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TI Designs: TIDA-00522 Reference Guide
Stabilizing Differential Amplifiers as Attenuators

TI Designs

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Design Resources

Design Page	All Design files
TINA-TI™	SPICE Simulator
LMH5401	Product Folder

Circuit Description

This design provides a reference for using a fully differential amplifier (FDA) at a gain lower than what is specified in the datasheet. In this example the LMH5401 which is specified at a gain of 4V/V is used as an attenuator with a gain of 0.5V/V.

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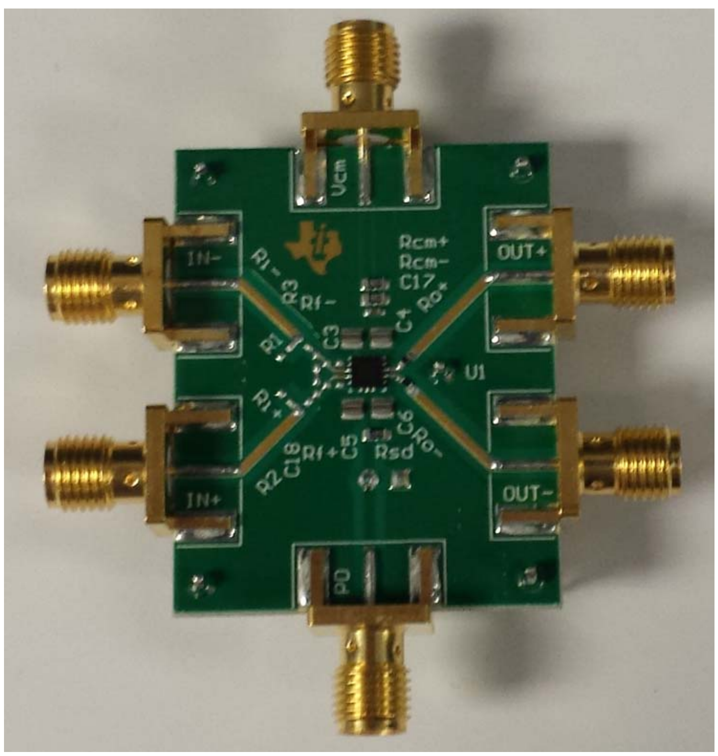

Figure 1 Reference Design Board

1 Design Summary

- Flexible Gain

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- Noise Shaping
- Supply Voltage: +5V or +-2.5V
- Supply Current: 60 mA

Although amplifiers are often used with large voltage gains there are times when the amplifier is used for other purposes, including attenuating a signal while providing source isolation. This reference design will show how to configure the LMH5401 for gains less than the 4V/V recommended in the datasheet.

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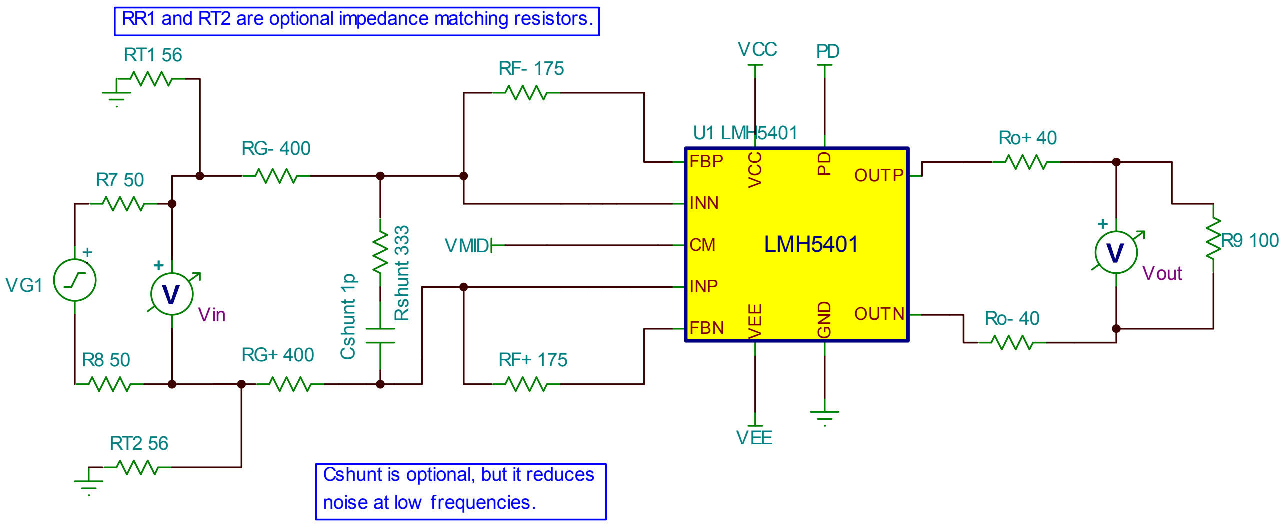

Figure 2 LMH5401 Basic Schematic (Note: Rf total = 200 Ω, there is 25 Ω on chip).

2 Theory of Operation

The LMH5401 as implemented on the standard EVM is not stable for gains less than 4V/V (Rf = 200, Rg = 50). Because amplifier stability is based on noise gain rather than signal gain, we can increase the noise gain to stabilize the amplifier while keeping the signal gain low. The method shown in this reference design uses the addition of a resistor and (optionally) a capacitor between the amplifier input pins to accomplish this increase in noise gain, while leaving the signal gain unchanged.

2.1 Equations

Fully differential amplifiers have a noise gain that is equal to $1 + (\frac{RF}{RG+RSeq})$. Where RF is the feedback resistance, RG is the gain set resistance and RSeq is the equivalent source and termination resistance. To simplify we will combine $RG + RSeq = RGT$. Adding a resistor between the amplifier input pins essentially adds another phantom input that also contributes to noise gain. Using superposition the new noise gain equation is equal to $1 + (\frac{RF}{RGT||0.5*RS})$ where the extra resistor Rs is the shunt resistor added between the amplifier input pins.

