Maximizing Signal Chain Distortion Performance Using High Speed Amplifiers

This technical note investigates the relationship between an amplifier's bandwidth and an analog-to-digital converter's (ADC) linearity. It explores tradeoffs to consider when selecting the best low-distortion fully-differential amplifier (FDA) to drive a differential-input ADC. Three Texas Instruments (TI) FDAs with a Gain-Bandwidth Product (GBWP) ranging from 27 MHz to 850 MHz are used to illustrate how amplifier bandwidth affects signal-chain linearity when driving an 18-bit, 2 MSPS ADC. For more information on the benefits of using FDAs for differential signaling, please reference *TI Precision Labs – Op Amps: Fully Differential Amplifiers*.

An amplifier's linearity can be quantified in terms of its total harmonic distortion (THD) performance. To prevent an ammplifier from degrading the signal chain linearity performance a standard rule of thumb is that the (THD) of the amplifier should be at least 10-dB better than the ADC in the frequency range of interest.

Why is amplifier linearity important? Poor linearity alters the input signal's magnitude and phase and adds spurious frequency components that result in poor signal fidelity and loss of information. An extreme illustration of this effect is shown in Figure 1 where an amplifier with limited linearity at the frequency of interest transforms a sine wave into a triangle wave.

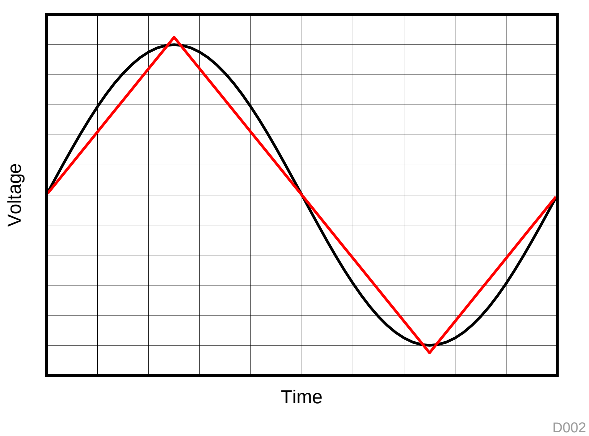

Figure 1. Linear Waveform and Distorted Waveform Representation

An amplifier with wide GBWP implies higher open-loop gain (A_{OL}) across frequency compared to an amplifier with narrower GBWP. To the first order amplifier linearity at any frequency depends on its loop-gain which is a function of its A_{OL} and its signal gain (Loop-gain is actually a function of noise gain however for simplicity we will assume here that noise gain = signal gain). Figure 2 shows the A_{OL} performance for three different TI FDAs. The THS4541 (850 MHz) has wider GBWP than both the THS4551 (135 MHz) and THS4531A (27 MHz).

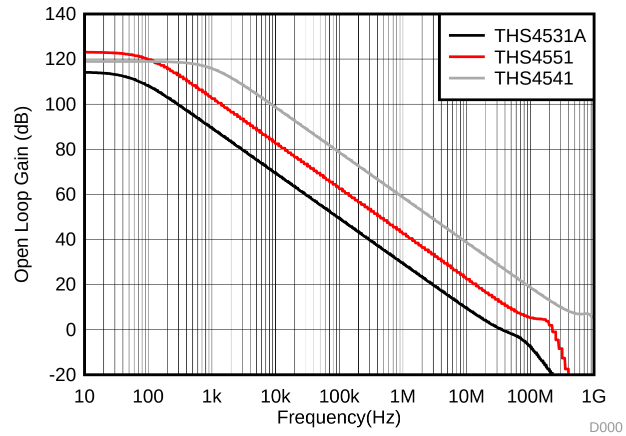

Figure 2. Open Loop Gain (A_{OL}) vs Frequency

Higher loop-gain also results in lower output impedance (Z_{OUT}) which enhances the amplifier's ability to drive the ADC. Figure 3 shows the closed loop output impedance with frequency for the same three TI devices where, again, the THS4541 has lower output impedance than both the THS4551 and THS4531A.

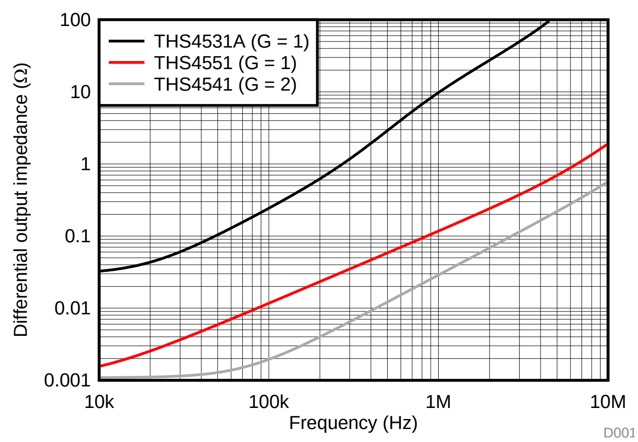

Figure 3. Output Impedance vs Frequency

For more information on why higher bandwidth amplifiers have better THD, please reference the *Has distortion got your amplifier down? Get more bandwidth!* blog post.

