SSI2130

FATKEYS™ VOLTAGE CONTROLLED OSCILLATOR

The SSI2130 is a new-generation voltage controlled oscillator subsystem for high-performance electronic musical instruments. A complete analog synthesizer voice can be constructed at low cost with one or more SSI2130's, a SSI2144 or SSI2140 Voltage Controlled Filter, and SSI2162/2164 VCA(s).

Buffered outputs include triangle, sawtooth, pulse with PWM control, and open collector square wave. An on-chip five channel mixer with linear control VCA's sums triangle, saw, and pulse waveforms plus two independent auxiliary inputs into a single current output.

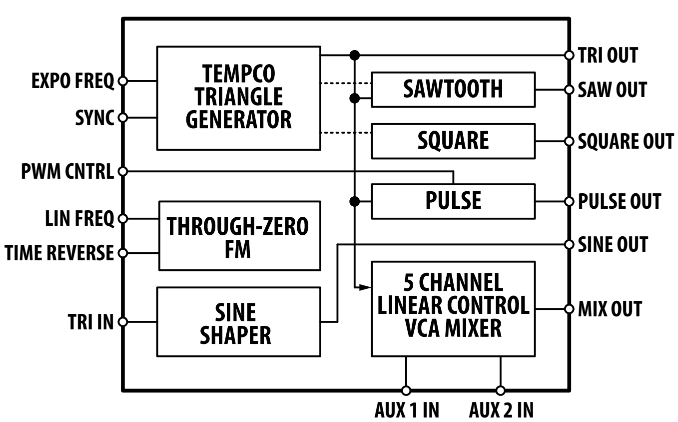
A precision analog multiplier provides unprecedented temperature-compensation, and careful attention was paid to improvement of triangle and sawtooth waveforms compared to previous-generation VCO IC's. Both soft and hard sync are provided.

An accurate and temperature-stable sine wave can be produced by the internal sine shaper circuit. Through-zero FM and PM can be achieved with an exernal comparator, op amp, and several discrete components.

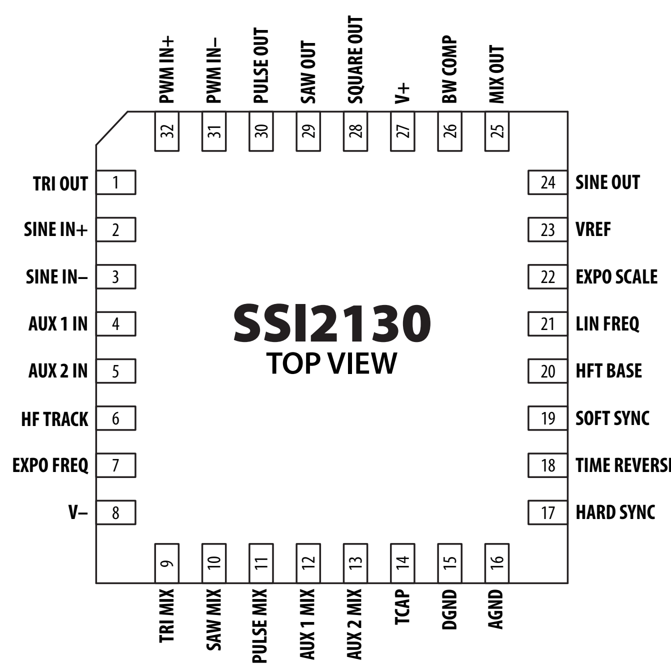
Optional trims are provided for expo scale and high frequency tracking that can be automated by CPU-calibrated systems. The SSI2130 requires minimal external components and is available in a diminutive 4x4mm QFN package.

FEATURES

- **Highly Integrated Synth Voice Front-End**
- **Triangle, Saw, Pulse, and Open Collector Square Wave Outputs**
- **On-Chip Five-Channel Mixer with VCA's**
- **Two Auxiliary Inputs**
- **Exceptional Temperature Stability**
- **Exponential and Linear Controls**
- **Integrated Sine Wave Shaper**
- **Optional Through-Zero FM and PM**
- **Few External Components**
- **Ultra-Compact 32-Lead 4x4 QFN Package**



SIMPLE BLOCK DIAGRAM



PIN CONNECTIONS
32-LEAD 4x4 QFN

The SSI2130 is available exclusively from Sound Semiconductor and its authorized resellers

PO Box 222, Standard, CA 95373 USA Phone 209-536-0492, www.soundsemiconductor.com