For the standard configuration where the source resistance is 50 Ohms and RG is 50 Ohms and RF is equal to 200 Ohms the EVM measured gain is 4V/V while the net gain is 2V/V due to the loss in the source resistance. The noise gain is 3V/V for this configuration. In order to implement this noise gain, use the values shown in the table below. Because the shunt resistor is applied to both inputs the value in the table is 2x the valued required for each input. If using two shunt resistors (one for each input) connect them to ground and use half of the table value on each input.

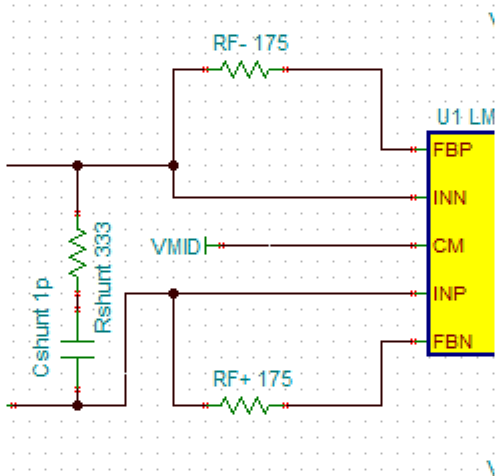

Figure 3 Stabilizing shunt resistor shown as Rshunt

Table 1 Shunt Resistor Selection for Various Gain Settings (Rf = 200 Ohms, Source = 50 Ohms)

(1)

Closed Loop Gain V/V*	Gain Set Resistor (Rg) Value	Shunt Resistor Value (Rs)	Shunt Capacitor Value (Cs)
4	50	Not Required	Not Required
2	100	600	0.5p
1	200	333	1p
0.5	400	256	1.2p
0.1	2000	210	1.5p
*Closed Loop Gain does not include loss in source resistance.			Rs,Cs Corner Frequency = ~500MHz

These resistor values are set for a noise gain of 3V/V. For a flatter frequency response, use smaller resistance values. This will result in higher noise levels, but will give much flatter response.

3 Designing for Low Gain Operation

The LMH5401 is a high speed amplifier which is compensated for stability for differential gain of 4V/V or higher as well as single ended gains of 2V/V or higher. Stability is based on the noise gain of the amplifier which must be above the minimum stable value stated above. In the simplest case noise gain is equal to $1+\frac{RF}{RG}$. Some applications require the isolation and buffering of an amplifier, but do not require voltage gain. These applications are the subject of this reference design.

The method that this paper proposes to add stability to low gain circuits is to directly increase the amplifier noise gain with a shunt resistor between the amplifier input pins. The resistive element can be placed across the input pins of the amplifier which are a virtual short circuit. Being a virtual short circuit with very little delta V is the primary reason that parasitic reactance has minimal influence on the circuit. This also means that a resistor added to this node adds only noise gain. There is no signal present at this node to amplify. This resistor also has very little impact on the amplifier input impedance because the voltage difference between the pins is kept close to 0V by the amplifier feedback loop.

