

Suppressing Even-Order Harmonic Distortion With Improved Board Layouts

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When using a high-speed operational amplifier to drive an ADC harmonic distortion is particularly important. The choice of amplifier as well as the layout is critical and this article is directed specifically on layout issues as they relate to even-order harmonic suppression.

Getting The Lowest Distortion

Most amplifiers are characterized at low gain for harmonic distortion and for those intended to be run at gains of less than 3, harmonic distortion does not depend strongly on layout: The lower the gain of the amplifier, the lower the influence of layout.

Where layout becomes more critical is for high-gain amplifiers, run at gains of 8, 10, 20 or more and which can be either voltage feedback or current feedback. Here we will deal most particularly with a wideband current-feedback solution with a bandwidth greater than 500 MHz, at gains of 4 or more, and a decompensated voltage-feedback solution with typical gain-bandwidth product exceeding 1 GHz.

One difficulty when using wideband amplifiers is the influence of board parasitics which can have multiple effects, such as adding some peaking to the frequency response at low gains, which is not desirable when flatness is an issue; in worst cases the amplifier can break into self-oscillation. Another effect is to provide a signal feedback path to the input.

We will analyze a few board layouts, and improve them to reach optimum specifications in a repeatable environment. The initial board to be used as a test vehicle is shown below:

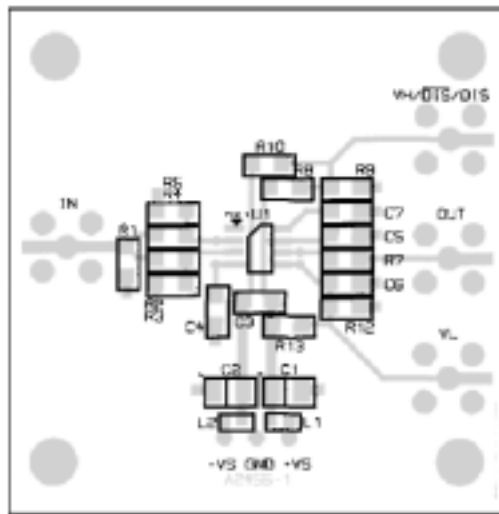


Fig. 1a: DEM-OPA68xU Demonstration Board; Component Side Silkscreen/Metal

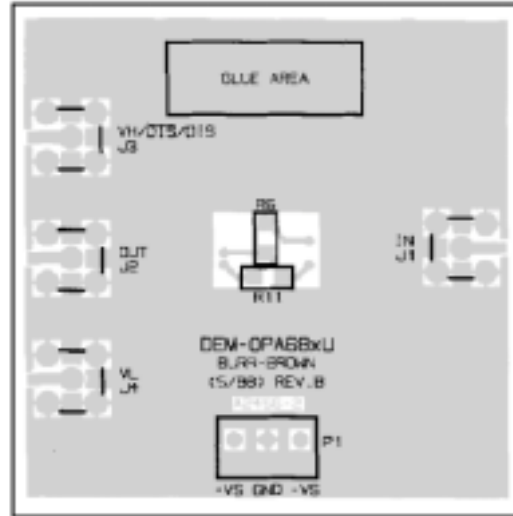


Fig. 1b: DEM-OPA68xU Demonstration Board; Bottom View

This board is an FR4, with two layers, intended to be used for either an inverting or non-inverting amplifier configuration. Its performance is reasonably good for moderate distortion targets and was intended to be a general-purpose evaluation vehicle.

The small-signal frequency response (see Fig. 2) for a wideband voltage-feedback amplifier (OPA847) on this board is configured at the minimum specified gain (12 V/V) to emphasize the peaking in the frequency response. This 3.9-GHz gain-bandwidth part is optimized to show a flat frequency response at $A_V=20$ V/V.