Rev. 2.4, December 2020

SPECIFICATIONS ($V_S = \pm 5V$, $V_{REF} = 2.5V$, f = 1kHz, $T_A = 25°C$; using Figure 1 circuit)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
POWER SUPPLY						
Supply Voltage Range - Positive	V+		+4.75	+5.0	+5.25	V
Supply Voltage Range - Negative	V–		–4.75		–18	V
Supply Current - Positive	I_{SY+}			3.75		mA
Supply Current - Negative	I_{SY-}			–2.90		mA
VREF Range			2.49	2.5	2.51	V
VREF Current Consumption				100		µA
VCO						
Frequency Sweep Range		Calibrated to ±1 cent error		1000:1		
Maximum Operating Frequency		T_{CAP} = 3.9nF		60		kHz
Maximum Charging Current				1.2		mA
EXPONENTIAL CONVERTER						
Exponential Conformity		Calibrated per "Expo Setup"		0.3		%
Exponential Scale Factor Drift		0-50˚C, ≤4kHz,1/10th semitone		200		ppm/°C
Multiplier Offset				0.5		mV
Multiplier Input Bias Current	I_{B-MULT}			10		nA
Control Constant - Expo				20		µA/Oct
OSCILLATOR SYNC						
Soft Sync Input Resistance				5		kΩ
Hard Sync Upper Threshold				1.55		V
Hard Sync Lower Threshold				1.0		V
Time Reverse Upper Threshold				1.55		V
Time Reverse Lower Threshold				1.0		V
TRIANGLE OUTPUT						
Upper Level				2.5		V
Lower Level				0		V
Maximum Output Source Current				6		mA
Maximum Output Sink Current				1		mA
SAWTOOTH OUTPUT						
Upper Level				2.5		V
Lower Level				0		V
Maximum Output Current		Sink or souce		6		mA
Discharge Time				1.6		µs
PULSE OUPUT/PWM INPUT						
Upper Level				2.5		V
Lower Level				–34		mV
Maximum Output Source Current				6		mA
Rise Time				70		ns
Fall Time				125		ns
PWM Bias Current	I_{B-PWM}			40		nA
SQUARE OUTPUT						
High Level Output Voltage	V_{OH}			2.5		V
Low Level Output Voltage	V_{OL}			80		mV
Low Level Output Voltage		Sink Current = 5mA		800		mV
Output Fall Time	T_{HL}			37		ns
SINE SHAPER						
Input Range		Into SINE+ and SINE– Pins		±2.5		V
Input Bias Current	I_{B-SI}			20		nA
Output Swing		Pin 24, 10kΩ Load		±2.5		V
Total Harmonic Distortion + Noise	THD+N	@1kHz, 22Hz-22kHz, 1.7V_{RMS}		0.76		%
Output Offset				3		mV
MIXER – AUDIO						
Auxiliary Input Signal Handling				±2.5		V
Aux Input Impedance				50		kΩ
Recommended Max Output Current				500		µA
Output Noise		(20Hz -20kHz, 1% THD)		–106		dBu
Total Harmonic Distortion + Noise		@1kHz, 22Hz-22kHz, 1V_{RMS}		0.3		%
MIXER – CONTROL						
Mute Attenuation				100		dB
Control Current at Full Attenuation				0		µA
Recommended Max Control Current				50		µA
Control Feedthrough				-60		dB

ABSOLUTE MAXIMUM RATINGS

Positive Supply Voltage	+5.25V
Negative Supply Voltage	–18V
Storage Temperature Range	-65°C to +150°C
Operating Temperature Range	-40°C to +85°C
Lead Temperature Range (Soldering, 10 sec)	260°C

ORDERING INFORMATION

Part Number	Package Type	Quantity
SSI2130Q-RT	32-Lead 4x4 QFN* - Tape and Reel	4000

*SSI Package ID "**PQN32**"
Mechanical drawing available at www.soundsemiconductor.com

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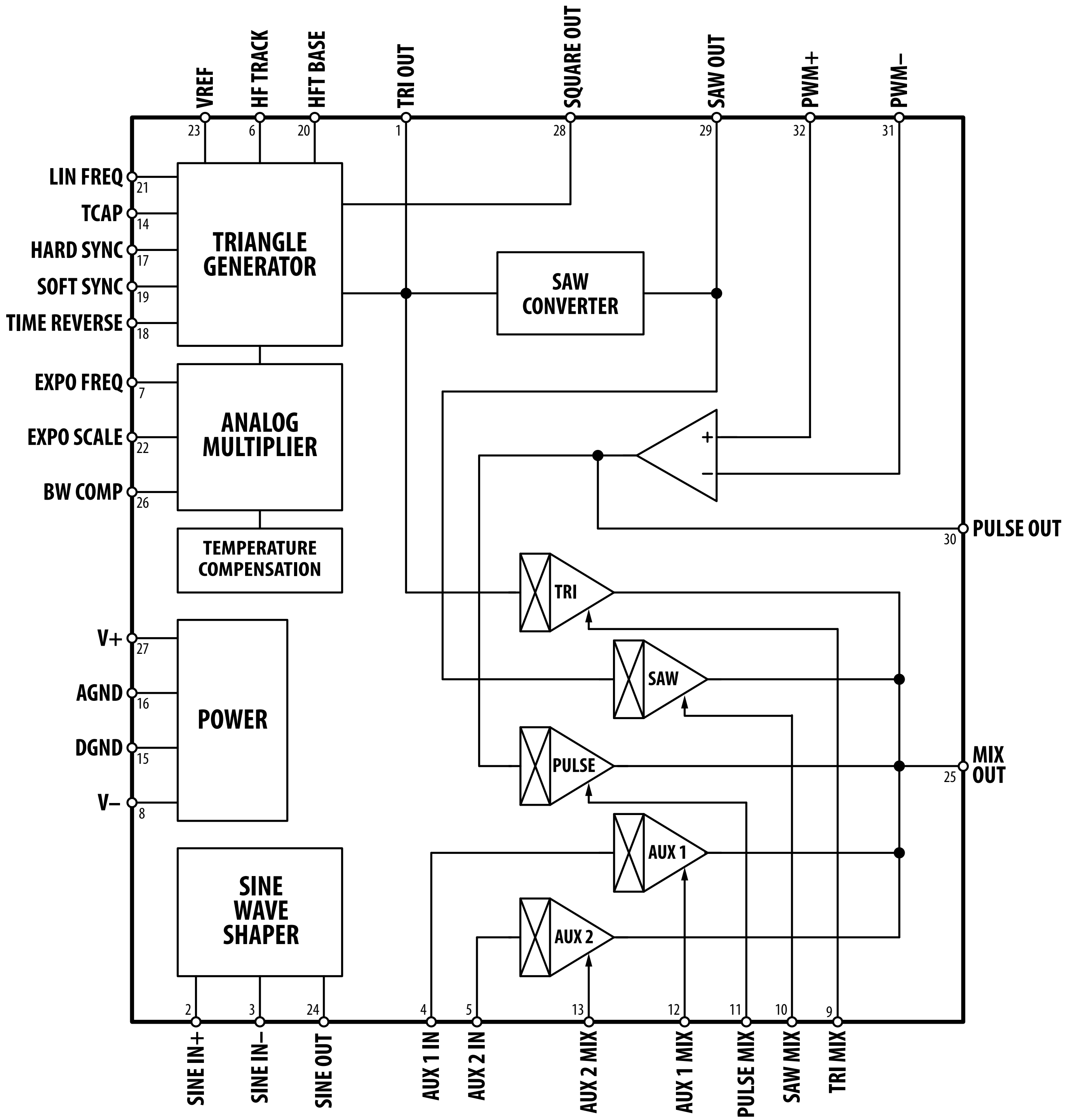


