BUILDING A 400MHz WIDE-BAND DIFFERENTIAL AMPLIFIER: IT'S A BREEZE WITH THE DIAMOND TRANSISTOR OPA660.

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In radio frequency (RF) technology, signals from oscilloscopes, monitors, transient recorders, and many other devices are usually connected to sensors and generators via coaxial lines. In any transmission, however, interference voltages caused by differences in potential between the sender and receiver and by electromagnetic interference distort the results, particularly when the signals being transmitted are sensitive and wide-band. Designers of this type of transmission system need shielded, symmetrical transmission lines and input differential amplifiers with high common-mode rejection, which bring home the signals without humming or radio interference.

Designing this type of differential amplifier used to be quite a chore, involving extensive and complicated hardware. But the development of new, monolithic ICs such as the Diamond Transistor OPA660 has changed all that. The OPA660 makes it easy to design a 400MHz differential amplifier offering –60dB common-mode rejection at a 1MHz frequency. This amplifier uses an open-loop amplifier structure with two identical high-impedance inputs and no feedback. The parameters such as wide bandwidth, stable operation, and excellent pulse processing, common-mode rejection, and harmonic distortion let the performance speak for itself.

BASIC TRANSMISSION STRUCTURES

Figure 1 shows a symmetrical transmission path with signal voltage V_S and cable termination resistors R_{IN} and R_t. A symmetrical voltage source normally uses amplifiers with complementary outputs or transformers to balance or adapt the circuits. The relatively high-impedance input resistor R_b limits the input potential drift through the input bias currents (I_{BIAS}), and the symmetrical differential amplifier input rejects interference voltages superimposed upon the input signal and its reference potential. The voltage-controlled current source converts the symmetrical input voltage V_{IN} either into an output current or into the asymmetrical output voltage V_{OUT} when a voltage drop is present at the external resistor R_{OUT}. V_{IN} and V_{OUT} are related as follows: $V_{OUT} = V_{IN} \cdot gm \cdot R_{OUT}$, where gm is the transconductance of the operational transconductance amplifier (OTA). The buffer following the input amplifier decouples the low-impedance load resistor from the high-impedance OTA output.

Instead of symmetrical signal excitation, many applications use the type of transmission path shown in Figure 2. A single-ended signal voltage V_{IN} drives an asymmetrical coaxial cable terminated on both sides. In this structure as well, the symmetrical differential amplifier input rejects interference voltages superimposed on the signal.

INSTRUMENTATION AMPLIFIER WITH FEEDBACK

OTAs and buffers have conventionally been designed using differential amplifiers as shown in Figure 3. The feedback path from the op amp output over R_4 generates a relatively low-impedance inverting input, which is equal to the R_3 resistor value. Inserting the buffer amplifier, BUF2, converts the low-impedance input to high impedance, while inserting the buffer amplifier, BUF1, optimizes the input symmetry and thus the common-mode rejection at DC and vs frequency.

The gain is R_4/R_3 during signal excitation at the inverting input and $1 + R_4/R_3$ during signal excitation at the noninverting input. A divider is inserted between R_1 and R_2 to compensate for these differing gains. Buffer 1 also synchronizes the signal delay times of the two inputs, which is important for good common-mode rejection at high frequencies. To achieve high common-mode rejection over frequency, it is important that the gain curve of the two input buffers be as identical as possible.
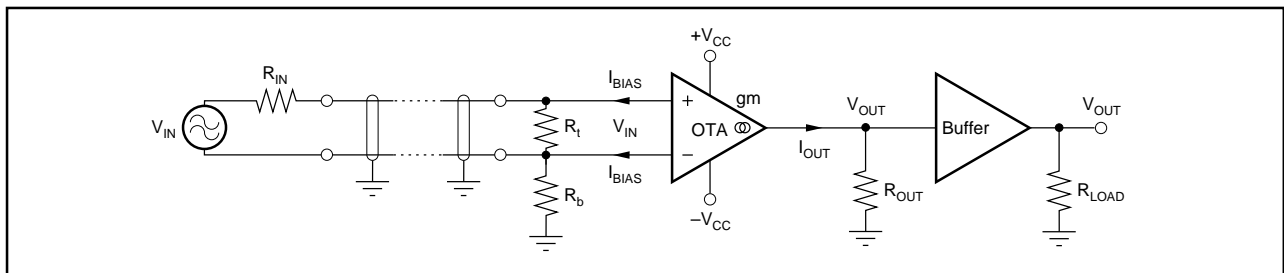

FIGURE 1. Basic Structure of a Symmetrical Transmission Path.

