Applications for a New Ultra-High Speed Buffer

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INTRODUCTION

Voltage followers have gained in popularity in applications such as sample and hold circuits, general purpose buffers, and active filters since the introduction of IC operational amplifiers. Since they were not specifically designed as followers, these early IC's had limited usage due to low bandwidth, low slew rate and high input current. Usage of voltage followers was expanded in 1967 with the introduction of the LM102, the first IC designed specifically as a voltage follower. With the LM102, engineers were able to obtain an order of magnitude improvement in performance and extend usage into medium speed applications. The LM110, an improved LM102, was introduced in late 1969. However, even higher speeds and lower input currents were needed for very fast sample and holds, A to D and D to A converters, coax cable drivers, and other video applications.

The solution to this application problem was attained by combining technologies into a single package. The result, the LH0033 high speed buffer, utilizes JFET and bipolar technology to produce a ultra-fast voltage follower and buffer whose propagation delay closely approaches speed-of-light delay across its package, while not compromising input impedance or drive characteristics. Table I compares various voltage followers and illustrates the superiority of the LH0033 in both low input current or high speed video applications.

CIRCUIT CONSIDERATIONS

The junction FET makes a nearly ideal input device for a voltage follower, reducing input bias current to the picoamp range. However, FET's exhibit moderate voltage offsets and offset drifts which tend to be difficult to compensate. The simple voltage follower of *Figure 1* eliminates initial offset and offset drift if Q_1 and Q_2 are identically matched transistors. Since the gate to source voltage of Q_2 equals zero volts, then Q_1's gate to source voltage equals zero volts. Furthermore as V_{P1} changes with temperature (approximately 2.2 mV/°C), V_{P2} will change by a corresponding amount. However, as load current is drawn from the output, Q_1 and Q_2 will drift at different rates, A circuit which overcomes offset voltage drift is used in a new high speed buffer amplifier, the LH0033. Initial offset is typically 5 mV and offset drift is 20 μV/°C. Resistor R_2 is used to establish the drain current of current source transistor, Q_2 at 10 mA.

The same drain current flows through Q_1 causing a voltage at the source of approximately 1.1V. The 10 mA flowing through R_1 plus Q_3's V_{BE} of 0.6V causes the output to sit at zero volts for zero volts in. Q_3 and Q_4 eliminate loading the input stage (except for base current) and CR_1 and CR_2 establish the output stage collector current.

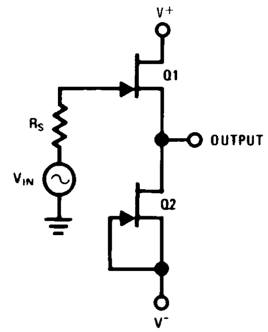

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FIGURE 1. Simple Voltage Follower Schematic

If Q_1 and Q_2 are matched, the resulting drift is reduced to a few μV/°C.

PERFORMANCE OF THE LH0033 FAST VOLTAGE FOLLOWER/BUFFER

The major electrical characteristics of the LH0033 are summarized in Table II. All the virtues of a ultra-high speed buffer have been incorporated.

Figure 3 is a plot of input bias current vs temperature and shows the typical FET input characteristics. Other typical performance curves are illustrated in *Figures 4* through *10*. Of particular interest is *Figure 8*, which demonstrates the performance of the LH0033 in video applications to over 100 MHz.

APPLICATIONS FOR ULTRA-FAST FOLLOWERS

The LH0033's high input impedance (10^{11} Ω, shunted by 2 pF) and high slew rate assure minimal loading and high fidelity in following high speed pulses and signals. As shown below, the LH0033 is used as a buffer between MOS logic and a high speed dual limit comparator. The device's high input impedance prevents loading of the MOS logic signal (even a conventional scope probe will distort high output impedance MOS). The LH0033 adds about a 1.5 ns to the total delay of the comparator. Adjustment of voltage divider R_1, R_2 allows interface to TTL, DTL and other high speed logic forms.

