TEXAS INSTRUMENTS

Application Report

SNOA565A – July 2011 – Revised April 2013

AN-2177 Using the LMH6554 as an ADC Driver

ABSTRACT

This application report discusses the use of the Texas Instruments LMH6554 as an ADC driver.

Contents

List of Figures

List of Tables

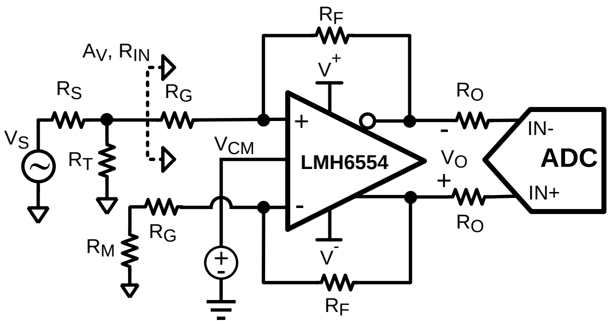
1 General Description

Texas Instruments latest family of ultra-high-speed data converters are capable of sampling frequencies in the low end of the GHz range and are designed to work with a fully differential signal. The combination of high frequencies and fully differential inputs translates into special requirements in terms of amplitude, phase match and high frequency hardware performance for single to differential conversion. The LMH6554 is part of the LMH™ high speed amplifier family.

Texas Instruments LMH6554 fully differential current feedback (CFB) operational amplifier is capable of performing the single-to-differential conversion required to drive these high speed ADCs. However, special considerations are required to ensure that the dynamic range of the circuit is not affected by the selected configuration. For more information, see *LMH6554 2.8 GHz Ultra Linear Fully Differential Amplifier* (SNOSB30).

2 Single-to-Differential Conversion

Traditionally, transformers have been used to provide single-to-differential conversion, but these are inherently band-pass by nature and cannot be used for DC-coupled applications. The LMH6554 provides excellent performance as a single-to-differential converter down to DC. Figure 1 shows a typical application circuit where an LMH6554 is used to produce a differential signal from a single ended source.



$$A_V = \left(\frac{2(1-\beta_1)}{\beta_1 + \beta_2}\right) \qquad \beta_1 = \left(\frac{R_G}{R_G + R_F}\right)$$

$$R_{IN} = \left(\frac{2R_G + R_M(1-\beta_2)}{1 + \beta_2}\right) \qquad \beta_2 = \left(\frac{R_G + R_M}{R_G + R_F + R_M}\right)$$

$$R_S = R_T \parallel R_{IN}$$

$$R_M = R_T \parallel R_S$$

Figure 1. Single-Ended Input with Differential Output

When using the LMH6554 in single-to-differential mode, the complimentary output is forced to a phase inverted replica of the driven output by the common-mode feedback circuit as opposed to being driven by its own complimentary input. Consequently, as the driven input changes, the common-mode feedback action results in a varying common-mode voltage at the amplifier's inputs, proportional to the driving signal. Due to the less-than-ideal common-mode rejection of the amplifier's input stage, a small common-mode signal appears at the outputs, which is superimposed on the differential output signal. The ratio of the change in output common-mode voltage to output differential voltage is commonly referred to as output balance error. The output balance error response of the LMH6554 over frequency is shown in Figure 2.

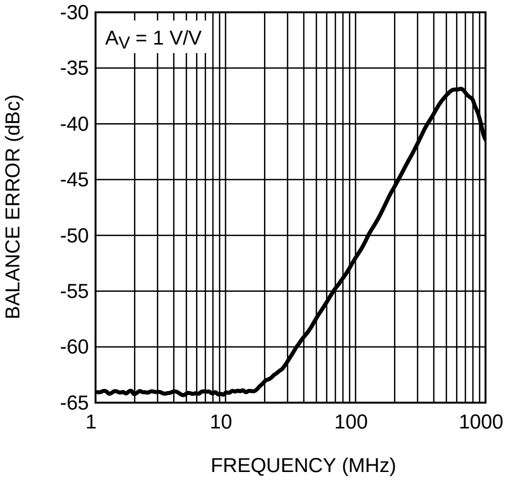


Figure 2. Balance Error

To match the input impedance of the circuit in Figure 1 to a specified source resistance, R_S, requires that $R_T||R_{IN}=R_S$. The equations governing R_{IN} and A_V for single-to-differential operation are also provided in Figure 1. These equations, along with the source matching condition, must be solved iteratively to achieve the desired gain with the proper input termination. Component values for several common gain configurations in a 50Ω environment are given in Table 1.