SSI2130 FUNCTIONAL BLOCK DIAGRAM

SSI2130 PIN DESCRIPTIONS

Pin(s)	Pin Name	Description
1	TRI OUT	Output of the triangle generator that swings between GND and VREF at a rate determined by size of the capacitor connected to TCAP and current output of the exponential converter. This signal is also fed internally to the mixer.
2	SINE IN+	Non-inverting input to the temperature-compensated sine converter. For correct operation SINE IN+ must be connected to GND through a 4.7kΩ resistor. Polarity of the sine wave converter output will be the same as the input to the SINE IN+ pin. For the best sine wave connect a 10µF capacitor and 4kΩ resistor in series from the TRI OUT pin to the SINE IN+ pin.
3	SINE IN–	Similar to the SINE IN+ pin but opposite polarity.
4, 5	AUX INs	The AUX 1 IN and AUX 2 IN pins are auxiliary signal inputs to the voltage-controlled mixer. Input impedance is 50kΩ and for optimum signal-to-noise ratio the amplitude should be less than ±2.5V. To minimize CV bleedthrough of audio signals, AC-coupling is recommended.
6	HF TRACK	The HFT OUT pin is a current output used to trim high-frequency tuning errors due to bulk emitter resistance in the exponential converter. For most applications two fixed resistors can be used, but an optional trim (see text) can further improve high frequency tracking. If not used, the pin can be left unconnected.
7	EXPO FREQ	Ground-referenced current input to the exponential converter. Sensitivity is set by current into the EXPO SCALE pin. It is typically set to 20µA/octave, using a 50kΩ resistor to give the common 1V/octave response.
8	V–	Negative supply. Recommend a 100nF local decoupling placed as close to the package as possible with a low inductance trace to ground.
9 – 13	MIX CONTROLS	Sets MIX OUT levels of internally-connected TRI, SAW, and PULSE waveforms, plus AUX 1 and AUX 2 inputs. 0µA mutes the input.
14	TCAP	Oscillator external timing capacitor connected to ground. For optimum performance, a capacitor with low dielectric absorption and low temperature coefficient should be used such as C0G/NP0 or polystyrene. Recommended value is 3.9nF.
15	DGND	Ground for exponential converter; typically connects to AGND externally.
16	AGND	Ground connection for the output stages and mixer.
17	HARD SYNC	A level-sensitive input for hard sync function. When driven high, an internal switch discharges TCAP to ground which resets the oscillator to the start of its cycle irrespective of oscillator phase. If not used, connect to ground.
18	TIME REVERSE	Controls direction of the triangle oscillator core and the slope of the sawtooth generator. When tied to V+ the sawtooth is a rising saw with rapid falling edge, and when tied to ground the sawtooth is a falling saw with rapid rising edge. In both cases the shape of the triangle waveform is exactly the same. If the TIME REVERSE pin is changed at audio frequencies it generates the effect of reversing the direction of oscillation to produce through-zero FM tones.
19	SOFT SYNC	Connects to an internal 5kΩ resistor that sets the lower threshold of the triangle waveform. A small DC voltage applied to the SOFT SYNC will shift the low point of the triangle waveform. An AC-coupled pulse will cause the falling slope of the triangle to reverse direction if the voltage on TCAP is at or below the level of the sync pulse. This has no effect if the capacitor connected to TCAP is charging. If not used the SOFT SYNC pin can be left unconnected.
20	HFT BASE	Direct connection to base of the high-frequency trim transistor. For normal operation connect the HFT BASE pin to ground.
21	LIN FREQ	A ground-referenced current input. Current into the LIN FREQ pin sets the linear scale of the exponential converter's output. It can be used for linear FM applications, or together with the TIME REVERSE pin to generate through-zero FM tones.
22	EXPO SCALE	A ground-referenced current input. Current into the EXPO SCALE pin sets sensitivity (scale) of the EXPO FREQ pin. For a 20µA/octave sensitivity feed a current of 94.34µA into the EXPO SCALE pin.
23	VREF	Reference voltage input, which must be fixed at 2.5V from a low-noise low-impedance voltage reference.
24	SINE OUT	Voltage output of the sine converter. If the sine converter is driven by the TRI OUT pin, then the output of the sine converter will be in the range -VREF to +VREF volts.
25	MIX OUT	Current output of the internal 5-channel mixer.
26	BW COMP	Provides frequency compensation for the exponential converter. Connect a 270Ω resistor in series with a 10nF capacitor to ground.
27	V+	Positive supply. Recommend a 100nF local decoupling placed as close to the package as possible with a low inductance trace to ground.
28	SQUARE OUT	Open-collector output driven from the oscillator's internal S-R flip flop. It requires an external pull-up resistor to V+; If not required it can be left unconnected.
29	SAW OUT	Output of the sawtooth generator, in the range 0V to VREF. The direction of the sawtooth is determined by the state of the TIME REVERSE pin: when TIME REVERSE is floating or held at V+ the sawtooth slowly rises and quickly falls, ands when TIME REVERSE is pulled to ground the sawtooth is slowly falling and quickly rising. This signal is also fed internally mixer.
30	PULSE OUT	Output of an internal comparator which can be used to generate PWM-type waveforms. The output is driven hard to ground or at VREF depending on the levels of the two inputs. This output is also fed to the internal mixer.
31	PWM–	Inverting input of the internal comparator. Input range is 0V to VREF.
32	PWM+	Non-inverting input of the internal comparator. Input range is 0V to VREF.