Loop-gain refers to an amplifier's small-signal performance (less than $100mV_{PP}$), however to maximize an ADCs dynamic range the amplifier needs to drive a large output signal (up to $10V_{PP}$). An amplifiers slew rate is a measure of its ability to drive large signals without distorting it. Higher slew rate results in better large signal performance. Slew rate for each FDA can be seen in Table 1.

Table 1. Slew Rate Comparison

	THS4531A	THS4551	THS4541
Slew Rate (V/µs)	200	220	1500

FDA AND SAR ADC EXAMPLE

The following example compares the THD performance of the three different TI FDAs discussed against the ADS9110 which is an 18-bit, 2 MSPS, differential-input precision SAR ADC.

Ideally the amplifier used to drive the ADC should have at least 10-dB better distortion performance. Assuming that HD2 and HD3 are the dominant sources of THD, the THD performance of the three amplifiers is calculated using Equation 1. The resultant THD for the three amplifiers and the ADS9110 is shown in Figure 4. The calculations assumed a $5V_{PP}$ output from the amplifier. Equation 2 calculates the overall system performance of the signal chain. Table 2, Table 3 and Table 4 summarize the THD performance of the three FDAs, the THD performance of the ADS9110 and the resultant signal chain THD.

$$\text{THD (dB)} = 20\log\left(10^{\frac{HD_2\,(dB)}{10}} + 10^{\frac{HD_3\,(dB)}{10}}\right) \quad (1)$$

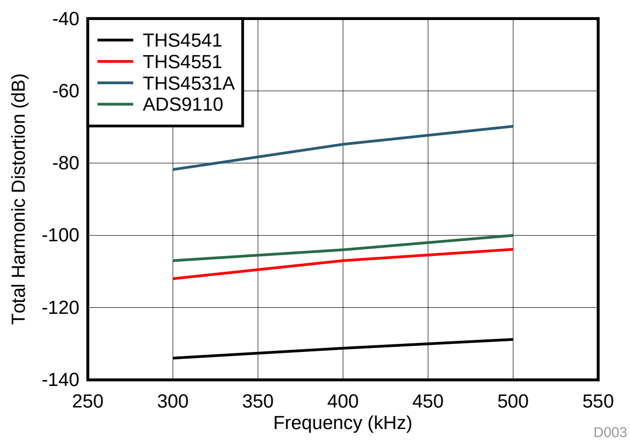

Figure 4. THD vs Frequency

$$THD_{SYSTEM} = 20\log\left(10^{\frac{THD_{AMP}}{20}} + 10^{\frac{THD_{ADC}}{20}}\right) \quad (2)$$

Table 2. THS4531A and System THD Performance

Frequency	ADS9110 (dB)	THS4531A (dB)	Signal Chain (dB)
0.3 MHz	–107	–81.8	–81.3
0.4 MHz	–104	–74.8	–74.5
0.5 MHz	–100	–69.8	–69.5

Table 3. THS4551 and System THD vs Performance

Frequency	ADS9110 (dB)	THS4551 (dB)	Signal Chain (dB)
0.3 MHz	–107	–112	–103.1
0.4 MHz	–104	–107	–99.3
0.5 MHz	–100	–103.8	–95.8

Table 4. THS4541 and System THD vs Performance

Frequency	ADS9110 (dB)	THS4541 (dB)	Signal Chain (dB)
0.3 MHz	–107	–134	–106.6
0.4 MHz	–104	–131.2	–103.6
0.5 MHz	–100	–128.8	–99.7

For our specified desired frequency range, Table 5 highlights the results of using the three FDAs as potential drivers to the ADS9110.

Table 5. Summary of Signal Chain Performance

FDA Product	Conclusion
THS4531A	With a GBWP of 27 MHz, the THS4531A degrades the overall signal chain THD by 20-30 dB.
THS4551	With a GBWP of 135 MHz, the THS4551 degrades the overall signal chain THD by 8 dB.
THS4541	With a GBWP of 850 MHz, the THS4541 degrades the overall signal chain THD by less than 1 dB.

In conclusion, an amplifier's linearity performance, to the 1st order, depends on its gain bandwidth product and slew rate. To preserve signal fidelity it is often required to select an amplifier whose bandwidth may be 100 times greater than the Nyquist bandwidth of the ADC it is driving. Higher gain bandwidth product also results in faster settling-time and lower output impedance which improves the amplifiers ability to drive an ADCs complex switched capacitor input impedance.