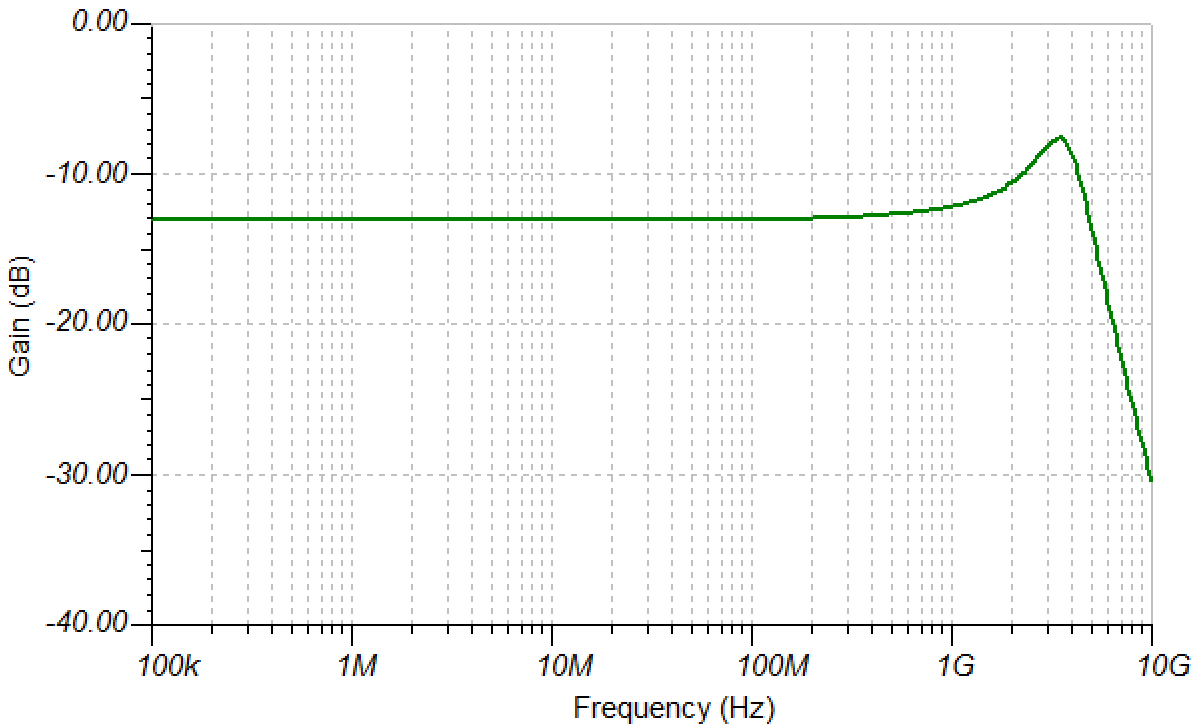

Figure 4 Gain = 0.5 V/V Frequency response, noise gain = 3V/V

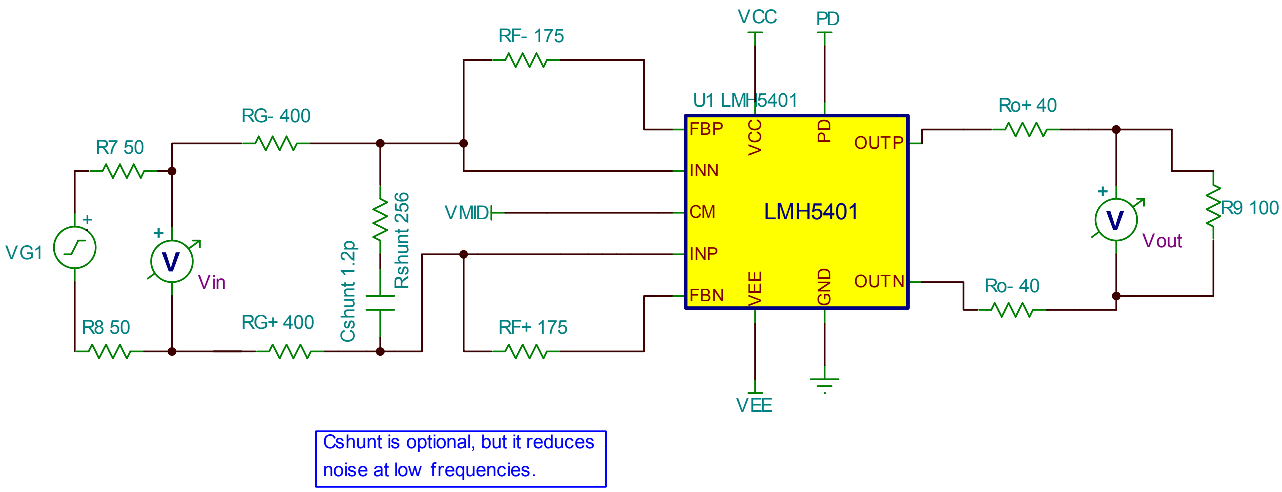

Figure 5 Gain = 0.5V/V, Noise Gain = 3V/V

4 Simulation

The plot in Figure 4 is the simulated frequency response for the circuit shown in Figure 5 . Adding noise gain to the amplifier adds noise. This is shown in Figure 6. The increase in noise is obvious when compared to a noise plot from an uncompensated circuit; this is shown in Figure 7. The narrow and sharp noise spike in Figure 7 is also a strong indicator that the circuit is unstable. The extreme peak in noise corresponds with a frequency of instability for the amplifier. Testing in the lab has confirmed that the simulation results are accurate with regard to the amplifier instability.

