

ADC32RF45: Amplifier to ADC Interface

ABSTRACT

This application report discusses interfacing RF sampling ADCs and RF amplifiers.

Contents

1	Introduction	2
2	Design Parameters	3
2.1	Source Resistance.....	3
2.2	Source Common Mode Voltage	4
2.3	ADC Input Resistance.....	5
2.4	AC Coupling	7
3	Printed Circuit Board Layout	8

List of Figures

1	Filter-Related Losses.....	3
2	Single-Ended Input Matching	4
3	Single-Ended Input Circuit.....	4
4	Terminated Filter Frequency Response	5
5	Filter With Only On-Chip Termination.....	5
6	Partially Terminated Filter Frequency Response.....	6
7	AC-Coupled Circuit Schematic.....	7
8	AC-Coupled Frequency Response	7

1 Introduction

System designs using amplifiers and analog-to-digital converters (ADC) should focus on using the best features of each device. Amplifiers provide power gain, isolation, voltage gain, and impedance transformation. Data converters would seem more simple, offering only the digitization of a voltage; however, the ADC sample rate is a degree of flexibility that can be quite powerful. This application note focuses on combining the best performance characteristics of amplifiers and ADCs for high speed, high linearity data capture. This document concentrates mainly on the LMH5401 family of amplifiers and the ADC32RF4x series of ADCs.

The LMH5401 family of amplifiers includes the LMH3401 fixed-gain amplifier, the LMH5401 fully-differential amplifier (FDA) and the LMH3404, dual-fixed-gain amplifier. Because the ADC32RF45 ADC is a dual-channel device, this document focuses on the LMH3404 amplifiers; however, the other amplifiers in the family can be used with similar design guidelines.

This application note covers a very specific system design. The design focuses on an RF signal with 750 MHz of bandwidth and a single-ended signal source, such as an antenna or mixer. The system consists of the amplifier, a simple, anti-alias filter, and the ADC.

The LMH3404 amplifier offers excellent performance up to 1-GHz signal bandwidth. This amplifier also offers 20 dB of gain and up to a 5-V differential signal swing. It is an excellent choice for our 750-MHz signal bandwidth system.

The LMH3404 amplifier has 7 GHz of -3 -dB bandwidth, and the ADC34RF45 has an input bandwidth of 4 GHz. Without a noise filter between the amplifier and the ADC, the ADC samples all noise in the 4-GHz bandwidth of the ADC. In order to reduce the sampled noise, and also to reduce the harmonic distortion of the sampled signal a low-pass filter is used between the amplifier and the ADC.

The ADC32RF45 is a high performance 14-bit, 3.0-GSPS ADC. With a 1.5-GHz first Nyquist zone, this ADC affords a very large amount of flexibility in filter design. With a 750-MHz desired signal bandwidth, there is an additional 1.5 GHz of frequency guard band to ensure that undesired noise and harmonic distortion products are rejected. Half of the frequency guardband is between the 750-MHz desired signal bandwidth and the 1.5-GHz first Nyquist band of the ADC. The other half of the frequency guardband is in the ADC second Nyquist band. This illustrates the benefit of oversampling, which is basically using a faster than necessary ADC to improve signal fidelity.

Designing a filter to pass the desired frequencies is fairly easy. However, one of the largest drawbacks to real filter implementation is the loss of signal through the filter, or insertion loss. This signal loss contributes dB-for-dB to the ADC noise figure. What may be even worse is that the amplifier driving the ADC will generate distortion at multiples of the filter loss. For example, if a filter has 7 dB of loss, the amplifier needs to drive a signal 7 dB stronger. This results in second-order products with 14 dB higher levels and third-order products will be 21 dB worse. Some of these distortion products (intermodulation in particular) cannot be filtered out, so keeping filter loss to a minimum is critical to system performance. For this reason this application report focuses on using a low loss, low component count filter.

As [Figure 1](#) shows, the filter works best with termination at both ends. The ADC input is 50 Ohms, which can provide termination for the filter output; however, the LMH5401 output impedance is 20 Ω , so termination resistors are required. In the following example, each RT would be 15- Ω . The losses in this example are 6 dB in the termination resistors and 1 to 2 dB in the filter. Low order filters are easier to manufacture and have lower losses. With oversampling lower, order filters still provide enough rejection to reduce noise and distortion to acceptable levels.