In addition to requiring more hardware, this type of system also has smaller bandwidth than the open-loop amplifier shown in Figure 2 due to the delay time in its amplifier feedback loop (phase shift).

A SYNTHESIS: OPEN-LOOP AMPLIFIER USING THE DIAMOND TRANSISTOR

The open-loop amplifier using the Diamond Transistor OPA660 and buffer amplifier BUF601 combines the best of both worlds, offering better bandwidth than a normal open-loop amplifier, excellent pulse responses down to rise/fall times of 1ns, and reduced hardware. The basic concept is shown in Figure 4.

The gain can be determined according to the following equation:

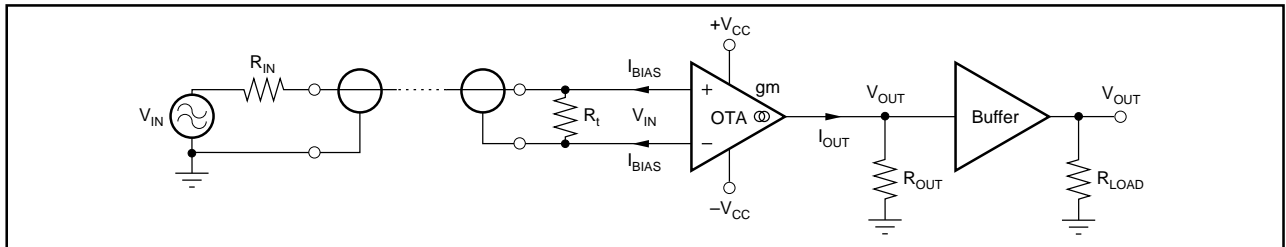$$V_{OUT} = V_{IN} \frac{R_{OUT}}{R_E + 2/gm}$$

FIGURE 2. Signal Transmission Using an Asymmetrical Coaxial Cable and a Signal Voltage Referred to Ground.
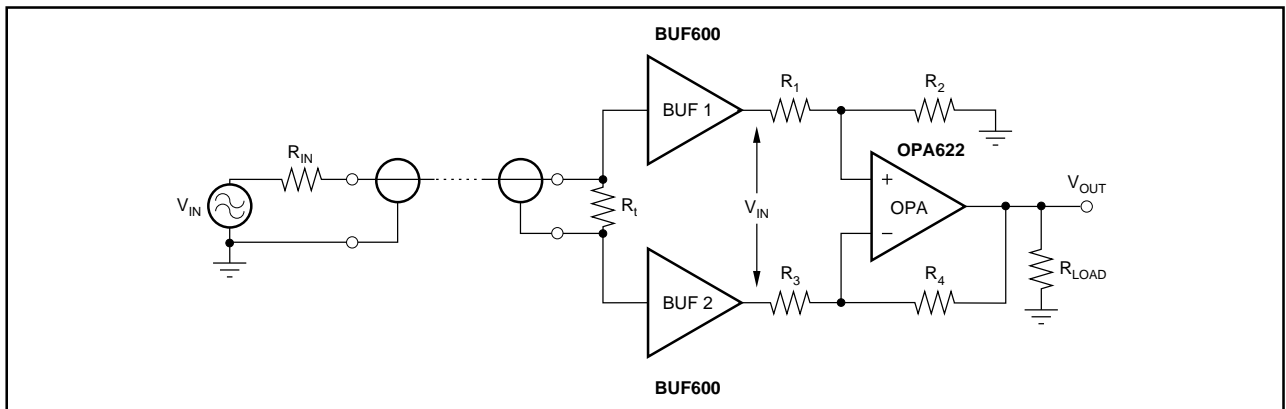

