

# TI Designs: TIDA-00654 Design Guide

## Cascaded LMH5401 and LMH6401 Reference Design



### TI Designs

TI Designs are analog solutions created by TI's analog experts. Reference designs offer the theory, component selection, and simulation of useful circuits. Circuit modifications that help to meet alternate design goals are also discussed.

### Circuit Description

This reference design consists of a fully-differential amplifier (LMH5401) cascaded with a digitally-controlled variable-gain amplifier (LMH6401) for wideband single-ended-to-differential conversion in both DC- or AC-coupled applications. The reference design is part of an analog signal chain driving an ADC in a typical receiver application. Evaluation of the design shows signal bandwidth close to 4.5GHz with maximum voltage gain of 30 dB and dynamic range of 32 dB configurable in 1-dB steps.

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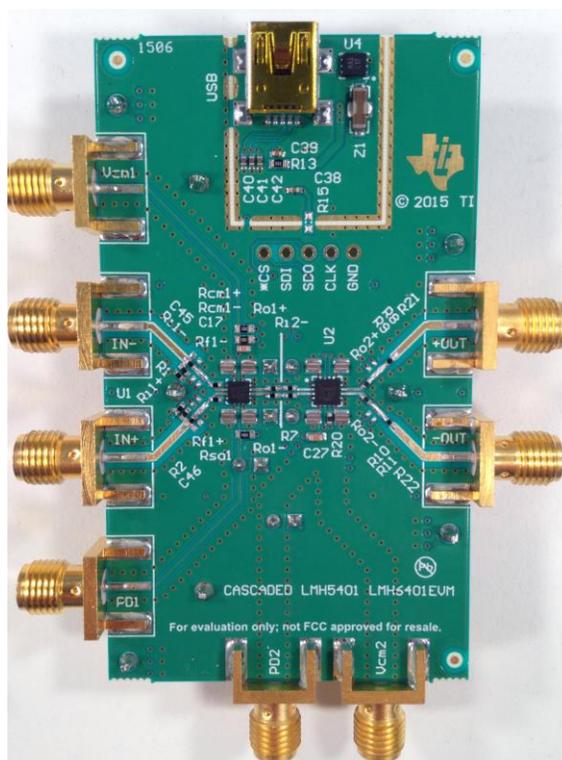


Figure 1: Reference-design Board



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## 1 Design Summary

- Supply Voltage: +5 V or +/- 2.5 V
- Supply Current: 129 mA
- LMH5401 and LMH6401 Output Common-mode Voltage Control:  $V_{MID} \pm 0.5 V$
- DC- or AC-coupled single-ended-to-differential signal conversion
- 30 dB maximum total voltage gain with 4.5GHz bandwidth
- Digitally-controlled gain range of 32 dB in 1dB gain steps

While designing receiver systems, one often encounters the need to convert a single-ended signal to a differential signal with bandwidths from DC to greater than 1 GHz. System design becomes even more challenging with varying input amplitudes that force the signal chain to automatically adjust its gain to maintain a constant level at the detector.

The conversion from single-ended to differential signaling is necessary because most of the commercially available high-frequency data converters (ADCs) accept differential signals for high SNR and SFDR performance. One could achieve the single-ended-to-differential conversion using a transformer or balun, but the limitation of such an approach is operation down to DC. For time-domain applications, the DC portion of a step response often has low-frequency gain droop due to the high-pass characteristic of a balun.

This reference design evaluates the performance of the LMH5401, the industry's fastest fully-differential amplifier (FDA), cascaded with the LMH6401, a digitally-controlled variable-gain amplifier (DVGA). This design is suitable for single-ended-to-differential conversion for both time-domain and frequency-domain applications. This design features DC- or AC-coupled 3dB signal bandwidth of 4.5GHz with total maximum voltage gain of 30 dB. Although this design converts a single-ended signal to a differential signal, it is also possible to use the same components as a fully differential solution.

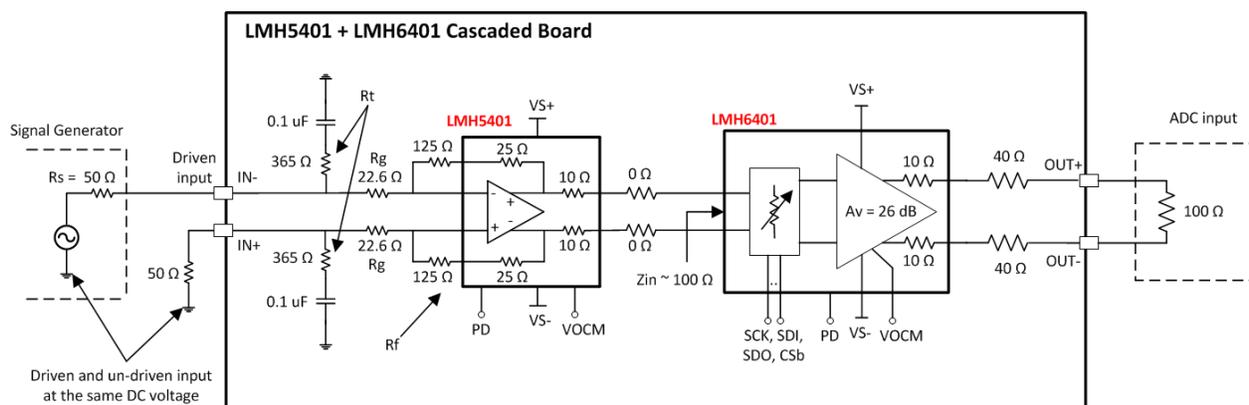


Figure 2: Cascaded LMH5401 and LMH6401 Schematic

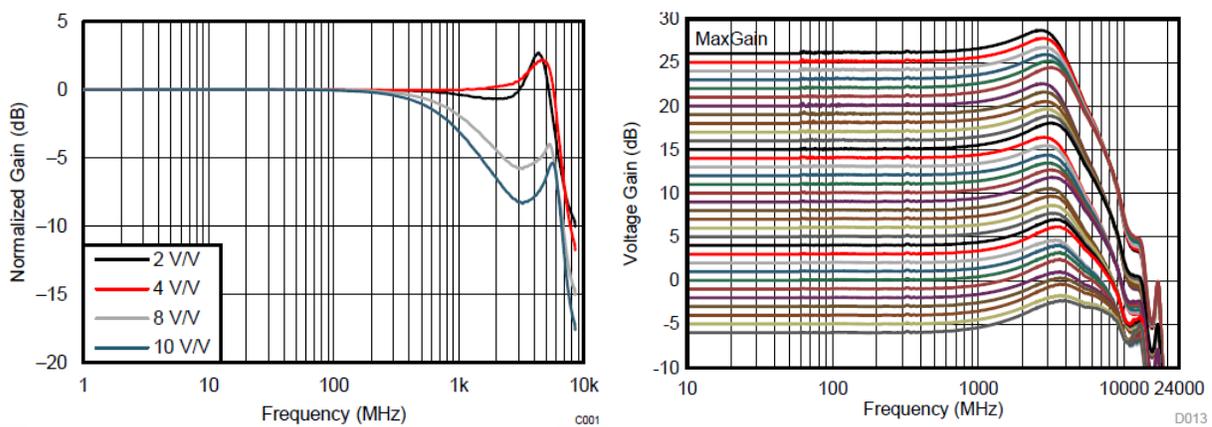
## 2 Theory of Operation

The basic schematic cascading the LMH5401 and LMH6401 is shown in Figure 2. This circuit converts a DC- or AC-coupled single-ended signal into a differential signal using an FDA (LMH5401) and then adjusts the signal amplitude with a DVGA (LMH6401). The cascaded signal chain is suitable for driving TI's high-speed 12-bit data converters (ADCs) for wide-band AC- or DC-coupled receiver applications.

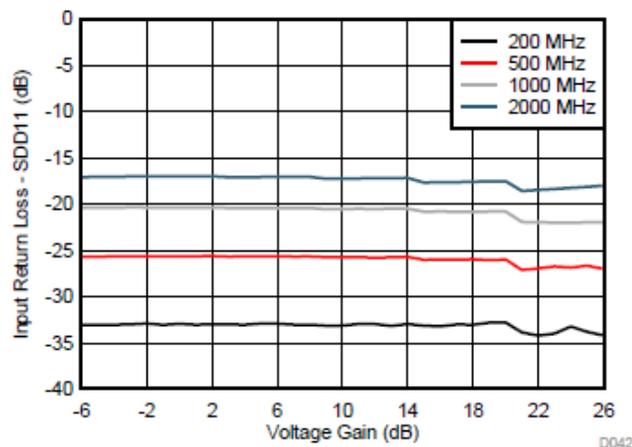
By choosing the appropriate feedback ( $R_f$ ), gain-setting ( $R_g$ ) and termination ( $R_t$ ) resistors, the LMH5401 is configured for a single-ended to differential gain of 4V/V as shown in Figure 2.  $R_t$  is selected to match the input impedance of the board to the source impedance (50Ω in this design).

