Application Note

Understanding THD and THD+N in Multiplexer Applications

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ABSTRACT

Total Harmonic Distortion (THD) and Total Harmonic Distortion plus Noise (THD + N) are key performance metrics for evaluating signal fidelity in analog systems. In applications such as audio, test and measurement and biomedical instrumentation, even minor distortions can significantly degrade performance and reliability. This application note explains the mathematical basis of THD and THD+N, outlines standard test setups for multiplexer (mux) characterization and highlights the impact of On-Resistance (R_{ON}) and R_{ON}-flatness on distortion performance. Practical examples are provided to illustrate how low-THD multiplexers, such as the TMUX4827 and TMUX7612, enhance performance in audio switching, precision measurement, programmable gain amplification loops and biomedical sensing. By Understanding THD behavior in mux devices and selecting components with optimized R_{ON} characteristics, engineers can make sure accurate signal reproduction and robust system performance across diverse applications.

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1 Introduction

In audio equipment, measurement systems, and communication devices, is crucial to make sure signals are reproduced as accurately as possible. Whether you are designing high fidelity speakers, calibrating sensitive lab instruments, or making sure clear data transmission, distortion and noise can degrade performance. That is where metrics like Total Harmonic Distortion (THD) and Total Harmonic Distortion plus Noise (THD+N) come in. THD measures the extent to which a system introduces harmonic content that was not present in the original signal. While THD+N includes both that distortion and any added noise, which makes this a more broader performance metric and more indicative of real-world performance.

Higher THD levels can result in a more distorted or degraded output, which can cause undesirable artifacts, such as muffled or *static* sound in audio applications. While a low THD makes sure the system accurately reproduces the original signal without introducing interference that can compromise performance. This becomes increasingly important in critical applications like medical devices or Test and measurement DAC's and ADC's where even the slightest distortion can have significant negative impacts on the precise measurements required. The THD performance of a device help engineers evaluate and compare components to make sure of clean and reliable signal outputs in the systems.

2 What is THD

To be more specific, THD is a measure of the distortion introduced to an input signal in the form of harmonics at the output due to device non-linearities. For a fixed frequency input, THD is calculated as the ratio of the Root Mean Square (RMS) sum of all harmonic amplitudes to the RMS amplitude of the fundamental input signal, and can be expressed as either a percentage, or as a decibel ratio:

$$\mathrm{THD}(\%) = \frac{\sqrt{\sum_{i=2}^{\infty} V_i^2}}{V_1} \times 100\% \mathrm{THD}(dB) = 20 \times log_{10} \frac{\sqrt{\sum_{i=2}^{\infty} V_i^2}}{V_1} \tag{1}$$

Where V_1 is the fundamental, V_i is the *i*th harmonic. Each amplitude is express in V_{RMS}.

3 What is THD + N

THD+N is similar to THD and in low noise environments can look similar. However, as system noise increases, the THD+N metrics becomes increasing more accurate relative to THD alone. Sources of system-level noise can include high frequency interference, crosstalk across channels or devices, power-line ground loop coupling at the 60Hz fundamental or the harmonics (120Hz, 240Hz…), and inter-modulation distortion. Several of these effects can be controlled with adequate shielding, PCB trace spacing, grounding or filtering techniques, but are difficult to eliminate entirely. In addition, semiconductor devices (including multiplexers) contribute thermal noise, flicker noise, and shot noise which can impact the baseline THD + N noise.

Total Harmonic Distortion plus Noise (THD+N) extends the definition of THD by including noise in the measurement:

$$\mathrm{THD+N}(\%) = \frac{\sqrt{\sum_{i=2}^{\infty} V_i^2 + V_N^2}}{V_1} \times 100\% \mathrm{THD+N}(dB) = 20 \times log_{10} \frac{\sqrt{\sum_{i=2}^{\infty} V_i^2 + V_N^2}}{V_1} \tag{2}$$

Where V_1 is the fundamental, V_i is the *i*th harmonic and V_N denotes the noies. Each amplitude is express in V_{RMS}.