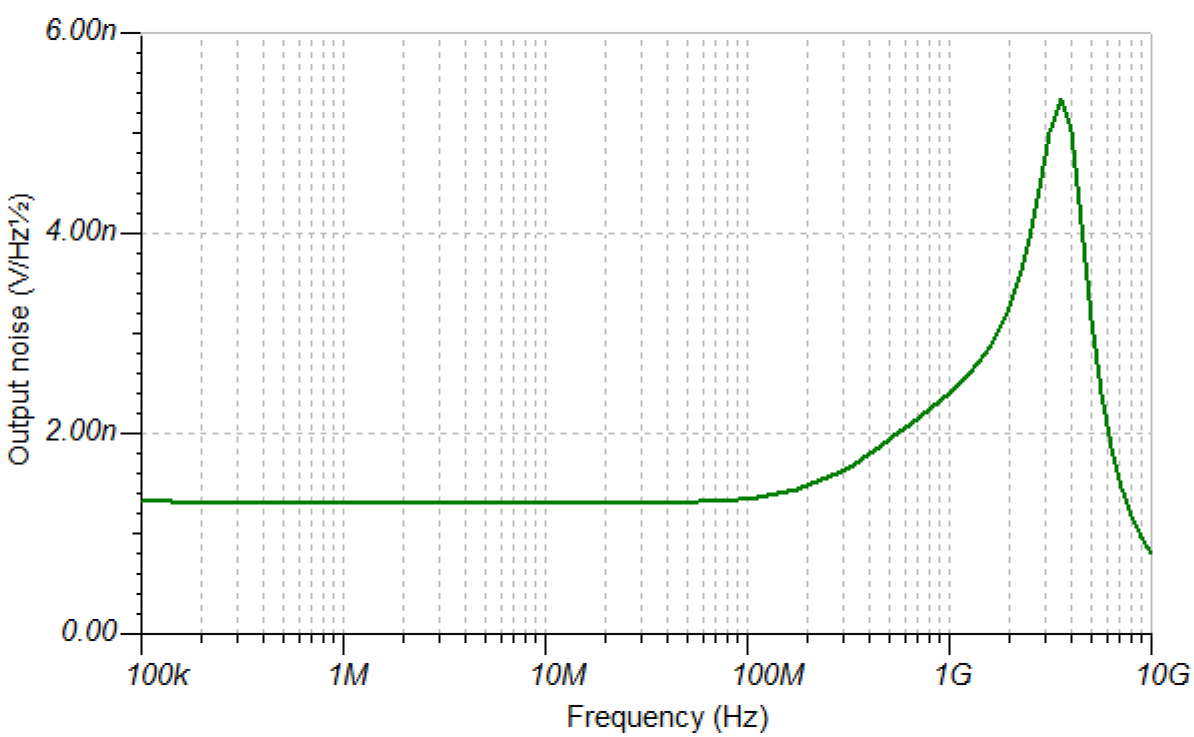

Figure 6 TINA-TI Noise Simulation, Av =0.5, Rs=255 Ohms, Noise Gain = 3

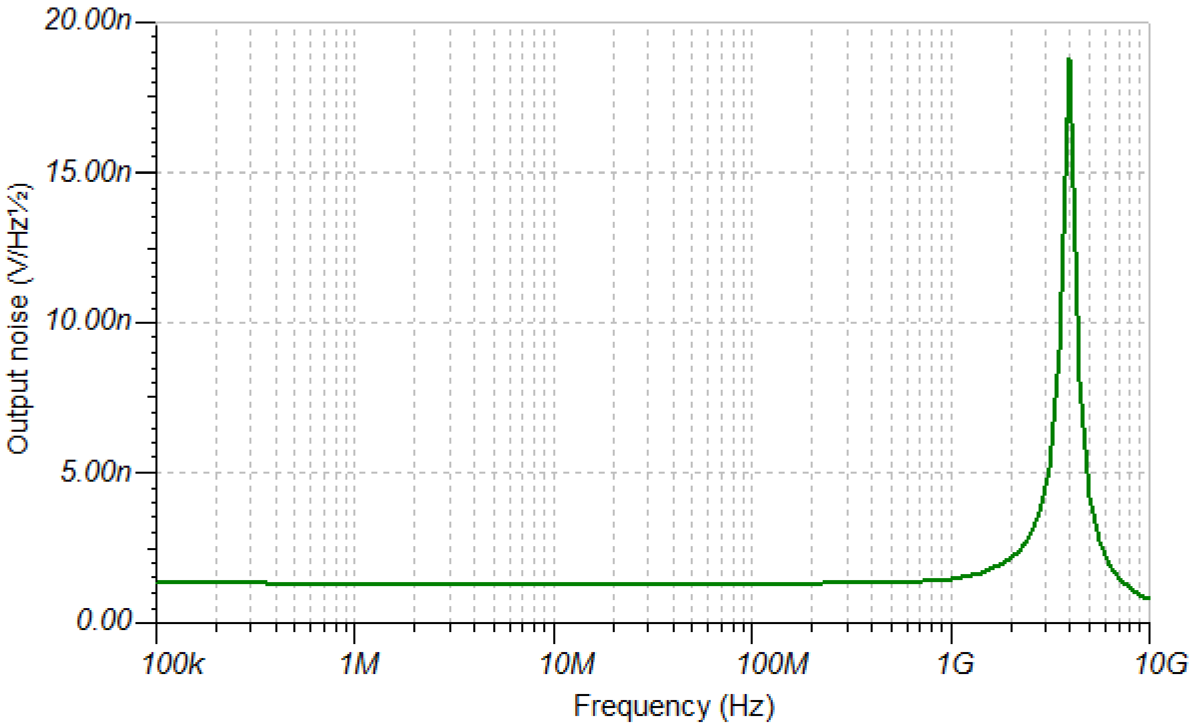

Figure 7 Noise Simulation, AV=0.5, uncompensated circuit, noise gain = 0.5

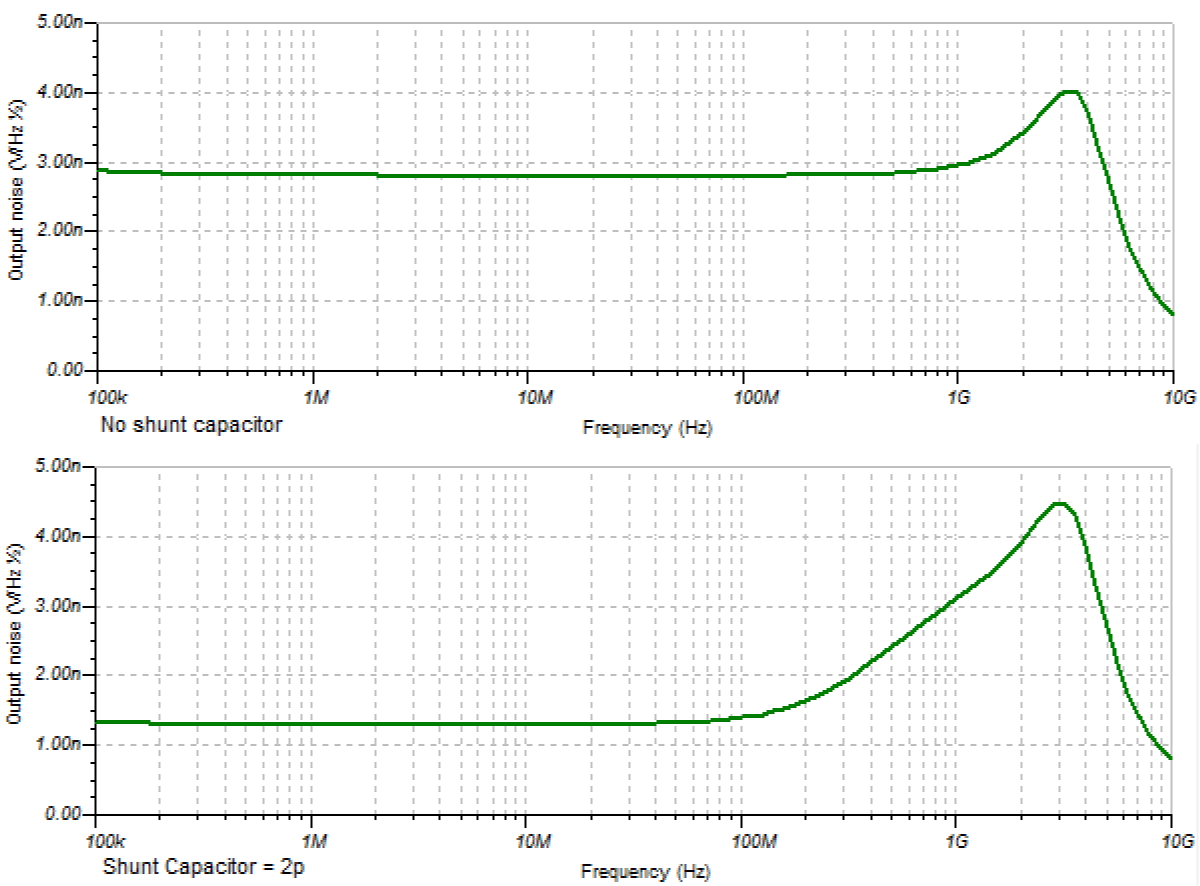

Figure 8. The LMH5401 has excess phase margin at low frequencies. We can use this fact to reduce noise at lower frequencies. The shunt resistor is 255 Ohms and the shunt capacitor is 1.2p. The frequency corner for the series RC circuit is $\frac{1}{2*\pi*R*C}$ which is equal