In a cascaded signal chain, the first stage should not limit the bandwidth performance. As shown in Figure 3 (left), the LMH5401 gain of 4 V/V (12dB) was chosen because this gain achieves the highest signal bandwidth of 6GHz in this single-ended-to-differential configuration. Although the LMH5401's -3dB bandwidth is 6GHz, the overall bandwidth of the cascaded circuit is limited to the LMH6401's -3dB bandwidth of 4.5 GHz. The LMH6401 acts as a low-pass filter at the output of LMH5401, filtering out the harmonics contributed by the LMH5401. The overall gain peaking in the frequency response of the cascaded configuration is about 4.5 dB at 4.5 GHz, due to the combined peaking of both devices.

The LMH6401 gain ranges from 26dB to -6dB in 1dB steps achieving a 32dB dynamic range. Gain control is achieved using an FTDI-to-USB SPI bus translator chip. To reduce gain errors from one gain setting to the other, it is important to note that the change in input impedance or input return loss of the 2<sup>nd</sup> stage across gain steps should be minimal. As shown in Figure 4, LMH6401 exhibits constant input impedance across gain settings making it suitable for wide-band automatic gain control (AGC) applications.



**Figure 3: LMH5401 (left) and LMH6401 (right) Frequency Response**

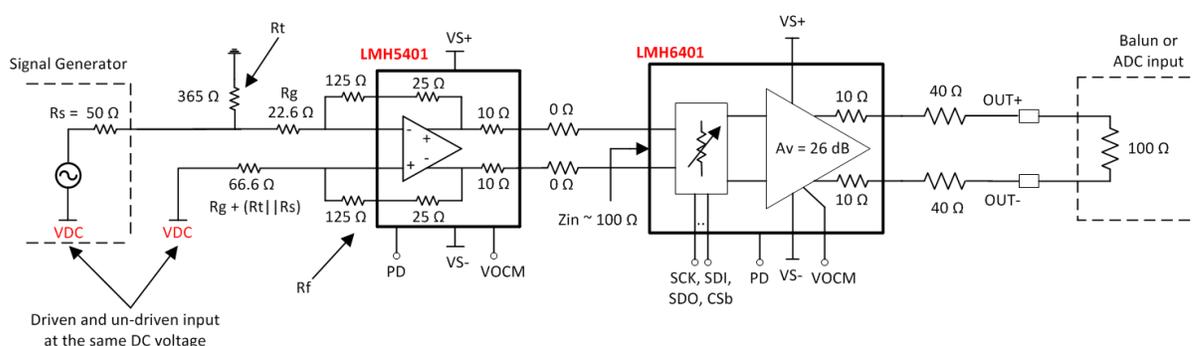


**Figure 4: LMH6401 Input Return Loss Across Gain Settings**

### 3 DC coupled single-ended to differential configuration

When using the LMH5401 and LMH6401 cascade in a DC-coupled single-ended-to-differential configuration, the input driven by the signal source as well as the undriven input should be maintained at the same DC voltage as shown in Figure 2. The DC common-mode voltage at both the inputs and outputs of the LMH5401 and LMH6401 should be within the limits specified in their respective device datasheets. In addition, the undriven input's termination ( $50\text{-}\Omega$  in this design) should be the same as the driving input's source impedance. This symmetry in the input impedance and DC voltages minimizes the FDA's output common-mode offset error and suppresses second harmonic distortion.

The reference-design board can be used with both single-ended input as well as differential inputs. As a result, the undriven input requires an off-board source impedance termination ( $50\Omega$  in this case) when used in a single-ended-to-differential configuration. In an actual system, however, the external  $50\Omega$  termination on the undriven input appears in parallel with the on-board  $365\Omega$  ( $R_t$ ) and can be replaced with an equivalent resistor of  $(R_s || R_t)$  or  $(50\Omega || 365\Omega)$ . This on-board resistor can be further combined with resistor  $R_g$  to obtain a single value of  $66.6\Omega$  at the undriven input, as shown in Figure 5.



**Figure 5: DC-coupled single-ended-to-differential configuration with  $R_g$  and  $(R_s || R_t)$  combined into a single resistor on the undriven input**

#### 3.1 Voltage-gain Calculation

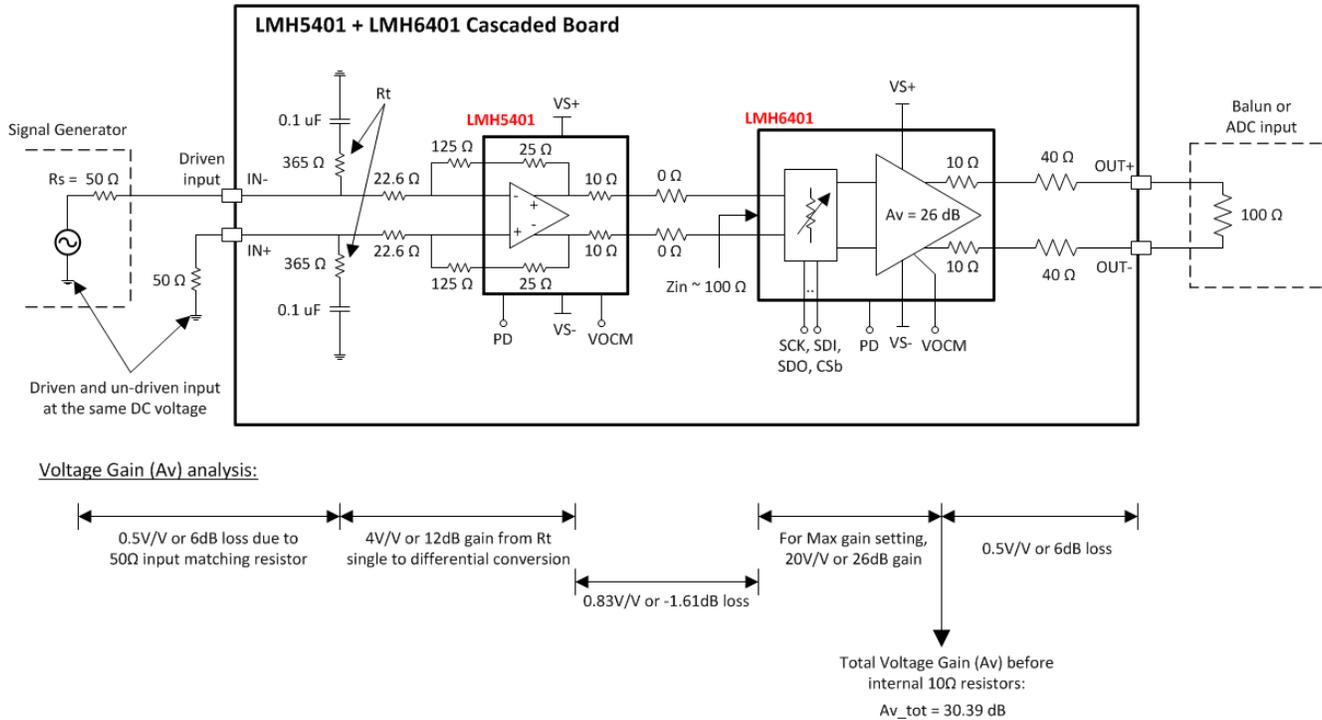
Figure 6 shows the voltage gain ( $A_v$ ) analysis of the cascaded signal chain. The LMH5401 gain is configured for a single-ended-to-differential gain of  $4\text{ V/V}$  by choosing the appropriate feedback ( $R_f$ ), gain setting ( $R_g$ ) and termination ( $R_t$ ) resistors. The termination resistor is chosen to match the input impedance to a given source impedance ( $50\Omega$  in this design).

Even though the LMH5401 is set for  $4\text{V/V}$  or  $12\text{dB}$  gain, there is a  $6\text{dB}$  loss between the signal source and the input impedance of LMH5401. As a result, the voltage gain from the signal generator to the LMH5401 output before its internal  $10\Omega$  resistor is  $6\text{dB}$ . Calculation of the LMH5401's voltage gain and bandwidth for different source impedances and gain settings is thoroughly explained in the LMH5401 datasheet. A quick reference calculation of the LMH5401's gain and input impedance is also provided in the Appendix. A table for standard single-ended-to-differential gain values for a  $50\Omega$  system is also provided in Table 1 below.

| $A_v$ (V/V) | $R_G$ ( $\Omega$ ) | $R_T$ ( $\Omega$ ) | $R_F$ (Total / External, $\Omega$ ) |
|-------------|--------------------|--------------------|-------------------------------------|
| 2           | 90.9               | 212                | 200 / 175                           |
| 4           | 22.6               | 357                | 152 / 127                           |
| 8           | 12.1               | 1100               | 250 / 225                           |
| 10          | 9.76               | 1580               | 300 / 275                           |

**Table 1: LMH5401 SE-to-Diff Gain Calculation Table for  $50\text{-}\Omega$  Systems**

The interface between the LMH5401 output and LMH6401 input has a 1.61dB voltage loss due to the voltage division between the 10Ω resistor on each output leg of the LMH5401 and the 100Ω input impedance of LMH6401. The LMH6401 has configurable gain from 26dB to -6dB in 1dB steps achieving a 32dB gain range. As a result, the total voltage gain of the cascaded signal chain from the signal generator to the LMH6401 outputs before the internal 10Ω resistors can be configured from 30.39 dB to -1.61 dB.



