SSI2190

PROCIRCUIT™ 6-INTO-1 VOLTAGE CONTROLLED MIXER*

The SSI2190 is a six-into-one voltage controlled mixer in a compact 24-lead SSOP package, based on a new-generation Operational Transconductance Amplifier (OTA) developed by Sound Semiconductor. The high-compliance current output allows easy paralleling of multiple SSI2190s.

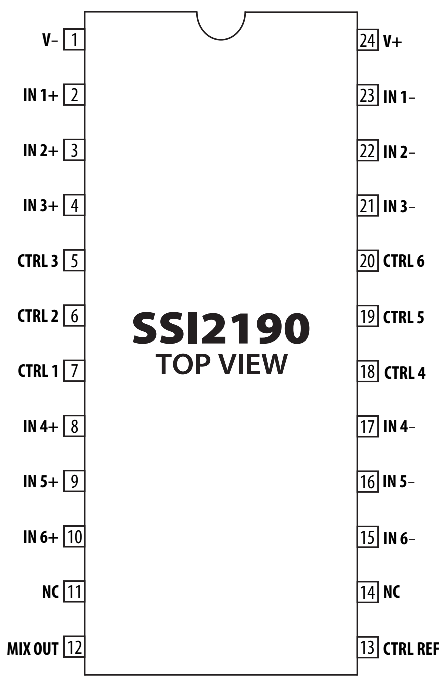
Each input channel has differential voltage inputs and a current-mode linear control input. Low distortion, low control feedthrough, full mute attenuation, and wide dynamic range round out the SSI2190s features.

The SSI2190 makes mixing of audio signals – as well as control voltages – a simple endeavor. Voltage controlled equalizers are easily designed. Differential inputs can be used for phase correction, and differential signal paths. As a generic audio building block, applications are only limited by one's imagination.

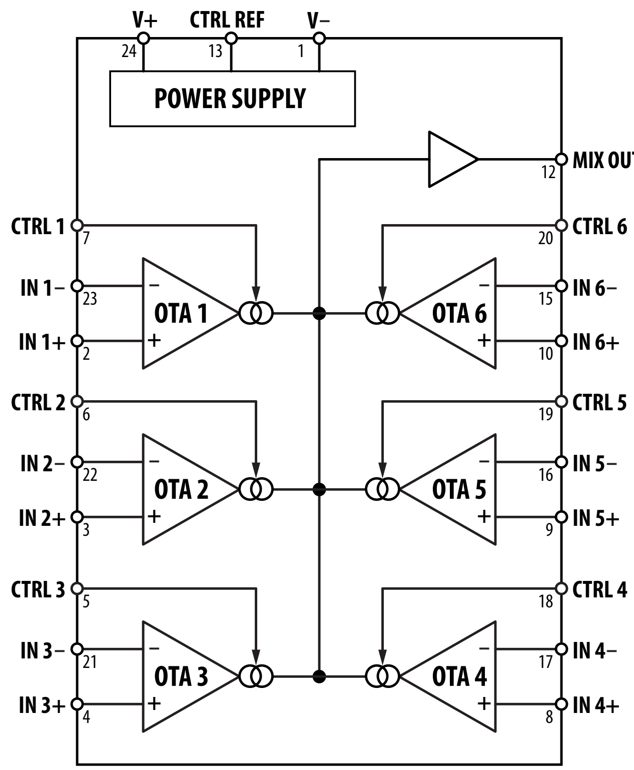
A wide supply voltage range (single or dual) allows use in a variety of audio gear from musical instruments and effects pedals to prosumer systems where large signal handling and headroom are desired.

FEATURES

- **Easy-to-Use Six Input into Single Output Audio Mixer**
- **Handles Input Signals up to 10V_{RMS}**
- **Linear Control OTA's**
- **Very Low Noise: Typical –91dBu**
- **Low Distortion – Typical 0.025%**
- **Mute Attenuation – Typical 100dB**
- **Low Control Feedthrough – Typical -60dB**
- **±4V to ±18V Operation**
- **Very Few External Components Required**



PIN CONNECTIONS
24-LEAD SSOP



FUNCTIONAL BLOCK DIAGRAM

*Patent Pending

The SSI2190 is available exclusively from Sound Semiconductor and its authorized resellers **Rev. 2.0, December 2024**