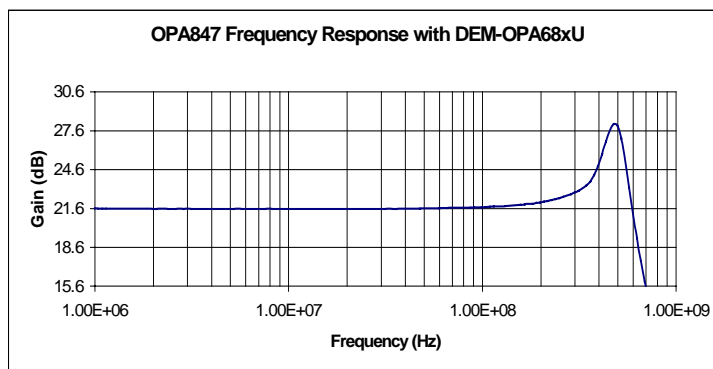
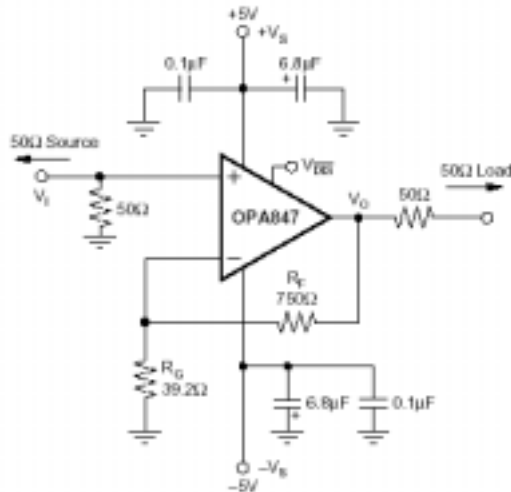


Fig. 2: OPA847 (G = +12) Small-Signal, Frequency Response On Test Board

You will notice a peaking that exceeds the typical 4-dB peaking specified in the datasheet.

Trying to link the excessive peaking of the frequency response to physical characteristics of the board brings us to look at different aspects of the circuit and layout.



Parasitics present include a capacitance across the source resistance, another across R_G , and an $R_F = 432 \Omega$.

Fig. 3: OPA847 ($G = +12 \text{ V/V}$) Schematic

Let's start with the circuit. Wideband amplifiers are sensitive to parasitic capacitance on the input pins, either inverting or non-inverting. This layout has two pads on each input that add parasitic capacitance, shown (Fig. 4) for the inverting input.

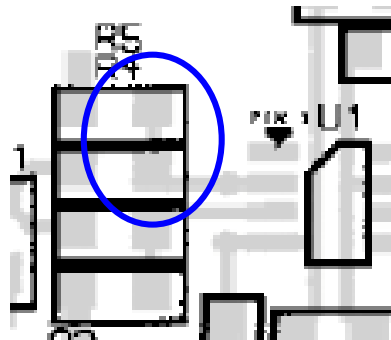


Fig. 4: Pads For Parasitic Capacitance On Inverting Pin

The top plate of the parasitic capacitance is, for the inverting node, the pads shown on Fig. 4. The bottom plate is the ground plane on the other layer and the insulator is the board material.

The parasitic capacitances generated by the ground plane are one effect of the location and shape of this plane. Opening the ground plane around the device as well as removing unnecessary pads will reduce, if not eliminate those parasitics.

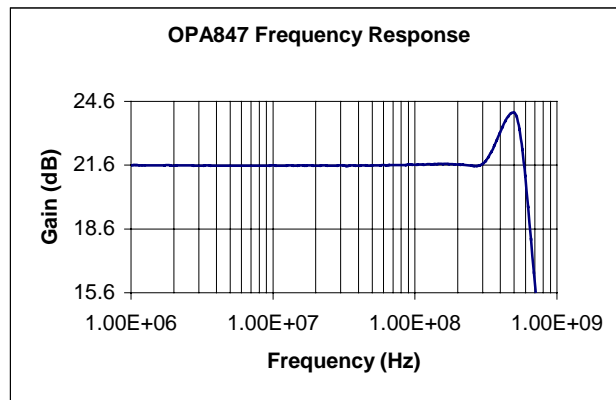


Fig. 5: OPA847 ($G = +12 \text{ V/V}$) Small-Signal Frequency Response

Implementation of solutions to the parasitics (Figs. 3 & 4, again) is shown in Fig. 5. Notice particularly that the peaking is reduced to 2.5 dB.

