Application Note

Passive Mux Selection Based on Bandwidth

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ABSTRACT

Analog muxes are used in a wide variety of applications today. From audio to high-speed interface and video systems, all these different applications require different performance parameters of the muxes. This application note describes which parameters are the most important and why. Application-specific muxes presented include:

- Video
- Hi-Speed interface USB
- HDMI
- DisplayPort™

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1 Introduction

Analog muxes are used in electronic systems to control a specific transmission path for an analog signal. These devices are used in a wide variety of applications, including audio and high-speed interface and video systems. However, every specific application requires the mux to be optimized for different parameters. This application note describes some important analog-mux parameters, such as on-resistance (RON), RON flatness, and bandwidth. Application-specific muxes are presented for:

- Video
- Hi-Speed interface USB
- HDMI
- DisplayPort

2 Key Performance Parameters

Different applications require different performance parameters of the analog muxes. The following are some important parameters of analog muxes.

2.1 On Resistance (RON) and RON Flatness

On-resistance (RON) is the resistance of the mux path between the drain and source terminal. It is the resistance introduced by the mux to the circuit when the mux is in the closed position. There are many factors that affect RON, such as:

- Temperature
- Input voltage
- Supply voltage
- Gate length “W”

Another important specification related to RON is RON flatness. RON flatness is a measure of how the RON changes over the operating voltage range of the mux. RON flatness can vary dramatically, depending on the type and design characteristics of the mux.Especially the audio applications require low flatness values, because the flatness causes harmonic distortion that should be kept as low as possible

Ideally, RON is as low as possible in order to keep the signal losses and propagation delays small. To achieve very low resistance and flatness for analog mux, two parameters are important. For both PMOS and NMOS, the size must be large as possible, and the voltage thresholds must be low as possible. Increasing the width and length (W/L) ratio of the silicon of a MOSFET not only increases the cost of the mux, but also results in higher parasitic capacitance and a larger silicon area. This larger parasitic capacitance reduces the bandwidth of the analog mux that can pass through the mux without distortion.

2.2 Bandwidth (BW)

Bandwidth is an important parameter to characterize the performance of many electrical systems. The bandwidth of a mux indicates the upper limit of the frequency of signals passing through the mux. The derivation was based on a low-pass filter circuit, which serves as a general model for systems exhibiting low-pass filter behavior.

The range of frequencies for which a filter does not cause significant attenuation is called the pass band, and the range of frequencies for which the filter does cause significant attenuation is called the stop band. RC low-pass filter always transition gradually from pass band to stop band. This means that it is impossible to identify one frequency at which the filter stops passing signals and starts blocking signals. Engineers need a way to conveniently summarize the frequency response of a filter, and this is where the concept of cutoff frequency comes into play.

The cutoff frequency of an RC low-pass filter is the frequency at which the amplitude of the input signal is reduced by 3 dB (3 dB reduction in amplitude corresponds to a 50% reduction in power). Thus, the cutoff frequency is also called the *–3 dB frequency*. The term bandwidth refers to the pass band width of a filter, and in the case of a low-pass filter, the bandwidth is equal to the –3 dB frequency (as shown in Figure 2-1)

Understanding the bandwidth capability of a signal mux helps to determine if a mux meets the performance requirements of the target application.