4 THD(+N) of Multiplexers

The THD + N test setup schematic for a multiplexer (MUX) device is shown in Figure 4-1. A low distortion sine wave source, V_{in}, is applied to the MUX channel under test S_1 to *D*. The output signal, noise and harmonics are captured by a precision digitizer. This measurement is conducted over a range of V_{in} frequencies (for example, for audio applications, sweep is 20Hz to 20kHz), and the results are combined to form a plot of THD + N across frequency.

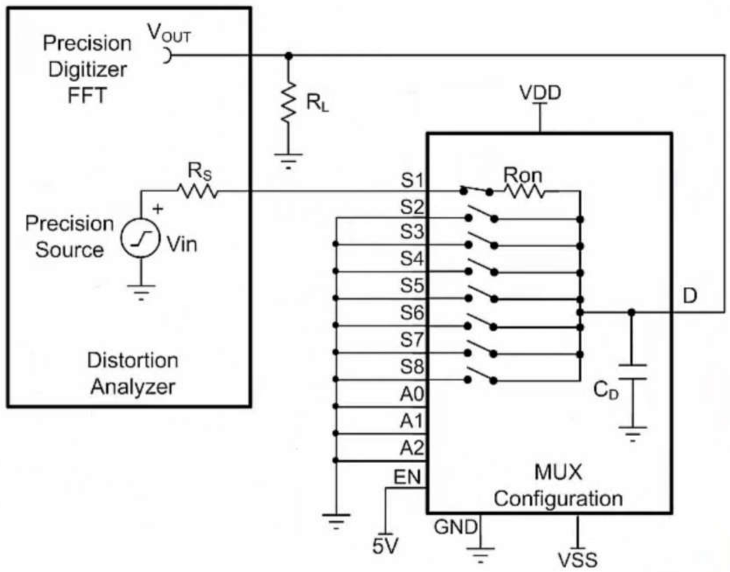

Figure 4-1. Test Setup Schematic for Measuring Multiplexer THD+N

4.1 Understanding THD(+N) of a Multiplexer

For multiplexed systems, the observed THD(+N) performance is a function of the On-Resistance (R_{ON}), R_{ON} flatness (variation of the mux channel R_{ON} across the applied signal range) of the device and the load resistance, R_L. As the ratio R_L/R_{ON} increases the THD+N performance improves. This is due to the creation of an amplitude-dependent voltage divider, as shown in Figure 4-2, through the combination of R_{on} and R_L. This follows then that the observed harmonic distortion of the mux output is minimized when R_L is larger, such as a high impedance input of a non-inverting amplifier.

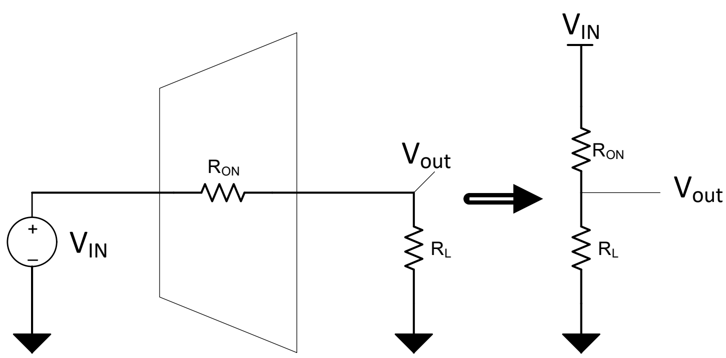

Figure 4-2. Voltage Divider Created by MUX R_{ON} and R_L

Typically, for applications where THD matters, the operational peak-to-peak voltage range can be a smaller range than the full voltage swing the mux is capable of. Therefore, this is important to verify that the operating voltage of a device does not fall in a region where the R_{ON} of the mux varies greatly. Some R_{on} curves are flat across the entire region, while others can have optimized performance across a specific input voltage region. Figure 4-3 shows how the same device can have different THD performance, given different operational peak-to-peak (V_{pp}) voltages.

