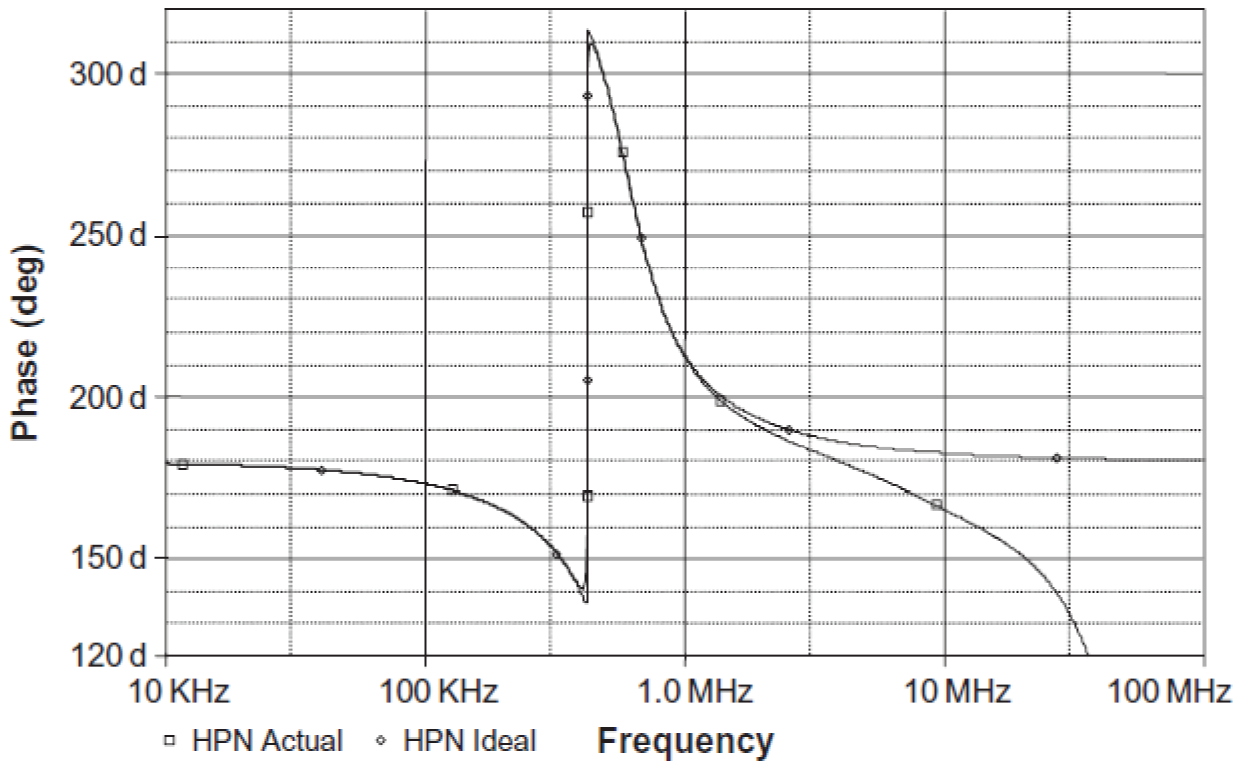

Figure 9(*b*). Phase response of proposed HPN circuit, simulated with parasitics extracted from chip layout.