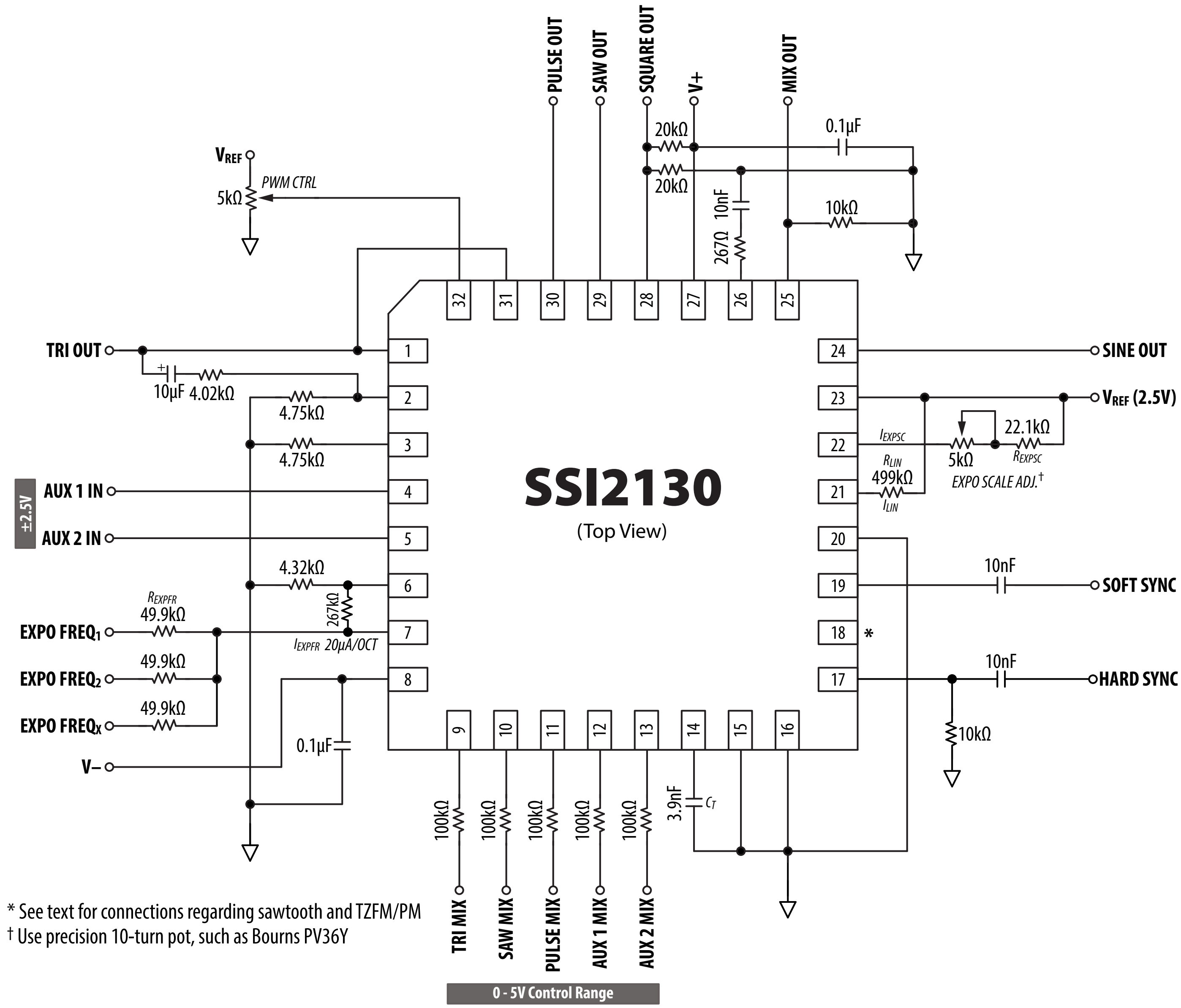


Figure 1: Typical Application Circuit

USING THE SSI2130

The SSI2130 is a compact and highly versatile analog voltage controlled oscillator subsystem for easy design of synthesizer voice front ends. Relevant inputs are ground-referenced current inputs to simplify combining multiple signals, outputs are voltages or currents as appropriate for interfacing to external components, a single reference voltage brings stability to the SSI2130, and power requirements are kept to a bare minimum for power-managed applications.

Typical Application

Figure 1 shows the complete circuit for a VCO circuit to generate triangle, sawtooth, PWM pulse, square and sine waveforms, together with soft sync, hard sync, a five-channel voltage-controlled mixer, and three (or more) 1V/octave control voltage inputs.

The positive supply comes into the SSI2130 at pin 27, and the negative supply at pin 8. Both supplies require local 100nF decoupling capacitors. Ground connections are on pins 15 and 16. The reference voltage is connected to pin 23.