Table 1. Gain Component Values for 50Ω System

Gain	R_F	R_G	R_T	R_M
0 dB	200Ω	191Ω	62Ω	27.7Ω
6 dB		91Ω	76.8Ω	30.3Ω
12 dB		35.7Ω	147Ω	37.3Ω

3 Common-Mode Level Considerations

The output common-mode level of the LMH6554 can be set by the level present at the VCM pin (either by a simple resistive divider circuit, a dedicated voltage reference, or a reference level define by an ADC), Figure 3, and has a typical range of ±1.25V relative to the common-mode level of the supply voltages (that is, $(V_+ + V_-)/2$). Often overlooked is the interaction between the output common-mode (VOCM) level and the input common-mode (VICM) level at the input terminals of the amplifier. The interaction between these two voltage levels is set by the feedback resistive network around the amplifier. This application bulletin focuses on analyzing some of the typical configurations of the LMH6554 with proper biasing to achieve optimal performance in driving Texas Instruments ultra-high-speed ADCs.

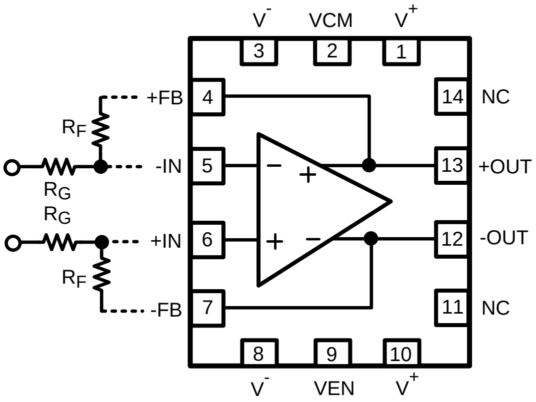


Figure 3. LMH6554 Pinout

4 LMH6554 DC-Coupled Configurations

The configuration shown in Figure 4 is a single-ended-to-differential conversion circuit set for a theoretical gain of 6dB. This configuration uses a dual symmetrical voltage supply of ±2.5V, thus setting the common mode of the entire amplifier to $V^+ + V^- = 0$. If the VOCM of the amplifier is set to 0V (Ground) via the VCM pin, the VICM is also set to 0V (assuming zero offset from the differential source V_S). Under these conditions the amplifier is configured for optimal performance, and full dynamic range of the amplifier is available without any biasing conflicts. The output series resistors R_O at each amplifier output helps to isolate the amplifier from any load parasitic that may potentially cause undesirable oscillations. R_O can be selected to match the ADC input resistance to properly balance the output impedance.

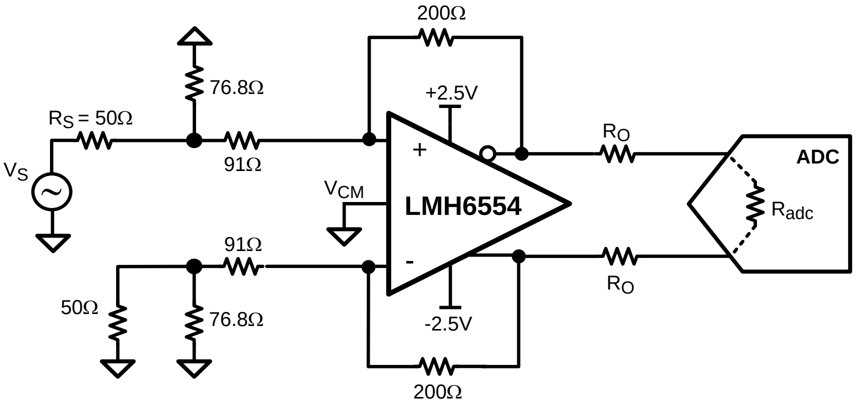


Figure 4. LMH6554 SE-Input ADC Driver Circuit with A = 6dB

Now let’s consider the case if VOCM is increased to 1.25V by connecting the VCM pin to a 1.25V reference voltage. It will be shown that the driver circuit dynamic has completely changed. If the previous circuit in Figure 4 is just transferred without any further consideration the bias conditions will change as displayed in Figure 5.