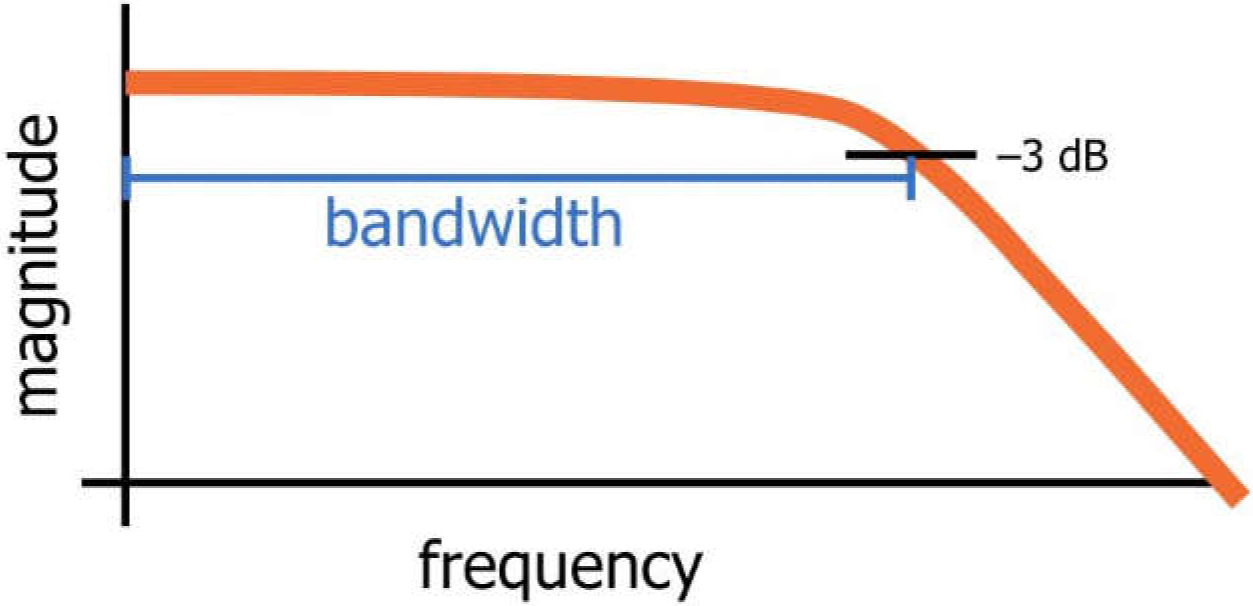

Figure 2-1. Bandwidth of Low-Pass Filter

2.3 Signal Harmornics and Distortion

System designers want to use muxes to accomplish simple signal routing, and wish the impact of the physical mux to the signal itself is as small as possible. The time dependant differences between shapes of the input and output signals are generally referred to as distortion. If some fraction of the frequency components of the input signal exceed the system bandwidth, the system response to this portion of the signal lags. As a result, the output signal does not accurately reproduce the fastest transitions of the input signal. This results in output signals that may have lower amplitudes, and wider and rounder edges, than the corresponding features in the input signal.

This section looks at a square wave to see what causes the square shape. A complex waveform can be constructed from the sine (and cosine) waves of various amplitude and phase relationships. This is the basis of Fourier analysis.

For example, a square wave can be constructed from multiple sine waves at different frequencies. The sine waves added, in addition to the fundamental frequency, are called harmonics; a square wave has harmonics at odd multiples of the fundamental frequency. As higher harmonics are added, the result gets closer to an ideal square wave.

The amplitude of the harmonics is equal to 1/N, where N is the harmonic (1, 3, 5, 7…). Each harmonic has the same phase relationship to the fundamental. If constructing a square wave from just the first two harmonic components, the beginnings of how the square shape occurs can be seen (waveform B of Figure 2-2). Figure 2-2 shows that the red trace is the ideal square waveform, and the green trace is the waveform with Nth harmonic at the correct amplitude. Interfering frequencies must be much higher in frequency than the fundamental frequency. If the system requires that third, fifth, or even higher harmonics must be passed, the 3-dB cutoff frequency must be above these harmonics: three, five, or seven or more times the fundamental frequency. If using the fifth harmonic components zero, three, and five to construct the square wave, it really starts to take shape (Figure 2-2 waveform C). If using more than 10th harmonic components to construct the square wave, it is really close to the ideal square waveform (Figure 2-2 waveform D).

From these graphs, it is easily understood that the high frequency harmonic content, and not a DC component, is responsible for the shape of a square wave.