The exponential control voltages (CV's) are brought into the SSI2130 through external resistors into a current summing node at pin 7. The exponential converter requires a single scale adjustment set by a current flowing into the EXPO SCALE pin 22. The components as shown set the sensitivity to 20µA/octave, with the trimmer allowing for manual fine adjustment. For correct operation it is also required to set a linear control current into the SSI2130's LIN FREQ pin 21. If linear frequency modulation is not required this pin should be supplied with a constant current of about 5µA using a 499kΩ resistor from VREF.

Due to normal silicon properties, the exponential converter has high frequency tracking errors. Resistors on pin 6 compensate by injecting a small correction current into the EXPO FREQ pin 7. An optional trim (see "Exponential Converter Setup and Trimming") can further improve high frequency performance. Pin 20 (HFT BASE) is connected to ground. The exponential converter also requires an external compensation network for stable operation, connected to pin 26, and the recommended values shown are suitable for a wide range of applications.

The SSI2130 supports several synchronization modes. SOFT SYNC (pin 19) requires a series 10nF capacitor for normal operation. The HARD SYNC (pin 17) also requires a 10nF capacitor plus a 10kΩ resistor to ground. When TIME REVERSE (pin 18) functions are not used, its pin left unconnected for normal rising sawtooth operation. See the later section on Through-Zero FM and PM modes using the TIME REVERSE pin.

The triangle oscillator requires a single high-quality timing capacitor connected to pin 14. The resulting voltage is then buffered and provided at the TRI OUT, pin 1. The SQUARE OUT (pin 28) is an open-collector output driven low when the triangle is falling, and is high impedance when the triangle is rising. An external resistor network pulls SQUARE OUT up to half of the positive supply rail to produce an output similar in amplitude to the triangle at pin 1. The SAW OUT (pin 29) is produced by the internal triangle-to-sawtooth converter, and sweeps from ground to VREF .

An internal comparator produces the pulse-width-modulated (PWM) waveform. One input of the comparator (pin 31) is connected to the buffered triangle output, while the second comparator input (pin 32) is connected to the wiper of a potentiometer or other voltage source to set pulse width.

The sine converter has differential inputs at pins 2 and 3. For the application circuit shown both pins require biasing to ground through 4.75kΩ resistors. The triangle waveform is AC-coupled through a 10µF capacitor, and then fed through a 4.02kΩ resistor into the sine converter. The resulting waveform is brought out to pin 24.

The final block in the SSI2130 is the 5-channel mixer. The first three input channels are shifted and scaled versions of the triangle, pulse and sawtooth waveforms. Two uncommitted mixer inputs are connected to AUX 1 IN (pin 4) and AUX 2 IN (pin 5). Each channel has a linear current-controlled amplifier, with control currents fed into pins 9 through 13. For typical operation the control range is 0µA (cutoff) to 50µA (maximum) – 100kΩ resistors are used for a control voltage range of 0 to +5V. The output of the mixer is a current output with high compliance, and in this circuit a single 10kΩ shunt resistor converts the output current into an output voltage.

Power Supplies and Grounding

The SSI2130 requires two stable supplies and a low-noise reference voltage. The positive supply V+ must be fed from a regulated 5V source. The negative supply V- can range from -5V to -18V, again from a regulated source. To improve noise performance and stability it is recommended V- is fed from a dedicated regulator. Both supplies should have local 100nF good quality ceramic decoupling capacitors placed close to the supply pins, together with local bulk supply rail decoupling capacitors of 10µF or more, and with good ground and supply trace routing practices applied throughout.

The SSI2130 has two separate ground connections on pins 15 and 16. Both must be connected to ground using thick short traces or closely positioned vias to a ground plane.

Operating the SSI2130 at these lower voltages allows the SSI2130 to be designed into most analog synthesizer systems (typically 12V or 15V bipolar rails), with the added benefit of the further supply rail noise rejection afforded by the local regulators.

Exposed Thermal Pad

The SSI2130's QFN package includes a standard metal pad ("EP") on the underside for improved thermal performance when mounted on a printed circuit board. Since SSI2130 power consumption is very low, the EP provides no practical thermal benefit. PCB land patterns can either include or omit the pad. Some contract assemblers prefer the pad to assist in package attach operations, so SSI recommends consultation with the contractor before deciding on the footprint. It is very important to note, however, that if a corresponding PCB land pad is provided it MUST NOT have any PCB electrical or ground connection.

Voltage Reference

The VREF pin establishes waveform amplitude. Since it's also used to set critical EXPO SCALE and LIN FREQ currents, VREF must be supplied with a stable 2.5 volts. A low-noise shunt reference is recommended, and can be fed from the same 5V that feeds V+, in conjunction with a suitable load resistor. If significant additional loads are to be placed on the VREF rail, it is recommended to buffer the rail with an op-amp; for precision applications an op-amp with a low offset voltage and drift is recommended.

Stability of the VREF source is critical to the overall temperature and tuning stability of the SSI2130. Two key parameters are used to specify the VREF source: absolute tolerance and temperature coefficient.

The SSI2130 is designed for a VREF that is within 0.5% of 2.5V. This is an allowed difference of ±12.5mV. To maintain the performance of the exponential converter over a wide operating temperature range the temperature coefficient of the VREF source needs to be accounted for. From the equation for the triangle frequency discussed later in Principles of Operation, output frequency is related to the inverse of VREF. Assuming all other things are constant, the expression to calculate the required ppm/°C specification given the accepted amount of drift in cents, *c*, and the expected maximum change in temperature, *dT*, is:

$$TC \le \frac{(2^{\frac{c}{1200}} - 1) \times 10^6}{dT} \; ppm / {}^\circ C$$

For example, for an application requiring six cents drift over a temperature shift of 30°C the maximum allowed temperature stability is 115.7 ppm/°C. A reference such as the LM4040C-2.5 would meet both tolerance and temperature requirements of the SSI2130.