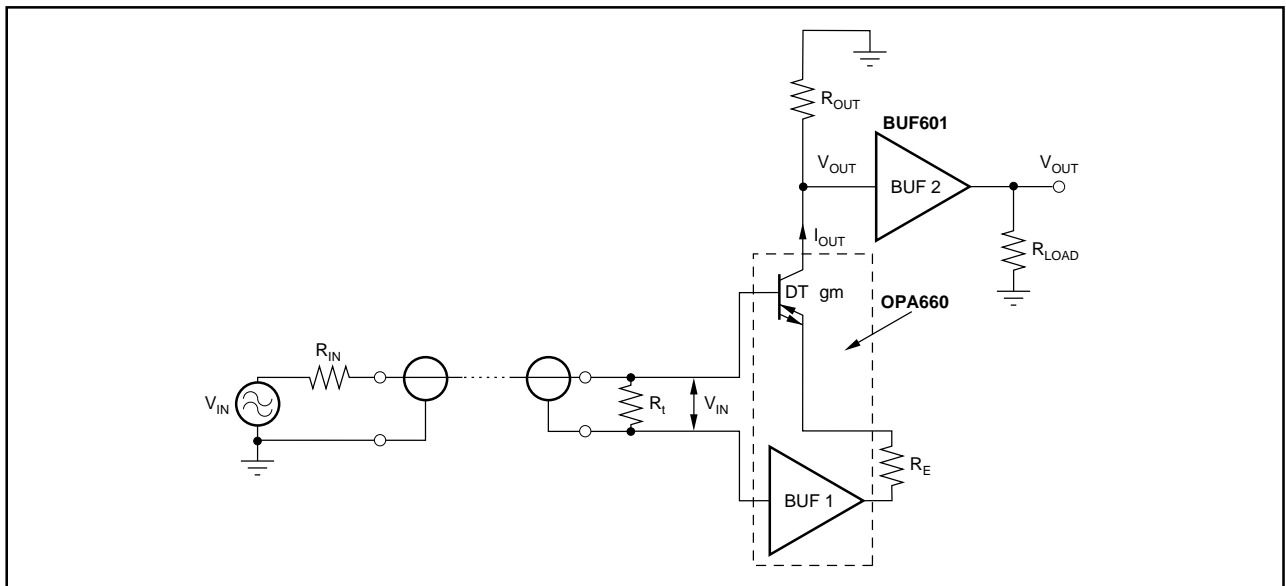FIGURE 3. Instrumentation Amplifier with Feedback.

FIGURE 4. Wide-Band Open-Loop Amplifier.

Since the actual symmetrical structure of the circuit layout greatly effects the bandwidth and common-mode rejection, a demo board was used to determine the characteristic transmission parameters that this configuration shows in practice. Figure 5 illustrates the demo board in detail. The silkscreen and layout tips can be extremely useful in designing your own layouts.

The OPA660 contains a transconductance amplifier nicknamed the Diamond Transistor and a buffer called the Diamond Buffer in an 8-pin package. The Diamond Transistor itself consists of a buffer identical to the Diamond Buffer, followed by a current mirror. On the output side, the buffers are connected to each other via the resistor R_8, forming the differential input stage. When the input voltage is differential, a current flows through R_8, is reflected in high-impedance form to Pin 8, and produces the output voltage at R_9. To drive low-impedance transmission lines or input resistors, the buffer amplifier BUF601 decouples the relatively high-impedance output of the differential amplifier. Both inputs and the output are laid out for 50Ω systems, but they can also be adapted to other characteristic impedances by replacing the resistors R_3, R_7, and R_{11}. Capacitor C_5 parallel to R_8 compensates the parasitic capacitor at Pin 8 of the OPA660, thus expanding the achievable bandwidth.

The resistors, R_4, R_6, and R_{10}, located at the front of the circuit in series to the high-impedance inputs, make it possible to set the frequency response at the end of the bandwidth for a flat response. The quiescent current of the OPA660 is ±20mA at an R_{16} of 560Ω.

TEST RESULTS

The amplifier stage is set to a gain of +4 at an R_9 of 240Ω and R_8 of 43Ω. The total gain from input to output, including the output divider R_{11}/R_L, is +2. Figure 6 illustrates the frequency response of the two inputs In+ and In–. The –3dB frequency (fg) is 400MHz. Figure 7 shows the impact of the capacitor C_5 on the bandwidth.