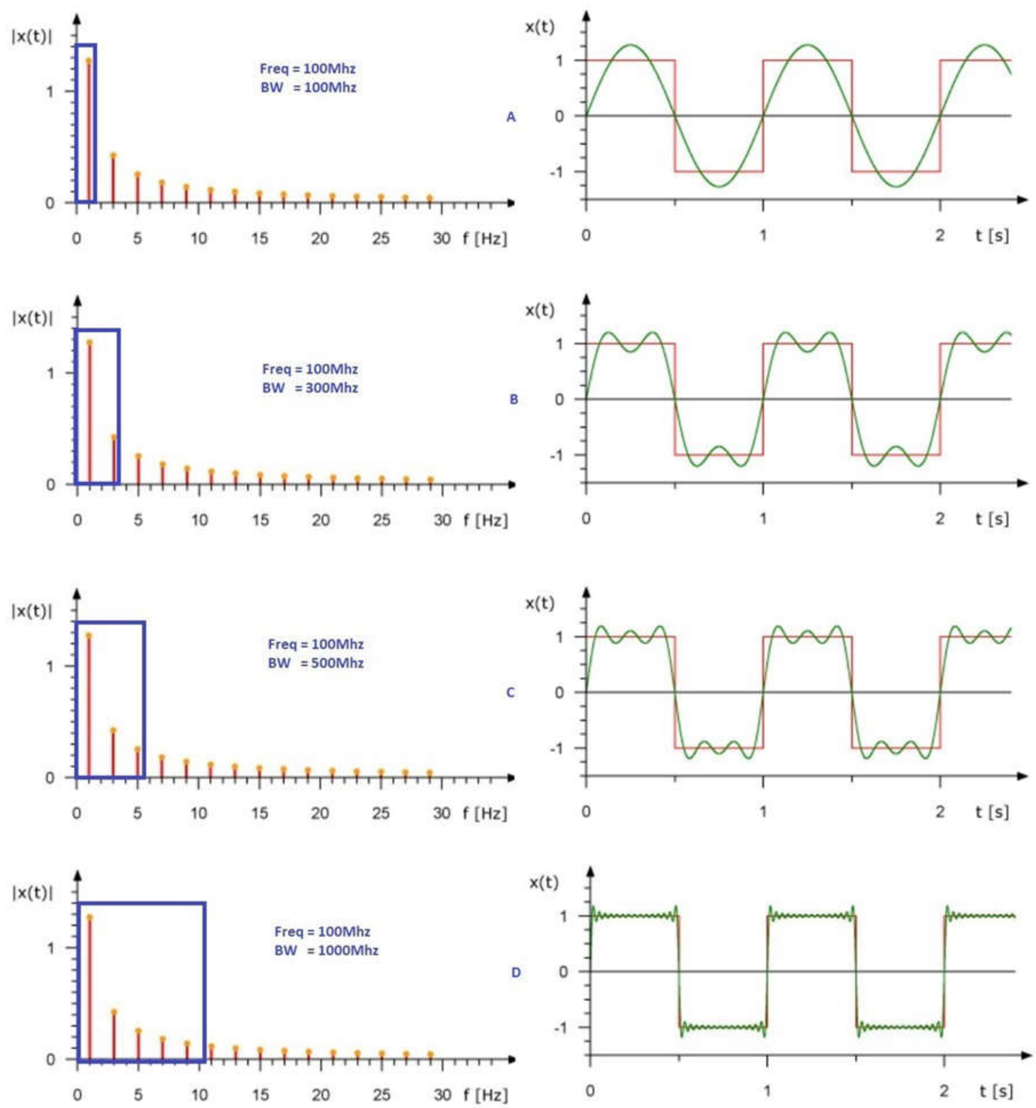

Figure 2-2. Square Wave With Different Harmonics

3 What is More Important for High-Speed Interface and Video Systems

System designers often need to make trade-offs between specifications in order to achieve optimal performance for the target application. The trade-off between RON and BW is important for high-speed interface and video signals. No matter how low Ron can be maintained in the chip manufacturing process, they still form an undesired low-pass filter that attenuates the mux output signal. Meanwhile, low RON muxes have larger parasitic capacitance that reduce bandwidth and cause signal distortion. Also, low-RON muxes require large chip sizes, which increases the mux cost.

There are several key features to consider when selecting the mux to use in a particular application. High-speed applications have unique requirements (with respect to the minimum acceptable 3 dB bandwidth). Understanding the bandwidth capability of a signal mux is key for high-speed interface and video systems

So what should be the min BW for a given datarate. A good rule of thumb is BW should be greater than or equal to 1.5 or 2 times Niquist. For example, USB2 (240 MHz) times 1.5 is 360 MHz – 480 MHz. Obvious, high bandwidth will provide sharper edges, but you don't want too much BW. Too much BW can have the undesired affect of passing unwanted signal (noise).