PO Box 1587, Arroyo Grande, CA 93421 USA, www.soundsemiconductor.com

SPECIFICATIONS (V_S = ±15V, V_{IN} = 0.775V_{RMS}, f = 1kHz, V_C = 5V, $V_{CTRLREF}$ = GND, T_A = 25°C; using Figure 1 circuit)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
POWER SUPPLY						
Supply Voltage Range	V_S		±4		±18	V
Supply Current - Positive	I_{SY+}	V_{IN} = GND; All channels active		+11.4	+12.5	mA
Supply Current - Negative	I_{SY-}	V_{IN} = GND; All channels active		–12.1	–13.0	mA
Power Supply Rejection Ratio	PSRR	60Hz; V_{IN} = GND		64		dB
CONTROL PORTS						
Control Current Range	I_{CTRL}	At CTRL pins, mute to full on	0		100	µA
Transconductance	g_m	V_{IN} = ±1V; After 60 seconds	7500	8100	8700	µS
Channel to Channel g_m Matching				±0.1		dB
Control Feedthrough*		V_{IN} = GND; V_C = 5V_{P-P} Sine		-60		dB
Maximum Attention		V_C = 0V; V_{IN} = +20dBu Sine; See Figure 2 Test Circuit		100		dB
SIGNAL INPUTS						
Maximum Input Voltage		At IN+ and IN– pins	V– +2V		V+ –2V	V
Maximum Differential Input Voltage		Between any IN+/IN– pair			±100	mV
Input Resistance				12		kΩ
Input Bias Current	I_B	V_{IN} = GND		2.0		µA
Input Offset Current	I_{OS}	V_{IN} = GND		40		nA
Common Mode Rejection	CMRR	V_{IN} = GND		73		dB
SIGNAL OUTPUT						
Output Compliance		See Figure 2 Test Circuit	V– +1V		V+ –1V	V
Output Offset Current		V_{IN} = GND		±1.2	±5.5	µA
Max Recommended Output Current		THD = 1%			800	µA
PERFORMANCE						
Output Noise		V_{IN} = GND; See Figure 2		–91		dBu
Headroom	HR	@1% THD; See Figure 2		+22		dBu
Total Harmonic Distortion	THD	See Figure 2		0.025		%
Channel Separation		Any channel to another†		88		dB
Slew Rate	SR			130		µA/µs

*see “Control Feedthrough and Offset Trim” for a detailed discusson
†Driven channel V_{IN} = 10V_{RMS} and V_C = 0V, measured channel V_{IN} = GND and V_C = 5V

ABSOLUTE MAXIMUM RATINGS

Supply Voltage	±20V
Maximum Control Current	500µA
Maximum Differential Input Voltage	±4V
Storage Temperature Range	-65°C to +150°C
Operating Temperature Range	-40°C to +85°C
Lead Temperature (Soldering, 10 sec)	260°C

ORDERING INFORMATION

Part Number	Package Type/Container	Quantity
SSI2190SS-TU	24-Lead SSOP* - Tube	58
SSI2190SS-RT	24-Lead SSOP* - Tape and Reel	4000

*SSI Package ID “**PSSL24**”, compliant with JEDEC MO-137-AE
Mechanical drawing available at www.soundsemiconductor.com

PIN DESCRIPTIONS ("x" refers to one of the six channels)

Pin(s)	Name	Description
1	V–	Negative supply. Recommend 100nF local decoupling capacitor placed as close to package as possible with a low inductance trace to ground.
2, 3, 4, 8, 9, 10	IN x+	Non-Inverting voltage signal inputs. Differential input should not exceed ±100mV.
5, 6, 7, 18, 19, 20	CTRL x	Control current input referenced to CTRL REF.
11, 14	NC	Leave these pins unconnected.
12	MIX OUT	High-compliance current output.
13	CTRL REF	Common reference for the control inputs. In a bipolar power supply system connect to control ground; if single supply to a pseudo ground. See Control Reference for more information about use of this pin.
15, 16, 17, 21, 22, 23	IN x–	Inverting voltage signal input. Differential input should not exceed ±100mV.
24	V+	Positive supply. Recommend 100nF local decoupling capacitor placed as close to package as possible with a low inductance trace to ground.