**Figure 6: Input GND-referenced DC-coupled Single-ended-to-differential Conversion**

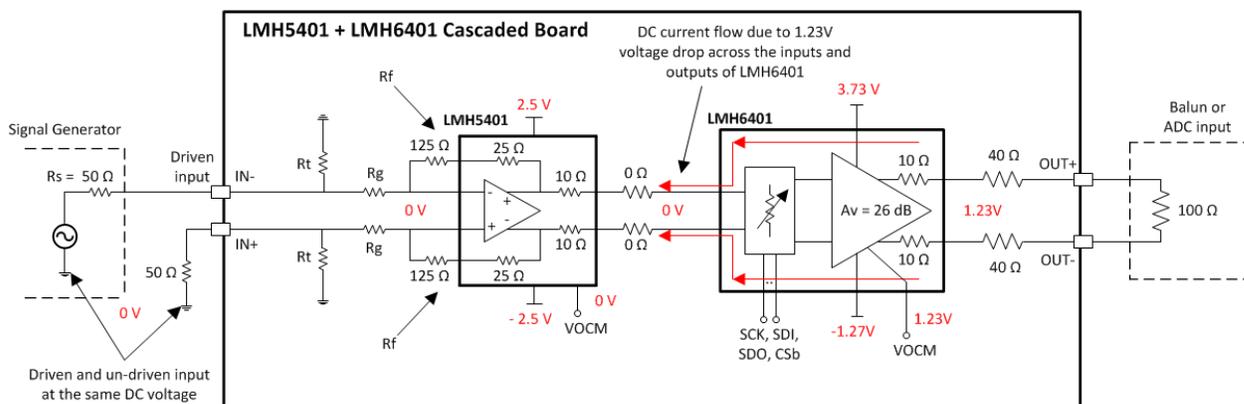
### 3.2 Common-mode Considerations

In DC-coupled applications, maintaining the devices within their common-mode specifications is important for reliable operation of the cascaded signal chain. The interface circuitry at the input and output normally dictate the common-mode settings of the DC-coupled cascaded signal chain.

Consider a system using the cascaded LMH5401 and LMH6401 design to convert a GND-referenced DC-coupled single-ended input to an output common-mode voltage of 1.23V (for example, the input common mode voltage of an ADC). When designing a DC-coupled system, the CM setting for each device is calculated by working backwards from the output to the inputs. In addition, supplies to the individual devices in a cascade are selected such that the output CM of each device is at mid-rail between the positive ( $V_{s+}$ ) and negative ( $V_{s-}$ ) supplies for best linearity performance.

Figure 7 shows one approach of the cascade design converting a GND-referenced DC-coupled input into an output CM voltage set to 1.23 V. In this approach, the LMH6401 supplies ( $V_{s+} = 3.73V$  and  $V_{s-} = -1.27V$ ) have been selected such that the output CM voltage is at mid-rail to achieve the best linearity performance. Since the input is GND referenced, the LMH5401's output CM is also set to 0V. This eliminates any DC current flow from the LMH5401's output to the input signal source. As a result, the LMH5401 supplies ( $V_{s+} = 2.5V$  and  $V_{s-} = -2.5V$ ) are centered with respect to the GND-referenced output CM voltage.

Since the LMH5401's output CM voltage is at 0V and the LMH6401's output CM voltage is at 1.23V, there will be DC current flowing through the internal  $R_f$  and  $R_g$  resistors of the LMH6401. This DC current is due to the 1.23V voltage drop between the LMH6401 outputs and inputs and is driven by the LMH6401's output common-mode circuitry. As a result of this additional DC current flow, there will be an increase in the LMH6401's supply current.



**Figure 7: Selected Supplies for LMH5401 Output CM = GND and LMH6401 Output CM = 1.23V**

A second and more appropriate approach is shown in Figure 8, where both the LMH5401 and LMH6401 supplies are selected such that their output CM voltages are at mid-supply = 1.23V. As a result, there is no DC current flow from the LMH6401 outputs to inputs. Since the LMH5401's output CM voltage is 1.23V and the input signal source is GND referenced, there will now be some DC current flow across the feedback and gain resistors of LMH5401. As a result, the LMH5401's input common-mode voltage ( $V_{ICM}$ ) will be set to the value calculated by equation 1 for GND referenced input signal:

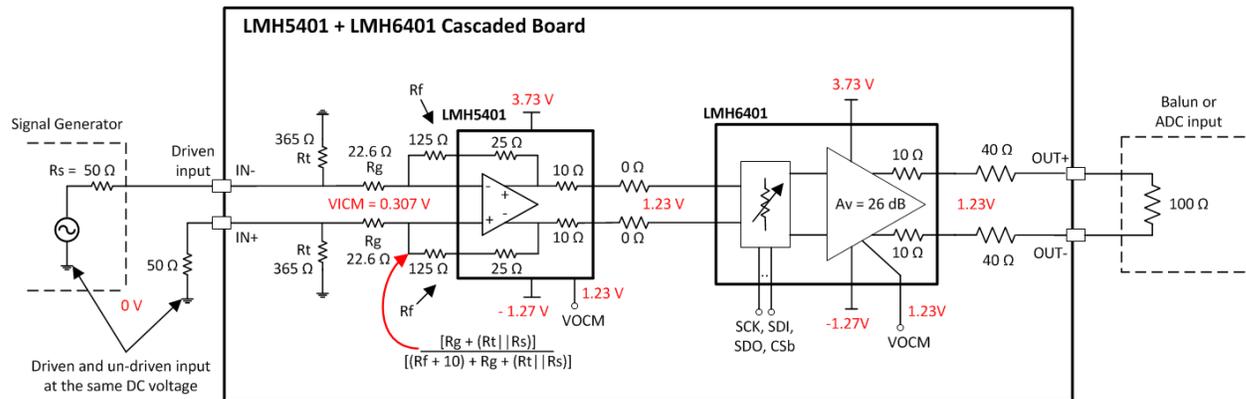
**Equation 1**

$$V_{ICM} = \frac{(R_g + (R_s || R_t))}{((R_f + 10) + R_g + (R_s || R_t))} * V_{OCM}$$

With the selection of  $R_s$ ,  $R_t$ ,  $R_f$  and  $R_g$  of LMH5401 as shown in Figure 8 and the output CM voltage ( $V_{OCM}$ ) at 1.23V, the LMH5401's input common-mode voltage ( $V_{ICM}$ ) is set to 0.293V. Since the LMH5401's output CM voltage appears after its internal 10Ω resistor, this resistor needs to be accounted for in the calculation of  $V_{ICM}$ . As shown in Table 2, the LMH5401's  $V_{ICM}$  falls well within its input common-mode voltage specifications.

| PARAMETER               | TEST CONDITIONS                | MIN               | TYP                        | MAX | UNIT | TEST LEVEL <sup>(2)</sup> |
|-------------------------|--------------------------------|-------------------|----------------------------|-----|------|---------------------------|
| <b>INPUT</b>            |                                |                   |                            |     |      |                           |
| Differential resistance | Open-loop                      |                   | 4600                       |     | Ω    | C                         |
| $V_{ICL}$               | Input common-mode low voltage  |                   | $V_{S-} - (V_{S-}) + 0.41$ |     | V    | A                         |
| $V_{ICH}$               | Input common-mode high voltage | $(V_{S+}) - 1.41$ | $(V_{S+}) - 1.2$           |     | V    | A                         |

**Table 2: LMH5401's Input Common-mode Voltage Specification**



**Figure 8: Selected Supplies for both the LMH5401 and LMH6401 Output CM = 1.23V**

With the second approach, the LMH5401 input common-mode voltage ( $V_{ICM}$ ) is offset from the mid-supplies  $((V_{s+}) - (V_{s-}))/2 = 1.23V$ . Most FDAs, however, require both the input common-mode ( $V_{ICM}$ ) and output common-mode ( $V_{OCM}$ ) voltages close to mid-supply to achieve the full dynamic range at the inputs and outputs.