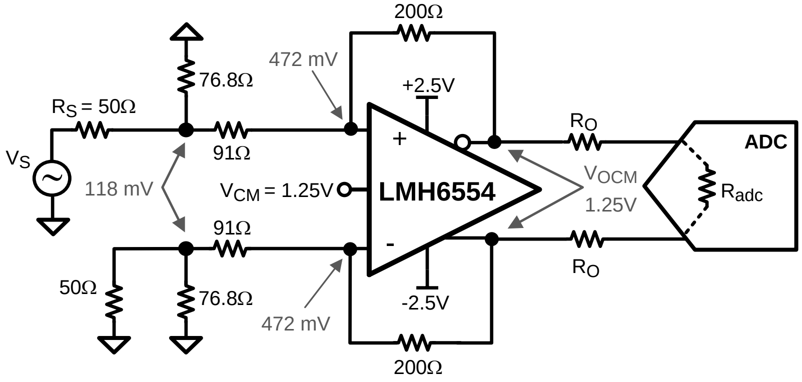


Figure 5. Previous Circuit with VCM = 1.25V

The circuit will exhibit very poor performance due to the following reasons:

- The VCM pin is already at the nominal limit of 1.25V.
- As specified in the LMH6554 datasheet (SNOSB30), the nominal single-ended output voltage swing is ±1.42V. With the VOCM level set to 1.25V this squeezes the SE output swing headroom and limits the swing at the most to be 170 mV.
- Because of the feedback resistor divider affect, the VOCM will affect the VICM level by shifting it 472 mV towards the positive supply. As specified in the datasheet, the nominal VICM range is ±1.3V. This shift in VICM may only be suitable for applications that can tolerate input signals of up to 1.3V − 472 mV = 828 mV.

Some of Texas Instruments ultra-high-speed ADCs require an input common-mode level of 1.25V. Refer to Texas Instruments ultra-high-speed ADC datasheets for more details. To properly configure the LMH6554 as an ADC driver in a fully DC-coupled signal path such that it meets this input common-mode requirement, the reference voltage VCMO of the ADC is utilized by connecting it to the VCM pin of the amplifiers to set the output common-mode level to 1.25V. Because the amplifier is configured for a fully DC-coupled signal path, the amplifier’s split power supply values need to be shifted to the recommended value of V^+ = 3.75V and V^- = −1.25V. This is recommended so that the amplifier’s output common-mode level matches the ADCs input common-mode level of 1.25V required for some Texas Instruments ultra-high-speed ADCs. However, shifting the supply voltages does not solve the problem at the input terminals of the amplifier given that the voltage level will remain at 472mV. In order to balance the input and output common-mode levels of the amplifier to the same level of 1.25V, an additional set of pull-up resistors is needed.

The pullup resistors are important in this configuration because they assist in forcing the dc bias conditions of the amplifier such that VOCM = VICM. Under this condition the amplifier will provide optimal performance. The value of the pullup resistor is easily calculated using Equation 1 and Equation 2. The VICM voltage is set by the voltage divider formed by the pullup resistor, and the remaining resistors in the feedback path toward the source; in this case the equivalent resistance is set by 91Ω in series with the parallel combination of 76.8Ω and the 50Ω shunt from the driving source. Using Equation 1 and Equation 2, the required pull-up resistance to the +3.75V supply is then calculated to be 243Ω (the closest 1% commercial value). To simply the calculation, set VICM = VOCM = 1.25V and V^+ = 3.75V.

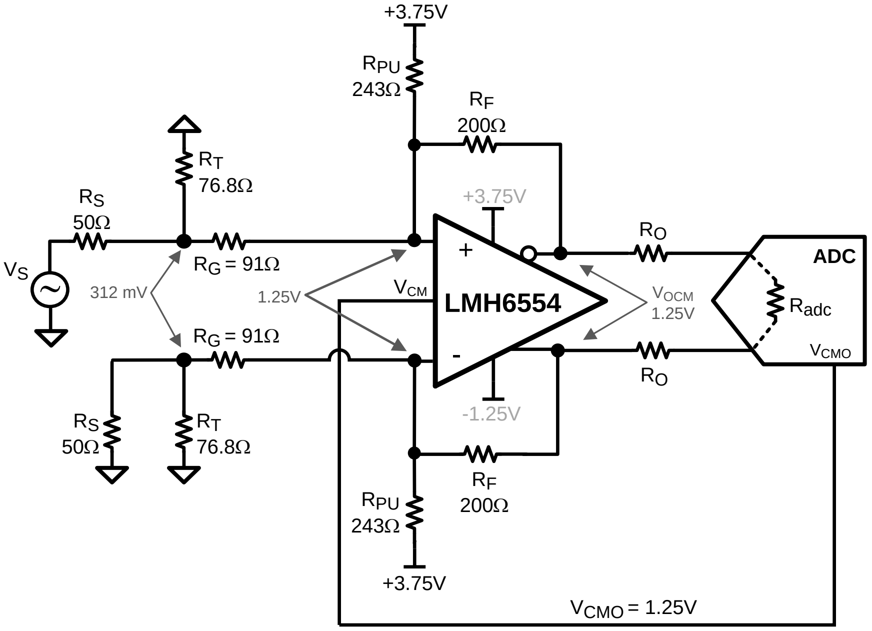


Figure 6. Fully DC-Coupled Configuration with Shifted Dual Supplies (VCM = 1.25V)