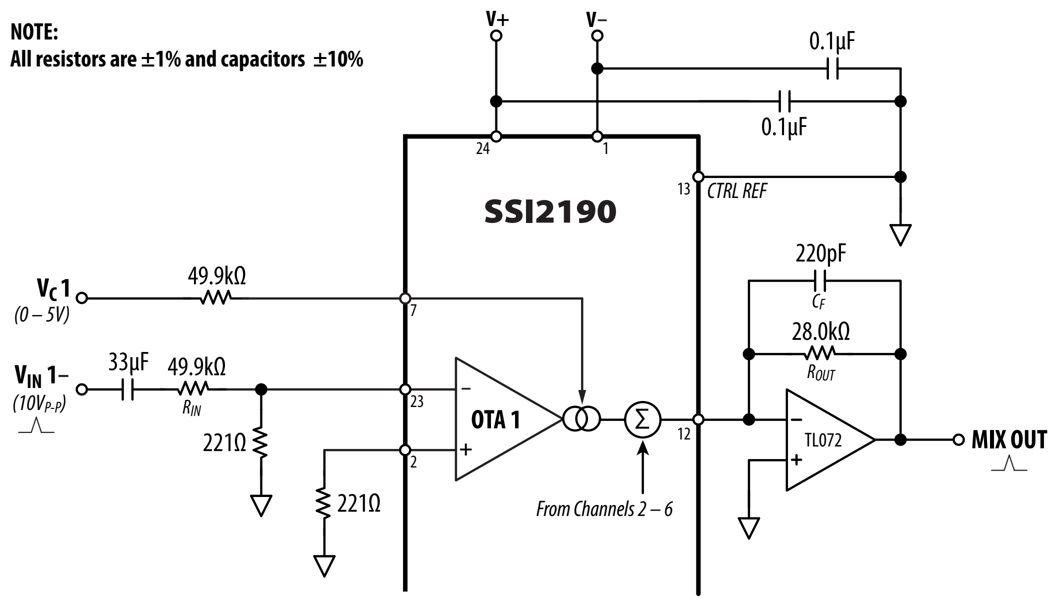


Figure 1: Typical Application Circuit

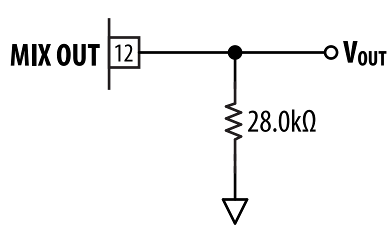


Figure 2: Test Circuit

USING THE SSI2190

The SSI2190 is a six-channel voltage-controlled mixer, with six operational transconductance amplifier (OTA) channels and one high-compliance current output driver. Each OTA channel has true differential inputs and a linear control range. Basic operation is described below; see the "Principles of Operation" section for further details on inner workings of the device and an application section that follows.

Signal Inputs

Each OTA channel has two differential signal inputs (IN+ and IN-), with an input that looks like the base of an NPN transistor. In the recommended configuration both inputs need a low-valued resistor (200-250 ohms) path to a common reference, typically signal common, and a higher series resistor to match the incoming signal level down to the ±50mV required for optimum operation.

The differential inputs allow the designer to easily correct any phase sign changes while giving full signal range. It also supports true differential signal handling, although note that this is not a substitute for a differential line receiver if that is required.

The input bias current of the NPN inputs requires the use of a DC blocking capacitor in the majority of AC signal circuits (e.g., audio mixing). For audio signal path applications the designer should limit the AC voltage across the capacitor to less than $80mV_{RMS}$ to avoid capacitor distortion. The following equation may be used to calculate values of C:

$$C = \sqrt{\frac{V_{IN}^2 - V_C^2}{(2\pi f)^2 V_C^2 R^2}}$$

Where V_{IN} = input voltage, V_C = voltage across the capacitor (80mV), f is the lowest frequency of interest, and R is the combined value of the two resistors in the input circuit (49.9kΩ + 221Ω = 50,121Ω).

The suggested value of 33µF together with the recommended 49.9kΩ input resistor shown in Figure 1, is suitable for most audio applications. Please note that this equation is not for calculating the -3dB frequency of the input circuit.

For applications that are sensitive to DC offsets the designer may include an external trim circuit that allows the designer to remove any offset present in the OTA channel. Both manual and automatic options are possible; see page 5.