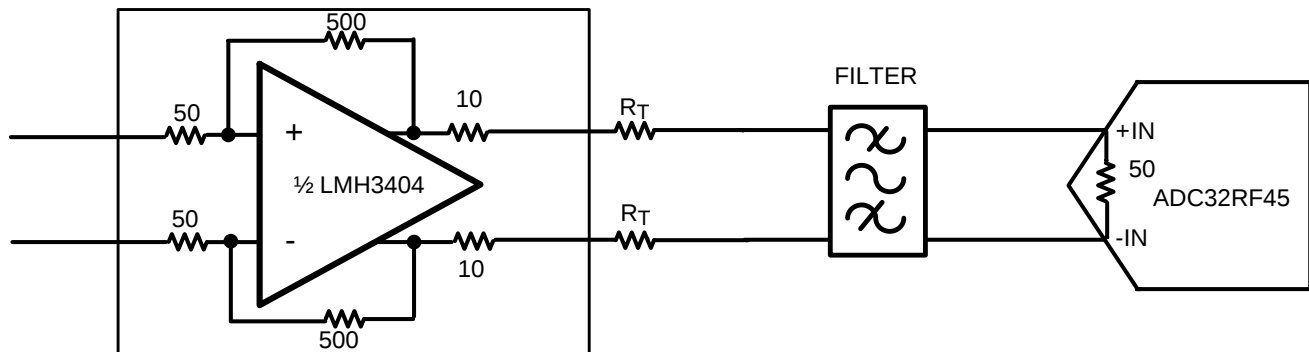


Figure 1. Filter-Related Losses

2 Design Parameters

Typically the ADC sets the initial design parameters. Our example ADC, the ADC32RF45, has an input full-scale voltage swing of 1.35 Vpp and a common mode voltage of 1.4 V. With an input impedance of 50 Ohms, the 1.35 Vpp input voltage is equivalent to approximately 7 dBm.

Working back down the signal chain from the ADC, next is the filter with expected losses of 1.5 to 2 dB. Termination resistors between the filter and the amplifier add another 3 dB (power) or 6 dB (Voltage). Because ADCs are not operated at full input amplitude, ignore the filter losses which brings the maximum voltage at the amplifier at 2.7 Vpp or 10 dBm. From the amplifier data sheet we see that a 1.4-V common mode and a swing of 2.7 Vpp is not possible on a single 5-V supply. This leaves two options, AC coupling or DC coupling but with split-power supplies. For the purposes of this application note the more difficult case of DC coupling is selected.

With DC coupling selected, use the following parameters:

- Positive supply voltage, $V+ = 4\text{ V}$
- Negative supply voltage, $V- = -1\text{ V}$
- Output common mode, $CM = 1.4\text{ V}$
- Source resistance, $R_s = 50\ \Omega$
- Total load resistance, $R_L = 100\ \Omega$ (50- Ω ADC + 50- Ω filter)
- Output voltage swing, $V_{out\ Max} = 2.7\text{ Vpp}$
- Input common mode (set by source) = 0 V

2.1 Source Resistance

Most signal sources have some inherent resistance or impedance. Most RF sources have a specific design resistance, such as a 50- Ω , single-ended source like a mixer or a transmission line. Other sources may have a higher resistance like a 100- Ω mixer or a 100- Ω shielded twisted pair transmission line. Many fully-differential amplifiers (FDA) are capable of converting single-ended sources into a differential signal. The LMH3404 is one example.

As Figure 2 shows, there are additional resistors required to match a single 50- Ω source to the LMH3404. With the addition of two resistors, the source impedance can be matched and the effective gain of the circuit is 8 V/V. For more details on single-ended operation, see the LMH3404 product data sheet (SBOS739).