$$R_{IN} = R_G + R_S \| R_T \tag{1}$$

$$R_{PU} = \frac{(V_{ICM} - V_+)}{V_{OCM}\left(\frac{1}{R_F}\right) - V_{ICM}\left(\frac{1}{R_{IN}} + \frac{1}{R_F}\right)} \tag{2}$$

With the added pullup resistors in place the circuit is now properly biased and the complete full dynamic range and swing capabilities of the amplifier are restored. There are a few considerations to keep in mind for a fully DC coupled configuration:

- The source must be able to sink (or source) current. For the displayed configuration there is about 6.24 mA being injected to the 50Ω signal source.
- If a filter is present between the source and the amplifier, then it must be able to pass DC levels or the circuit must be re-configured to work with an AC coupled source.
- Keeping the circuit symmetrical helps to reduce undesired common-mode responses.

The fully dc-coupled configuration can be modified to work with an AC-coupled source in case the sourcing/sinking condition can not be met. Because the source is now ac-coupled it changes the input resistance as depicted in Equation 1 and thus the input bias condition. To maintain the same value of input common mode of 1.25V, the pull-up resistors have to be increased to 332Ω. Additionally, AC-coupling the non-drive input with a 50Ω termination in series with capacitor C keeps the circuit fully symmetrical and helps reduce offsets due to differences between the differential feedback paths.

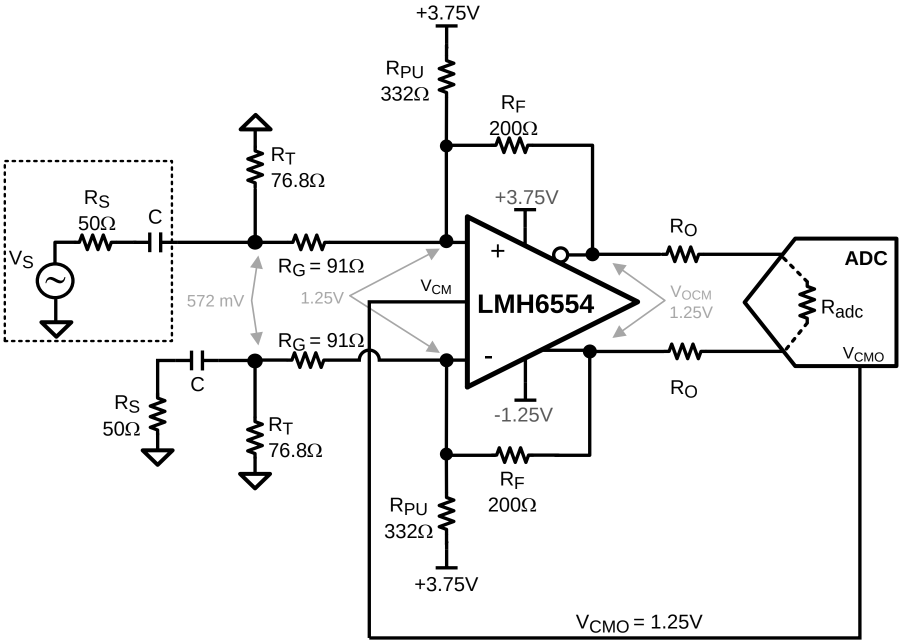


Figure 7. AC-Coupled Source Configuration (VCM = 1.25V)

5 LMH6554 AC-Coupled Configuration

AC-coupled configurations are attractive especially for those applications requiring a single voltage supply. The LMH6554 is capable of handing single-supply applications while maintaining optimal performance. AC-coupling the inputs allow the amplifier to self-bias to the same common-mode level set at the output. If the single-supply voltage of the LMH6554 is +5V, to achieve optimal performance the common-mode level should typically be set to mid-supply rail of VCM = 2.5V as shown in Figure 8. AC-coupling the LMH6554 for a single-supply application to drive Texas Instruments ultra-high-speed ADCs is also possible. It is recommended that under these conditions, the VCMO pin of the ADC be connected to ground so that the ADC will self-bias its differential inputs to the optimal input common mode using internal circuitry. Refer to Texas Instruments ultra-high-speed ADC datasheets for more details.