TABLE I. COMPARISON OF VOLTAGE FOLLOWERS

Parameter	Conventional Monolithic Op Amp LM741	First Generation Voltage Follower LM102	Second Generation Voltage Follower LM110	Specially Designed Voltage Follower LH0033
Input Bias Current	200 nA	3.0 nA	1.0 nA	0.05 nA
Slew Rate	0.5 V/μs	10V/μs	30V/μs	1500V/μs
Bandwidth	1.0 MHz	10 MHz	20 MHz	100 MHz
Prop. Delay Time	350 ns	35 ns	18 ns	1.2 ns
Output Current Capability	±5 mA	±2 mA	±2 mA	±100 mA

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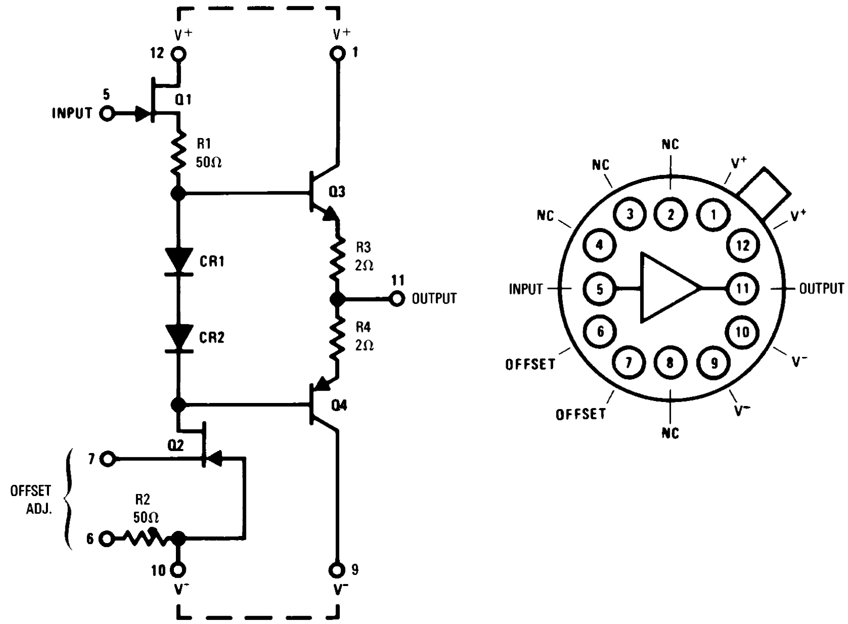

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Top View

FIGURE 2. LH0033 Schematic

TABLE II

Parameter	Conditions	Value	Parameter	Conditions	Value
Output Offset Voltage	R_S = 100 kΩ	5 mV	Output Current Capability		±100 mA peak
Input Bias Current		50 pA	Slew Rate	R_S = 50Ω, R_L = 1k	1500V/µs
Input Impedance	V_{IN} = 1.0 Vrms R_L = 1k, f = 1 kHz	10^{11} Ω	Propagation Delay		1.2 ns
Voltage Gain	V_{IN} = 1.0 Vrms R_L = 1k, f = 1 kHz, R_S = 100k	0.98	Bandwidth	V_{IN} = 1.0 Vrms R_S = 50Ω, R_L = 1k	100 MHz
Output Voltage Swing	V_S = ±15V, R_S = 100k R_L = 1k	±13V			