to 520 MHz. This is almost one order of magnitude lower in frequency than the noise spike at ~3.7GHz shown in Figure 7 which means that the additional capacitor will have minimal impact on stability while significantly reducing noise gain at lower frequencies where stability is not a problem. Note that figure 8 (bottom) low frequency (~1.3nV) matches the uncompensated value of Figure 7.

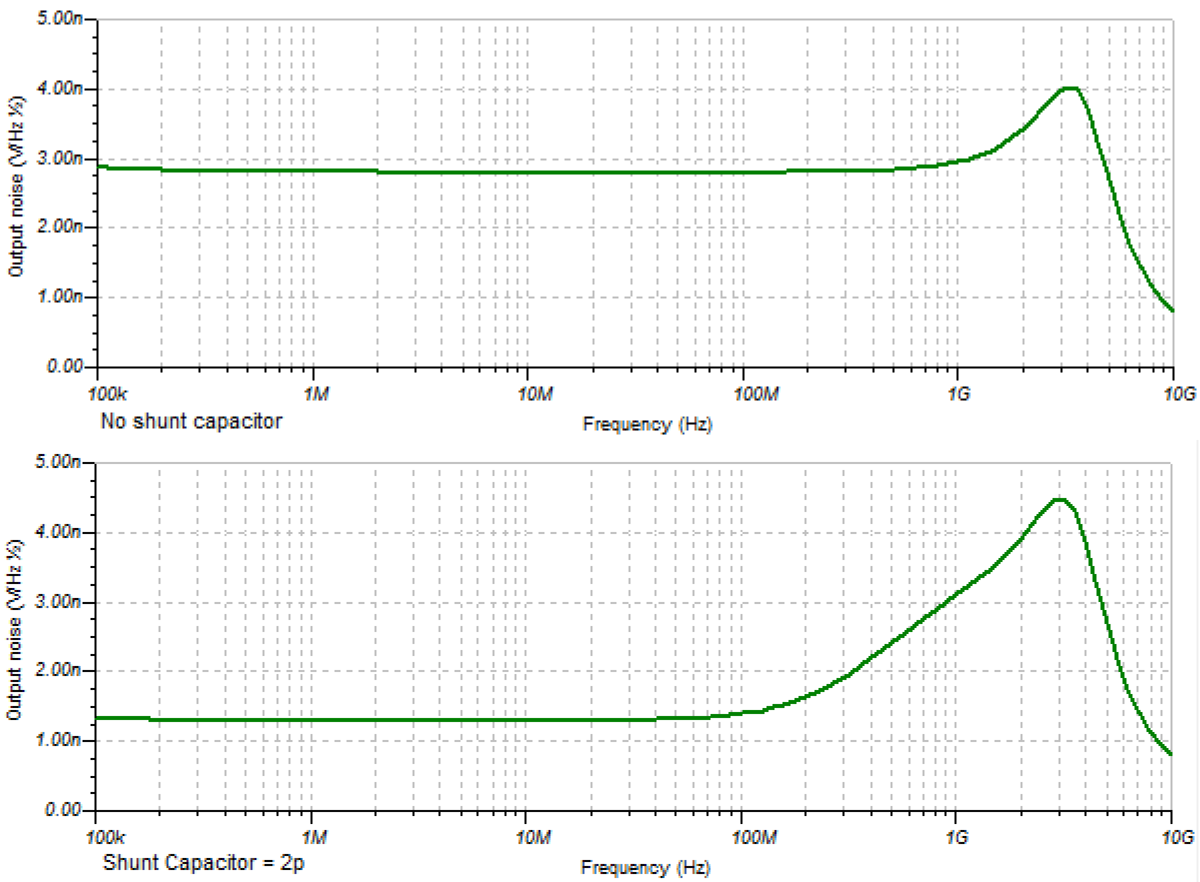

Figure 8 TINA-TI Noise Simulation, Av =0.5, Rs=154 Ohms, noise gain = 4 (Top plot no Cshunt, Bottom plot, Cshunt = 2p)