Bypassing the VCM pin of the LMH6554 is recommended to reduce noise contributions from either the resistive divider, external sources, or a fixed low-power low-noise 2.5V reference.

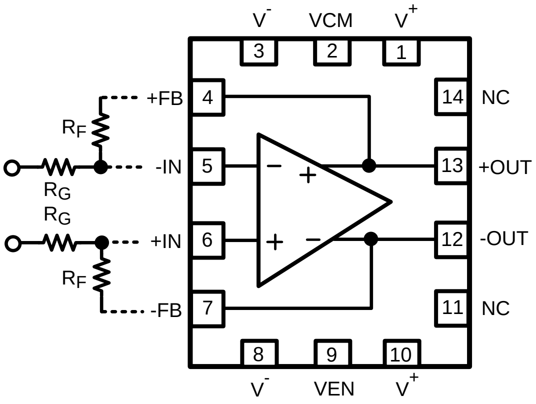


Figure 8. Fully AC-Coupled Single Supply Configuration (VCM = 2.5V)

6 LMH6554 Gain Compression at GHz Frequencies

While the LMH6554 exhibits excellent performance for frequencies in the upper MHz spectrum, the situation is quite different when the input frequency approaches the GHz range. If relatively good linearity is required, then it is important to ensure that the amplifier is working below the 1dB compression point or the ADC performance will be compromised by the distortion products coming from the driving amplifier. In order to test for linearity, the input-referred 1dB compression point of the circuit in Figure 7 was measured with a 100Ω load at 750 MHz and 1GHz. The power gain of the circuit is nominally −3dB due to the fact that the swing at the input; output ports is the same but the input impedance is 50Ω while the load is 100Ω. Results shown in Figure 9 from the 1dB compression point test show that the corresponding input power level at 750 MHz is +7dBm while at 1GHz it reduces to +3.9 dBm. Assuming that the ADC is connected directly to the amplifier, it would make sense to operate the amplifier below the limits mentioned above, meaning that at 750 MHz it could be operated with an input power of about +4dBm, while at 1GHz the maximum input power should not exceed 0dBm. The best performance is usually achieved when the amplifier is operating well below the compression zone.

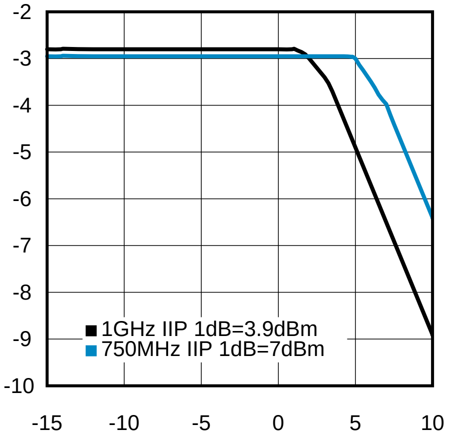


Figure 9. 1dB Compression Point of the LMH6554 at 750 MHz and 1 GHz.

7 Interconnect at GHz Frequencies

One important point that is commonly overlooked for high-speed GHz range amplifiers is the interconnect. Wiring techniques that seem to have no effect at lower frequencies become problematic at GHz frequencies. For example, open segments of PCB traces and unpopulated sections of the board connected to the main signal path can become resonant or produce undesirable reflections if the amplifier is operating in the GHz region. Figure 10 shows the LMH6554 stand-alone evaluation board with the 14-pin LLP package configured for the circuit shown in Figure 4. On the evaluation board it is evident that the high-speed coaxial-microstrip interconnect and well-designed interfaces reduce the effect of discontinuities. Un-driven ports are terminated with 50Ω SMA loads, and all DC blocking is done by coaxial structures or good quality capacitors geometrically compatible with the microstrip line. For this particular circuit configuration the source and load were AC coupled, and in order to avoid any imbalance in the circuit, DC blocking was added to the un-driven input port and the unused output.

