

Feedforward Compensation Speeds Op Amp

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A feedforward compensation method increases the slew rate of the LM101A from $0.5/\mu\text{s}$ to $10\text{V}/\mu\text{s}$ as an inverting amplifier. This extends the usefulness of the device to frequencies an order of magnitude higher than the standard compensation network. With this speed improvement, IC op amps may be used in applications that previously required discretes. The compensation is relatively simple and does not change the offset voltage or current of the amplifier.

In order to achieve unconditional closed loop stability for all feedback connections, the gain of an operational amplifier is rolled off at 6 dB per octave, with the accompanying 90 degrees of phase shift, until a gain of unity is reached. The frequency compensation networks shape the open loop response to cross unity gain before the amplifier phase shift exceeds 180 degrees. Unity gain for the LM101A is designed to occur at 1 MHz. The reason for this is the lateral PNP transistors used for level shifting have poor high frequency response and exhibit excess phase shift about 1 MHz. Therefore, the stable closed loop bandwidth is limited to approximately 1 MHz.

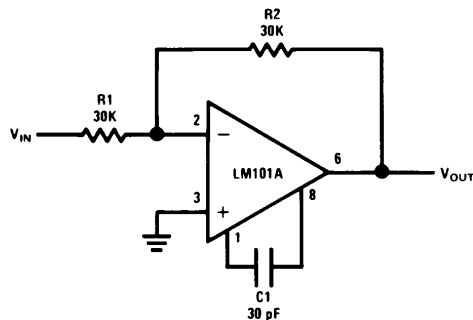


Figure 1. Standard frequency compensation

Usually, the LM101A is frequency compensated by a single 30 pF capacitor between Pins 1 and 8, as shown in Figure 1. This gives a slew rate of $0.5\text{V}/\mu\text{s}$. The feedforward is achieved by connecting a 150 pF capacitor between the inverting input, Pin 2, and one of the compensation terminals, Pin 1, as shown in Figure 2. This eliminates the lateral PNP's from the signal path at high frequencies. Unity gain bandwidth is 10 MHz and the slew rate is $10\text{V}/\mu\text{s}$. The diode can be added to improve slew with high speed input pulses.

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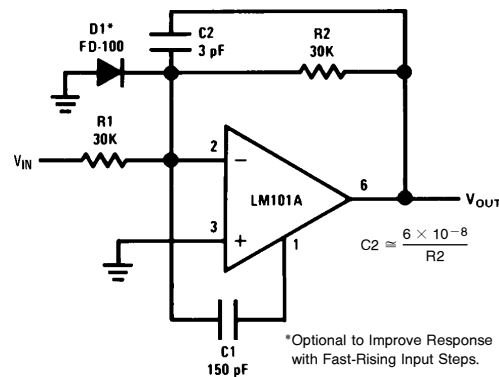


Figure 2. Feedforward frequency compensation

Figure 3 shows the open loop response in the high and low speed configuration. Higher open loop gain is realized with the fast compensation, as the gain rolls off at about 6 dB per octave until a gain of unity is reached at about 10 MHz.

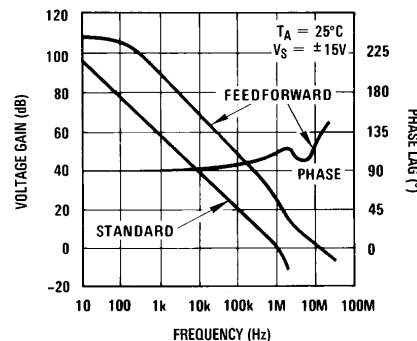
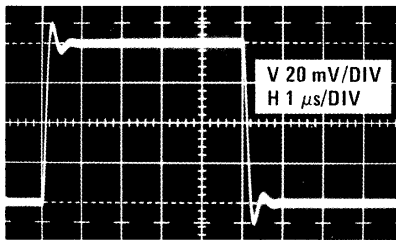


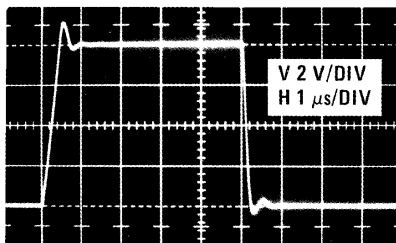
Figure 3. Open loop response for both frequency compensation networks

Figures 4 and 5 show the small signal and large signal transient response. There is a small amount of ringing; however, the amplifier is stable over a -55°C to $+125^{\circ}\text{C}$ temperature range. For comparison, large signal transient response with 30 pF frequency compensation is shown in Figure 6.



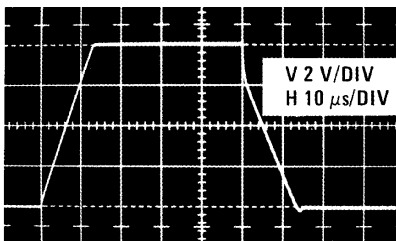
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Figure 4. Small signal transient response with feedforward compensation



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Figure 5. Large signal transient response with feedforward compensation



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Figure 6. Large signal transient response with standard compensation

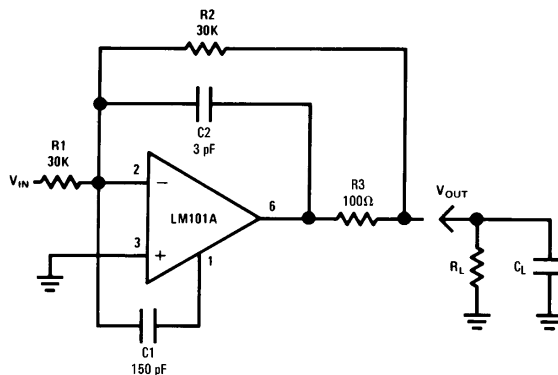
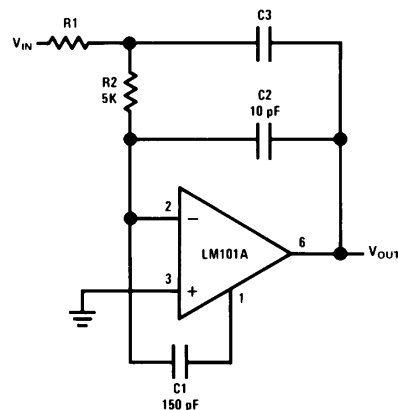


Figure 7. Capacitive load isolation

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As with all high frequency, high-gain amplifiers, certain precautions should be taken to insure stable operation. The power supplies should be bypassed near the amplifier with .01 μF disc capacitors. Stray capacitance, such as large lands on printed circuit boards, should be avoided at Pins 1, 2, 5, and 8. Load capacitance in excess of 75 pF should be decoupled, as shown in Figure 7; however, 500 pF of load capacitance can be tolerated without decoupling at the expense of bandwidth by the addition of 3 pF between Pins 1 and 8. A small capacitor C_2 is needed as a lead across the feedback resistor to insure that the rolloff is less than 12 dB per octave at unity gain. The capacitive reactance of C_2 should equal the feedback resistance between 2 and 3 MHz. For integrator applications, the lead capacitor is isolated from the feedback capacitor by a resistor, as shown in Figure 8.

Feedforward compensation offers a marked improvement over standard compensation. In addition to having higher bandwidth and slew, there is vanishingly small gain error from DC to 3 kHz, and less than 1% gain error up to 100 kHz as a unity gain inverter. The power bandwidth is also extended from 6 kHz to 250 kHz. Some applications for this type of amplifier are: fast summing amplifier, pulse amplifier, D/A and A/D systems, and fast integrator.



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Figure 8. Fast integrator

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