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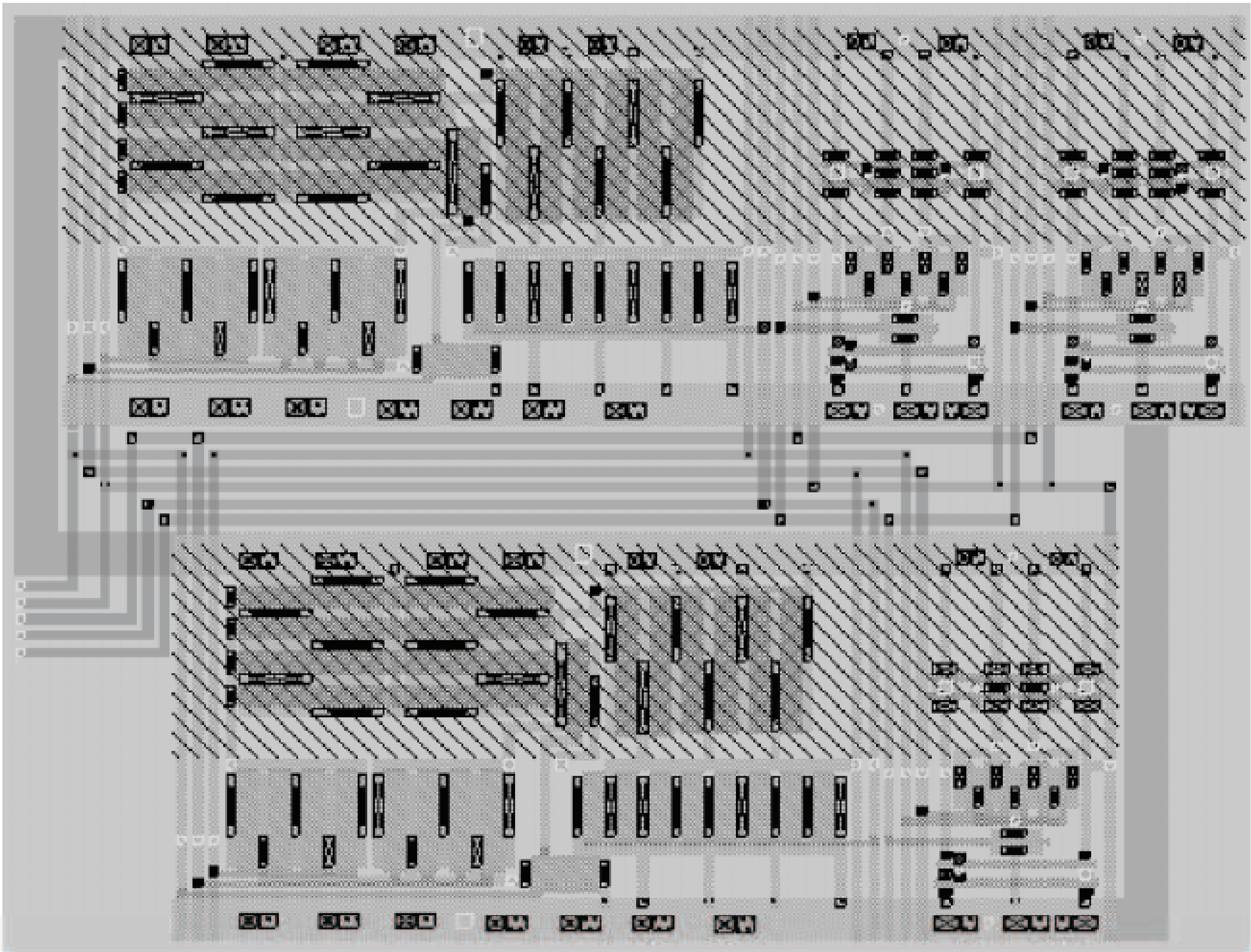

Figure 9(c). Layout of the filter chip implemented with SCMOS 2 μm technology.

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- the parameters can each be independently adjusted to any desired value without disturbing the others.
- Figure 10 shows the simulated HPN responses for $Q = 1.41$ and for $Q = 2.55$, both with the same zero frequency and pass-band gain.
- The Q parameter is changed by tuning the gms of OTAs