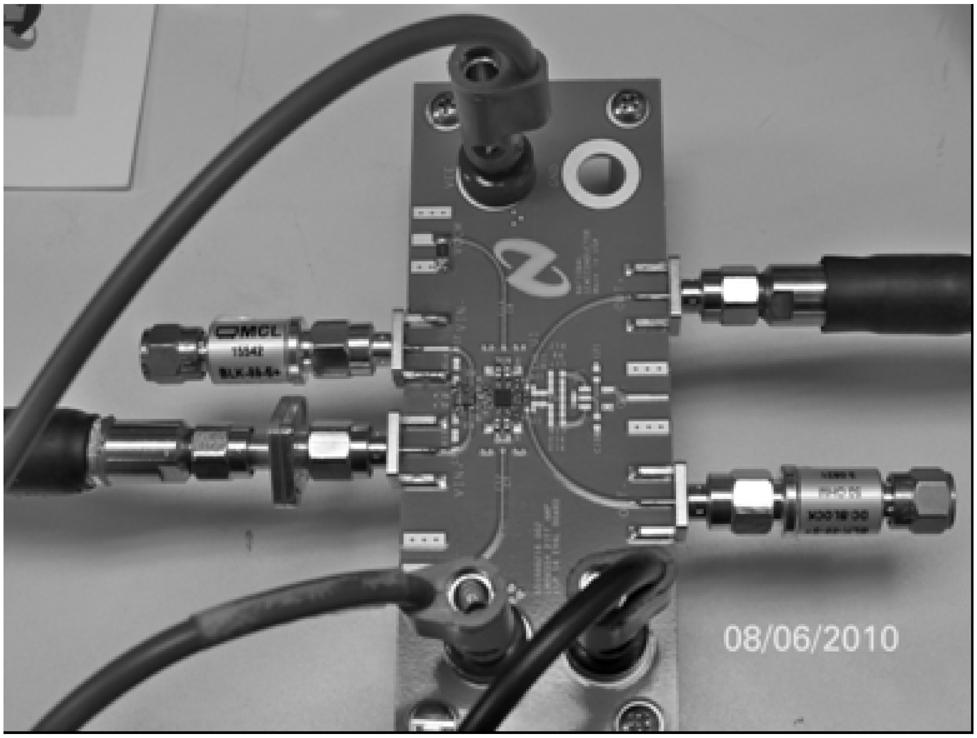


Figure 10. LMH6554 RF Test Setup

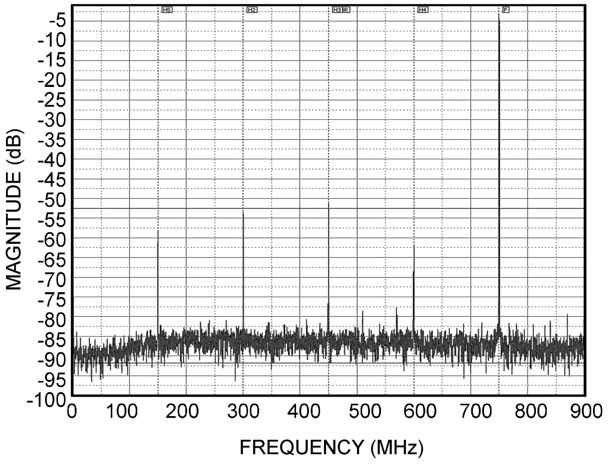
8 LMH6554 Driving a High-Speed 12-Bit ADC

In order to test the application ideas presented in the previous sections, a set of LMH6554 evaluation boards were configured for an AC-coupled source as shown in Figure 8 and for a fully DC-coupled with shifted split supplies as shown in Figure 7. Both of these driver configurations were interfaced with a high-speed 12-bit ADC (ADC12D1800) with an input frequency of 1.05 GHz at 1.5 dBm. Given that the main interest is to characterize the “raw” performance of the LMH6554+ADC system, there was no filtering between the output of the LMH6554 and the input port of the ADC. The selected ADC was configured according to the following parameters shown in Table 2.

Table 2. ADC Test Parameters

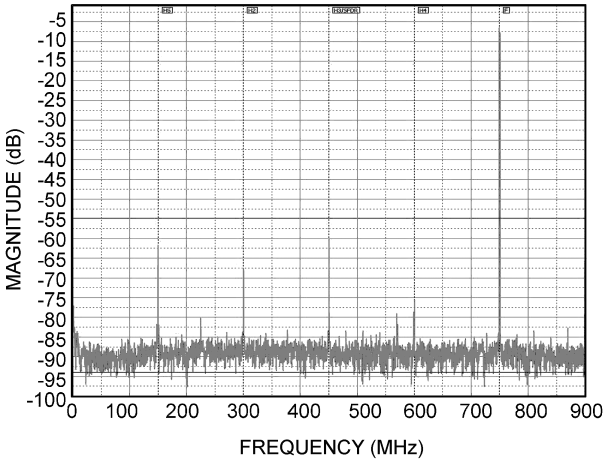
Parameter	Value
ADC Full-Scale Range	800 mVpp
ADC Common-Mode Level	1.25V
ADC DC-Input Impedance	100Ω
Input Mode	Single I channel unused port terminated on 50Ω
Input Frequency (at LMH6554 input port)	1.05 GHz @ +1.5 DBm with 1.5 GHz low-pass filter