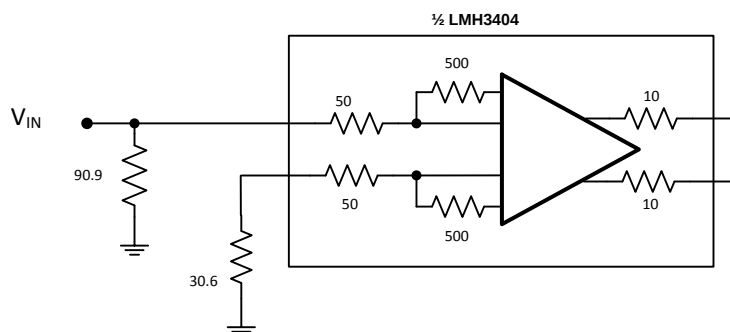


Figure 2. Single-Ended Input Matching

With two on-chip gain set resistors of 50- Ω each, the LMH3404 is internally matched for 100- Ω differential source resistances. Adding additional external resistors can match other source resistances.

2.2 Source Common Mode Voltage

With the ADC common-mode voltage of 1.4 V, the ideal source common mode would also be 1.4 V. One of the benefits of using an FDA amplifier is the ability to shift common mode. The LMH3404 can shift common-mode voltages from mid-supply -2 V to mid-supply 1 V. In this example, the mid-supply voltage is 1.5 V. With a source resistance of 50 Ω , the amplifier input pin voltage will be approximately 80 mV or 1.42 V from the mid-supply voltage. While the static bias voltage of 80 mV is within the acceptable range, the input voltage range prevents the amplifier from achieving full output voltage swing of 2.7 V. To counter this resistors are added to the positive supply. These resistors shift the amplifier input pin voltage from 80 mV to approximately 600 mV.