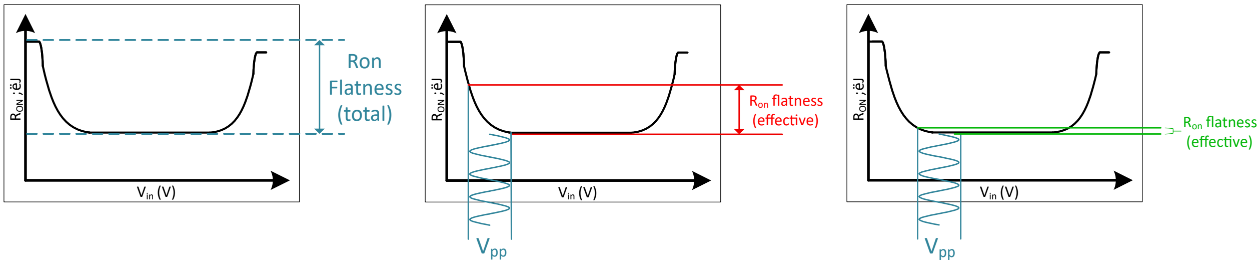

Figure 4-3. R_{ON} Curve With Optimized (Green) V_{pp} Region vs Unoptimized (Red) V_{pp} Region

To optimize THD performance, the recommendation is to use the R_{ON} region of the multiplexer that is the flattest. Figure 4-4, shows the optimized THD Regions for common of R_{ON} curves for analog multiplexers. Figure 4-5 highlights how an ultra-flat R_{ON} optimizes THD performance in the TMUX4827.

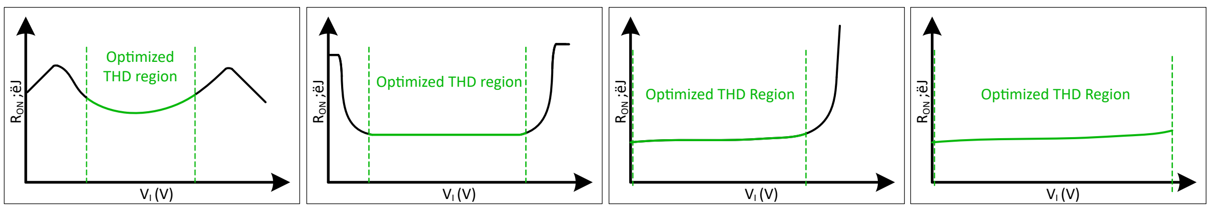

Figure 4-4. Best Region (Green) of V_{IN} for Optimized THD Performance

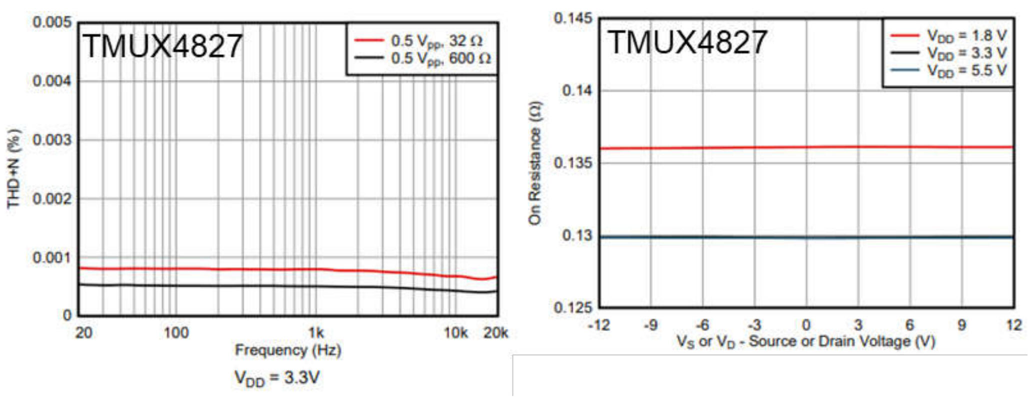

Figure 4-5. TMUX4827 Achieves Optimized THD Performance Through Ultra-Flat R_{ON}