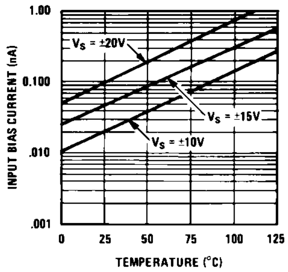

FIGURE 3. Input Bias Current vs Temperature

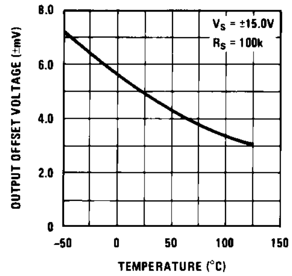

FIGURE 4. Output Offset Voltage vs Temperature

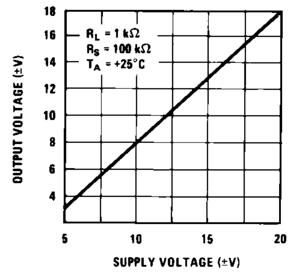

FIGURE 5. Output Voltage vs Supply Voltage

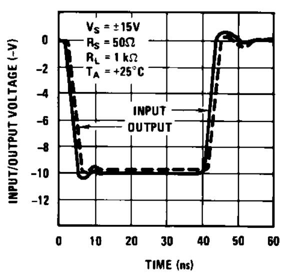

FIGURE 6. Negative Pulse Response

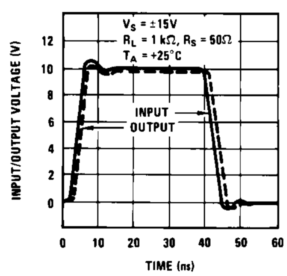

FIGURE 7. Positive Pulse Response

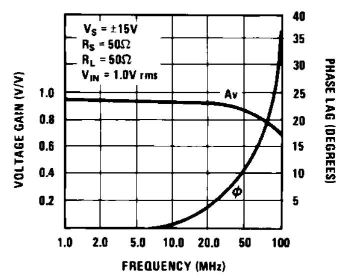

FIGURE 8. Frequency Response

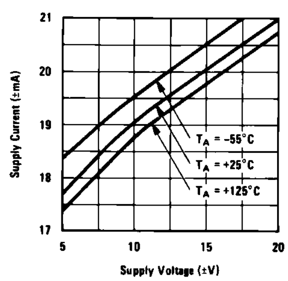

FIGURE 9. Supply Current vs Supply Voltage

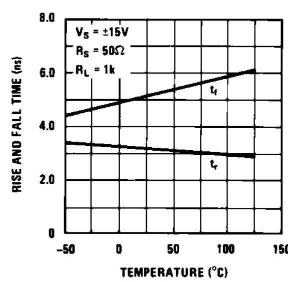

FIGURE 10. Rise and Fall Time vs Temperature

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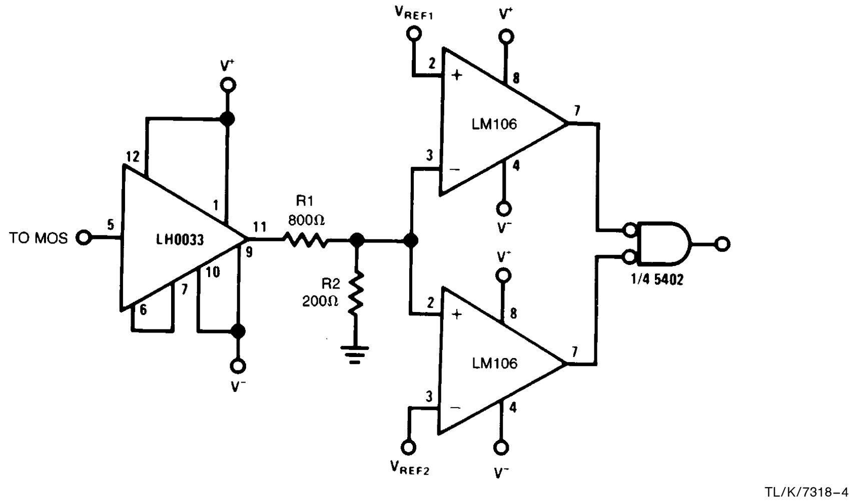

FIGURE 11. High Speed Dual Limit Comparator for MOS Logic

The LH0033 was designed to drive long cables, shielded cables, coaxial cables and other generally stringent line driving requirements. It will typically drive 200 pF with no degradation in slew rate and several thousand pF at a reduced rate. In order to prevent oscillations with large capacitive loads, provision has been made to insert damping resistors between V^+ and pin 1, and V^- and pin 9. Values between 47 and 100Ω work well for $C_L > 1000$ pF. For non-reactive loads, pin 12 should be shorted to pin 1 and pin 10 shorted to pin 9. A coaxial driver is shown in *Figure 13*. Pin 6 is shorted to pin 7, obtaining an initial offset of 5.0 mV, and the 43Ω coupled with the LH0033's output impedance (about 6Ω) match the coaxial cable's characteristic impedance. C_1 is adjusted as a function of cable length to optimize rise and fall time. Rise time for the circuit as shown in *Figure 12*, is 10 ns.