Based on Equation 1, one may increase the value of  $R_g$  to level shift the FDA input common-mode voltage. However, one must be careful not to violate the noise gain (NG) specification of the FDA while increasing the value of  $R_g$ . Noise gain (NG) or inverse feedback factor ( $1/\beta$ ) is an important parameter that determines the stability of an amplifier that is not unity-gain stable. For amplifiers that are not unity-gain stable, the device datasheet usually specifies a noise gain below which the FDA becomes unstable. Noise gain (NG) for an FDA as shown in Figure 17 is given by the expression:

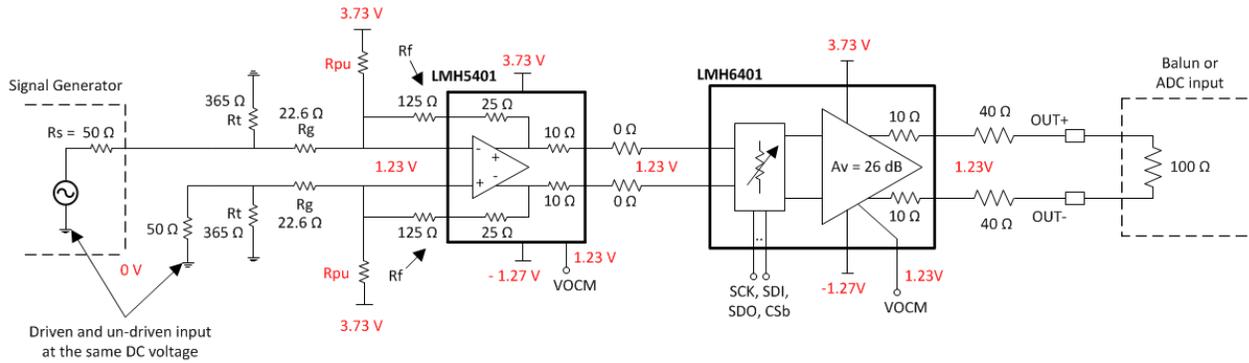
**Equation 2**

$$NG = 1 + \frac{R_f}{R_g + (R_s || R_t)}$$

From equation 2, noise gain is inversely proportional to the gain setting resistor ( $R_g$ ). Hence, increasing  $R_g$  could level shift the FDA's input common-mode voltage ( $V_{ICM}$ ) to its optimal value but also degrade the noise gain causing the FDA to oscillate. The LMH5401 is stable with  $NG \geq 3$  as specified in the datasheet. With the resistor values for an LMH5401 signal gain of  $4V/V$  (12dB) as shown in Figure 8, the NG is  $3.25V/V$ , which is close to the minimum value of 3. This example demonstrates that one must carefully select  $R_g$  when balancing between the input common-mode voltage and the noise gain.

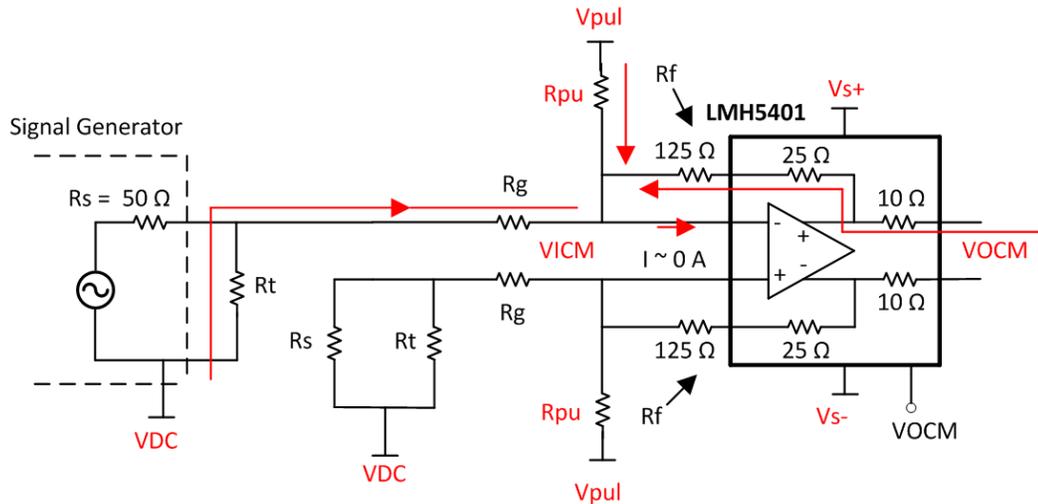
**3.1.1 Common-mode Level shifting at the LMH5401 inputs:**

As shown in Figure 9, another method of centering the LMH5401's input common-mode voltage is with the common-mode level shifting resistors ( $R_{pu}$ ) at the input pins connected to a positive supply. The  $R_{pu}$  resistor is usually tied to the positive supply ( $V_{s+}$ ) or negative supply ( $V_{s-}$ ) depending on whether the FDA's input common-mode voltage needs to be shifted up or down from the current value. With the LMH5401's resistors in Figure 8, the input common-mode voltage from Equation 1 is about 0.293V. This  $V_{ICM}$  value needs to be level shifted up to 1.23V so that it is centered with respect to the supplies:  $V_{s+} = 3.73V$  and  $V_{s-} = -1.27V$ . As a result, the  $R_{pu}$  will be connected to the nearest positive supply voltage ( $V_{s+}$ ) or 3.73V.



**Figure 9: Common-mode Level Shifting at the LMH5401 Inputs**

The value of  $R_{pu}$  is calculated by solving the KCL equation at the VICM node, as shown in Figure 10. For simplicity, only the LMH5401 path is shown as the LMH6401 contributes no DC current. As the FDA is symmetric across the driven and undriven input paths, applying KCL equation on only one path is sufficient to determine the value of  $R_{pu}$ .



**Figure 10: Direction of Currents at the LMH5401 VICM node**

Summing the currents at the VICM node gives the following equation:

**Equation 3**

$$\frac{VDC - VICM}{Req} + \frac{V_{pul} - VICM}{R_{pu}} + \frac{VOICM - VICM}{Rf + 10} = 0$$

where,  $Req = Rg + (Rs || Rt)$

Solving for  $R_{pu}$  gives the following equation:

**Equation 4**

$$R_{pu} = \frac{V_{pul} - VICM}{\frac{(VICM - VDC)}{Req} + \frac{(VICM - VOICM)}{Rf + 10}}$$

Usually, the FDA's VICM is set equal to VOICM to achieve full-scale dynamic performance at the inputs and outputs. As a result, the  $R_{pu}$  equation reduces to:

**Equation 5**



The feedback signal ( $V_{in+}$ ) is usually not an issue if it is a small signal and is within the input common-mode limits  $V_{ICL}$  and  $V_{ICH}$  as shown in Table 2. However, for large signal swings at the output due to inter-stage resistive loss between the LMH5401 and LMH6401, the feedback signal ( $V_{in+}$ ) can be high enough to swing close to the input common-mode limits and cause serious distortion. While using the LMH5401 and LMH6401 cascade, such a scenario also exists for lower gain settings of the LMH6401. In this case, the LMH5401's output has to swing higher to maintain a fixed output swing at the LMH6401. As a result, it is advisable to keep the loss between stages as low as possible to avoid degradation in linearity performance. This also shows the difficulty of using the LMH6401 at negative gain values.

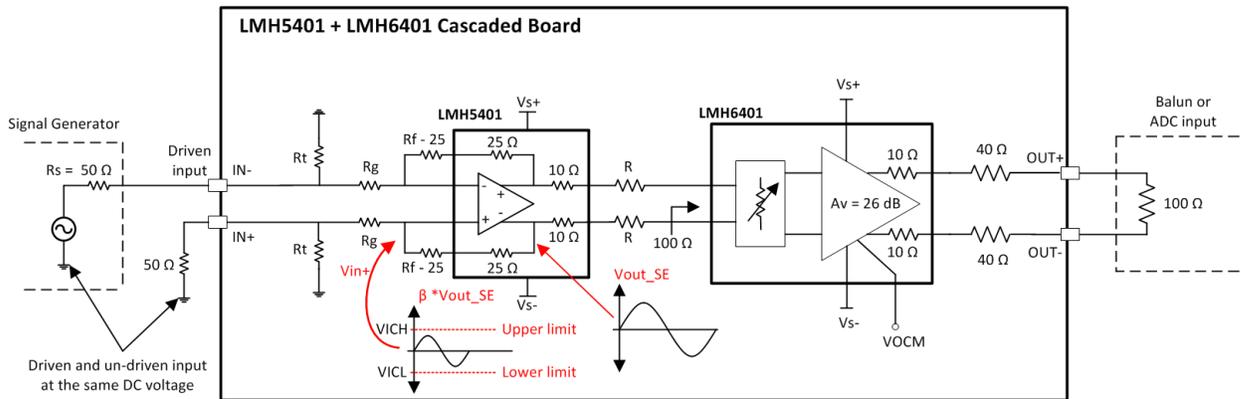


Figure 12: Feedback-signal Voltage Levels at the Undriven Input in SE-to-Diff configuration

#### 4 AC coupled single-ended to differential configuration

Figure 13 shows the cascaded board used in an AC-coupled single-ended-to-differential configuration with external DC blocking at the inputs and outputs as well as an ac-coupling capacitor between the stages. Using the cascade in an ac-coupled configuration relaxes the common-mode requirements between the stages by isolating the input and output common-mode voltages of the individual devices. The voltage-gain calculation for the ac-coupled single-ended-to-differential configuration is similar to the calculation in the DC-coupled configuration.