5 Low THD Multiplexer Applications

Low THD multiplexers are essential in applications where signal fidelity and accuracy are important. In audio systems, where clarity and precise reproduction of sound is paramount, low THD muxes makes sure that signal integrity is maintained without introducing distortions that can negatively impact the listening experience. This is especially important in high-fidelity audio equipment or professional audio setups, where even slight distortion can be noticeable. Figure 5-1 shows how the TMUX4827, with 0.001% THD+N and 1mΩ R_{ON}-flatness, can be used in an audio system to switch between internal and external speakers or different audio sources.

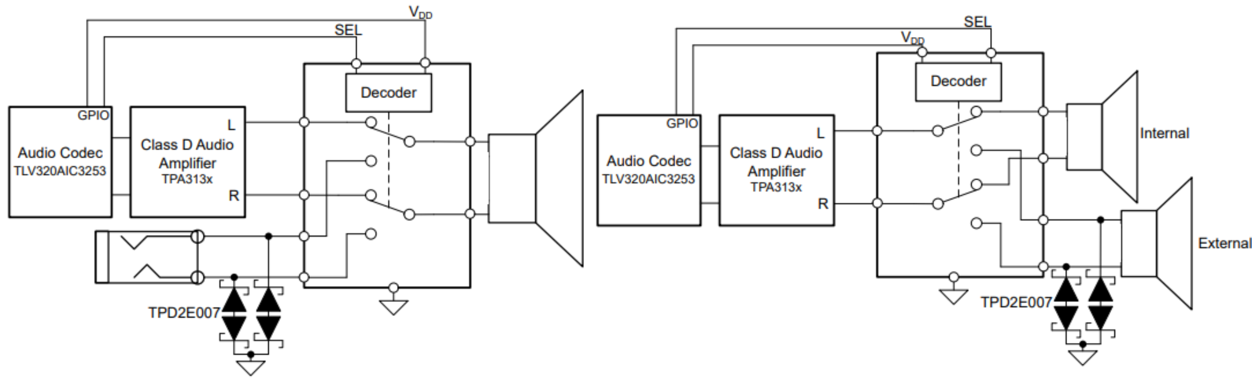

Figure 8-1. Audio Amplifier Switching

Figure 5-1. Using a Low THD Mux for Audio Amplifier Switching

In test and measurement scenarios, particularly with ADC's and DAC's, low THD muxes are required to preserve the precision of the analog-to-digital or digital-to-analog conversion process, making sure accurate signal representation for accurate analysis and diagnostics. Additionally, muxes used in PGA feedback loops require low THD to maintain high Signal-to-Noise Ratio (SNR) to minimize the amplification of noise. Figure 5-2 shows how the TMUX7612 can be used to switch feedback resistors in a PGA to change amplification of the input signal.