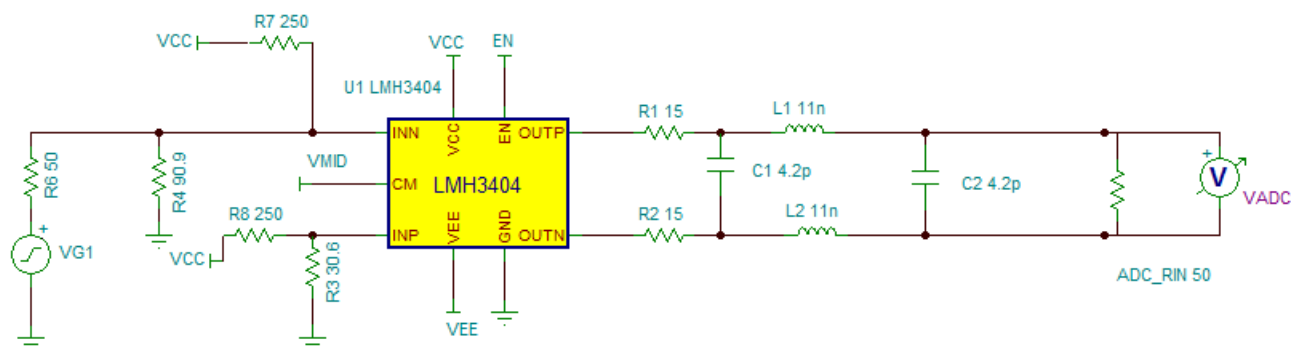


Figure 3. Single-Ended Input Circuit

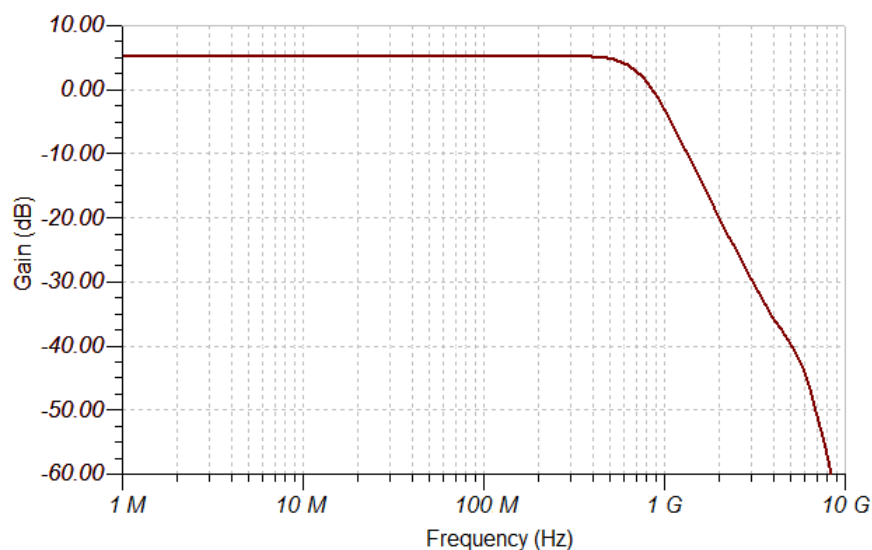


Figure 4. Terminated Filter Frequency Response

2.3 ADC Input Resistance

As previously mentioned, the ADC input resistance is 50 Ω . The first option when designing a filter is to terminate it, both input and output, with the designed characteristic impedance. The example in Figure 5 uses a filter with a 50- Ω characteristic impedance. The matching resistors R1 and R2 are only 15- Ω each because there are 10- Ω resistors on each of the LMH3404 chip outputs. When it is practical to use doubly-terminated filters, this is the best choice. The frequency response for this circuit is shown in Figure 4.