$$(g_{m1} = g_{m3} = 420\,\mu A/V,\ g_{m2} = 200\,\mu A/V)$$

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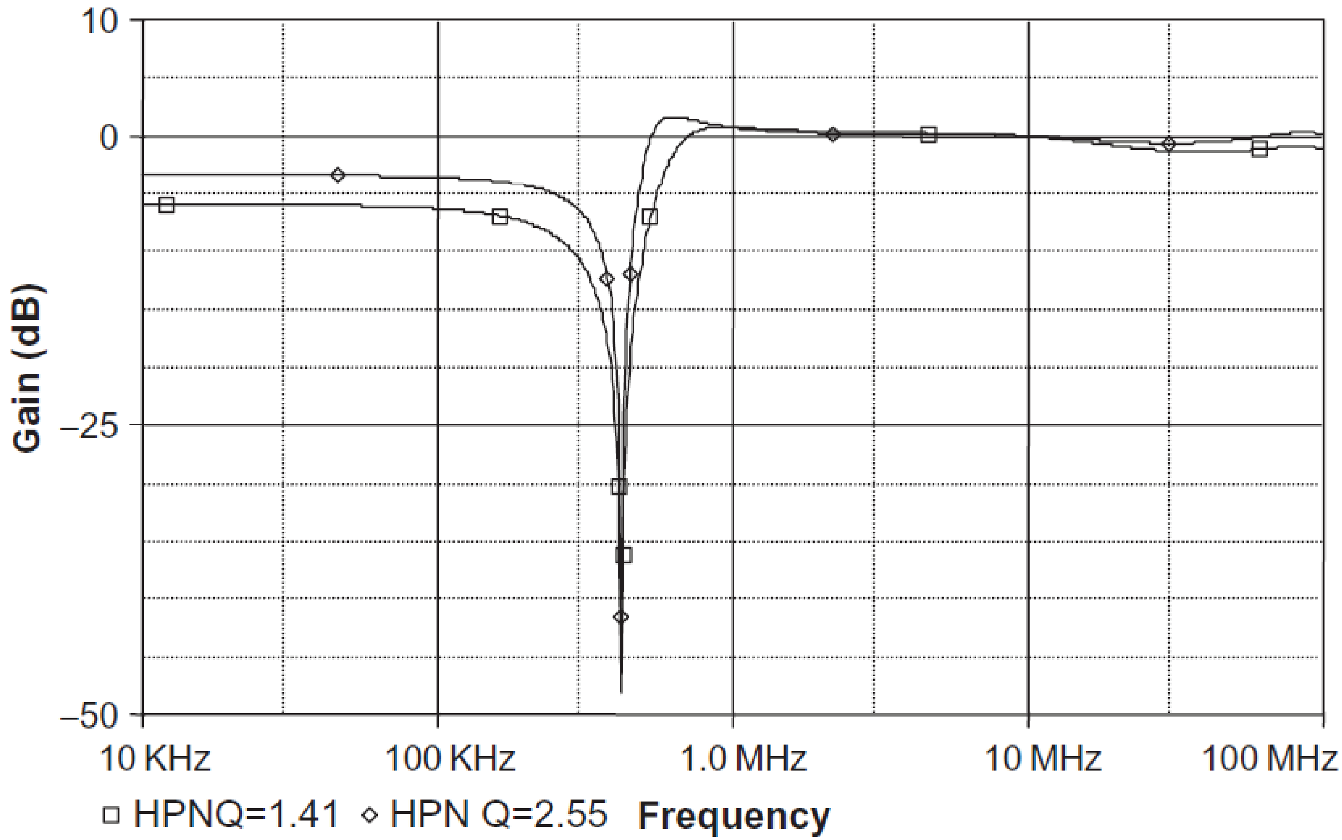

Figure 10. Frequency response of proposed HPN circuit for $Q = 1.41$ together with the response for $Q = 2.55$.