OUTPUT WAVEFORMS

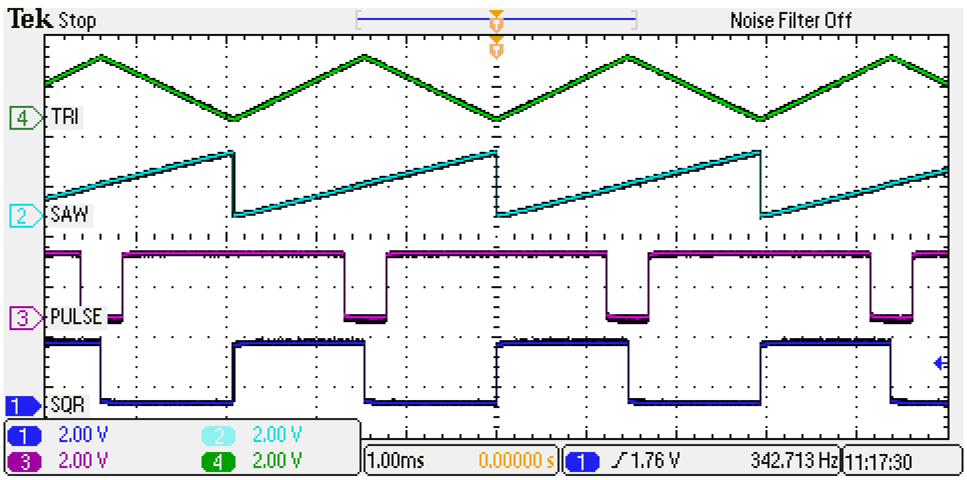


Figure 2: The SSI2130's Primary Waveforms

The SSI2130 generates triangle and square waveforms, and internal processing blocks produce saw, sine and variable width pulse waveforms. See Figure 2.

Triangle

The triangle output TRI OUT is a buffered version of the voltage developed across TCAP. The lower point is at GND and the upper point is set by VREF. Hard sync resets the voltage on TCAP to GND pulling the triangle down to the lower point. Soft sync causes the falling triangle to switch direction towards the upper point. See "Syncronization" for more detail.

Square

The square wave is directly generated as part of the triangle generation. It is an open-collector output requiring an external pullup to the desired "high" level, and when low will pull the pin to GND. The output is high when the triangle is rising, and is pulled low when the triangle is falling. The maximum voltage on this pin must be less than or equal to V+.

Saw

The saw wave is produced by an internal tri-to-saw converter. It has its lower point at GND and upper point at VREF. The shape of the saw wave is controlled by the TIME REVERSE pin: when high or not connected the saw has a rising slope and fast drop, and when low (grounded) the saw has a fast rise and falling slope ("reverse-saw").

Variable Width Pulse (PWM)

An internal comparator in the SSI2130 can be used to generate a variable-width pulse. This is most commonly used to generate PWM waves based on the triangle or saw waves. Depending on the driving waveform two subtly different PWM sounds can be generated. Triangle-based PWM (PWM-T) maintains a constant time period between the centres of the pulses when the threshold voltage changes (e.g., LFO modulation).

Saw-based PWM (PWM-S) locks one edge of the PWM waveform to the abrupt edge of the sawtooth waveform and varies the position of the other edge as the threshold voltage is varied. This results in minor frequency deviations due to the centers of the PWM pulses moving with the threshold voltage. This can produce a gentle vibrato as part of the overall PWM modulation effect.

If its necessary to force the output of the comparator to a hard low or high it is possible to pull the comparator input pin slightly above VREF or slightly below GND. In this mode the output of the comparator is forced high or low without any spikes. See "Pulse Width Modulation" in the Applications section.

Sine

The sine converter block has a differential input and generates a low-distortion sine wave when driven by the triangle wave. Both inputs should be connected to ground through 4.75kΩ resistors. The driving voltage is fed to one of the inputs either through a DC blocking capacitor, or direct-coupled together with a compensating DC offset applied to the other input.

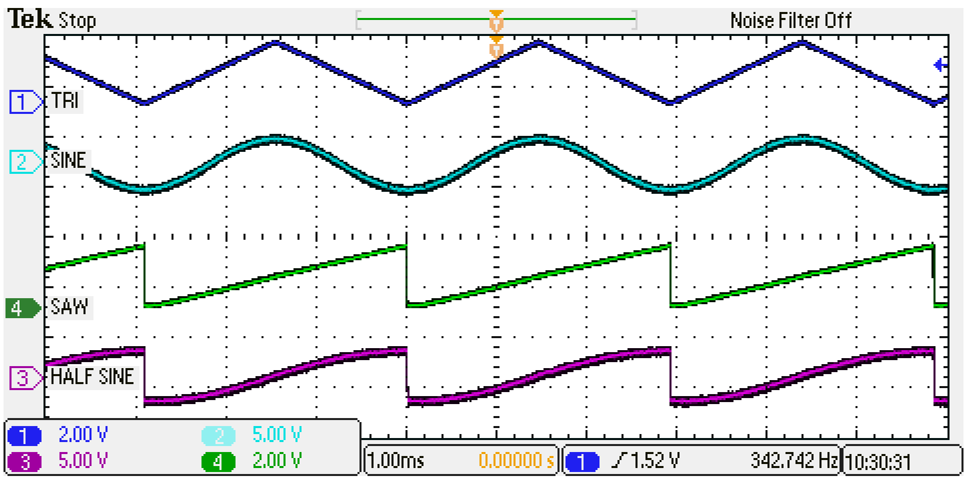


Figure 3: SSI2130's Triangle-Derived Sine and Sawtooth-Derived Half Sine

If the sine converter is driven by the saw wave then it is possible to generate a half-sine waveform. Figure 3 shows the triangle and sine, plus sawtooth and half-sine.