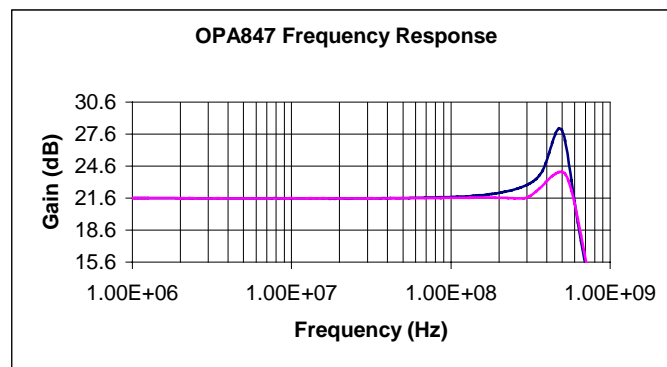


Fig. 6: Comparison Between Initial and Final Frequency Responses

The second problem exhibited by this original board, and the main subject of this article, is harmonic distortion. Harmonic distortion has numerous different sources, but include:

- Harmonic Distortion due to the output stage of the amplifier
- Parasitic feedback to the input that is then amplified

The first source is common to all amplifiers and is usually the major contributor to total harmonic distortion. Parasitic feedback can, especially for high gain amplifiers, dominate even-order levels even if output stage distortion is low. The feedback path is typically as ground current.

Harmonic distortion will be measured under the following sets of conditions:

- $V_O = 2 \text{ Vpp}$ measured at the output of the amplifier
- $R_L = 100 \Omega$
- $V_S = \pm 5 \text{ V}$

The first measurement comes from the original test board and is shown in Fig. 7.

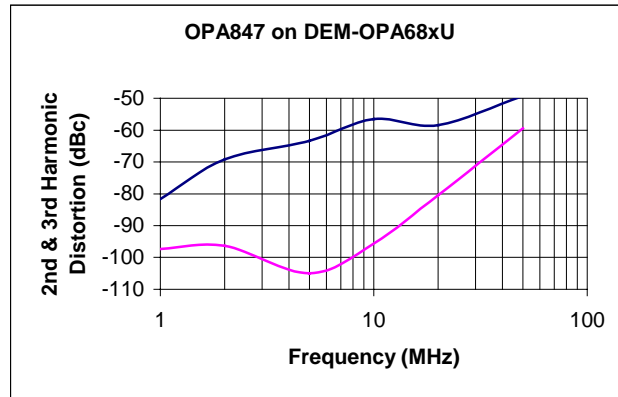


Fig. 7: OPA847 (G = +20) Harmonic Distortion Vs. Frequency, Original Test Board

Using 5 MHz as a reference point, the 2nd harmonic distortion comes to -63 dBc with the test board vs. -74dBc (typical) on the OPA847 datasheet. 11 dB are lost due to layout. Several assumptions can be made on the root cause of this elevated distortion. First, let's have a look at the schematic.

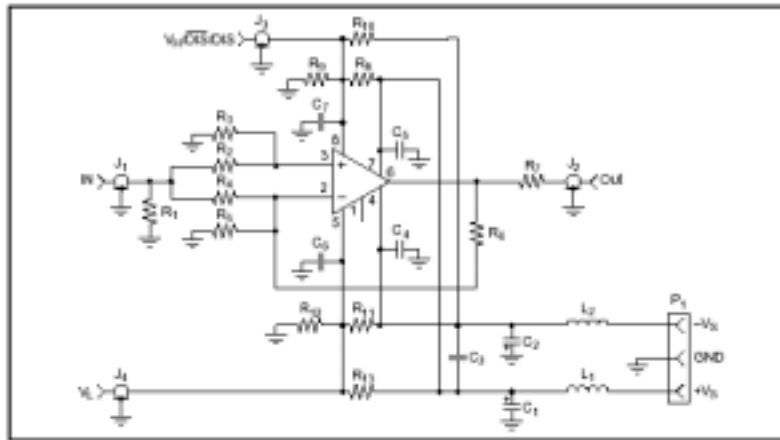


Fig. 8: Schematic Of Original Test Board

The amplifier being configured at a gain of 20 (26 dB) any signal at the 2nd harmonic frequency greater than -89 dBm fed back in the non-inverting input or -88 dBm to the inverting input will create the higher harmonic distortion seen. That said, the most obvious feedback path for these signals is through the ground to R₃ or R₅ (Fig. 8).