Signal Output

The SSI2190 has a high-compliance current output. It can either drive a ground-referenced current input (e.g., inverting opamp, SSI2140, SSI2144, SSI2164, etc), or a current-to-voltage shunt resistor as shown in Figure 2. This could be used, for example, in summing multiple SSI2190s, and/or feeding directly into the input of an SSI2140 VCF.

The opamp feedback resistor of 28kΩ gives unity gain for each channel; for more channels this resistor would need reducing to avoid the output from clipping. The 220pF capacitor sets the -3dB point to about 25kHz to limit circuit noise.

Note that in Figure 1 the phase relationship between input and output is maintained, as shown by the phase spikes (_/_). If phase inversion is required then the input signal should be connected to the IN+ pin of the OTA cell instead.

Control Port

Each channel of the mixer is controlled by a current fed into its CTRL pin. Typically a series resistor converts the control inputs into voltage control for a VCA-like interface. Figure 1 shows a 49.9kΩ control input resistor for a 0V to 5V control voltage range giving the desired 0-100µA control current range. All six CTRL inputs are referenced to the voltage on the CTRL REF pin. If this pin was biased at, say, +100mV then this would create a mute region of operation once the control voltage falls to around 100mV.

The control characteristic of the SSI2190 control port is given by the following equation:

$$I_{OUT} = g_m \times K_{GAIN} \times V_{IN}$$

$$\text{where } K_{GAIN} = I_{CTRL} / 100\mu A$$

The output voltage is set by either the shunt load resistor ($V_{OUT} = I_{OUT} \times R$) or the feedback resistor of the opamp ($V_{OUT} = -I_{OUT} \times R_{OUT}$) as shown in Figure 1.

For the SSI2190 the g_m is typically 8100uS. For example, using the input circuit of Figure 1 a 10V input signal appears as 44mV at the input terminal, and at 100µA control current the output current is:

$$I_{OUT} = 8100uS \times 100\mu A/100\mu A \times 44mV = 356\mu A.$$

To convert this back to a voltage at unity gain requires a 28kΩ resistor, giving a 10V output for a 10V input.

Unused Channels

Unused mixer channels must have their two signal inputs (IN+ and IN-) tied together and then to ground, either directly or through a small resistor. Alternatively unused channels can be paralleled with other channels for lower noise.

Unused CTRL inputs should be left unconnected. Do not connect control inputs directly to ground as this will likely cause excessive current to flow and overheat the SSI2190.

Supplies

Supplies from ±4V to ±18V are possible, which should be regulated and include good power supply design practices. Decoupling capacitors, such as those shown in Figure 1, should be placed close to both supply pins with short low-impedance traces to ground.

Single supply operation is described in the Applications section. A single decoupling capacitor should be placed closed to the V+ pin with a short low-impedance trace to ground, and the V- pin should be connected to ground with a short low-impedance trace.

Control Reference

The CTRL REF pin sets the voltage aty which all six CTRL pins are held. It must be connected to a low impedance voltage source, which in most cases would be signal ground, but it can be connected to a bias circuit as described later in the Applications section.

Component Selection

The signal inputs of the SSI2190 require careful component selection and routing. For each channel the two inputs should ideally see the same low impedance to the signal common (typically ground), using 1% tolerance resistors or better. The input series resistor(s) are of much higher value, typically 30-60k ohms. Resistors should be good quality metal film or thin film types. If a DC-blocking electrolytic series capacitor is used then its value should be large enough to ensure the minimum required value is within the tolerance.

For supply decoupling capacitors, use good quality 100nF ceramic capacitors of X7R or better dielectric with a suitable voltage rating.

Control Feedthrough and Offset Trim

The SSI2190 was designed for low output offset which eliminates the need for trimming in most applications such as mixing audio signals with slowly varying gains. When mixing DC signals, or where the gain control has rapid transitions, the designer may need to consider external trimming to reduce offsets which otherwise introduce audible thumps or clicks (often referred to as "Control Feedthrough"). The recommended circuit to trim out offsets is shown in Figure 3.

The combination of the trimmer (R1), the two feed resistors (R2, R3), and the two grounding resistors (R4, R5) places a small bias voltage on the inputs of the SSI2190's OTA. Adjusting the trimmer introduces an imbalance in the bias voltage which can trim out internal offset currents.