5 Measured Results

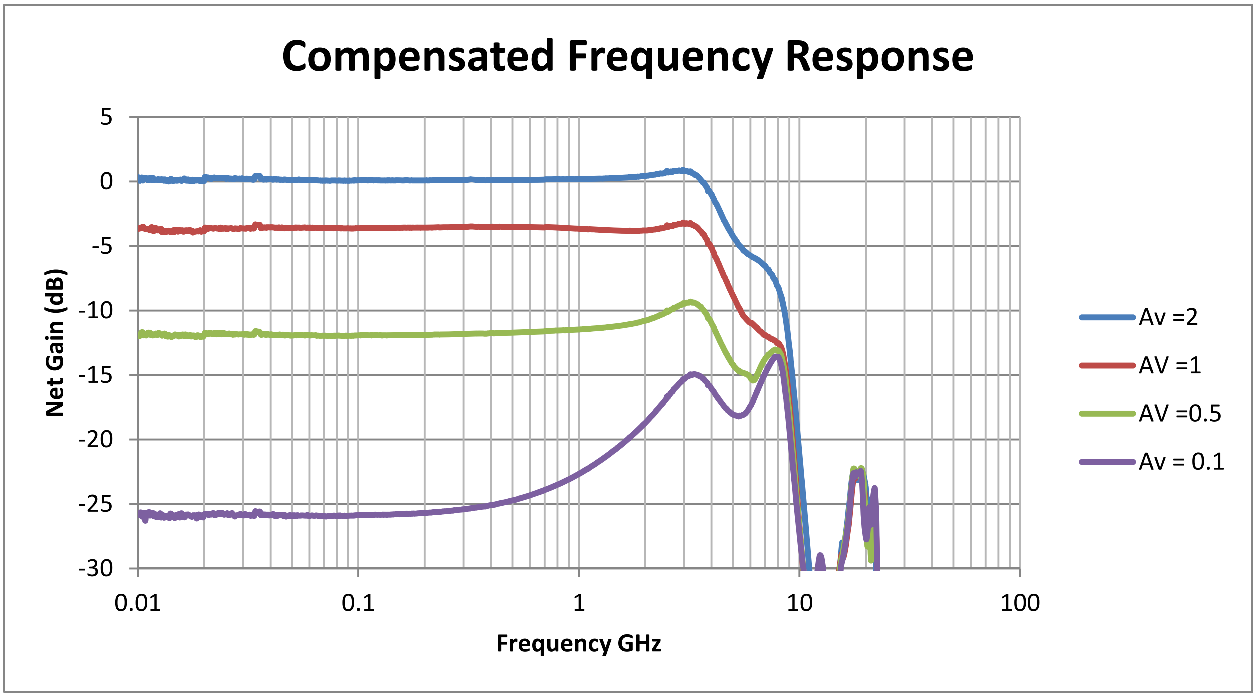

Figure 9 Measured frequency response for various gains

Using the component values in Table 1 we made measurements of different gains. The frequency response curves are shown in Figure 9. These results show that while the amplifier can be configured for arbitrarily low gain settings there is a point of diminishing returns when the gain is set to a gain of less than 1V/V (net gain of -6dB). The frequency response of the curves with gain of less than 1V/V is not flat and has undesirable peaking. This is an artifact of the feedback network which reduces the ability of the amplifier to provide large amounts of attenuation.

Since the frequency response did not agree with initial TINA simulations it would be instructive to find possible causes of the discrepancy. In order to match the measured results there are only small changes needed to be made to the TINA models. For a Gain of 2 the model changes are shown below in Figure 10. What is clear from these adjustments is that at frequencies above 1GHz very small parasitic reactance can have measurable impacts on the circuit.

The added elements in the adjusted model are capacitors C2 and C3. The physical structures on the design board responsible for this capacitance is the section of trace from the FBP pin to the INN pin and also from the FBN pin to the INP pin. The other elements in the adjusted model are inductors L2 and L3. These represent the trace inductance on the amplifier input pins.

