Circuit 1:
Telecopic OP AMP with “BAD” Bias of cascode:
The currents are balanced so that all transistors have,
\[ I_{ds} = I_{ref} \]
except for M13 which has,
\[ I_{ds,13} = 2 \cdot I_{ref} \]
Since,
\[ I_i = I_s = I_{ss} \]
then,
\[ V_{gs} = V_{gs,13} = V_{gs,ss} \] (all \( W/L \)'s are equal also)
This also implies that,
\[ V_{gs} = V_{gs,ss} \]
similarly,
\[ V_{gs} = V_{gs,ss} \]
So if the input has,
\[ V_{id} = 0 \]
Thus the total swing is only $2V_T$, not too good. In the positive direction we could use a high swing configuration as was described for the cascoded current source. On the low side we can use a better circuit.

**Circuit 2:**

Telescopic with a cascode bias that gives a better swing in the negative direction. Maximum voltage in the positive direction is given by $V_{OUTMAX}$ going linear when,

$$V_{OUTMAX} = V_A - V_{DSAT}$$

Negative swing is limited by $M8$ going linear,

$$V_{OUTMIN} = V_A - V_T$$

Set $V_A$ so that $M1$ & $M2$ are at the edge of saturation

$$V_{OUTMAX} + V_{DD} - V_{DSAT} > V_{OUTMIN} - V_{A} - V_{T}$$
This means that, 
\[ V_{c} = V_{i} + V_{DRAIN} + V_{DSAT} \]
Since this will set, 
\[ V_{DS} = V_{DSAT} \]
To calculate the \((W/L)_{2}\) and \(I_{B}\) do this we set, 
\[ V_{DS}, = V_{i} + V_{DSAT} + V_{DSAT} \]
Since, 
\[ V_{DS}, = V_{i} + V_{DSAT} \]
\[ V_{DSAT} = (V_{DS} - V_{i}) + V_{DSAT} + V_{DSAT} \]
If we say, 
\[ V_{DS} = V_{i} \]
then 
\[ \left( \frac{2 \cdot I_{D}}{k_{r} \cdot \left( \frac{W}{L} \right)} \right)^{1/2} = \left( \frac{2 \cdot I_{D}}{k_{r} \cdot \left( \frac{W}{L} \right)} \right)^{1/2} \cdot \left( \frac{1}{\left( \frac{W}{L} \right)^{1/2}} + \frac{1}{\left( \frac{W}{L} \right)^{1/2}} \right)^{2} \]

so, 
\[ \left( \frac{W}{L} \right)_{2} = I_{B} \left( \frac{W}{L} \right)_{2} + \left( \frac{W}{L} \right)_{2} \]
if, 
\[ \left( \frac{W}{L} \right)_{2} = 10 \quad \left( \frac{W}{L} \right)_{2} = 2 \quad I_{B} = 0.79 \mu A \quad I_{B} = 10.5 \mu A \]
then, 
\[ \left( \frac{W}{L} \right)_{2} = \frac{1}{15} \]
Gain and \(R_{O}\)
\[ G = g_{m} \quad \text{(cascoding has no effect on \(g_{m}\))} \]
\[ R_{O} = \left[ \left( g_{m} \cdot r_{o} \right) \cdot \left( r_{o} \right) \right] \parallel \left[ \left( g_{m} \cdot r_{o} \right) \cdot \left( r_{o} \right) \right] \]
\[ A_{o} = g_{m} \cdot \left[ r_{o} \cdot r_{o} + \left( r_{o} \cdot r_{o} \cdot r_{o} \cdot r_{o} \right) \right] \]

Gain keeps increasing as we decrease the current.
Folded Cascode Circuit 3: M1 Linear, M2 Linear, M4 Linear, M6 Linear, M8 Linear

Folded Cascode - VID and VIC Sweeps

More on OP Amps: Eccos and Folded Cascode

Folded Cascode - VID and VIC Sweeps
There is some current splitting at the point of the folding. However when calculating GM the output (drain of M8) is grounded so $R_{UP}$ is about 1/gm with $R_{DOWN}$ being $r_o$. 

$$GM = gm \cdot \frac{R_{DOWN}}{R_{UP} + R_{DOWN}}$$

The loss in $R_{OUT}$ as well since M10 must sink DC current from both M2 and M8, thus reducing its $r_o$.

<table>
<thead>
<tr>
<th>CASCODE</th>
<th>FOLDED CASCODE</th>
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</thead>
<tbody>
<tr>
<td>$A_v$</td>
<td>336K</td>
</tr>
<tr>
<td>$R_{OUT}$</td>
<td>2.446KΩ</td>
</tr>
<tr>
<td></td>
<td>1.486KΩ</td>
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</tbody>
</table>
High Swing Folded Cascode

Circuit 4:

M15-M16 perform level shift to bias M9 and M10 at the edge of linear.
M7 and M8 have 1/2 sized W/L because the current is Iref/2.
The connection to M5 from M14 sets the M3 at the edge of linear operation.
The W/L’s are 1 unless otherwise shown. This is smaller than you would want to use, but this was done to show the ratioing that is required to place the output in high swing.
The Gain and Rout calculations are the same as for circuit 3 and are carried out as described by DP-21 to DP-23.