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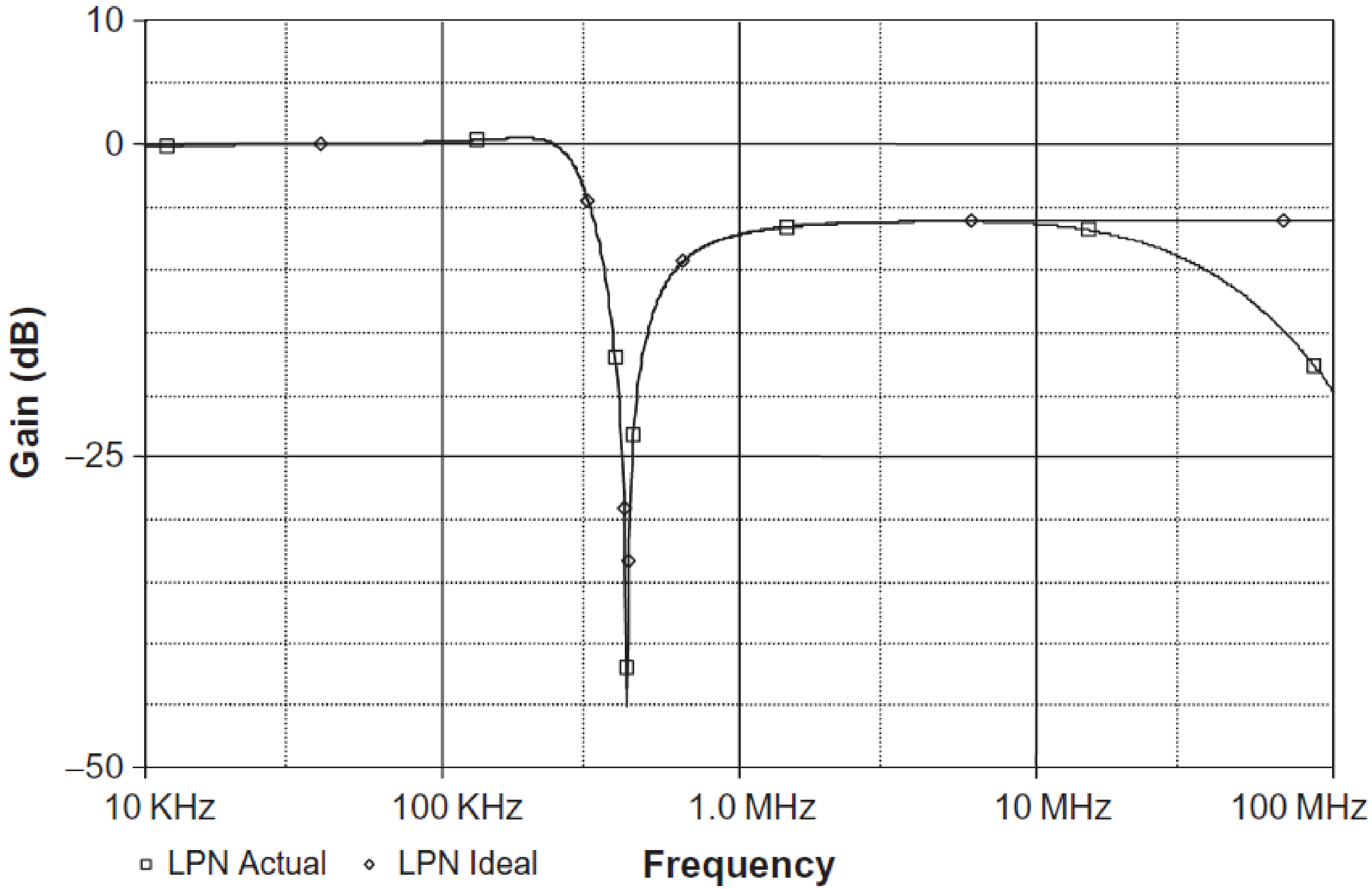

Figure 11(a). Frequency response of proposed LPN circuit, simulated with parasitics extracted from chip layout.