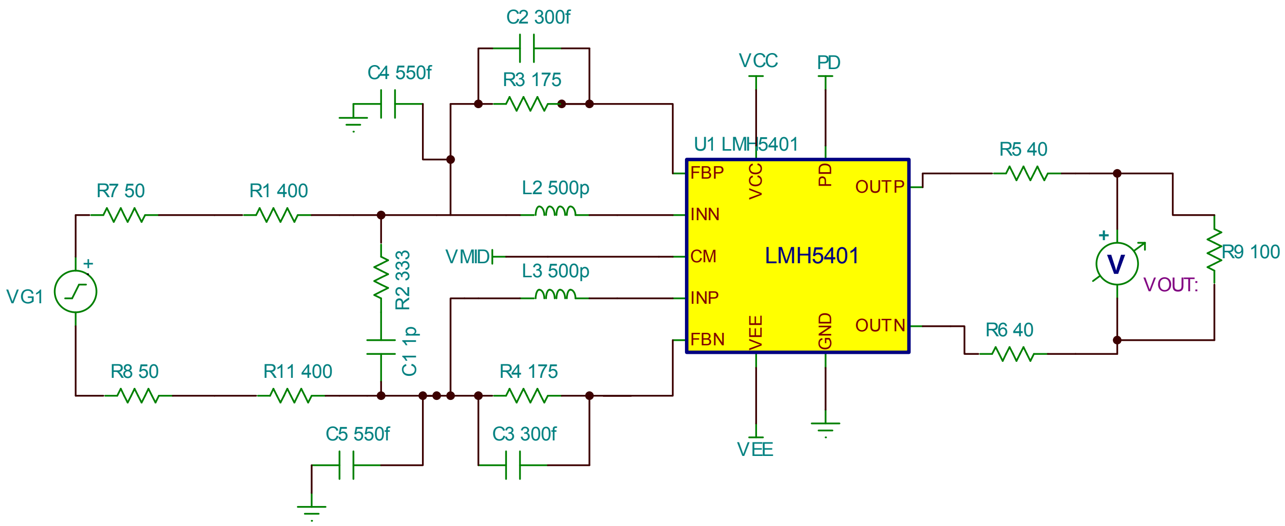

Figure 10 Adjusted TINA Schematic

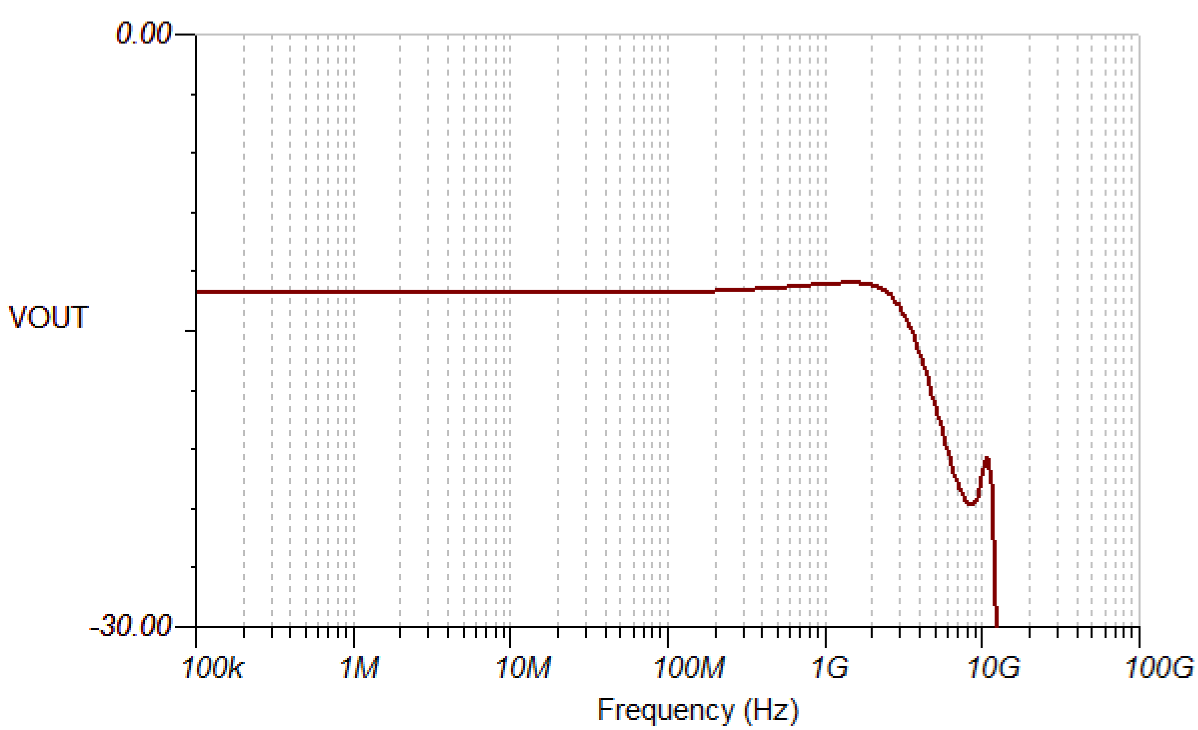

Figure 11 Simulation Results for Av =0.5 V/V, Approximating Measured Results (see schematic in Figure 10)

The results shown in Figure 11 match fairly well with the measured results shown in Figure 9. The model does not agree exactly, though. This indicates there are other circuit elements that are not completely modeled. This is common when working at frequencies above 1GHz. Every circuit element has small reactances that will impact behavior at these frequencies. This is one reason that it is very important to build prototype circuits to test performance.

6 Board Schematics

The schematics for the reference design are shown below in Figure 12.