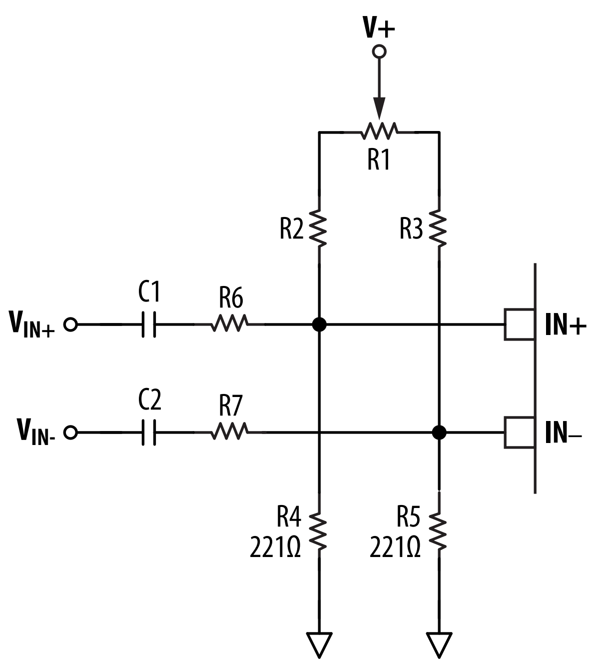


Figure 3: Offset Trim (C1 and C2 are Optional – for AC-Coupled Circuits Only)

This method of adjusting for offset offers superior temperature stability by applying a known offset voltage to the inputs. The conventional trim circuit familiar to legacy OTA IC users replaces R4 and R5 with a low-value trimmer with the wiper to signal common, but this approach is very susceptible to temperature effects as it relies on the input bias currents which are very temperature sensitive – allowing offset trim to shift over temperature.

The trim range needs to cover the maximum specified output offset current of the SSI2190, which is ±5.5µA. The minimum gm is 7,500uS giving a required maximum trim bias range of ±733µV. Because the trim voltage is derived from the positive supply rail then this also needs to be included in the calculation. Using typical circuit values from Figure 1, R4 and R5 are both 221Ω. Resistors R6 and R7 are notionally in parallel with R4 and R5 respectively, but given that R6 and R7 are significantly larger than R4 and R5 their effect is minimal. In the case of AC-coupled inputs (via C1 and C2) they will have no effect on the DC bias.

When the trimmer wiper is in mid position the trim circuit is in balance. Maximum offset trim is given when the wiper is at either of the extremes. For calculation consider one extreme (e.g., the wiper is at the R2 end), and let bottom resistors R4 = R5 = Rb, and top resistors R2 = R3 = Rt, then:

$$\frac{RbVs}{Rt+Rb}-\frac{RbVs}{Rt+Rb+R1}=733\mu V$$

When solving this quadratic equation choose the positive result and ignore the negative result.

For convenience a number of common scenarios are calculated in the following table using readily-available resistor and trimmer values. In all cases use good quality metal film or thin film resistors of 1% tolerance and low temperature coefficient, and good quality cermet trimmers.

		Positive Supply				
		2.495V	**5V**	**9V**	**12V**	**15V**
Trimmer Value	**1kΩ**	27kΩ	36kΩ	51kΩ	56kΩ	62kΩ
	5kΩ	56kΩ	82kΩ	110kΩ	130kΩ	150kΩ
	10kΩ	82kΩ	110kΩ	160kΩ	180kΩ	200kΩ
	25kΩ	120kΩ	180kΩ	240kΩ	270kΩ	300kΩ

Note that noise on the positive supply rail will be injected into the signal path through the trim resistors. This can be addressed either by a low pass filter or using a local voltage reference to provide a low noise regulated bias supply. For example, the 2.495V column in the table above is suitable for the TL431 voltage reference diode. The filtered or regulated bias supply can be used for all six channel trims as the current required is less than 100µA.

Trimming the SSI2190 requires a little patience but rewards the effort with offset of less than 0.25µA.

For trimming it is necessary to disconnect all of the inputs, or set them to 0V. In the case of an AC-coupled signal path set the signal level as low as possible. Setup requires individually controlling the gain setting of each applicable channel, and measuring the DC voltage generated by the output current.