The common-mode gain over frequency curve shown in Figure 8 demonstrates the rejection of interference voltages on both input voltages. The interference remains less than –18dB over the entire bandwidth, starting at a common-mode gain of –68dB. While the 400MHz differential amplifier amplifies differential signals by 4, the common-mode noise of the same frequency that appears at the output is multiplied only by 0.125. Table I lists the common-mode gain for several frequency levels.

f_{IN}	CG
1MHz	–60dB
10MHz	–45dB
100MHz	–23dB

TABLE I. Several Common-Mode Gains.

The harmonic distortions shown in Figure 9 and Table II for two different output voltages over frequency are outstanding parameters for a 400MHz differential amplifier and prove that the OPA660 and BUF601 provide excellent reproduction of wide-band input signals even without feedback. Furthermore, the low noise voltage density of 7.7nV/√Hz makes it possible to process even very small signals.
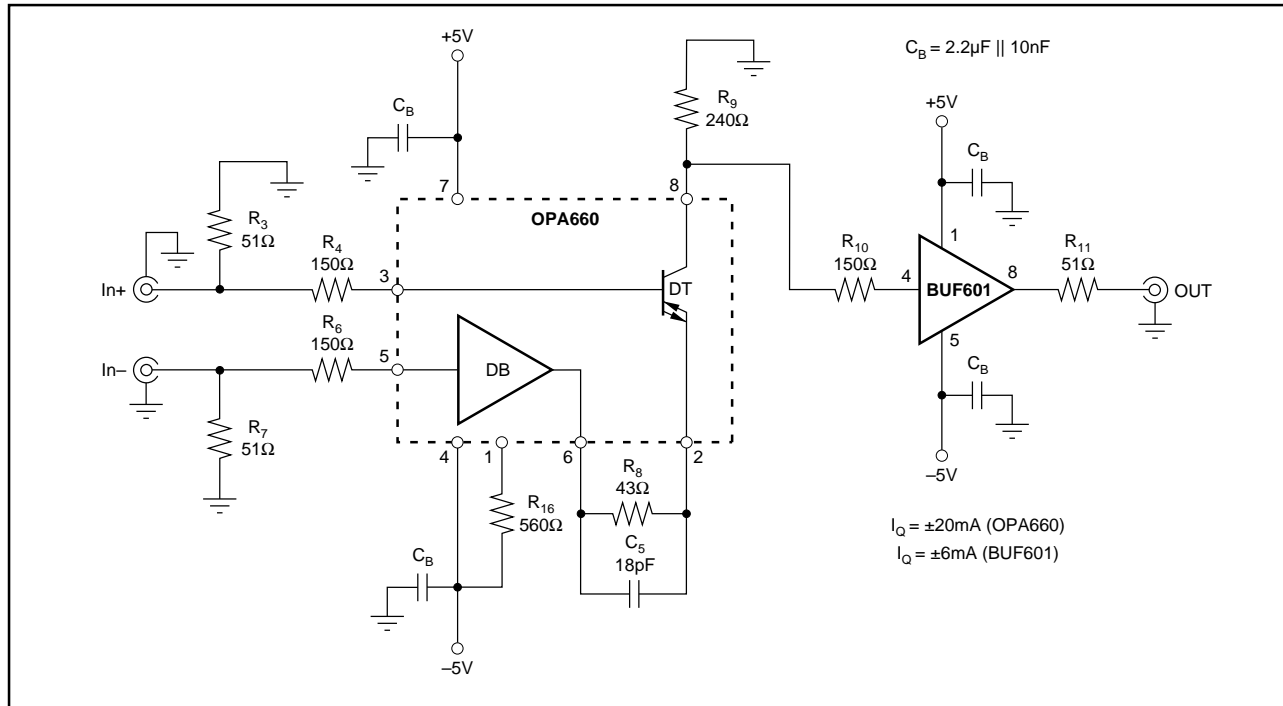

FIGURE 5. Circuit Diagram of the Demo Board.