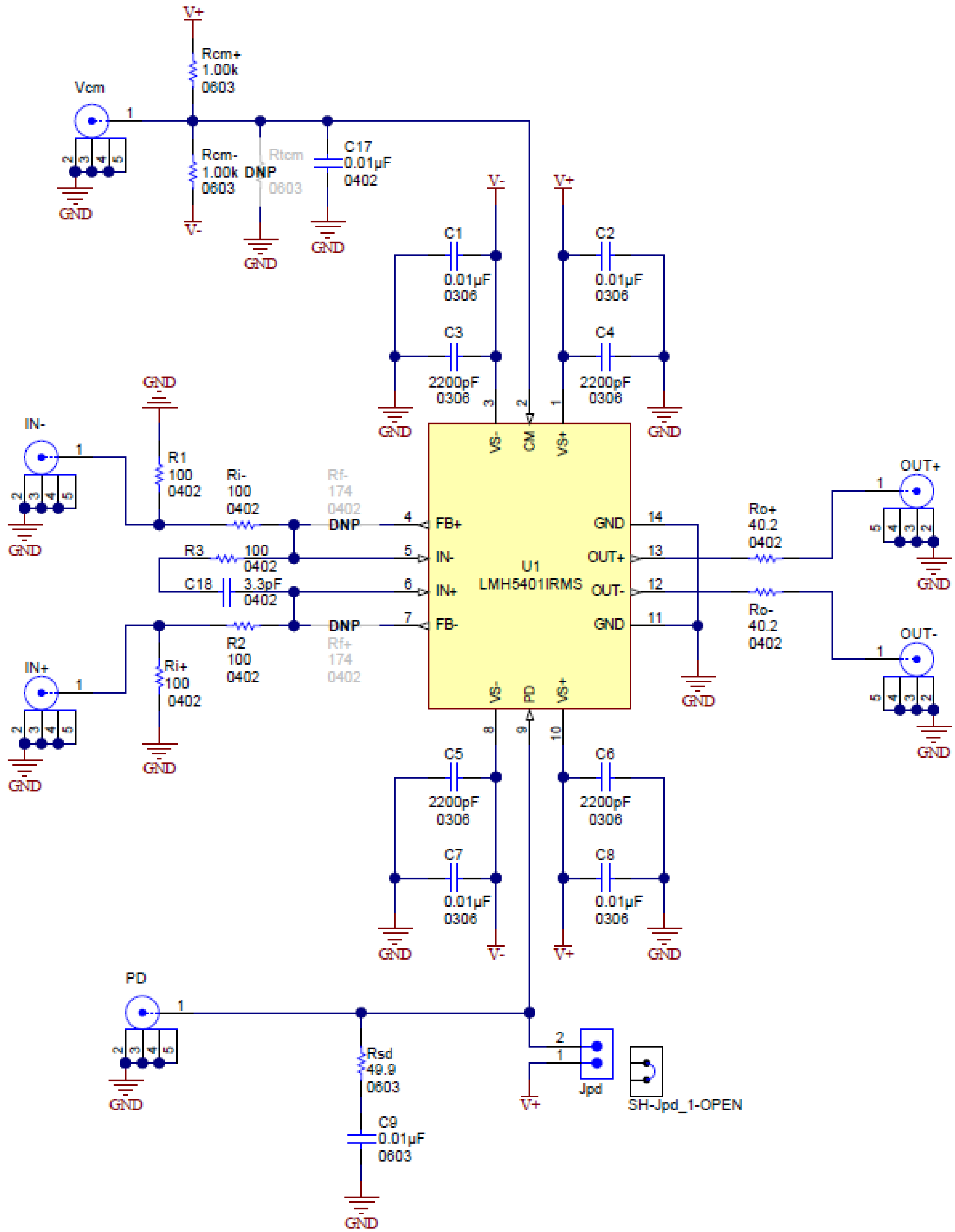

Figure 12 Signal Path Schematic

7 BOM

Designator	Quantity	Value	Description	Size	PartNumber	Manufacturer
!PCB	1		Printed Circuit Board		XX####	Any
C1, C2, C7, C8	4	0.01uF	CAP, CERM, 0.01uF, 25V, +/-20%, X7R, 0306	0306	LLL185R71E103MA01L	MuRata
C3, C4, C5, C6	4	2200pF	CAP, CERM, 2200pF, 50V, +/-20%, X7R, 0306	0306	LLL185R71H222MA01L	MuRata
C9	1	0.01uF	CAP, CERM, 0.01uF, 16V, +/-10%, X7R, 0603	0603	GRM188R71C103KA01D	MuRata
C10, C13, C14	3	10uF	CAP, TA, 10uF, 10V, +/-10%, 0.9 ohm, SMD	3216-18	TPSA106K010R0900	AVX
C11	1	0.1uF	CAP, CERM, 0.1uF, 10V, +/-10%, X5R, 0402	0402	C1005X5R1A104K	TDK
C12, C17	2	0.01uF	CAP, CERM, 0.01uF, 25V, +/-10%, X7R, 0402	0402	C1005X7R1E103K	TDK
C18	1	3.3pF	CAP, CERM, 3.3 pF, 25 V, +/- 5%, C0G/NP0, 0402	0402	GRM1555C1E3R3CA01D	MuRata
GND, TPG1, TPG2	3	Black	Test Point, TH, Multipurpose, Black		5011	Keystone Electronics
IN+, IN-, OUT+, OUT-, PD, Vcm	6		Connector, SMT, End launch SMA 50 ohm	SMA End Launch	142-0701-851	Emerson Network Power
Jpd	1		Header, TH, 100mil, 2x1, Gold plated, 230 mil above insulator	TSW-102-07-G-S	TSW-102-07-G-S	Samtec, Inc.
R1, R2, R3, Ri+, Ri-	5	100	RES, 100, 1%, 0.063 W, 0402	0402	CRCW0402100RFKED	Vishay-Dale
Rcm+, Rcm-	2	1.00k	RES, 1.00k ohm, 1%, 0.1W, 0603	0603	CRCW06031K00FKEA	Vishay-Dale
Ro+, Ro-	2	40.2	RES, 40.2 ohm, 1%, 0.063W, 0402	0402	CRCW040240R2FKED	Vishay-Dale
Rsd	1	49.9	RES, 49.9 ohm, 1%, 0.1W, 0603	0603	CRCW060349R9FKEA	Vishay-Dale
SH-Jpd_1-OPEN	1	1x2	Shunt, 100mil, Gold plated, Black		382811-6	AMP
U1	1		8GHz Ultra Wideband Fully Differential Amplifier, RMS0014A	RMS0014A	LMH5401IRMS	Texas Instruments
V+	1	Red	Test Point, TH, Multipurpose, Red		5010	Keystone Electronics
V-	1	Yellow	Test Point, Multipurpose, Yellow, TH	Yellow Multipurpose Testpoint	5014	Keystone
C15, C16	0		CAP, CERM, xxxF, xxV, [TempCo], xx%, [PackageReference]	0603	Used in BOM report	Used in BOM report
RB+, RB-, Rtcm	0		RES, xxx ohm, x%, xW, [PackageReference]	0603	Used in BOM report	Used in BOM report

Designator	Quantity	Value	Description	Size	PartNumber	Manufacturer
Rf+, Rf-	0	174	RES, 174, 1%, 0.063 W, 0402	0402	CRCW0402174RFKED	Vishay-Dale

8 About the Author

Loren Siebert has been an applications engineer with National Semiconductor and Texas Instruments since 2000. Loren has supported high speed amplifiers in a wide array of applications ranging from video buffers to communications devices. Prior to working in the semiconductor industry Loren was an RF engineer for Cellular One, McCaw Cellular, Nextel and AT&T Wireless.

References:

AN-1719 Noise Figure Analysis Fully Differential Amplifier

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