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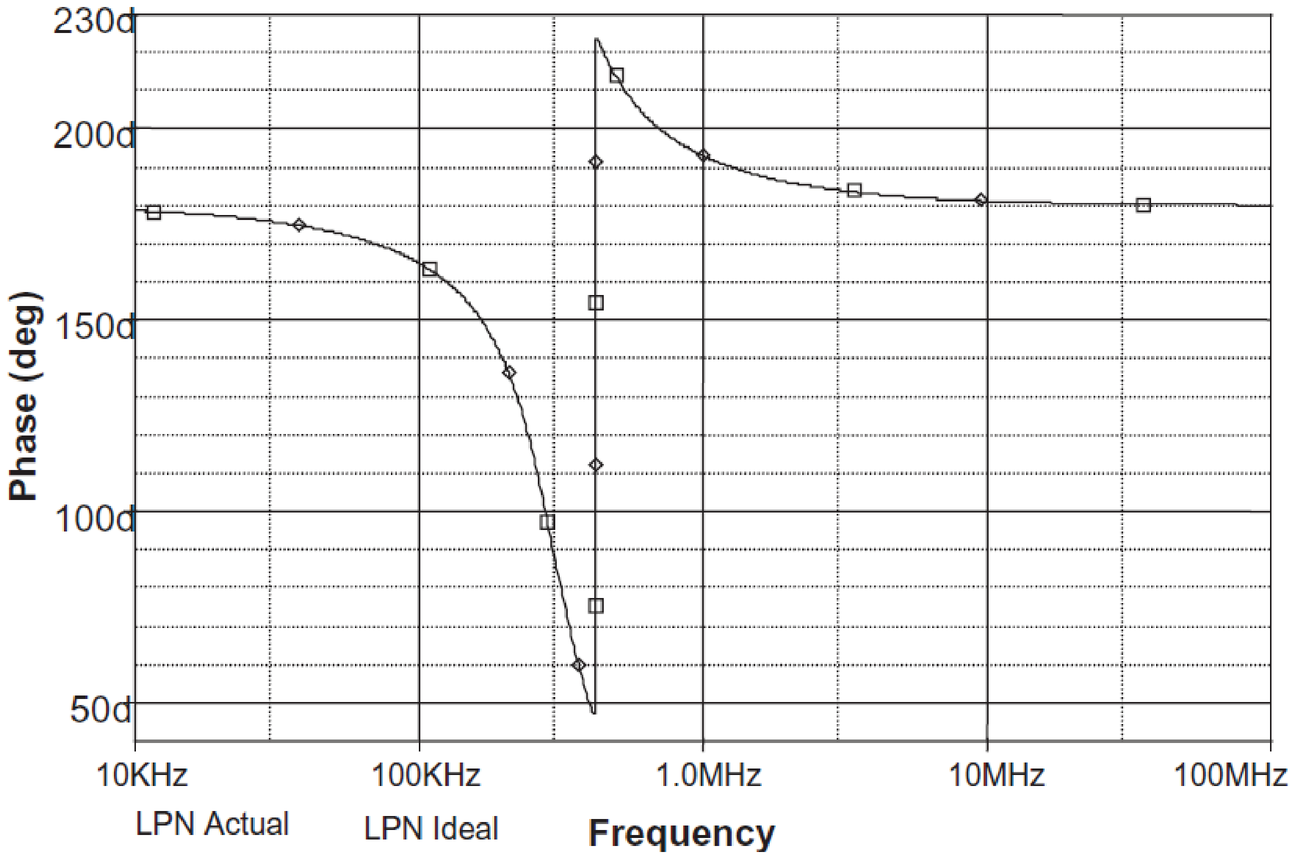

Figure 11(*b*). Phase response of proposed LPN circuit, simulated with parasitics extracted from chip layout.