FIVE CHANNEL MIXER

The SSI2130 includes a five-input current-controlled mono mixer to combine several internal and external signals into one output current. Three internal signals – triangle, saw, and pulse – are level-shifted to remove the VREF/2 DC offset, and then scaled. There are also two external auxiliary inputs (AUX1 and AUX2) that are mixed with the other channels.

Each channel of the mixer is controlled by a current fed into its MIX pin. Typically a series resistor converts the control inputs into voltage control for a VCA-like interface. Figure 1 shows 100kΩ control input resistors for a 0V to 5V control voltage range ; control input resistors as low as 50kΩ can be used. Unused mix control inputs should be left floating or connected to ground via resistors no less than 50kΩ. Do not connect control inputs directly to ground.

The mixer's output is a high-compliance current output. It can either drive directly a current-to-voltage resistor, as shown in Figure 1, or into a ground-referenced current input (e.g., SSI2140, SSI2144, SSI2164, etc). This could be used, for example, in summing multiple SSI2130s, and/or feeding directly into the input of an SSI2140 VCF or SSI2164 VCA.

TIMING CAPACITOR

The characteristics of the timing capacitor connected to TCAP directly affect the frequency range and stability of the VCO. For best performance a capacitor with very low temperature coefficient should be selected, for example C0G/NP0. A value of 3.9nF puts the range of the exponential converter over the audio range found in a typical music synthesizer.

Other values will produce different tuning ranges, with a useful range from 1nF to 10nF. Smaller values are limited by the upper frequency of the VCO and the effects of leakage currents at low frequencies.

EXPONENTIAL CONVERTER AND LINEAR MODULATION

In a musical application a linear control voltage or current (e.g.,1V per octave) is converted into an exponential signal to control a linear-in-frequency oscillator (e.g.,20µA per kHz). The SSI2130 integrates a high-quality temperature-compensated exponential converter. The converter takes a current and computes a corresponding exponential current which then drives the linear response triangle oscillator.

The exponential converter has three ground-referenced current inputs and one current output. The EXPO FREQ pin allows multiple control currents, or control voltages with voltage-to-current resistors, to be summed. The EXPO SCALE pin sets the scale of the exponential converter, or the "sensitivity" of the exponential function (how many microamps or volts per octave). The third input LIN FREQ is a linear frequency control that can be used for linear FM, through-zero FM, vibrato without pitch shift, and more. The output frequency is a simple linear function of the current into this pin, such that if there is no current flowing into it then the oscillator stops (zero frequency).

HF TRACK is a current output that can be used to apply a trim offset to the exponential converter. This automatically compensates for internal resistive losses that cause the oscillator to go flat at high frequencies. It can be fed into the EXPO FREQ pin through a trimmer for manual adjustment, through a fixed resistor network for simpler but less accurate tuning at the upper end of the frequency range, or it can be automated in microprocessor-tuned instruments.

For manual and automated trimming procedures please refer to "Exponential Converter Setup and Trimming."

SYNCHRONIZATION

The SSI2130 supports two oscillator synchronization methods: soft sync and hard sync.

Soft sync synchronizes the SSI2130 to an external signal when the triangle waveform is falling and close to GND. A capacitively-coupled pulse on the SOFT SYNC input will cause the triangle to switch from falling to rising. If the voltage on TCAP is too high then synchronization will not take place. The synchronization is "soft" in that it only occurs within a narrow part of the oscillating cycle; at all other times it has no effect. Leave pin 19 unconnected if not used. See Figure 4.

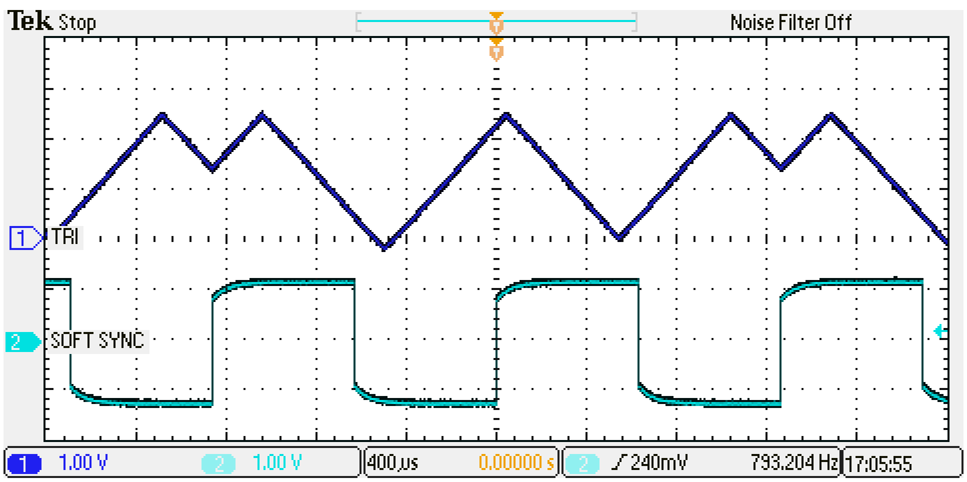


Figure 4: "Soft" Sync

Hard sync occurs at any point in the oscillating cycle. The HARD SYNC pin has two modes of operation. If held high it stops the oscillator with the triangle output at GND. This can be used to force the SSI2130 to stop and wait for some future event. If a short pulse is used, for example, the pin is capacitively-coupled to an external signal (with pull down), then hard sync will only occur on a fast rising edge (e.g., square, pulse, or falling saw) and will immediately force the triangle to GND and begin rising. Ground the HARD SYNC pin directly if not needed. See Figure 5.