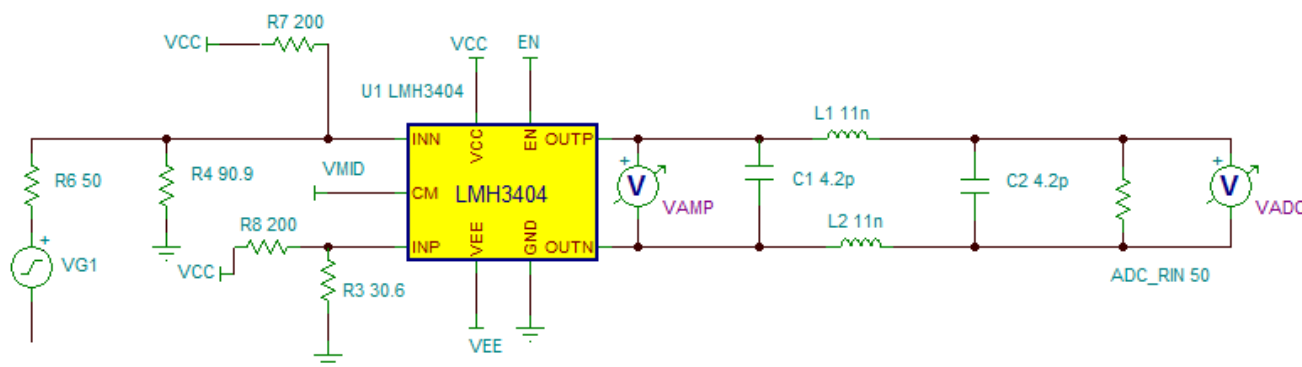


Figure 5. Filter With Only On-Chip Termination

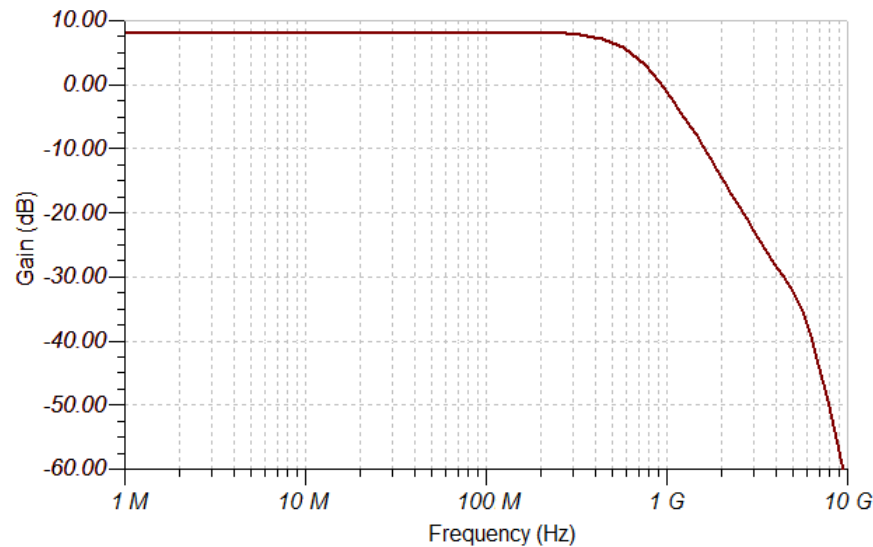


Figure 6. Partially Terminated Filter Frequency Response

The ADC32RF45 has a full-scale input voltage of 1.35 V. A doubly-terminated filter increases the voltage at the amplifier to 2.7 V while filter losses will further increase the voltage required at the amplifier by up to 3 dB or nearly 3.8 V. When operating an amplifier on only 5-V supply, the output voltage for highly linear operation is limited to around 4 Vpp. Even when the signal is below the maximum amplifier voltage, there are still benefits to running the amplifier at a lower output voltage. The main benefit of lower operating voltage is lower distortion products. Second order distortion products reduce dB by dB with signal amplitude. Third-order products decrease twice as fast, so a single dB reduction in signal swing gives 2 dB of distortion reduction for third-order products. For this reason the losses between the amplifier and the ADC should be kept to a minimum.

One option to reduce the losses between the amplifier and the ADC is to reduce the value of the termination resistors between the amplifier and the filter. This is shown in Figure 5. The LMH3404 has 20 Ω of on-chip resistance, so the filter still has some termination. Simulation shows that this change reduces the termination loss by 2.5 dB, as shown in Figure 6. Unfortunately, it also shifts the filter frequency response down in frequency from 750 MHz to 620 MHz. It also reduces the load impedance seen by the amplifier from 100 Ω to 70 Ω . The benefits of the decreased loss are partially negated by the lower load resistance. Simulation shows better linearity without the termination resistors. If this approach is taken, the amplifier and the filter and the ADC all need to be in very close proximity, otherwise traveling waves from the impedance mismatch will cause distortion.

Another option for reducing losses between the amplifier and the ADC is to use simpler, low order filters. The high sampling rate of the ADC gives a large Nyquist bandwidth and makes lower order filters practical.

2.4 AC Coupling

Whenever an actual DC voltage is not a part of the signal being sampled, AC coupling the amplifier and the ADC should be considered. With AC coupling, the amplifier common mode voltage and the ADC common mode voltage are separated and so a single 5-V power supply can be used for the amplifier. This removes the need for a negative voltage power supply. With a single 5-V supply, the CM pin is biased to 2.5 V. The 2.5-V reference can be made from a simple resistor divider. [Figure 7](#) shows a sample circuit with AC coupling. The sample circuit uses 0.1- μ F capacitors for coupling. The frequency response for this circuit is shown in [Figure 8](#). The low frequency corner is approximately 50 kHz. If lower frequencies need to be sampled, select a larger value capacitor.