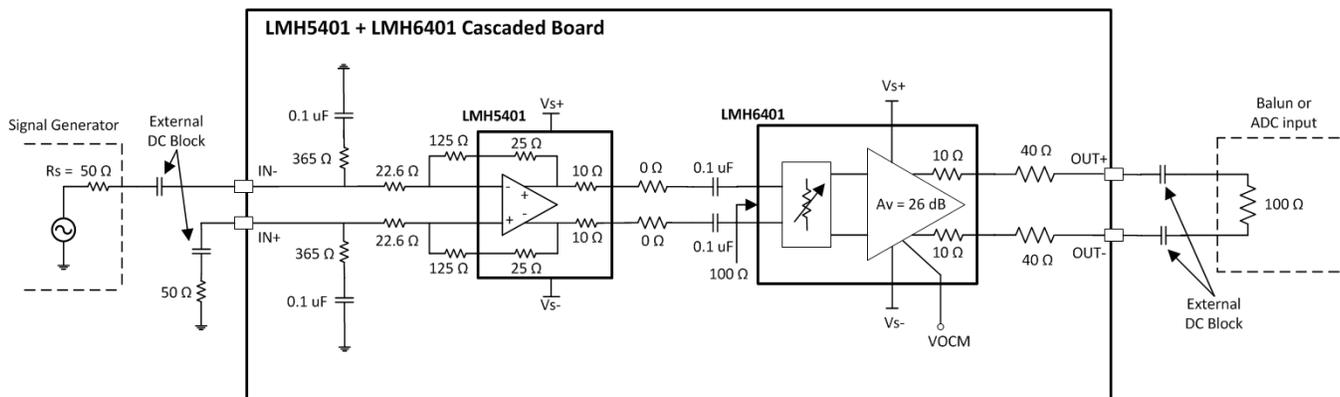
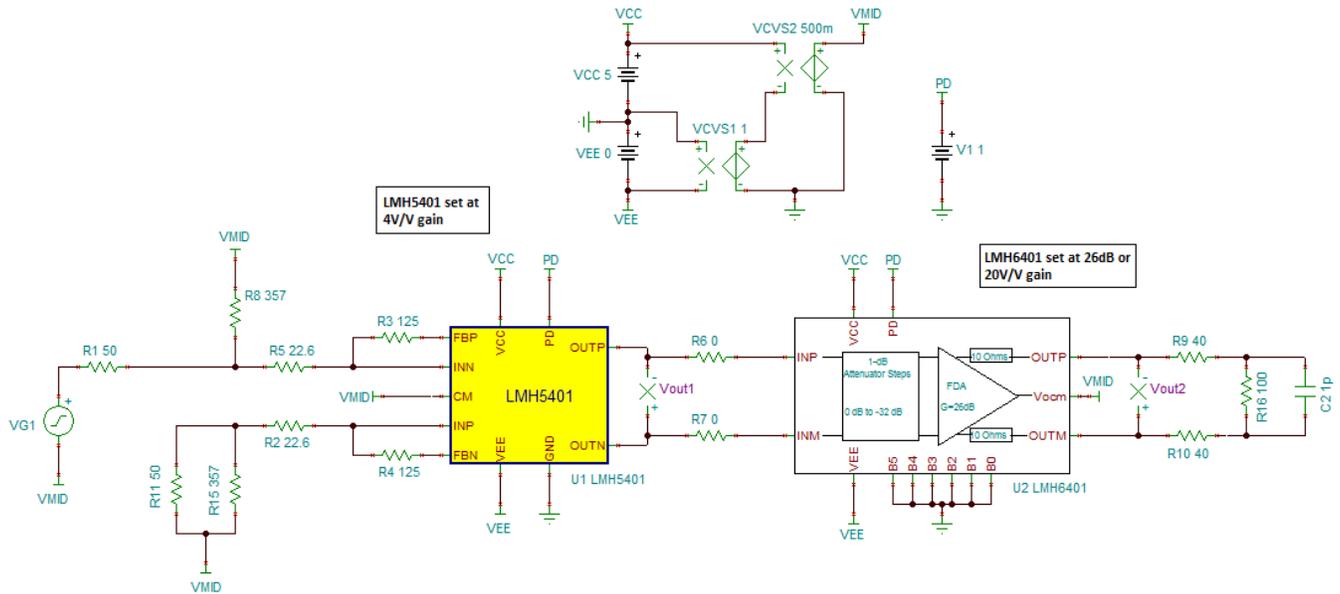


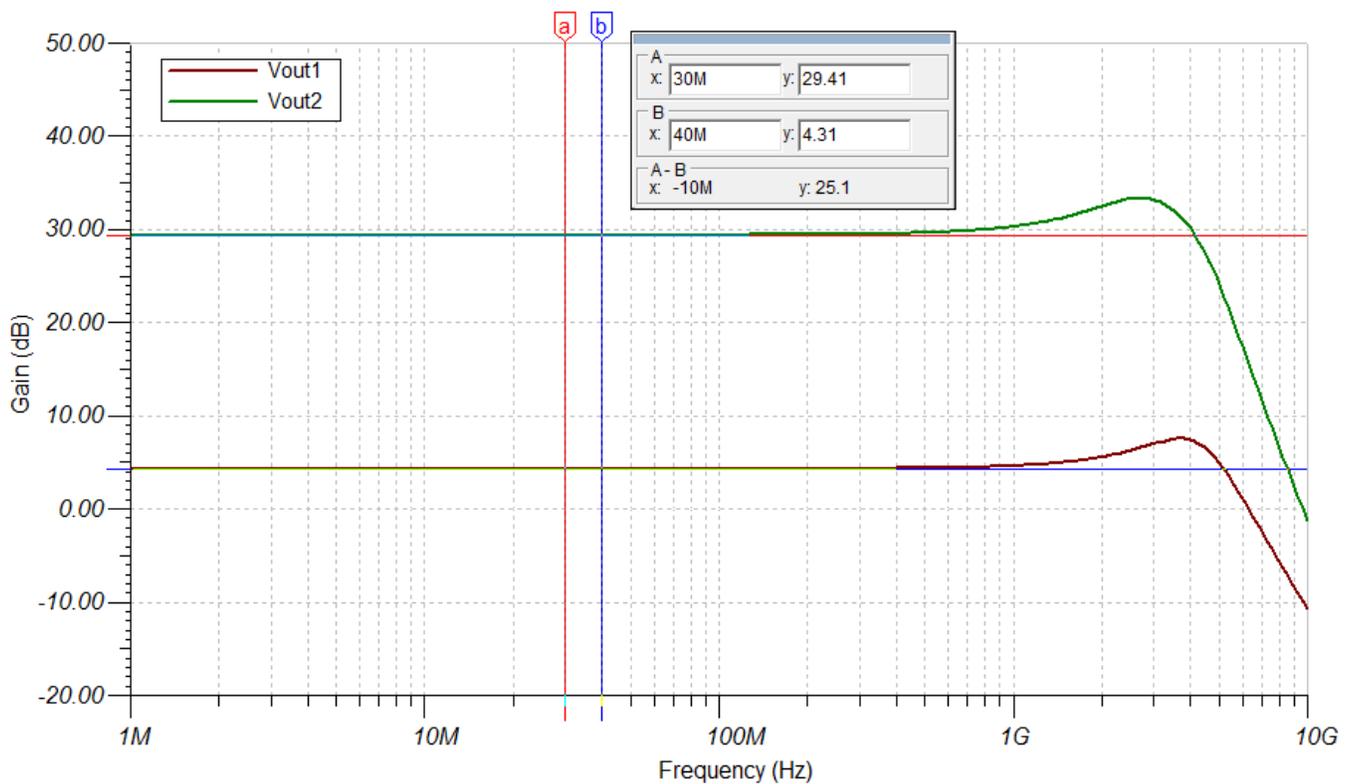
Figure 13: AC-coupled Single-ended-to differential Cascaded Configuration

## 5 Simulation

Figure 14 shows the setup used in the TINA-TI simulator to simulate the cascaded LMH5401 and LMH6401 reference design in a DC-coupled single-ended-to-differential configuration. As shown in the plot of Figure 14, total voltage gain is 29.41 dB with a -3dB bandwidth of 4.5 GHz. Note that the gain is specified after the internal 10Ω resistor of the LMH6401.