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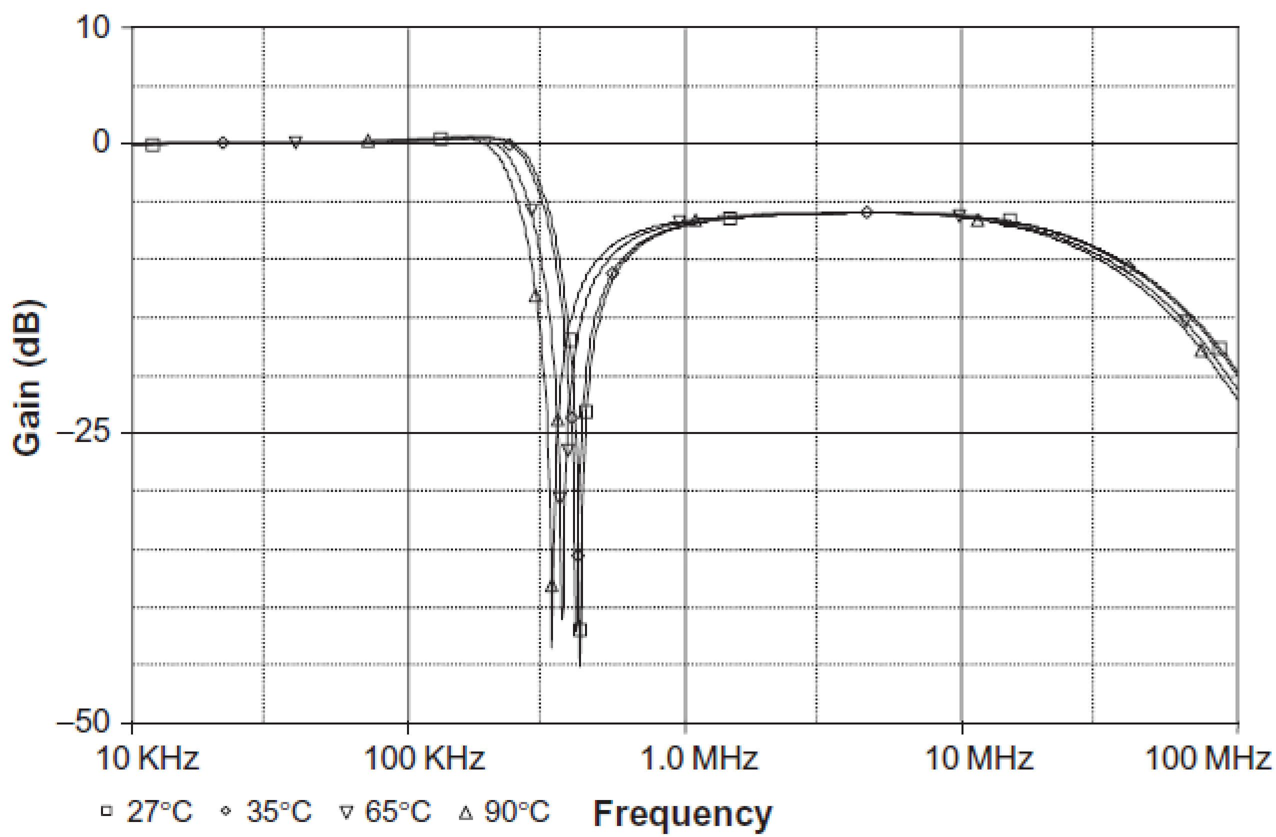

Figure 11(c). Temperature dependence of proposed LPN circuit, simulated with parasitics extracted from chip layout.

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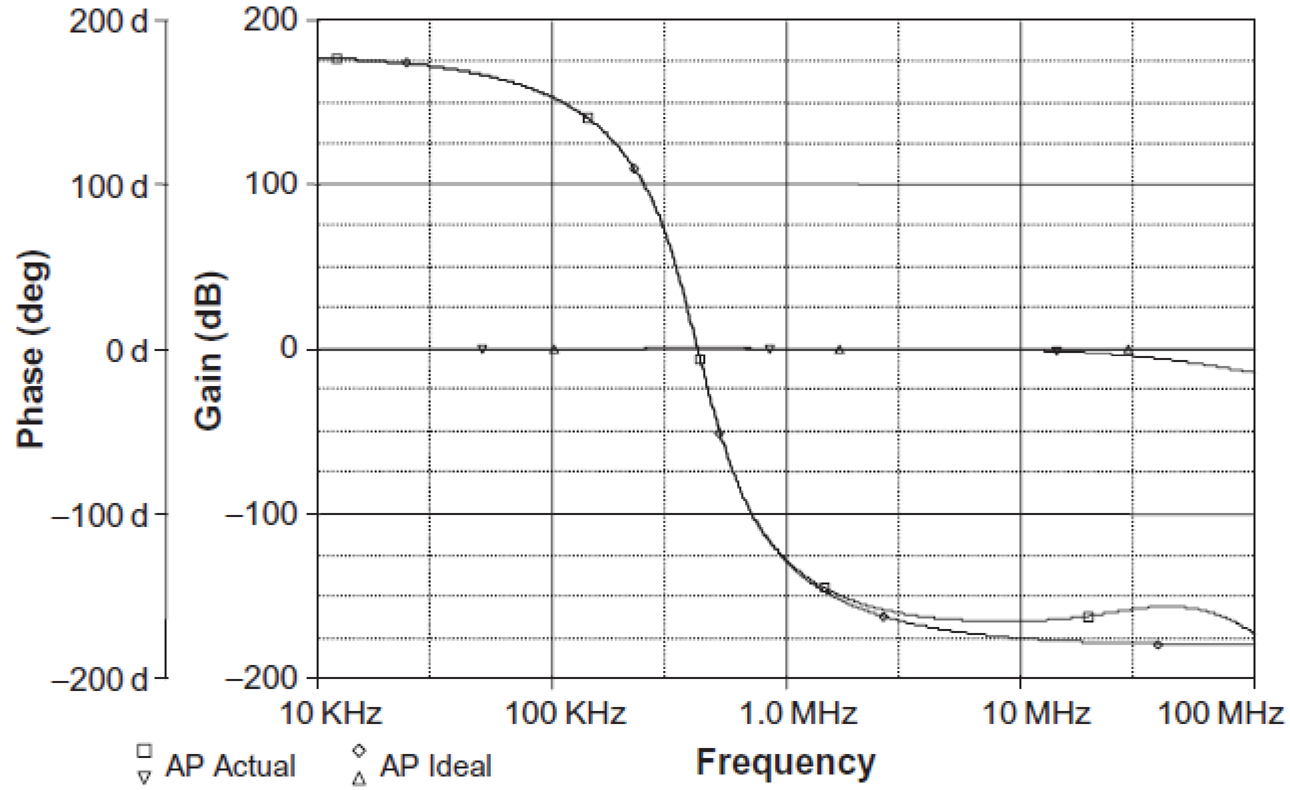