3.1 Muxes for USB Systems

USB is a high-speed interface that enables devices to communicate over a standard interface. Multiple USB devices can be connected to a computer, and analog muxes are used to route the USB signal to different devices or ports. Most of the latest USB applications also require charging the portable devices over the USB interface. The USB 2.0 and USB3.1 specification is for high-speed signals that require high-bandwidth and low-capacitance analog muxes.

The Niquist frequency of USB2 HS is 240 MHz, 2.5 GHz for USB3 SS Gen1 and 5 GHz for USB3 Gen2. Picking the right mux is very important to pass USB compliance tests. For some analog muxes TI offers for USB applications, see Table 3-1.

Table 3-1. TI Muxes for USB Systems

Part	Function	Ron (Ω)	BW (Mhz)	Supply (V)	OVP (V)	ESD	System
TS3USB31E	SPST	6.5	1100	2.25–4.3	x	HBM 8 kv	USB2 HS
TS3USB30E	SPDT	6	900	3–4.3	x	HBM 8 kv	USB2 HS
TS3USB221	SPDT	3	1100	2.6–3.6	x	HBM 2 kv	USB2 HS
TS3USB221A	SPDT	3	900	2.6–3.6	x	HBM 7 kv	USB2 HS
TS5USBC41	SPDT	5.6	1200	2.3–5.5	20/24	HBM 2 kv	USB2 HS
TS3USB3000	SPDT	5.7	6100	2.3–4.8	9	HBM 3.5 kv	USB2 HS
TS3USB3031	SP3T	4.5	6500	2.5–4.3	x	HBM 2 kv	USB2 HS
HD3SS3212	SPDT	5	8000	3–3.6	x	HBM 2 kv	USB3.1 SS Gen1/2
TMUXHS4212	SPDT	5	13000	3–3.6	x	HBM 2 kv	USB3.1 SS Gen2/3
HD3SS3411	SPDT	5	7500	3–3.6	x	HBM 2 kv	USB3.1 SS Gen1/2
TMUXHS4446	SPDT/ crosspoint	5	9500	3-3.6	x	HBM 2kv	USB3.1 SS Gen1/2, USBC DP alt mode

3.2 Muxes for High Speed Video Systems (HDMI, Displayport)

HDMI and DisplayPort are high-speed video interfaces for transmitting uncompressed video data from an HDMI or DisplayPort source device to a compatible computer monitor, video game console, or HDTV. The HDMI and DisplayPort signal consist of four low-voltage differential signal (LVDS) pairs for the red, green, blue (RGB) video. An ideal HDMI and DisplayPort mux contains four differential pairs of 1:2 or 2:1 muxes with high bandwidth to avoid degrading video quality.

The Niquist frequency of HDMI 2.0 is 3 GHz, and 4 GHz for DP1.4. For some analog muxes TI offers for HDMI and DisplayPort video applications, see Table 3-2.

Table 3-2. TI Muxes for Video Systems

Part	Function	Ron (Ω)	BW (Mhz)	Supply (V)	OVP (V)	ESD	System
HD3SS215	SPDT	8	7000	3–3.6	x	HBM 1.5 kv	HDMI2.0/DP1.2
HD3SS214	SPDT	8	8000	3–3.6	x	HBM 2 kv	DP1.4
TS3DV642	SPDT	8.2	6900	2.6–4.5	x	HBM 2 kv	HDMI2.0/DVI
TMUXHS4612	SPDT	8	10000	3 - 3.6	x	HBM 2kV	HDMI2.1/ DP2.1

4 Summary

Analog muxes are often given a bandwidth specification. This indicates that the mux does not pass all frequencies in a time-varying signal. Analog signals through this system are attenuated. System designers need to make trade-offs between specifications in order to achieve optimal performance for the target application. This application note provides a relative guide in terms of importance of RON and BW for high-speed interface and video systems.

5 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision * (September 2019) to Revision A (July 2024) **Page**

- Updated Section 3.1 5
- Updated Section 3.2 6

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