**Figure 14: TINA-TI Simulation of DC-coupled Single-ended-to-differential Cascaded Configuration**



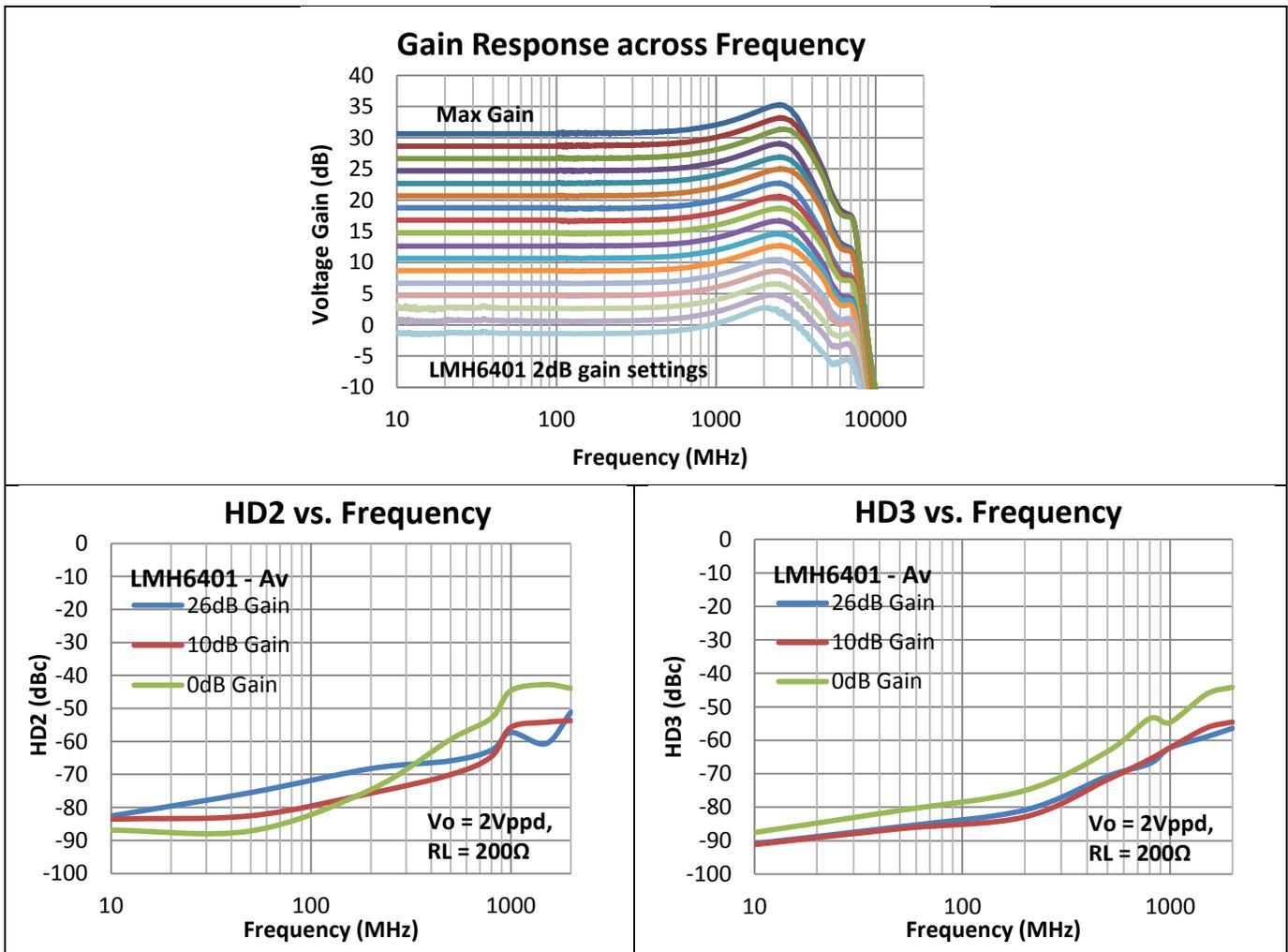
**Figure 15: AC Small-signal Analysis of the Cascaded Signal Chain**

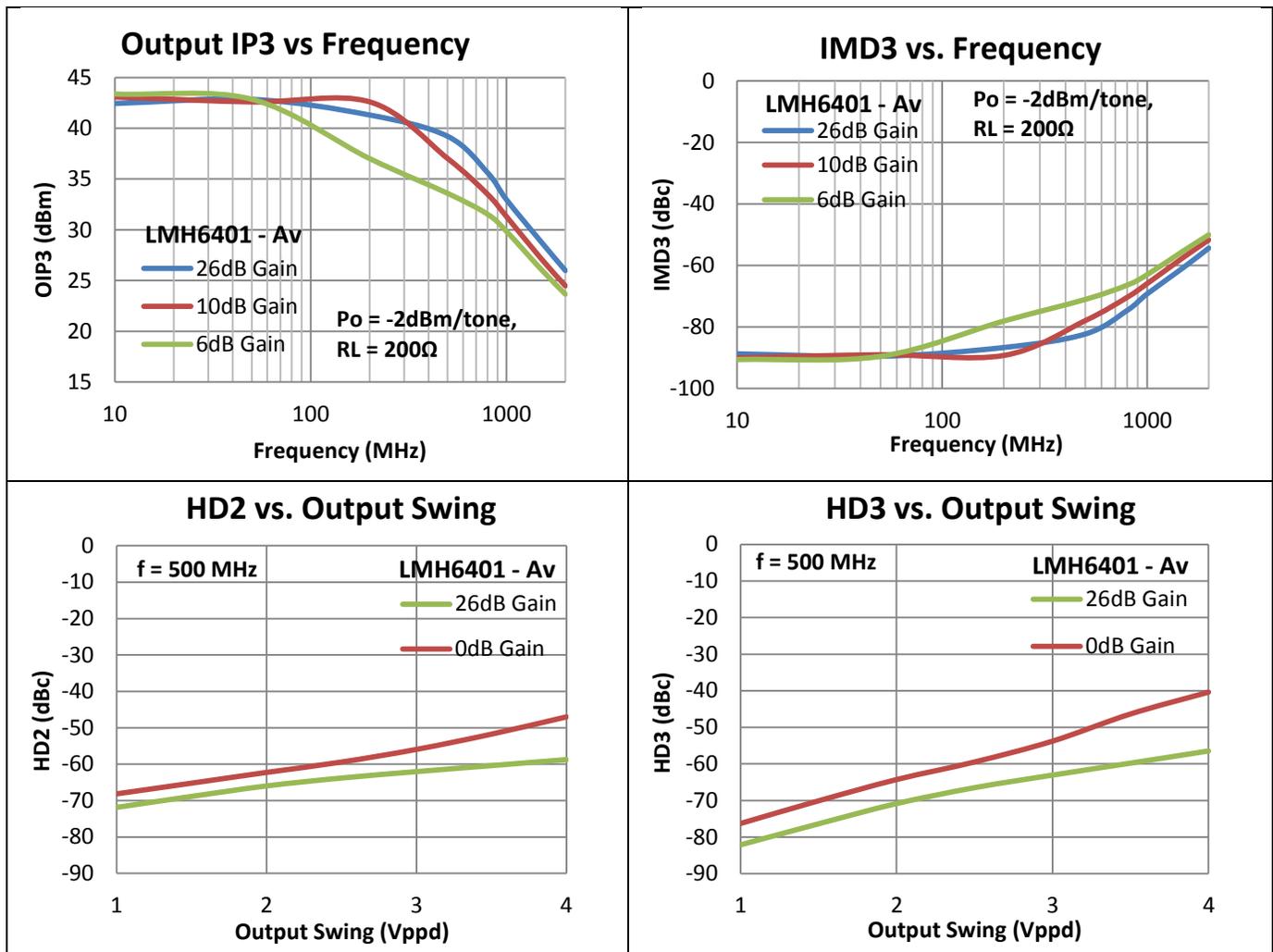
## 6 Measured Results

The measurements below were made on the cascaded board with a single-ended 50-Ω input and a 200-Ω load on the differential output. For converting the differential output to a single-ended output for the 50-Ω test equipment, an external balun, such as Marki's BAL-0010, was used. The 200-Ω output load includes the external balun, the two internal 10Ω resistors of the LMH6401 and the two on-board 40Ω resistors. Unless otherwise noted, the output amplitude is 2Vpp (diff) before the internal LMH6401 10Ω resistor on each output leg. Both the devices have split supplies of ±2.5V.

The LMH6401 gain is controlled with the on-board USB-to-SPI FTDI bus translator chip and the LMH6401EVM GUI software available under the LMH6401's product folder at [www.ti.com](http://www.ti.com).

As noted earlier, the cascaded reference design supports both a single-ended-to-differential configuration as well as differential-to-differential configuration. As noted earlier, when using the cascaded board for single-ended-to-differential conversion, an external 50Ω termination pad should be used on the undriven input. External DC-blocks, such as Mini-circuits BLK-89-S+, should be used for ac-coupling the inputs and outputs.





### 7 Future Prospects of using the LMH5401 + LMH6401 cascaded reference design

As mentioned earlier and as shown in Figure 16, this reference design is part of an analog signal chain which can be used as a driver for TI's high-speed 12-bit data converters in a typical receiver application. Very good performance from DC to 2 GHz can be achieved with the cascaded reference design in a single-ended-to-differential configuration.