The performance of the ADC with the fundamental at about −3dB below full scale (corresponding to a 1.5 dBm input power at the input of the LMH6554) shows the presence of a significant third order harmonic (HD3), Figure 11. Correlating this result with the actual linearity performance of the LM65554 suggests that distortion coming from the amplifier is the root cause for the presence of the third harmonic. Reducing the input power level at the LMH6554 input by 3dB results in a significant reduction of the third harmonic and improvement of the overall ADC performance as shown in Figure 12. Additionally, it is clear that the LMH6554 is unable to drive the ADC to full scale at GHz frequencies due to the inherent degradation in linearity and if optimal performance is required then the amplifier must be working well below the 1dB compression point and the addition of filtering stages would be recommended. With the addition of a dual 1.6GHz low-pass filter the effects of distortion products coming from the LMH6554 is reduced as shown in Figure 13.



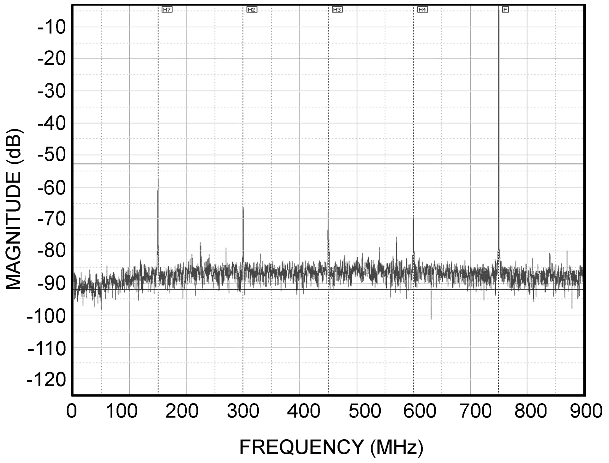
Fund Amplitude:	−3.127 dBFS
Fund Frequency:	749.982 MHz
Fund Bin:	6,827
SNR:	52.694 dBFS
SFDR:	50.628 dBFS
THD:	−47.869 dBFS
Sinad:	46.627 dBFS
ENOB:	7.453 Bits FS
Integrated Noise:	−52.594 dBFS
Average Noise:	−91.728 dBFS/Bin
DC Level:	−66.711 dBFS
Harmonic 2:	−53.480 dBFS
Harmonic 3:	−50.990 dBFS
Harmonic 4:	−61.966 dBFS
Harmonic 5:	−57.924 dBFS
Harmonic 6:	−62.479 dBFS
Harmonic 7:	−60.832 dBFS
Harmonic 8:	−66.334 dBFS
Harmonic 9:	N/A dBFS
Harmonic 10:	N/A dBFS

Figure 11. ADC Performance, Pin = 1.5 dBm AC-Coupled Mode (LMH6554 is Entering Compression Range)



Fund Amplitude:	−6.089 dBFS
Fund Frequency:	749.982 MHz
Fund Bin:	6,827
SNR:	54.845 dBFS
SFDR:	59.481 dBFS
THD:	−56.197 dBFS
Sinad:	52.502 dBFS
ENOB:	8.429 Bits FS
Integrated Noise:	−54.845 dBFS
Average Noise:	−93.979 dBFS/Bin
DC Level:	−56.212 dBFS
Harmonic 2:	−67.568 dBFS
Harmonic 3:	−60.025 dBFS
Harmonic 4:	−77.011 dBFS
Harmonic 5:	−61.850 dBFS
Harmonic 6:	−65.444 dBFS
Harmonic 7:	−63.690 dBFS
Harmonic 8:	−78.422 dBFS
Harmonic 9:	N/A dBFS
Harmonic 10:	N/A dBFS