HIGH PROCESSING POWER, LOW POWER REQUIREMENTS

The most important job of a differential amplifier is to reject common-mode interference arising during the transmission of analog signals. The 400MHz differential amplifier using the OPA660 impressively demonstrates how easy it now is to design wide-band input amplifiers for test devices, monitors, transient recorders, and other RF devices. While achieving excellent parameters for bandwidth, common-mode rejection, and frequency response, the OPA660 and BUF601 also offer such low power consumption that the entire differential amplifier can be powered from a separate battery supply—a truly compact, high-performance alternative.
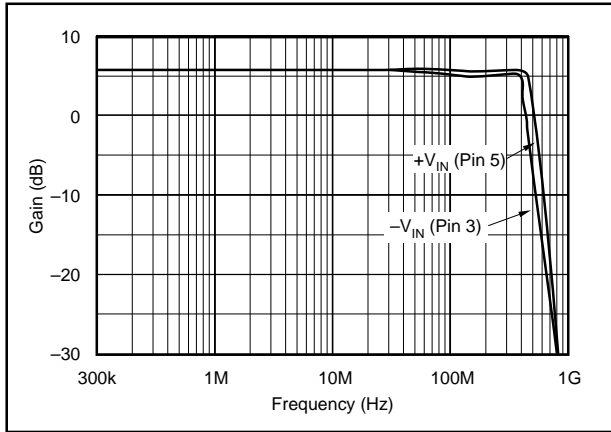

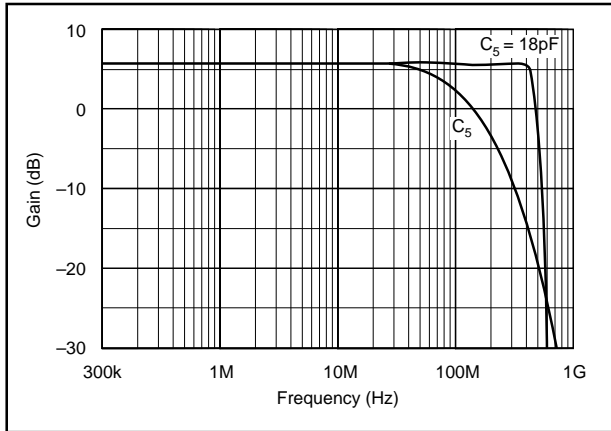FIGURE 6. Frequency Responses of the Inputs In+ and In–.

FIGURE 7. Impact of Capacitor C_S on the Bandwidth.

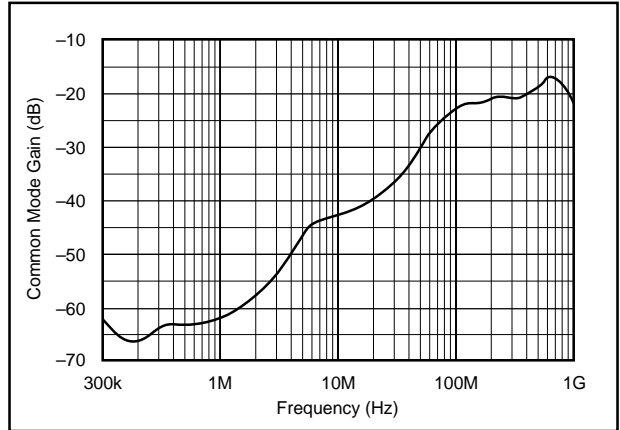| f	V_{OUT}	HARMONIC DISTORTION
10MHz	1Vp-p 1st Harmonic	–61dB
10MHz	1Vp-p 2nd Harmonic	–64dB
10MHz	2Vp-p 1st Harmonic	–57dB
10MHz	2Vp-p 2nd Harmonic	–55dB

TABLE II. Harmonic Distortion.
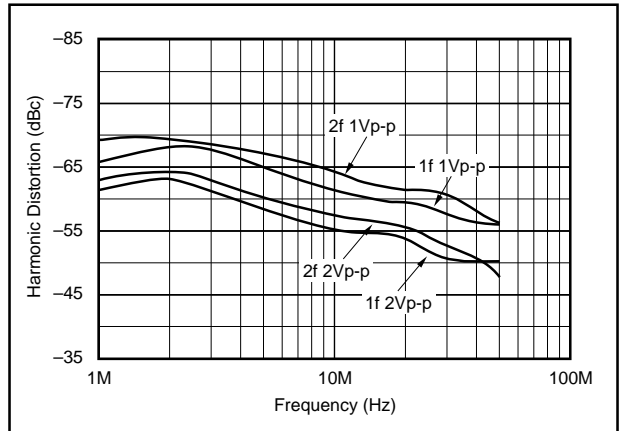

FIGURE 8. Common-Mode Gain.

FIGURE 9. Harmonic Distortion.

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