Figure 12. Frequency response of proposed AP circuit, simulated with CMOS macro models of OPAMPs and OTAs.

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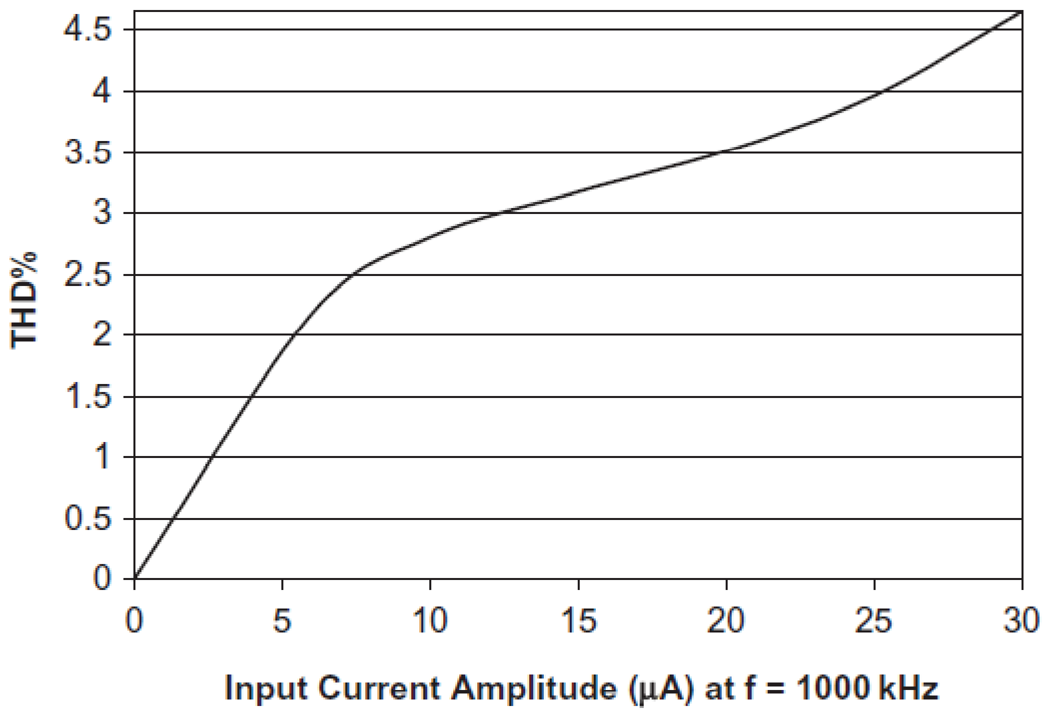

Figure 13. Dependence of total harmonic distortion at output of circuit 1 on input signal amplitude; input is a 1000 kHz sinusoidal current signal.

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