**Homework 1**

**P13.1.4** Determine *Rin* in Figure P13.1.4.

**Short solution:** *IP* = 0 ⇒ *VP* = 0 ⇒ *VN* = 0 ⇒  → .

**P13.1.5** Determine *IO* in Figure P13.1.5 assuming *VSRC* = 2 V.

**Solution: Step 1 – Initialize.** Given circuit parameters, value of *VSRC*, and *IO* are entered, virtual short circuit is indicated, and zero current at the inputs and in the virtual short circuit is marked.

**Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.** *VO* = 3*IO* ⇒  ⇒  ⇒  mA ⇒ voltage drop across the 8 kΩ resistor is 2(2 – 1.2*IO*) ⇒  → *IO* = 4/0.6 = = 20/3 = 6.67 mA. Check that *VO* = 3*IO* = +20 V, where -20 V < +20 V < 30 V.

**P13.1.11** Determine *R* in Figure P13.1.11 so that the op amp just reaches saturation

**Short solution:** *VP* = 6×4/6 = 4 V ⇒ *VN* = 4 V ⇒ *Ii* =

(6 – 4)/4 = 0.5 mA ⇒ *Ir* = 0.5 *mA* ⇒ *VO* = (4 – 0.5*R*) = -10 → *R* = 28 kΩ. Note that *VO* cannot be +15 V because that would mean that *Ir* and *Ii* flow in the opposite direction.

**P13.1.19** Determine *VO* in Figure P13.1.19.

**Solution: Step 1 – Initialize.** Given circuit parameters, 90 mV source, and *VO* are entered, virtual short circuit is indicated, and zero current at the inputs and in the virtual short circuit is marked.

**Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.** Because of the virtual short circuit, the 60 Ω and 30 Ω resistors on the LHS are effectively in parallel, as are the 60 Ω and 30 Ω resistors on the RHS, each parallel resistance being 60×30/90 = 20 Ω. The two 20 Ω are in series ⇒ 90/40 mA ⇒ currents In 60 Ω and 30 Ω resistors are as shown ⇒ currents in 1 kΩ resistors are 0.75 mA in the directions shown ⇒ *VP* = 0.75 V ⇒ *VN* = 0.75 V ⇒ *VO* = 0.75 + 0.75 = 1.5 V.

**P13.1.27** The switch in Figure P13.1.27 is closed at *t* = 0, with the capacitor initially uncharged. Determine *vO*, given *vSRC* = 10cos100*t* V, *t* ≥ 0.

**Solution: Step 1 – Initialize.** Given circuit parameters, voltage sources, and *vO* are entered, virtual ground is indicated, and zero current at the inputs and in the virtual ground is marked.

**Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.** Because of the virtual short circuit,  mA and  A, *iC* = *ii*1 + *ii*2,  + 0 =  = -(100*t* + 20sin100*t*) V.

**P13.2.15** Determine:

(a) *R* in Figure P13.2.15 so that *IS* = 0; (b) maximum and minimum *VSRC* for operation in the linear region.

**Solution: Step 1 – Initialize.** Given circuit parameters and voltage source are entered, virtual ground is indicated, and zero current at the inputs and in the virtual grounds is marked. It is assumed from the outset that *IS* = 0.

**Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.**(a) *IS* = 0 ⇒ current through *R* = current through 10 kΩ resistor = *VSRC*/10 mA. Both op amps are in the inverting configuration ⇒ output of first op amp is -4*VSRC* and output of second op amp is +8*VSRC*. KCL at input of first op amp:  → *R* = 70 kΩ.

(b) Second op amp reaches saturation before the first op amp, when ±8*VSRC* = ±12 → *VSRC* = ±1.5 V.

**P13.2.16** Determine *vO* in Figure P13.2.16 in terms of *v*1 and *v*2.

**Solution: Step 1 – Initialize.** Given circuit parameters, sources, and *vO* are entered, virtual short circuit and virtual ground are indicated, and zero current at the inputs, in the virtual short circuit, and in the virtual ground is marked.

**Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.** From virtual short circuit voltage at of node ‘b’ is *v*2. The lower op amp is in the inverting configuration having an input *vO* and a gain of -0.5. Hence, the voltage of node ‘a’ is -0.5*vO*. Current in 10 kΩ resistor on LHS is (*v*2 + 0.5*vO*)/10. From KCL at node ‘b’: (*v*1 – *v*2)/5 = (*v*2 + 0.5*vO*)/10 → *vO* = 4*v*1 – 6*v*2.

**P13.2.19** Show that in Figure P13.2.19, Z*in* = *R*2/*Z*. This means that if *Z* is an ideal capacitor, then *Z* = 1/*jωC*, and Z*in* = *jωCR*2*.* This means thatan ideal inductor having *L* = *ωCR*2 appears across the input terminals. Conversely, if Z is an ideal inductor having *Z* = *jωL*, then and Z*in* = *R*2/*jωL =* 1/(*jωL*/*R*2), which represents an ideal capacitor having *C* = *L*/*R*2.. This type of circuit is known as a **gyrator**.

**Solution: Step 1 – Initialize.** Given circuit parameters, and virtual short circuits are indicated, and zero current at the inputs and in the virtual short circuits is marked. **VI** and **II** are entered, so that *Zin* = **VI** / **II.**

 **Step 2 – Simplify.** Circuit is in simple enough form.

**Step 3 – Deduce.** From virtual short circuits, all inputs of op amps are at voltage **VI** ⇒ current in lowest *R* is **VI**/*R* ⇒ output voltage of lower op amp is **VI** + *R*×**VI**/*R* = 2**VI** ⇒ current in *R* and *Z* in series is (2**VI** – **VI** )/*R* = **VI**/*R* ⇒ output voltage of upper op amp is **VI** – *Z*×**VI**/*R* = **VI**(1 – *Z*/*R*) ⇒ **II** = (**VI** – **VI**(1 – *Z*/*R*))/*R* = **VI***Z*/*R*2 → *Zin* = *R*2/Z.