Another application that utilizes the low input current, high speed and high capacitance drive capabilities of the LH0033 is a shield or line driver for high speed automatic test equipment. In this example, the LH0033 is mounted close to the device under test and drives the cable shield thus allowing higher speed operation since the device under test does not have to charge the cable.

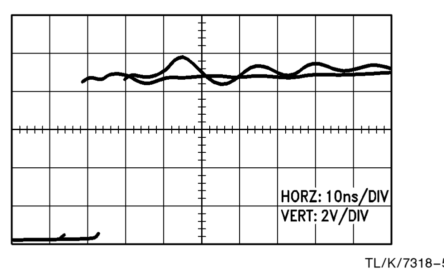

FIGURE 12. LH0033 Pulse Response into 10 Foot Open Ended Coaxial Cable

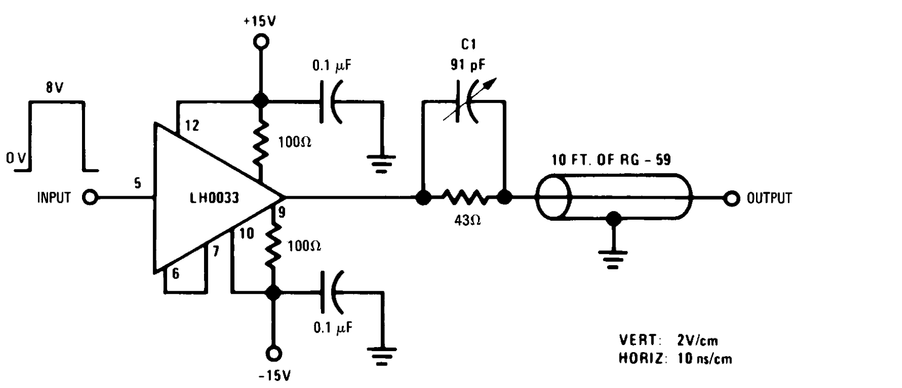

FIGURE 13

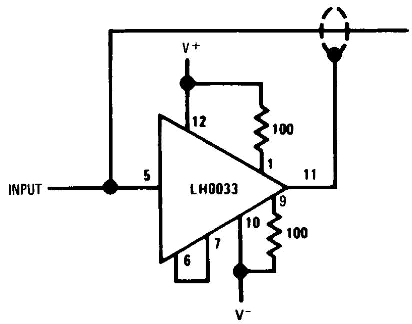

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FIGURE 14. Instrumentation Shield/Line Driver

The LH0033's high input impedance and low input bias current may be utilized in medium speed circuits such as Sample and Hold, and D to A converters. *Figure 15* shows an LH0033 used as a buffer in medium speed D to A converter.

Offset null is accomplished by connecting a 100Ω pot between pin 7 and V^-. It is generally a good idea to insert 20Ω in series with the pot to prevent excessive power dissipation in the LH0033 when the pot is shorted out. In non-critical or AC coupled applications, pin 6 should be shorted to pin 7. The resulting output offset is typically 5 mV at 25°C.

The high output current capability and slew rate of the LH0033 are utilized in the sample and hold circuit of *Figure 16.* Amplifier, A1 is used to buffer high speed analog signals. With the configuration shown, acquisition time is limited by the time constant of the switch "ON" resistance and sampling capacitor, and is typically 200 or 300 ns.

A_2's low input bias current, results in drifts in hold mode of

$$\frac{50\ \text{mV}}{\text{sec}}\ \text{at } 25°\text{C} \quad \text{and} \quad \frac{1\text{V}}{\text{sec}}\ \text{at } 125°\text{C}.$$

The LH0033 may be utilized in AC applications such as video amplifiers and active filters. The circuit of *Figure 17* utilizes boot strapping to achieve input impedances in excess of 10 MΩ.