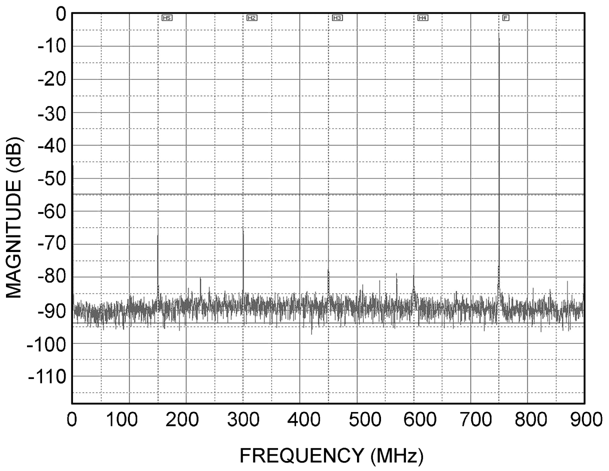
Figure 12. ADC Performance, Pin = -1.5 dBm AC-Coupled Mode (LMH6554 is Well Below 1dB Compression Point)



Fund Amplitude:	−2.953 dBFS
Fund Frequency:	749.978 MHz
Fund Bin:	6,826
SNR:	52.817 dBFS
SFDR:	57.817 dBFS
THD:	−53.055 dBFS
Sinad:	49.963 dBFS
ENOB:	8.007 Bits FS
Integrated Noise:	−52.817 dBFS
Average Noise:	−91.950 dBFS/Bin
DC Level:	−40.038 dBFS
Harmonic 2:	−65.914 dBFS
Harmonic 3:	−67.413 dBFS
Harmonic 4:	−68.972 dBFS
Harmonic 5:	−58.993 dBFS
Harmonic 6:	−56.322 dBFS
Harmonic 7:	−59.899 dBFS
Harmonic 8:	−69.454 dBFS
Harmonic 9:	N/A dBFS
Harmonic 10:	N/A dBFS

Figure 13. ADC Performance, Pin = 1.5 dBm AC-Coupled Mode with 1.6GHz LP Filters Between the LMH6554 and the ADCs Input Port (LMH6554 is Entering Compression Range)

The fully DC-coupled configuration with shifted supplies was tested with a Pin = −1.5dBm. The ADC performance shown in Figure 14 is practically equal to that of the AC-coupled configuration.



Fund Amplitude:	−5.896 dBFS
Fund Frequency:	749.982 MHz
Fund Bin:	6,827
SNR:	54.798 dBFS
SFDR:	63.071 dBFS
THD:	−56.193 dBFS
Sinad:	52.473 dBFS
ENOB:	8.424 Bits FS
Integrated Noise:	−54.798 dBFS
Average Noise:	−93.932 dBFS/Bin
DC Level:	−19.592 dBFS
Harmonic 2:	−65.158 dBFS
Harmonic 3:	−61.739 dBFS
Harmonic 4:	−76.478 dBFS
Harmonic 5:	−62.136 dBFS
Harmonic 6:	−61.533 dBFS
Harmonic 7:	−64.373 dBFS
Harmonic 8:	−77.612 dBFS
Harmonic 9:	N/A dBFS
Harmonic 10:	N/A dBFS

Figure 14. ADC Performance at Pin = -1.5dBm and Fully DC-Coupled Configuration

9 Summary

The overall performance of the LMH6554+ADC system is summarized in Table 3.

Table 3. LMH6554 ADC System Performance

	AC-Coupled Pin = +1.5dBm	AC-Coupled Pin = +1.5dBm With 1.6 GHz LP Filters	AC-Coupled Pin = -1.5dBm	DC-Coupled Pin = -1.5dBm
SNR	52.594 dBFS	52.817 dBFS	54.845 dBFS	54.798 dBFS
SFDR	50.628 dBFS	57.956 dBFS	59.481 dBFS	63.071 dBFS
THD	−47.869 dBFs	−53.055 dBFS	−56.197 dBFS	−56.193 dBFS
SINAD	46.627 dBFS	49.963 dBFS	52.502 dBFS	52.473 dBFS
ENOB	7.453 Bits FS	8.006 Bits FS	8.429 Bits FS	8.424 Bits FS
Integrated Noise	−52.594 dBFS	−52.817 dBFS	−54.855 dBFS	−54.798 dBFS

10 Conclusion

The LMH6554 is a suitable ADC driver for frequencies up to around 1GHZ and can be interfaced to high-speed data converters in DC- or AC-coupled configurations as long as the bias point of the amplifier is optimized for the target application, and the linearity constraints are taken into consideration. The addition of filtering stages is recommended if optimum performance is required and can be implemented in distributed, lumped or hybrid configurations.

The performance of the system at GHz frequencies is dependant on the layout, and actual hardware selection given that transmission line effects start to become noticeable.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265