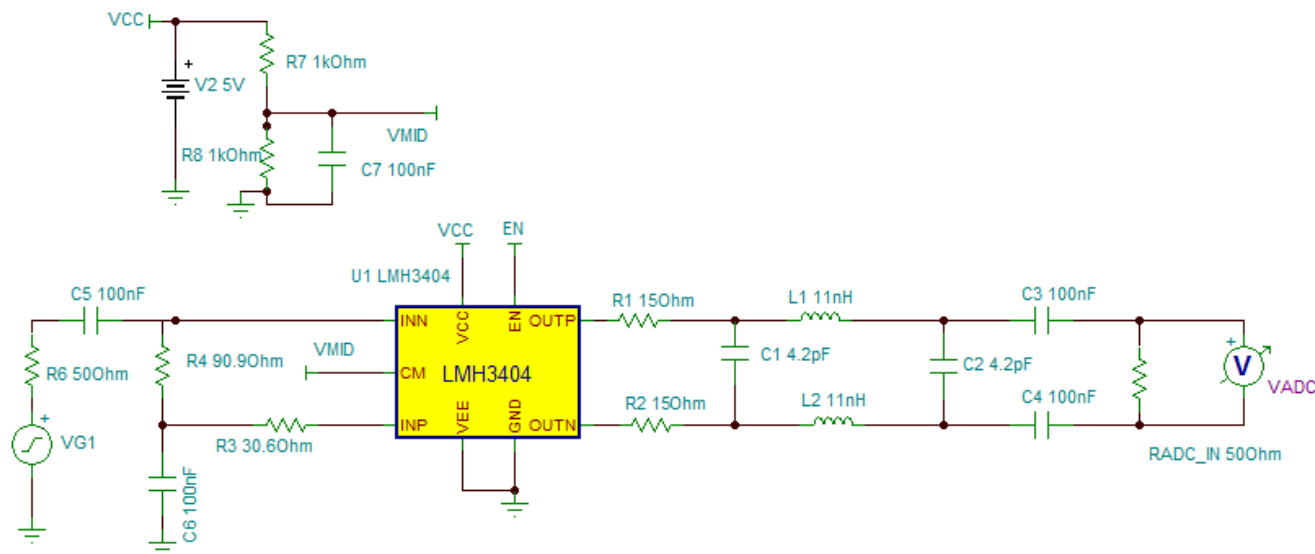


Figure 7. AC-Coupled Circuit Schematic

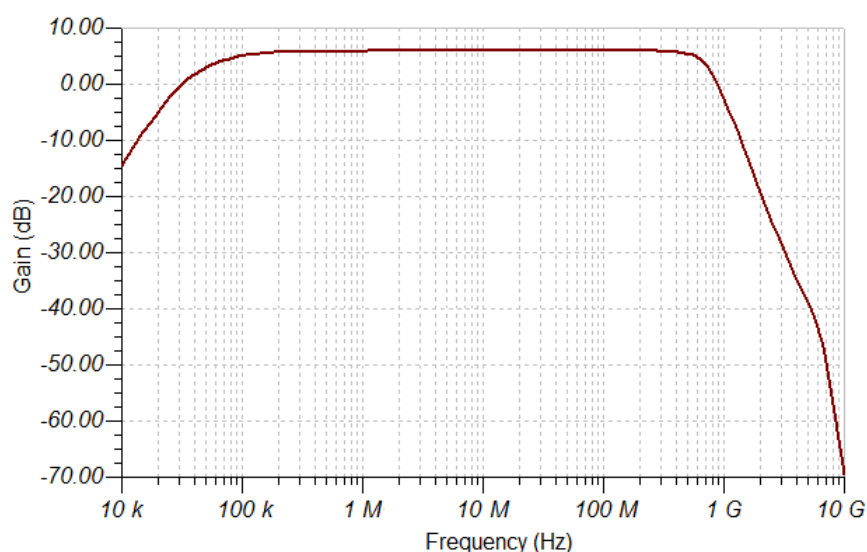


Figure 8. AC-Coupled Frequency Response

3 Printed Circuit Board Layout

The layout of the printed circuit board (PCB) has a dramatic influence on the system performance. Long PCB traces have a significant reactive characteristic. Inductance of long PCB traces limit system bandwidth and can also cause unwanted antenna effects. Signals on distant portions of the system board are readily picked up by long traces. When routing input and output traces for an amplifier, keep the input traces isolated from the output traces. When input and output traces are placed in close proximity there will be output-to-input coupling which could cause the amplifier to oscillate.

Power supply decoupling capacitors should be used and should be placed within 2 mm of the amplifier power pins. While bypass coupling capacitors are important, they are no substitute for using entire PCB planes to distribute power. If one entire board layer cannot be devoted to a particular supply voltage, have as much area as possible devoted to each voltage supply. See the LMH3404EVM user's guide ([SBOU166](#)) for a suggested amplifier board layout. Likewise; use the ADC32RF45EVM as a reference for the ADC layout.

Filter implementation is challenging at high frequencies as well. When laying out the filter on the PCB, it is helpful to remove ground and power planes for at least .020 in below the filter elements. This reduces the detuning of the filter response by the ground and power planes. Design filters for a frequency at least 10% higher than desired, because even with careful board design, the filter response will be shifted down. When designing a filter, make sure to carefully read the capacitor and inductor data sheets to be sure they will operate properly at the frequencies desired. Some common passive components are not specified for operation above 100 MHz.

While advancements in high performance, active circuits are making system designs more robust, there is still a need for the use of passive components. Using these filter techniques can make the most of that last passive stage in the signal path.

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