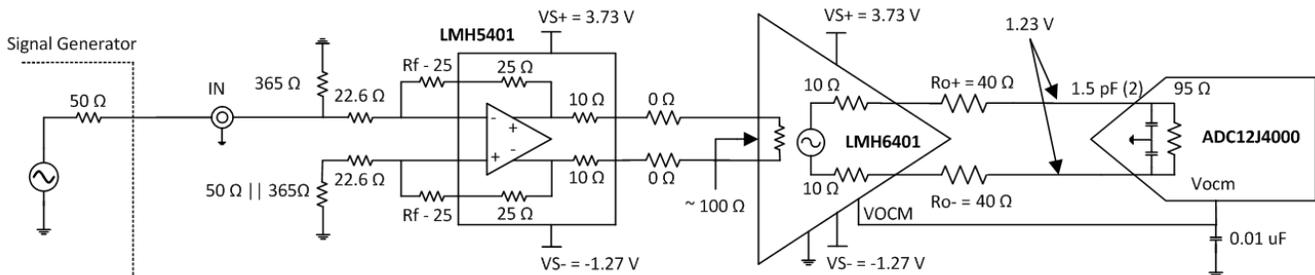


Figure 16: Typical LMH5401 and LMH6401 Cascade Driving ADC12J4000 in SE-to-Diff configuration

## 8 Appendix

### 8.1 Single-ended-to-Differential Amplifier Gain Calculation

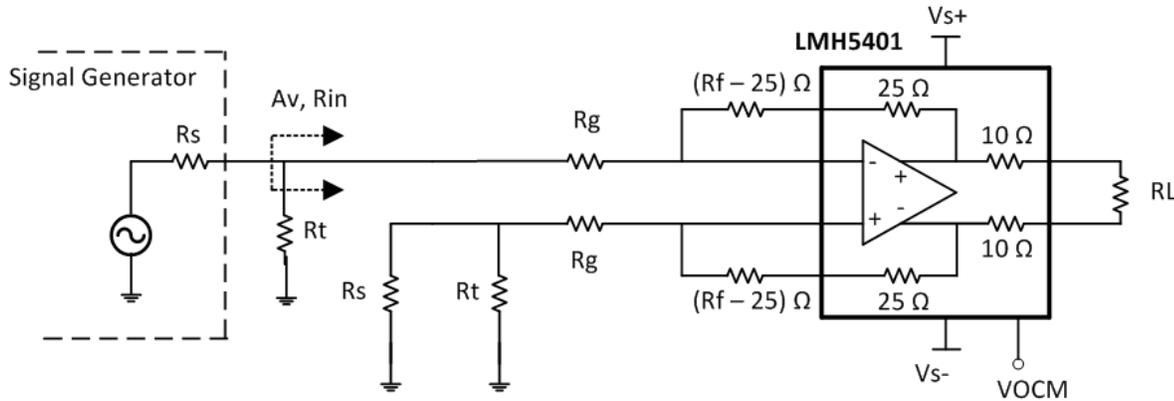


Figure 17: Fully-differential amplifier for SE-to-Diff conversion

#### Equations:

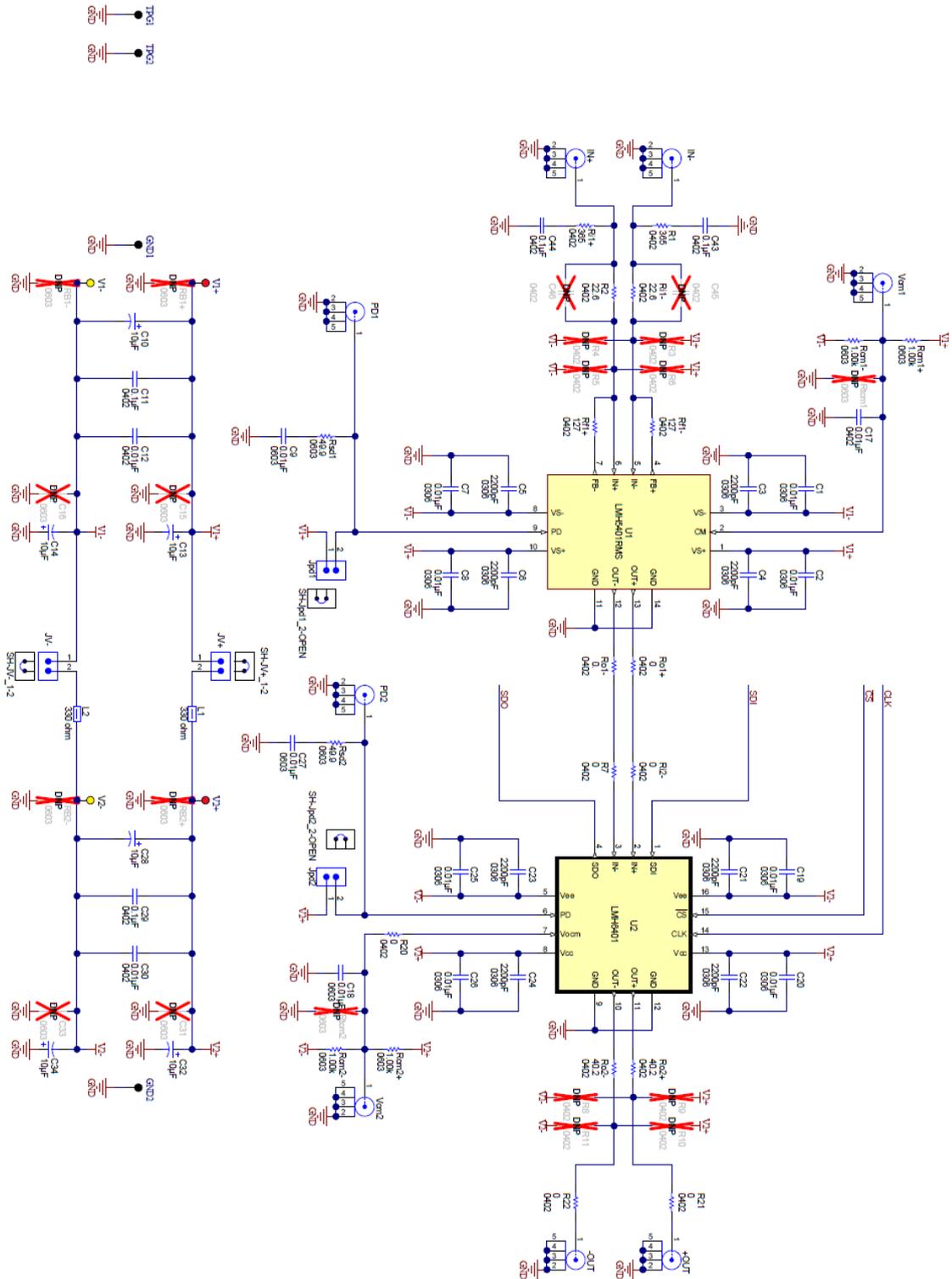
$$A_V = \left( \frac{2(1 - \beta_1)}{\beta_1 + \beta_2} \right) \quad \beta_1 = \left( \frac{R_G}{R_G + R_F} \right)$$

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

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

## 9 Board Schematics

The schematics for the reference design are shown below in Figure 18.



