LINEAR TECHNOLOGY

DESIGN NOTES

Source Resistance Induced Distortion in Op Amps

Design Note 84

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Introduction

Almost all op amp data sheets have Typical Characteristic Curves that show amplifier total harmonic distortion (THD) as a function of frequency. These curves usually show various gains and output levels but almost always the input source resistance is low, typically 50Ω. In some applications, such as active filters, the source impedance will be much larger. If the input impedance of the op amp is nonlinear with voltage, the resulting distortion will be significantly higher than the values indicated in the data sheet.

Test Circuit

It is quite easy to evaluate source resistance induced distortion. Connect the amplifier as a unity-gain buffer operating on ±15V supplies. Feed a low distortion $20V_{P-P}$ signal to the noninverting input through a source resistor and measure the output signal distortion. The setup is shown in Figure 1. The readings at 1kHz and 10kHz were recorded for various values of source resistance from 100Ω to 100k. The measured results for several op amps are plotted in Figures 2 and 3.

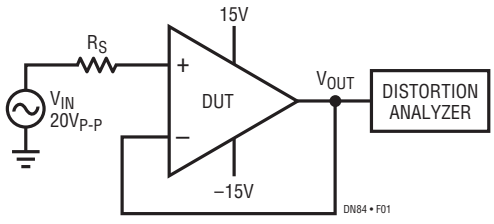

Figure 1

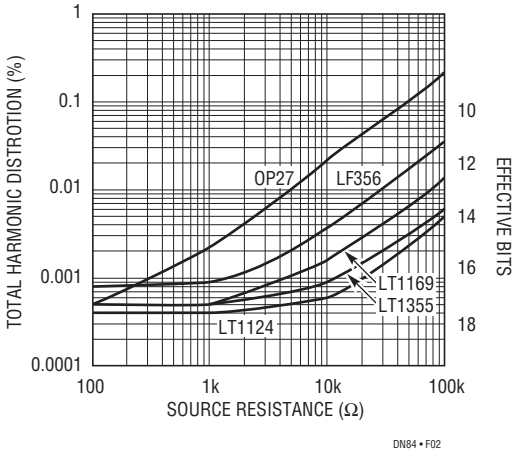

Figure 2. 1kHz Distortion vs Source Resistance

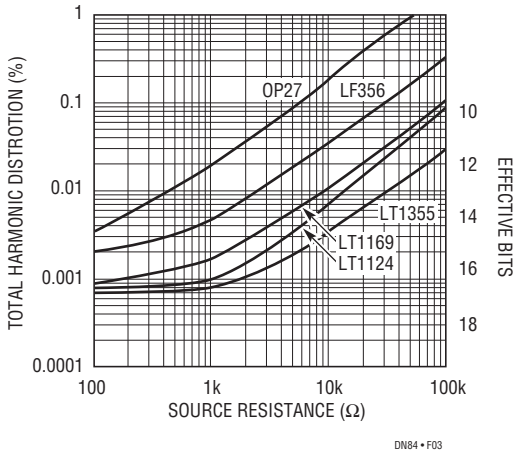

Figure 3. 10kHz Distortion vs Source Resistance

Results

Unfortunately there is no easy way to predict which amplifiers will have the lowest source resistance induced distortion from the data sheets. There are two main causes of the distortion: nonlinear input resistance and nonlinear input capacitance. At first thought, one would not expect the small input capacitance of an op amp to cause distortion at a few kHz. But a 10k source is loaded 0.01% by 1pF at 1.6kHz! Therefore a change in input capacitance of 1pF will cause measurable distortion at 1kHz. For lowest distortion we want an amplifier with low input capacitance as well as very high (and constant) input resistance.

FET input op amps have the highest input resistance but they also have a significant nonlinear input capacitance. The LF356 is a typical FET input op amp; the distortion is 5 to 20 times worse with a 10k source compared with a low source resistance. The LT®1169 is a new dual FET input op amp with very low input capacitance (1.5pF) and therefore has about three times lower distortion than the LF356.

The OP27 is a popular high speed precision op amp that has very low distortion when driven from a 50Ω source. Unfortunately the input bias current cancellation circuit works well only at very low frequencies; at 1kHz the input resistance is very nonlinear. The distortion from the OP27 is 50 times worse with a 10k source than with a 100Ω source. The LT1124 is a dual low noise precision op amp that uses a different input bias current cancellation circuit. The LT1124 has the least source resistance induced distortion at 1kH of any of the op amps tested. The LT1355 is a member of a new family of low power, high slew rate op amps that have outstanding high frequency performance. The LT1355 has the least source resistance induced distortion at 10kHz of any op amp tested.

Figure 4 shows a 20kHz Butterworth active filter as might be used for anti-aliasing or band limiting in a data acquisition system. Figure 5 shows the frequency response of the circuit. Note that for signals well below the cutoff frequency, the capacitors have no effect and the op amp

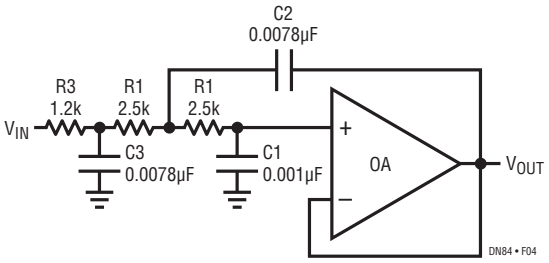

Figure 4

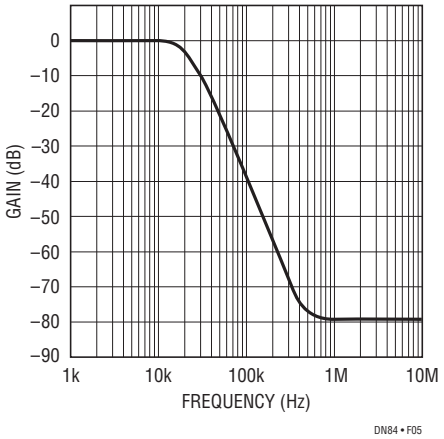

Figure 5. Filter Frequency Response

sees a 6.2k source resistance. Distortion was measured with several op amps in the circuit to confirm the data shown in Figures 2 and 3. Table 1 shows the results of the best op amps.

Table 1. Filter Distortion

Amplifier	100Hz	1kHz	2kHz	5kHz	10kHz
LT1124	0.0004%	0.0005%	0.0008%	0.0021%	0.0090%
LT1355	0.0005%	0.0006%	0.0010%	0.0035%	0.0052%
LT1169	0.0005%	0.0012%	0.0024%	0.0080%	0.0100%

Source resistance induced distortion usually limits the dynamic range of unity-gain RC active filters. An interesting high performance alternative is the LTC1063 and LTC1065. These fifth order, switched-capacitor low-pass filters are not only smaller and easier to use, their distortion is less than 0.01% even with 10k source resistance.

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