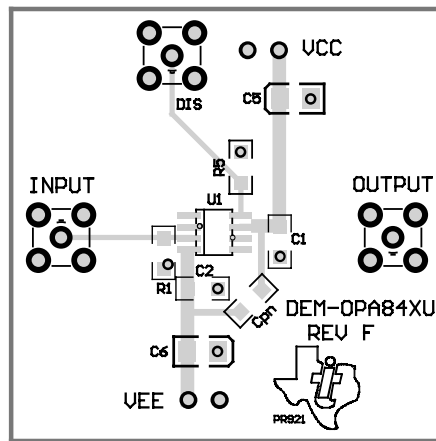
These resistors need to be considered as inputs from the ground plane signal as far as harmonic distortion is concerned. Experience has shown that having a common ground for these paths helped. An explanation could be that having same length path from the ground to each resistor allows signal to be rejected by the amplifier.

Another less obvious path is capacitive coupling, also at the input pins, through resistor pads (Fig. 3, again). The solution is to open the ground plane further around the part.

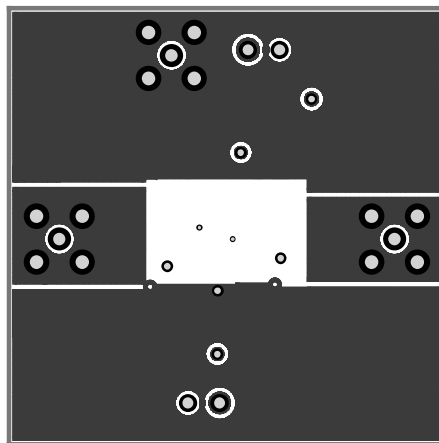
In order to avoid circulating current, two ground planes have been used to create a constant line impedance (Figs. 9b and 9c). The plane on Fig. 9b was divided in four allowing each portion of the plane to be connected through only a single point to the plane on Fig. 9c.

In order to limit noise coming from the power supply great care has been taken in turning away from the inputs the current return path from each supply.

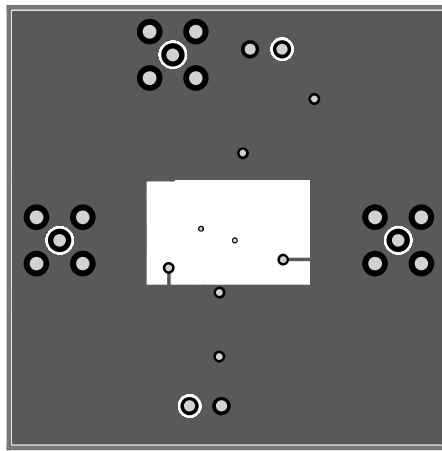
An implementation of this board is shown in Figure 9.



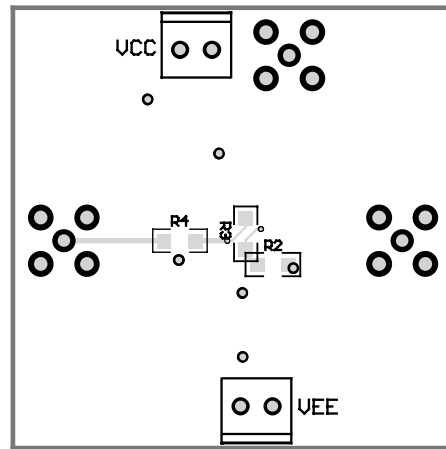
(a)



(b)



(c)



(d)

Fig. 9: Board Layout: (a) Top, (b) Mid Layer2, (c) Mid Layer 1, (d) Mirrored Bottom Layer

Comparison of the frequency response between the different boards was shown in Fig. 6, while harmonic distortions are compared in Fig. 10.

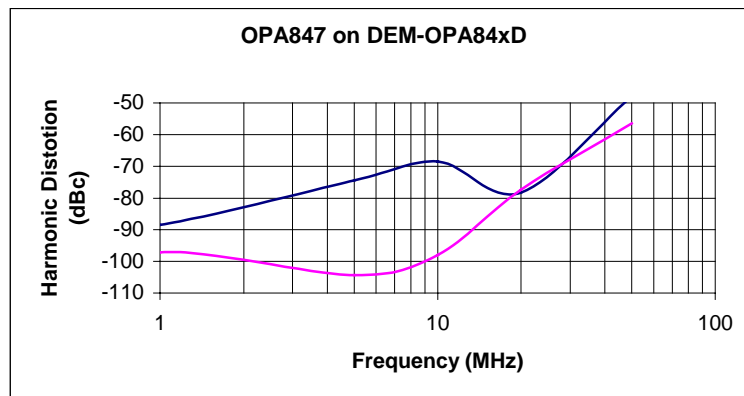


Fig. 10: Harmonic Distortion Of The New Board

This last board brings 10 dB, or more, 2nd harmonic distortion improvement up to 30 MHz showing how sensitive high-gain devices are to layout design.