**Figure 18: Signal Path Schematic**

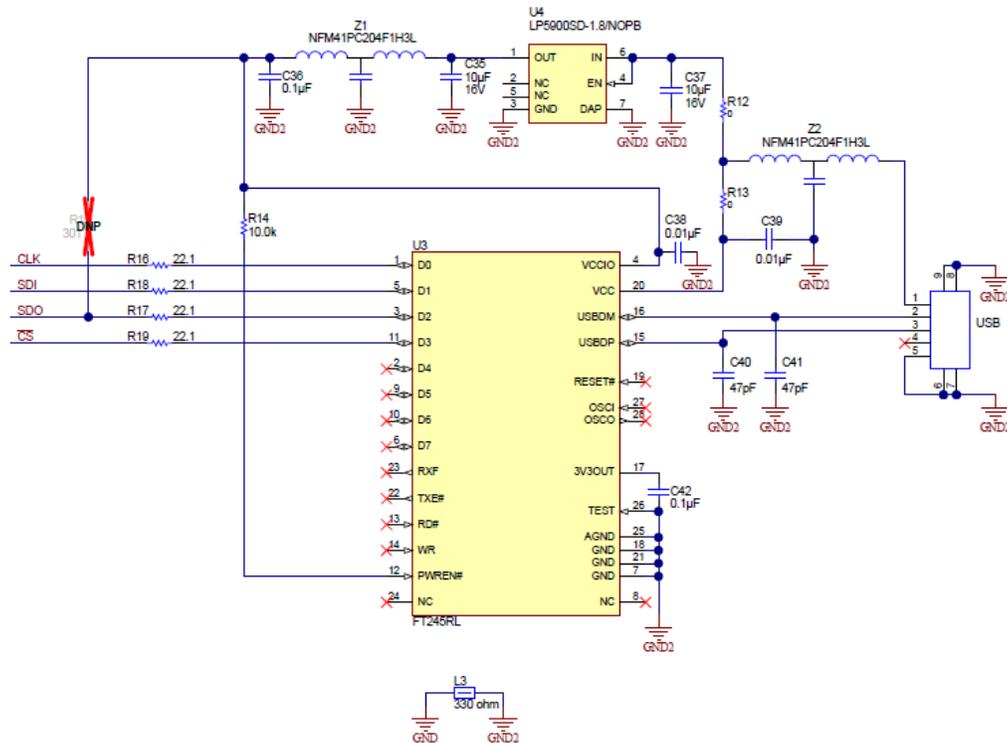


Figure 19: Digital Control Schematic

10 BOM

| Designator                                 | Quantity | Value  | Description                                | Size           | Part Number        | Manufacturer          |
|--|----------|--------|--|----------------|--------------------|-----------------------|
| IPCB                                       | 1        |        | Printed Circuit Board                      |                |                    | Any                   |
| +OUT, -OUT, IN+, IN-, PD1, PD2, Vcm1, Vcm2 | 8        |        | Connector, SMT, End launch SMA 50 ohm      | SMA End Launch | 142-0701-851       | Emerson Network Power |
| C1, C2, C7, C8, C19, C20, C25, C26         | 8        | 0.01uF | CAP, CERM, 0.01uF, 25V, +/- 20%, X7R, 0306 | 0306           | LLL185R71E103MA01L | MuRata                |
| C3, C4, C5, C6, C21, C22, C23, C24         | 8        | 2200pF | CAP, CERM, 2200pF, 50V, +/- 20%, X7R, 0306 | 0306           | LLL185R71H222MA01L | MuRata                |
| C9, C18, C27                               | 3        | 0.01uF | CAP, CERM, 0.01uF, 16V, +/- 10%, X7R, 0603 | 0603           | GRM188R71C103KA01D | MuRata                |
| C10, C13, C14, C28, C32, C34               | 6        | 10uF   | CAP, TA, 10uF, 10V, +/- 10%, 0.9 ohm, SMD  | 3216-18        | TPSA106K010R0900   | AVX                   |
| C11, C29, C36, C42, C43, C44               | 6        | 0.1uF  | CAP, CERM, 0.1uF, 10V, +/- 10%, X5R, 0402  | 0402           | C1005X5R1A104K     | TDK                   |
| C12, C17, C30                              | 3        | 0.01uF | CAP, CERM, 0.01uF, 25V, +/- 10%, X7R, 0402 | 0402           | C1005X7R1E103K     | TDK                   |
| C35, C37                                   | 2        | 10uF   | CAP, CERM, 10uF, 16V, +/- 10%, X5R, 0805   | 0805           | EMK212BJ106KG-T    | Taiyo Yuden           |

| Designator  | Quantity | Value         | Description  | Size               | Part Number       | Manufacturer           |
|---|----------|---------------|--|--------------------|-------------------|------------------------|
| C38, C39  | 2        | 0.01uF        | CAP, CERM,<br>0.01uF, 16V, +/-<br>10%, X7R, 0402   | 0402               | C1005X7R1C103K    | TDK                    |
| C40, C41  | 2        | 47pF          | CAP, CERM,<br>47pF, 50V, +/-5%,<br>C0G/NP0, 0402   | 0402               | GRM1555C1H470JZ01 | MuRata                 |
| GND1,<br>GND2,<br>TPG1,<br>TPG2   | 4        | Black         | Test Point, TH,<br>Multipurpose,<br>Black  |                    | 5011              | Keystone Electronics   |
| Jpd1, Jpd2,<br>JV+, JV-   | 4        |               | Header, TH,<br>100mil, 2x1, Gold<br>plated, 230 mil<br>above insulator   | TSW-102-<br>07-G-S | TSW-102-07-G-S    | Samtec, Inc.           |
| L1, L2, L3  | 3        | 330 $\Omega$  | Ferrite Bead, 330<br>ohm @ 100 MHz,<br>1.5 A, 0603   | 0603               | BLM18SG331TN1D    | MuRata                 |
| R1, Ri1+  | 2        | 365 $\Omega$  | RES, 365, 1%,<br>0.063 W, 0402   | 0402               | CRCW0402365RFKED  | Vishay-Dale            |
| R2, Ri1-  | 2        | 22.6 $\Omega$ | RES, 22.6, 1%,<br>0.063 W, 0402  | 0402               | CRCW040222R6FKED  | Vishay-Dale            |
| R7, R21,<br>R22, Ri2-   | 4        | 0             | RES, 0, 5%, 0.063<br>W, 0402   | 0402               | CRCW04020000Z0ED  | Vishay-Dale            |
| R12, R13  | 2        | 0             | RES, 0 ohm, 5%,<br>0.1W, 0603  | 0603               | CRCW06030000Z0EA  | Vishay-Dale            |
| R14   | 1        | 10.0k         | RES, 10.0k ohm,<br>1%, 0.063W, 0402  | 0402               | CRCW040210K0FKED  | Vishay-Dale            |
| R16, R17,<br>R18, R19   | 4        | 22.1          | RES, 22.1 ohm,<br>1%, 0.063W, 0402   | 0402               | CRCW040222R1FKED  | Vishay-Dale            |
| Ro1+, Ro1-,<br>R20  | 3        | 0             | RES, 0 ohm, 5%,<br>0.063W, 0402  | 0402               | ERJ-2GE0R00X      | Panasonic              |
| Rcm1+,<br>Rcm1-,<br>Rcm2+,<br>Rcm2-                                       | 4        | 1.00k         | RES, 1.00k ohm,<br>1%, 0.1W, 0603  | 0603               | CRCW06031K00FKEA  | Vishay-Dale            |
| Rf1+, Rf1-  | 2        | 127           | RES, 127, 1%,<br>0.063 W, 0402   | 0402               | CRCW0402127RFKED  | Vishay-Dale            |
| Ro2+, Ro2-  | 2        | 40.2          | RES, 40.2 ohm,<br>1%, 0.063W, 0402   | 0402               | CRCW040240R2FKED  | Vishay-Dale            |
| Rsd1, Rsd2  | 2        | 49.9          | RES, 49.9 ohm,<br>1%, 0.1W, 0603   | 0603               | CRCW060349R9FKEA  | Vishay-Dale            |
| SH-Jpd1_2-<br>OPEN, SH-<br>Jpd2_2-<br>OPEN, SH-<br>JV+_1-2,<br>SH-JV-_1-2 | 4        | 1x2           | Shunt, 100mil,<br>Gold plated, Black   |                    | 382811-6          | AMP                    |
| U1  | 1        |               | 8GHz Ultra<br>Wideband Fully<br>Differential<br>Amplifier,<br>RMS0014A   | RMS0014A           | LMH5401RMS        | Texas Instruments      |
| U3  | 1        |               | USB FIFO IC,<br>28SSOP   | SSOP28             | FT245RL           | FTDI                   |
| U4  | 1        |               | Ultra Low Noise,<br>150mA Linear<br>Regulator for<br>RF/Analog<br>Circuits Requires<br>No Bypass<br>Capacitor, 6-pin<br>LLP, Pb-Free | SDB06A             | LP5900SD-1.8/NOPB | Texas Instruments      |
| USB   | 1        |               | MINI USB 2.0<br>SMT TYPE AB 5  | 9.2x9.9x4<br>mm    | 651-305-142-821   | Würth Elektronik eiSos |

| Designator                                       | Quantity | Value  | Description  | Size                                | Part Number        | Manufacturer         |
|--|----------|--------|--|-------------------------------------|--------------------|----------------------|
|  |          |        | CONTACTS R/A,<br>SMD   |                                     |                    |                      |
| V1+, V2+   | 2        | Red    | Test Point, TH,<br>Multipurpose, Red                                 |                                     | 5010               | Keystone Electronics |
| V1-, V2-   | 2        | Yellow | Test Point,<br>Multipurpose,<br>Yellow, TH                           | Yellow<br>Multipurpose<br>Testpoint | 5014               | Keystone             |
| Z1, Z2   | 2        | 0.2uF  | Filter, LC, 0.2uF,<br>1806, SMT                                      | 1806                                | NFM41PC204F1H3L    | MuRata               |
| C15, C16,<br>C31, C33                            | 0        |        | CAP, CERM,<br>xxxF, xxV,<br>[TempCo], xx%,<br>[PackageReferenc<br>e] | 0603                                | Used in BOM report | Used in BOM report   |
| C45, C46   | 0        |        | CAP, CERM,<br>xxxF, xxV,<br>[TempCo], xx%,<br>[PackageReferenc<br>e] | 0402                                | Used in BOM report | Used in BOM report   |
| FID1, FID2,<br>FID3                              | 0        |        | Fiducial mark.<br>There is nothing<br>to buy or mount                | Fiducial                            | N/A                | N/A                  |
| R3, R4, R5,<br>R6, R8, R9,<br>R10, R11           | 0        |        | RES, xxx ohm,<br>x%, xW,<br>[PackageReferenc<br>e]                   | 0402                                | Used in BOM report | Used in BOM report   |
| R15  | 0        | 301    | RES, 301 ohm,<br>1%, 0.1W, 0603                                      | 0603                                | CRCW0603301RFKEA   | Vishay-Dale          |
| RB1+, RB1-<br>, RB2+,<br>RB2-<br>Rtcm1,<br>Rtcm2 | 0        |        | RES, xxx ohm,<br>x%, xW,<br>[PackageReferenc<br>e]                   | 0603                                | Used in BOM report | Used in BOM report   |
| U2   | 0        |        | 5 GHz Ultra<br>Wideband Digital<br>Variable Gain<br>Amplifier        | 16UQFN                              | LMH6401            | Texas Instruments    |

## 11 About the Author

Rohit Bhat has been an applications engineer with Texas Instruments since 2012. Rohit has been supporting TI's high-speed amplifiers in applications requiring high-speed analog signal processing which includes but not limited to video, test and measurement and communications.

### References:

[LMH5401 datasheet](#)

[LMH6401 datasheet](#)

[AN-2177 Using the LMH6554 as an ADC Driver](#)

<http://www.ti.com/tool/lmh6401evm>

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