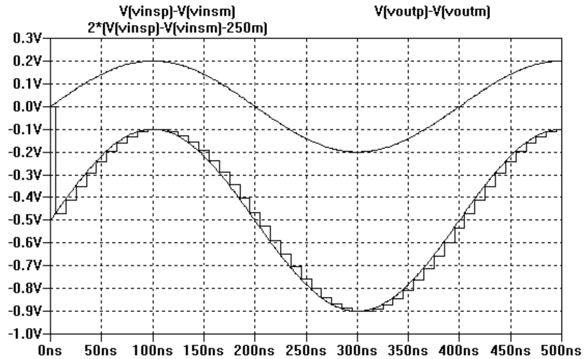

Figure 2.52 Simulation results for Ex. 2.5.

A Single-Ended to Differential Output S/H

Many input signals are single-ended, meaning the (one) input signal swings around V_{CM}. It is desirable in the first stage of the mixed-signal circuit to S/H the signal and then to change it into a fully-differential signal for further processing. A good single-to-differential converter will hold the op-amp's input common-mode voltage at V_{CM} for low distortion (important). In order to meet this goal consider the modified, from Fig. 2.46, S/H seen in Fig. 2.53. Again, we can write, (noting the C_F capacitors are discharged when the ϕ_1 switches are on)

$$Q_{I,F,total}^{\phi_1} = C_{I+} \cdot (v_{in} - V_{CM} \pm V_{OS}) + C_{I-} \cdot (V_{CM} - V_{CM} \pm V_{OS}) \tag{2.88}$$

When the ϕ_3 switches turn on the charge on the C_I capacitors is

$$Q_I^{\phi_3} = C_{I+} \cdot \left(\frac{v_{in}}{2} + \frac{V_{CM}}{2} - V_{CM} \pm V_{OS}\right) + C_{I-} \cdot \left(\frac{v_{in}}{2} + \frac{V_{CM}}{2} - V_{CM} \pm V_{OS}\right) \tag{2.89}$$

noting that the change in charge on the C_I capacitors redistributes through the C_F capacitors. The charge on the feedback capacitors is then

$$Q_F^{\phi_3} = 2C_F \cdot (v_{out} - V_{CM} \pm V_{OS}) \tag{2.90}$$

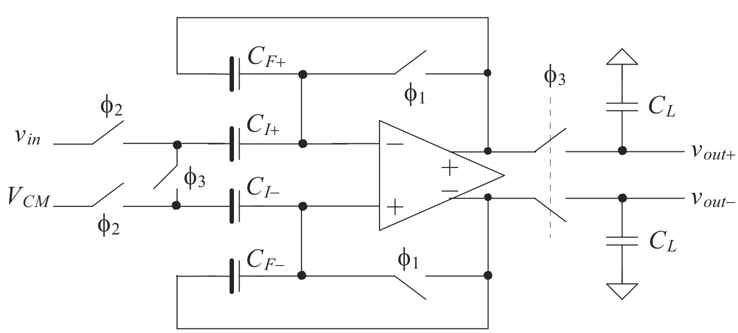

Figure 2.53 S/H for single-ended to differential conversion.

Equating the redistributed charge through C_{F+} and C_{I+}

$$C_{I+} \cdot (v_{in} - V_{CM} \pm V_{OS}) - C_{I+} \cdot \left(\frac{v_{in}}{2} + \frac{V_{CM}}{2} - V_{CM} \pm V_{OS}\right) = C_{F+} \cdot (v_{out+} - V_{CM} \pm V_{OS}) \tag{2.91}$$

or, re-writing for both paths

$$C_{F+} \cdot (v_{out+} - V_{CM} \pm V_{OS}) = C_{I+} \cdot \left(\frac{v_{in}}{2} - \frac{V_{CM}}{2}\right)$$

$$C_{F-} \cdot (v_{out-} - V_{CM} \pm V_{OS}) = C_{I-} \cdot \left(-\frac{v_{in}}{2} + \frac{V_{CM}}{2}\right) \tag{2.92}$$

Assuming $C_{I+} = C_{I-}$, $C_{F+} = C_{F-}$, and taking the difference in the S/H outputs gives

$$\frac{(v_{out+} - v_{out-}) \pm 2V_{OS}}{v_{in} - V_{CM}} = \frac{C_I}{C_F} \tag{2.93}$$

The output is shifted up or down by the offset. Note that this topology doesn't employ correlated double sampling (CDS). Also note that if we model the op-amp's offset with a single voltage source in series with the non-inverting input of the op-amp then one of the inputs will go to $V_{CM} + V_{OS}/2$ while the other input will go to $V_{CM} - V_{OS}/2$ (we've just indicated that the inputs of the op-amp are at a potential of $V_{CM} \pm V_{OS}$). Hence the factor of two in Eq. (2.93). In other words, if we re-write all of the equations in this chapter by replacing V_{OS} with $V_{OS}/2$ then the factor of two in Eq. (2.93) will go away. Simulations at CMOSedu.com are invaluable to understanding the operation of the circuits in this chapter. For example, see the simulation for Fig. 2.53.

2.2.3 The Discrete Analog Integrator (DAI)

The final sampling circuit we'll discuss in this chapter is an analog building block that we will find useful in implementing our data converters using feedback. The discrete analog integrator, DAI, is shown in Fig. 2.54. The two clocks signals, ϕ_1 and ϕ_2, form nonoverlapping clock signals. The common mode voltage, V_{CM} , falls halfway between the mixed-signal system's high- and low-reference voltages (generally *VDD* and ground). Note that the parasitic capacitance to ground associated with the bottom-plate of C_I is charged back and forth between v_1 and v_2 but doesn't affect the amount of charge transferred to the feedback capacitor, C_F. For this reason this DAI is often called a *parasitic-insensitive integrator*.

Table 2.2 shows the various relationships between the possible inputs and outputs for the DAI of Fig. 2.54. Let's derive the input/output relationships for the most general situations where both v_1 and v_2 are the inputs.

Table 2.2 Discrete analog integrator (DAI) input/output relationships.

Input	Output connected to ϕ_1	Output connected to ϕ_2
v_1 = input and $v_2 = V_{CM}$	$\frac{z^{-1}}{1-z^{-1}} \cdot \frac{C_I}{C_F}$	$\frac{z^{-1/2}}{1-z^{-1}} \cdot \frac{C_I}{C_F}$
v_2 = input and $v_1 = V_{CM}$	$\frac{-z^{-1/2}}{1-z^{-1}} \cdot \frac{C_I}{C_F}$	$\frac{-1}{1-z^{-1}} \cdot \frac{C_I}{C_F}$
v_1 and v_2 are both inputs	$\frac{V_1(z) \cdot z^{-1} - V_2(z) \cdot z^{-1/2}}{1-z^{-1}} \cdot \frac{C_I}{C_F}$	$\frac{V_1(z) \cdot z^{-1/2} - V_2(z)}{1-z^{-1}} \cdot \frac{C_I}{C_F}$