Introduction
By taking advantage of advances in process technology and innovative circuit design, Linear Technology Corporation has developed a series of C-Load op amps which are tolerant of capacitive loading, including the ultimate, amplifiers which are stable with any capacitive load. These amplifiers span a range of bandwidths from 1MHz to 140MHz. They are suited for a wide range of applications from coaxial cable drivers to capacitive transducer exciters.

The Problem
The cause of the capacitive load stability problem in most amplifiers is the pole formed by the load capacitance and the open-loop output impedance of the amplifier. This output pole increases the phase lag around the loop which reduces the phase margin of the amplifier. If the phase lag is great enough the amplifier will oscillate.

External networks can be used to improve the amplifier’s stability with a capacitive load but have serious drawbacks. For instance, most designers are familiar with the use of a series resistor $R_S$ between the load and the amplifier output. The optimum value of $R_S$ depends on the load capacitance, so this approach isn’t useful for ill-defined loads. Further disadvantages of the external approach include reduced output swing and drive current, and increased component count.

An Example
Figure 1 shows an example of a competitor’s medium speed device which is sensitive to capacitive loading. When 50pF is paralleled with a 5kΩ load, the response exhibits considerable ringing. With a 75pF load the device oscillates. By comparison, the transient responses of the 50MHz LT1360 voltage feedback amplifier (Figure 2) shows the improvement in stability achieved in the latest generation of C-Load op amps. In fact the LT1360 maintains a stable transient response for any capacitive load.

The Solution
LTC’s new family of voltage feedback amplifiers adjusts the frequency response of the op amp to maintain adequate phase margin regardless of the capacitive load thus, the amplifiers cannot oscillate. These C-Load amplifiers are great in systems where the load is not fixed or is ill-defined. Examples include driving coaxial cables that
may or may not be terminated, driving twisted-pair trans-
mission lines, and buffering the inputs of sampling A/D
converters that present time varying impedances.

Table 1 lists LTC’s unconditionally stable voltage feed-
back C-Load amplifiers. Table 2 lists other voltage feed-
back C-Load amplifiers that are stable with loads up to
10,000pF. Figure 3 shows overshoot as a function of
capacitive load being driven for a wide variety of LTC op
amps. Note that the unconditionally stable amplifiers
(LT1355, LT1358 and LT1363) have the greatest over-
shoot for $C_L = 10\text{nF}$. Overshoot actually declines as $C_L$ is
increased beyond $10\text{nF}$.

### Table 1. Unity-Gain Stable C-Load Amplifiers Stable with All
Capacitive Loads

<table>
<thead>
<tr>
<th>Singles</th>
<th>Duals</th>
<th>Quads</th>
<th>GBW (MHz)</th>
<th>$I_g$/Amp (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT1200</td>
<td>LT1201</td>
<td>LT1202</td>
<td>11</td>
<td>1</td>
</tr>
<tr>
<td>LT1220</td>
<td>—</td>
<td>—</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>LT1224</td>
<td>LT1208</td>
<td>LT1209</td>
<td>45</td>
<td>7</td>
</tr>
<tr>
<td>LT1354</td>
<td>LT1355</td>
<td>LT1356</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>LT1357</td>
<td>LT1358</td>
<td>LT1359</td>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>LT1360</td>
<td>LT1361</td>
<td>LT1362</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>LT1363</td>
<td>LT1364</td>
<td>LT1365</td>
<td>70</td>
<td>6</td>
</tr>
</tbody>
</table>

### Table 2. Unity-Gain Stable C-Load Amplifiers Stable with
$C_L \leq 10,000\text{pF}$

<table>
<thead>
<tr>
<th>Singles</th>
<th>Duals</th>
<th>Quads</th>
<th>GBW (MHz)</th>
<th>$I_g$/Amp (mA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LT1012</td>
<td>—</td>
<td>—</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>—</td>
<td>LT1112</td>
<td>LT1114</td>
<td>0.65</td>
<td>0.32</td>
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<td>LT1097</td>
<td>—</td>
<td>—</td>
<td>0.7</td>
<td>0.35</td>
</tr>
<tr>
<td>—</td>
<td>LT1457</td>
<td>—</td>
<td>2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

All LTC op amps with adjustable bandwidth can be
stabilized for a range of capacitive loads. The bandwidth
of current feedback amplifiers is set by the external
feedback resistor. Graphs which allow selection of the
proper feedback resistor for $C_L$ values to $10,000\text{pF}$
appear in the data sheets of most LTC current feedback
amplifiers. As an example, Figure 4 shows the LT1206,
a 60MHz current feedback amplifier with 250mA output
current, driving loads of $1000\text{pF}$ and $10,000\text{pF}$ while
remaining stable.

### Figure 3. Overshoot vs Capacitive Load

### Figure 4. LT1206

**Conclusions**

Linear Technology has developed families of medium
and high speed amplifiers which are much easier to
apply than their predecessors. Stable operation with
capacitive loads can be achieved without critical exter-
nal components or loss of output drive. Amplifiers
which are stable with any capacitive load are ideal for
applications where the load is not well defined. These
amplifiers can simplify even low frequency designs by
insuring stability under all conditions of loading. For
more information on C-Load op amps see the February
1994 issue of *Linear Technology Magazine*.

For literature on our Operational Amplifiers,
call **1-800-4-LINEAR**. For applications help,
call (408) 432-1900, Ext. 456