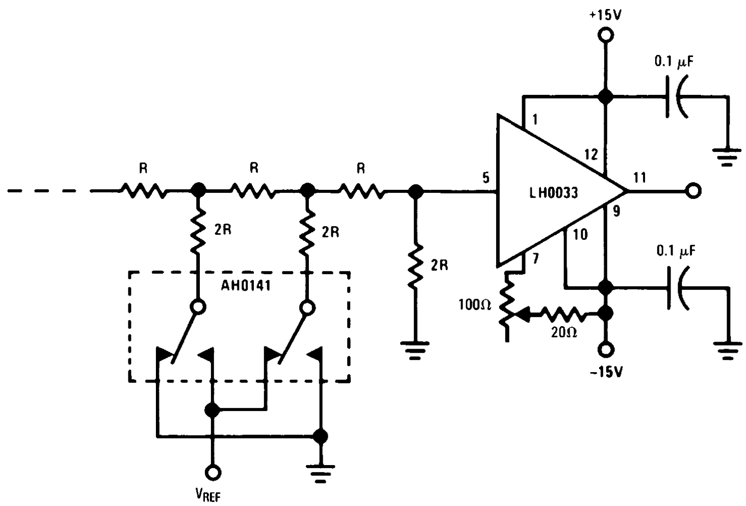

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FIGURE 15

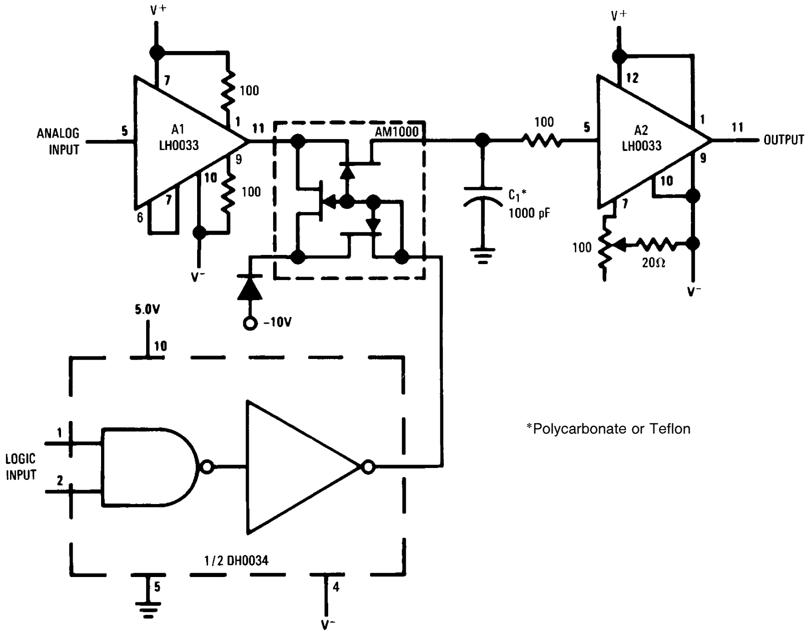

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FIGURE 16. High Speed Sample and Hold

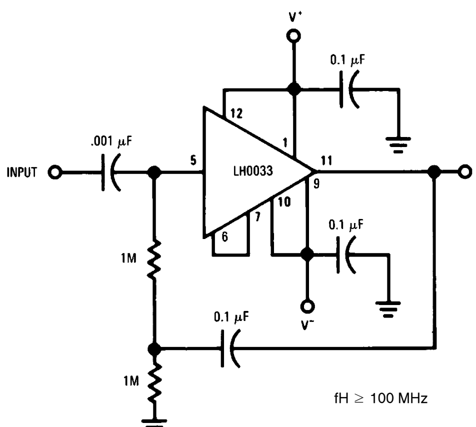

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FIGURE 17. High Input Impedance AC Coupled Amplifier

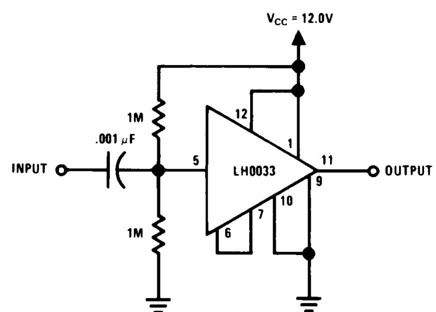

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FIGURE 18. Single Supply AC Amplifier

A single supply, AC coupled amplifier is shown in *Figure 18.* Input impedance is approximately 500k and output swing is in excess of 8V peak-to-peak with a 12V supply.