The following steps describe an effective trimming procedure:

1. Let the circuit warm up (allow 60-90 seconds)
2. Start with all channels muted (all control currents = 0µA)
3. For each used channel in turn:
    a. Set the gain control current to 100µA
    b. Adjust the associated trimmer until the output offset voltage is at its minimum
    c. Set the gain control current back to 0µA

Automatic trimming is also possible. A bipolar DAC generatres a small trim voltage that can be applied to the unused input. A trim procedure similar to manual trimming can then be implemented in software.

PRINCIPLES OF OPERATION

The SSI2190 uses Sound Semiconductor's next generation Operational Transconductance Amplifier cell, together with a patented low-noise, high-compliance current output stage. The following two sections describe how they work.

Operational Transconductance Amplifier

The general structure of the Operational Transconductance Amplifier (OTA) is shown in Figure 4:

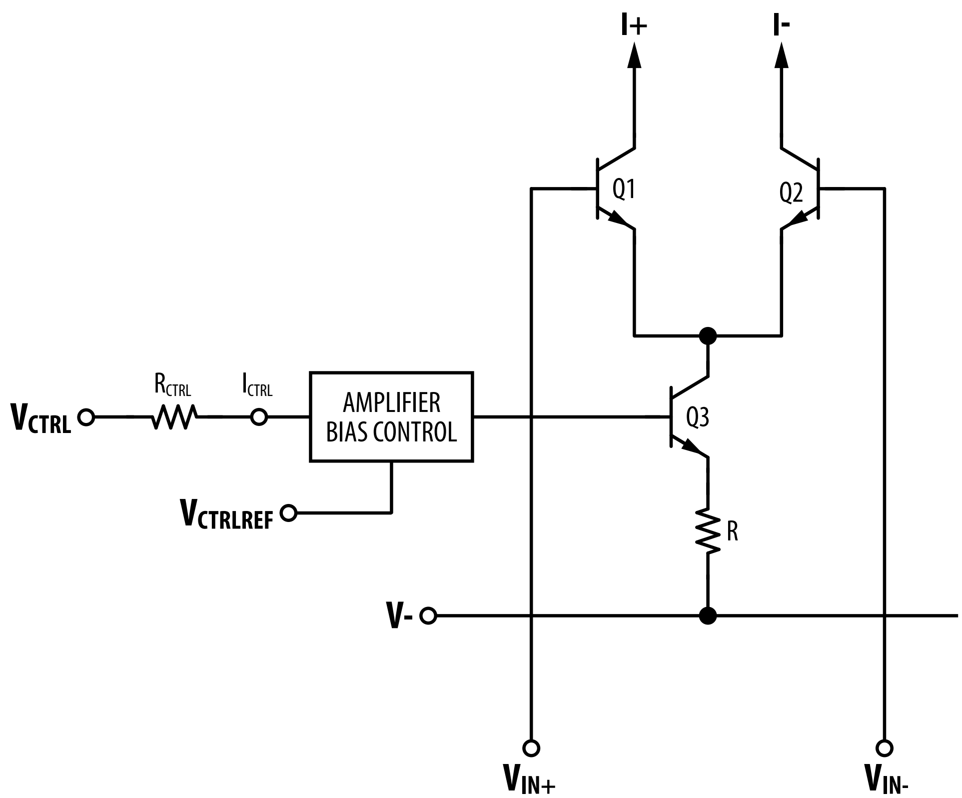


Figure 4: Simplified Schematic of Operational Transconductance Amplifier

The two signal inputs, V_{IN+} and V_{IN-}, drive the bases of the two input transistors Q1 and Q2. Their emitters are connected together and feed into a variable current sink (Q3 and R). The Amplifier Bias Control converts the control current, I_{CTRL}, to drive Q3 which sets up the common current flowing through Q1 and Q2.

When the base voltages of both Q1 and Q2 are the same then I+ will be the same as I-. When V_{IN+} goes slightly more positive than V_{IN-}, more current will flow through Q1 and because of the balancing effect of Q3, less current will flow through Q2. And vice versa. Due to the tanh curve responses of Q1 and Q2, over small base voltage ranges a linear relationship between V_{IN-}/V_{IN+} and the corresponding I+/I- is obtained. Designers may find that overdriving the inputs produces a pleasant soft distortion effect.