Fig. 11 compares the distortion results for the OPA847. Notice the improvement in harmonic distortion for the 2nd harmonic.

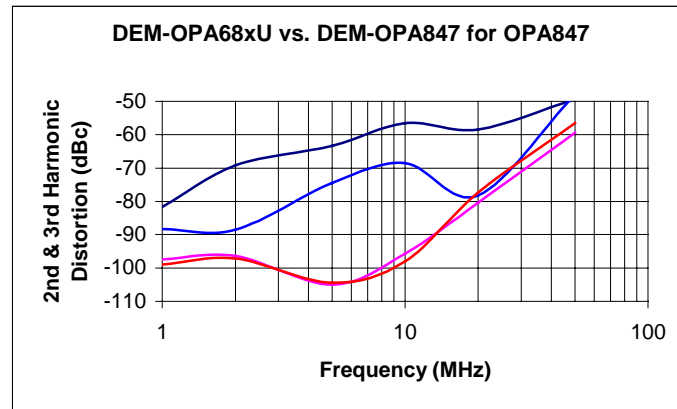


Fig. 11: Harmonic Distortion Vs. Frequency Comparison Between The Two Boards

Using the OPA847 in a differential configuration can bring further improvement in harmonic distortion, an example is given in Fig. 12.

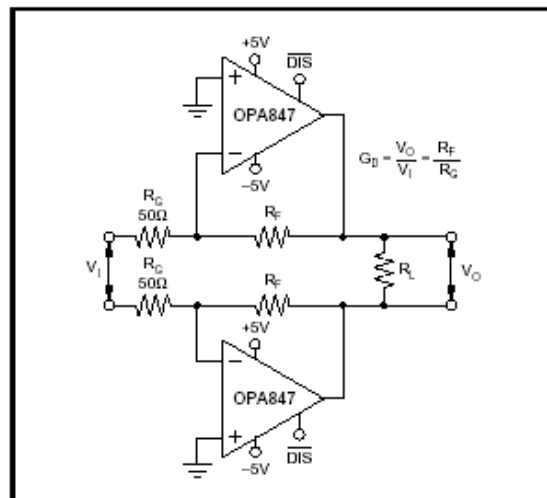


Fig. 12: OPA847 Differential Circuit

Differential circuits have the advantage of canceling the 2nd harmonic, the most dominant term, opening the door to very low distortion at higher frequencies.

Fig. 13 shows harmonic distortion for the circuit of Fig. 12 with a gain of 40V/V, a 400 Ω load, and an output voltage of 4Vpp.

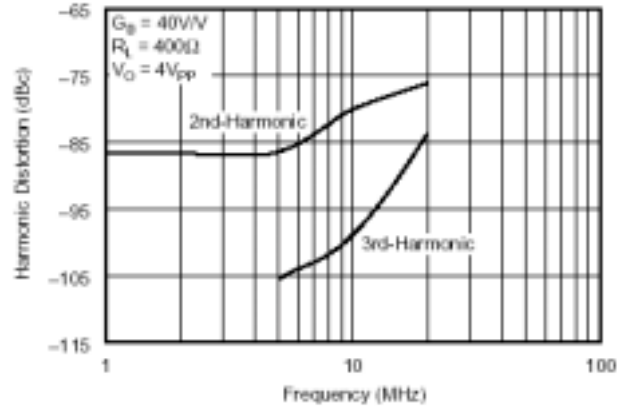


Fig 13: OPA847 Differential Circuit Harmonic Distortion

About The Author

Xavier Ramus is an applications engineer for high-speed signal processing products at TI-Tucson, AZ. He earned MSEE degrees from ESME-Sudria (Paris, France) and San Jose State University (San Jose, CA). His spare-time interests include history, antiques and running.