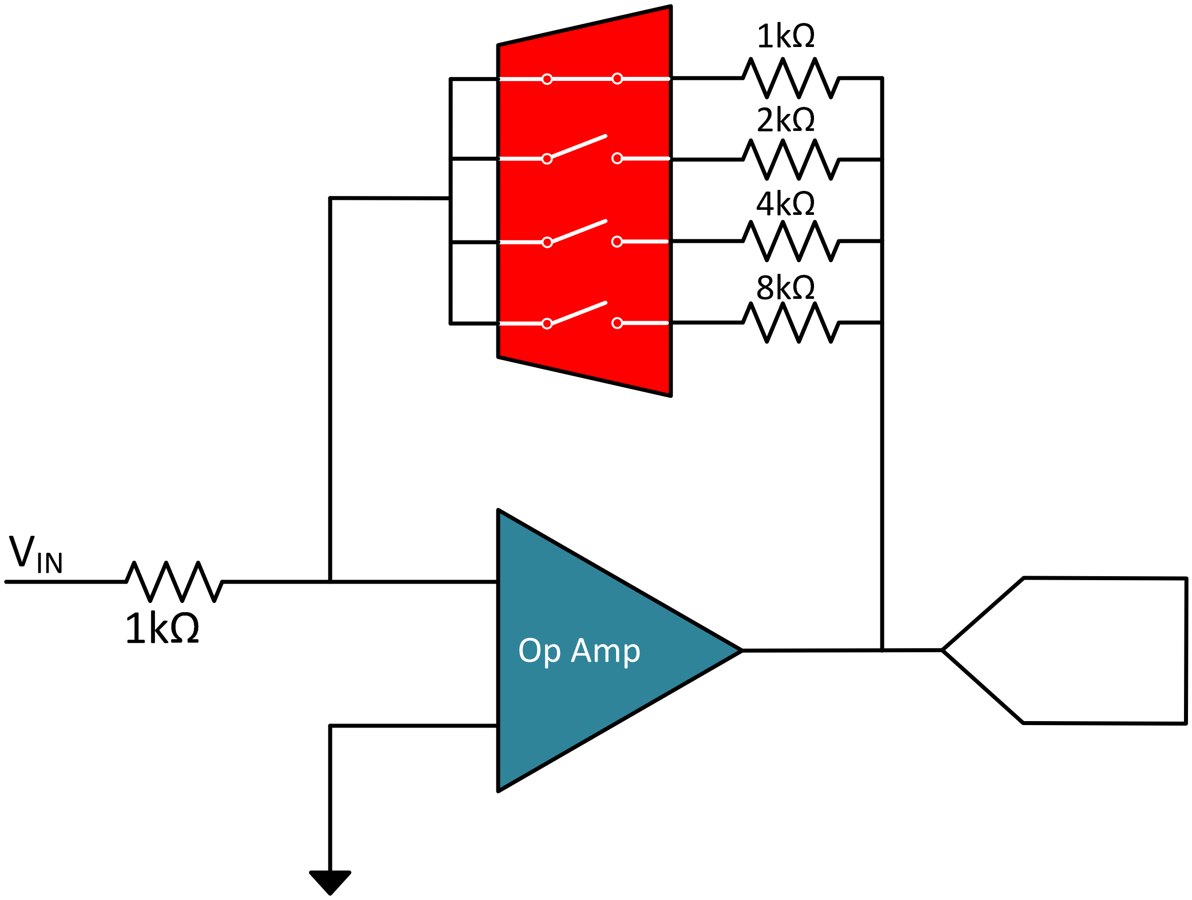

Figure 5-2. TMUX7612 Used in PGA Feedback Loops to Vary Gain Amplification

Similarly, in biomedical applications low THD is critical to capturing and analyzing physiological signals with minimal distortion. Whether heart beat (ECG), brain (EEG) or muscle activity (EMG) is being sensed, even small distortions in these sensitive measurements can lead to incorrect diagnoses or compromised research outcomes, making low THD muxes a vital component in maintaining the quality and reliability of biomedical data. Muxes can be used to switch between different sensors in an ECG setup. The low THD performance allows for accurate sensing of biomedical signals.