The Amplifier Bias Control is set by the current, I_{CTRL}, flowing into the CTRL pin. This is referenced to the voltage on the common CTRL REF pin. The control current is:

$I_{CTRL} = (V_{CTRL} - V_{CTRLREF}) / R_{CTRL}$

The recommended value for R_{CTRL}, 50kΩ, gives a control range of 0 – 5V. However if CTRL REF is increased by a few tens of millivolts above ground then control current will only flow once the external control voltage has reached this level, giving a threshold for the gain control.

The output of the OTA stage is a pair of currents, I+ and I-. These two outputs are internally summed together with the outputs from the other channels. These currents then feed into the Output Stage.

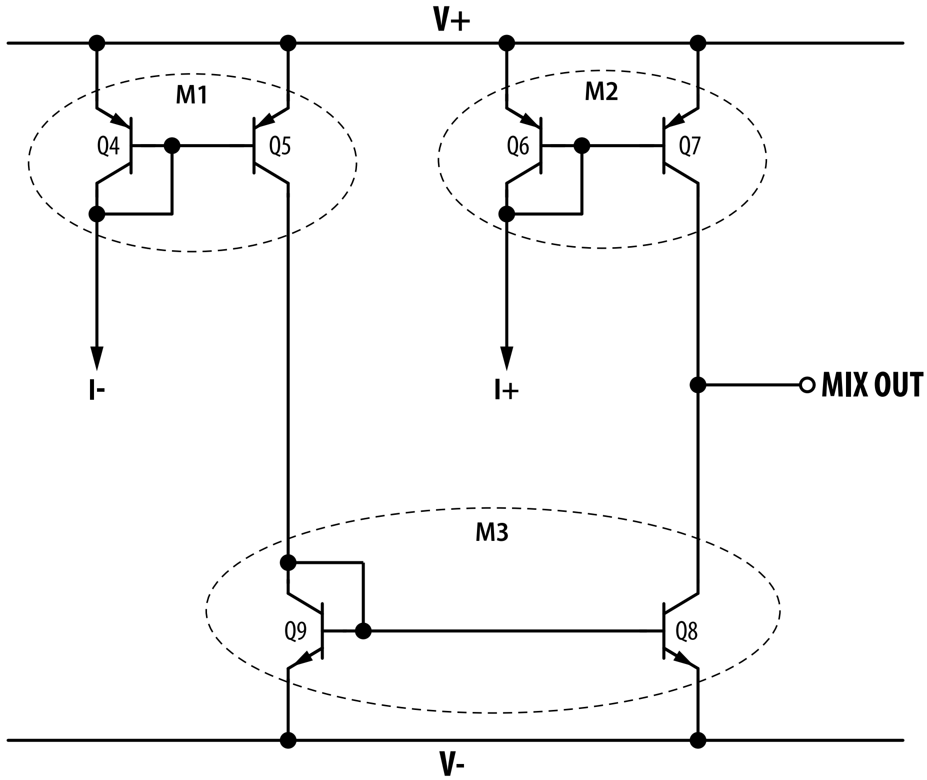


Figure 5: Simplified Schematic of Output Stage

Output Stage

The output stage of the SSI2190, as shown in Figure 5, comprises a novel low-noise design giving high output compliance for voltage mode operation and a high output drive capability for current mode operation.

There are three current mirrors in the output stage. The two upper mirrors, M1 (comprising Q4 and Q5) and M2 (Q6, Q7), invert the polarity of the input currents I+ and I-. The two inverted currents then feed into the two sides of the lower current mirror, M3 (Q8, Q9).

If the two inputs I+ and I- are the same then the outputs of M1 and M2 are the same, M3 is in balance, and no current flows through the MIX OUT pin. If I+ increases, then more current flows out of M2. But since M3's input current has not changed then the resulting additional current from M2 must flow out of the MIX OUT pin. Conversely, if the current in I- increases then M1's output current increases causing M3's output current to increase with the result that more current is pulled in from the MIX OUT pin.

Output compliance – how close to the supply rails the output pin can get – is set by the characteristics of M2 and M3. Internal transistors in the SSI2190 achieve a compliance of close to 1V of both rails.