The LH0033 may be readily used in applications where symmetrical supplies are unavailable or may not be desirable. A typical application might be an interface to an MOS shift register where $V^+ = 5.0V$ and $V^- = -25V$. In this case, an apparent output offset occurs. In reality, the output voltage is due to the LH0033's voltage gain of less than unity.

The output voltage shift due to asymmetrical supplies may be predicted by:

$$\Delta V_O \cong (1 - Av)\frac{(V^+ - V^-)}{2} = .005\,(V^+ - V^-)$$

where: Av = No load voltage gain, typically 0.99.

V^+ = Positive Supply Voltage.

V^- = Negative Supply Voltage.

For the foregoing application, ΔV_O would be −100 mV. This apparent "offset" may be adjusted to zero as outlined above.

Figure 19 shows a high Q, notch filter which takes advantage of the LH0033's wide bandwidth. For the values shown, the center frequency is 4.5 MHz.

The LH0033 can also be used in conjunction with an operational amplifier as current booster as shown in *Figure 20*.

Output currents in excess of 100 mA may be obtained. Inclusion of 150Ω resistors between pins 1 and 12, and 9 and 10 provide short circuit protection, while decoupling pins 1 and 9 with 1000 pF capacitors allow near full output swing.

The value for the short circuit current is given by:

$$I_{SC} \cong \frac{V^+}{R_{LIMIT}} = \frac{V^-}{R_{LIMIT}}$$

where: $I_{SC} \leq 100$ mA.

SUMMARY

The advantages of a FET input buffer have been demonstrated. The LH0033 combined very high input impedance, wide bandwidth, very high slew rate, high output capability, and design flexibility, making it an ideal buffer for applications ranging from DC to in excess of 100 MHz.

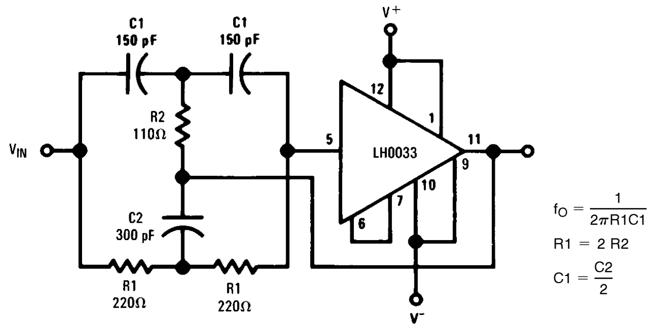

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FIGURE 19. 4.5 MHz Notch Filter

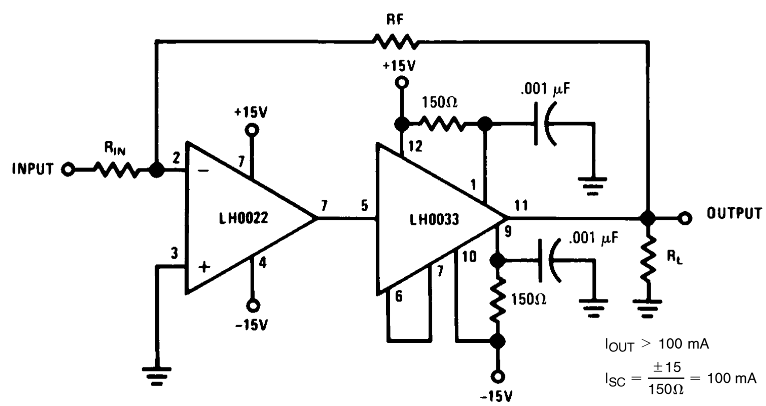

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FIGURE 20. Using LH0033 as an Output Buffer

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