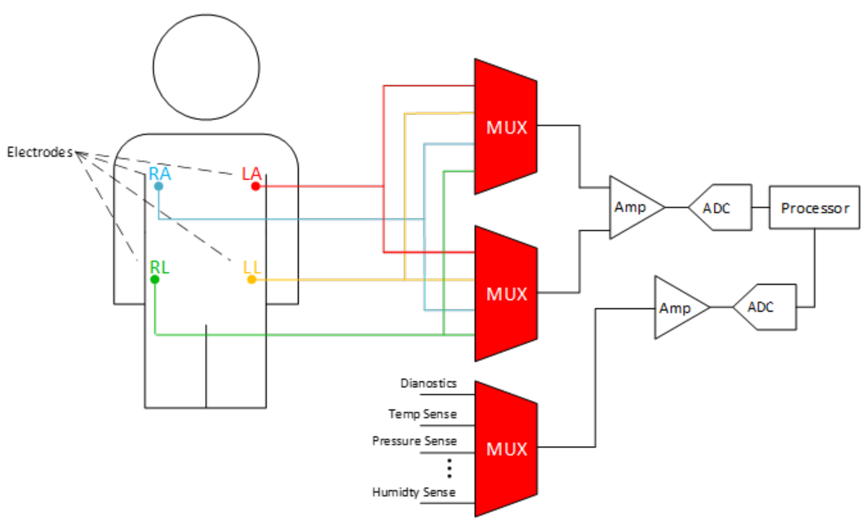

Figure 5-3. Multiplexing ECG Signals Require Low THD Muxes to Maintain Signal Accuracy

6 Low THD Mux Device Recommendations

Table 6-1. Low THD Analog Multiplexer Recommendations

Device	Configuration	I/O Voltage (max)	Supply Voltage	R_{on} (typ)	R_{on} flatness	THD
TMUX4827	2:1, 2 Channel	-12V to +12V	1.8V to 5.5V	0.13Ω	0.001Ω	0.0006%
TMUX2889	2:1, 2 Channel	-5.5V to +5.5V	1.8V to 5.5V	0.15Ω	0.001Ω	0.0006%
TS5A12301E	2:1, 1 Channel	0V to 5.5V	2.25V to 5.5V	0.5Ω	0.1Ω	0.003%
TS5A3159	2:1, 1 Channel	1.65V to 5.5V	1.65V to 5.5V	0.75Ω	0.15Ω	0.01%
TS5A22364	2:1, 2 Channel	-3.2V to 5.5V	2.3V to 5.5V	0.65Ω	0.18Ω	0.01%
TS5A22362	2:1, 2 Channel	-3.2V to 5.5V	2.3V to 5.5V	0.65Ω	0.18Ω	0.01%
TS5USBA224	2:1, 2 Channel	-2.2V to 3.3V	3.3V	4Ω	1.5Ω	0.05%
TMUX7612	1:1, 4 Channel	4.5V to 50V, ±4.5V to ±25V	4.5V to 50V, ±4.5V to ±25V	1Ω	0.0003Ω	0.0006%
TMUXS7614D	1:1, 8 Channel	4.5V to 50V, ±4.5V to ±25V	4.5V to 50V, ±4.5V to ±25V	1Ω	0.0003Ω	0.0006%
TMUX5412	1:1, 4 Channel	4.5V to 50V, ±4.5V to ±25V	4.5V to 50V, ±4.5V to ±25V	21Ω	0.005Ω	0.001%

7 Summary

Total Harmonic Distortion (THD) and THD+N are key metrics for signal fidelity, particularly in audio and precision analog systems. Multiplexer can introduce distortion depending on the On-Resistance characteristics, with certain operating regions delivering optimized performance. By examining the measurement setups, R_{ON} curves, and real application cases, designers can better understand when to consider THD performance and how to minimize the affects.

8 References

1. Texas Instruments, *TMUX4827*, product folder
2. Texas Instruments, *TMUX2889*, product folder
3. Texas Instruments, *TS5A12301E*, product folder
4. Texas Instruments, *TS5A3159*, product folder
5. Texas Instruments, *TS5A22364*, product folder
6. Texas Instruments, *TS5A22362*, product folder
7. Texas Instruments, *TS5USBA224*, product folder
8. Texas Instruments, *TMUX7612*, product folder
9. Texas Instruments, *TMUXS7614D*, product folder
10. Texas Instruments, *TMUX5412*, product folder

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