SINE SHAPER

The SSI2130 includes a high-quality temperature-compensated sine shaper. It has differential inputs SINE- and SINE+ and a single output SINE OUT. For best operation both inputs must be biased to GND with 4.75kΩ resistors. Signals are then fed to one or both inputs. The preceeding Output Waveforms section shows the sine shaper generating sine and half-sine waves.

There are two recommended ways to drive the sine shaper. The capacitor-coupled method is shown in Figure 1. This couples the triangle output to the SINE+ input through a 4.02kΩ mix resistor and a 10µF DC-blocking capacitor to remove the VREF/2 DC bias. This is the simplest scheme, although it suffers from increasing distortion at low frequencies due to impedance of the capacitor.

The second method is direct DC coupled, which requires a VREF/2 DC bias to feed to the SINE- input. See Figure 6.

TEMPERATURE COMPENSATION

All transistor-junction-based exponential converters are sensitive to thermal effects, which is a fundamental property of semiconductor physics. The SSI2130 incorporates automatic temperature compensation circuits to ensure stable tuning over a wide range of thermal drift.

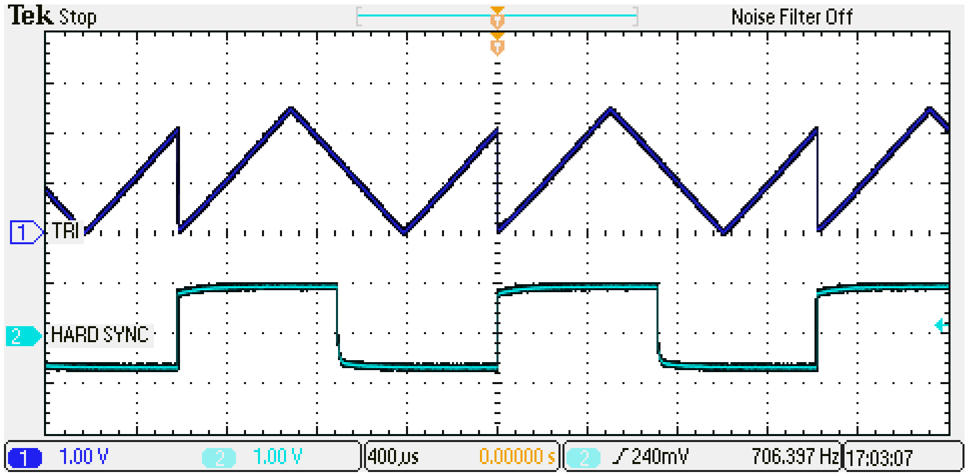


Figure 5: "Hard" Sync

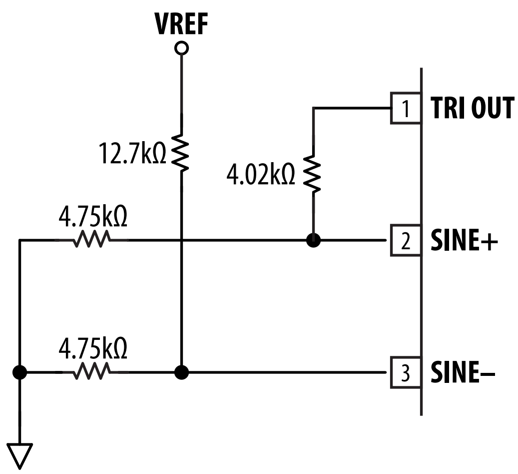


Figure 6: DC-Coupled Sine

Note that the SSI2130 itself is a very low power device which minimizes self-heating effects. Any temperature changes are mainly due to the operating environment.

The SSI2130 utilizes fully automatic temperature compensation. No set up or adjustment is necessary or possible. The only adjustments possible are related to setting the tuning scale and high-frequency compensation - both are described below.

CRITICAL COMPONENT SELECTION

The SSI2130 is designed from the ground-up to require very few critical components or values. For stable operation the value of VREF needs to be within 0.5% of 2.5V. However, for best performance over temperature it is important to use tuning and trimming components with very low thermal coefficients.

Capacitors

The timing capacitor connected to TCAP should be COG/NP0, polystyrene, or polycarbonate. Decoupling capacitors should be X7R or better.

Trimmers

Any trimmers used to set SCALE, HF TRIM and tuning should be high-quality cermet types. Depending on the application either single-turn or ten-turn trimmers may be used.

Resistors

All resistors used to set currents or voltages connected to the SSI2130 should have low temperature coefficients, ideally 100pm/°C or better. Both sine shaper bias resistors should be matched to 1% or better. SSI recommends good quality metal film through-hole resistors, or thin film resistors for surface mount assembly. Where resistors are connected to trimmers, for example setting the SCALE current, resistor tolerance is less critical. However SSI still recommends using 1% resistors as general practice for higher precision and lower temperature coefficient properties and therefore used throughout this data sheet.

EXPONENTIAL CONVERTER SETUP AND TRIMMING

The SSI2130 can be used to build high-precision audio oscillators covering a 1000:1 (ten octave) range with less than one cent tuning error. To achieve this, two parameters allow setup of the SSI2130. For less critical applications it is possible to use fixed trim settings for acceptable levels of tuning performance; for example, an LFO.

The two parameters that may require trimming are scale and high-frequency trim. Scale sets the sensitivity of the EXPO FREQ pin in terms of current-per-octave or current-per-decade. For example, a VCO application with 100kΩ resistors would require a 10μA/octave scale.

Secondly, at the upper end of the SSI2130's frequency range the effects of parasitic resistance in exponential converter transistors results in the oscillator running slower than desired. The SSI2130 incorporates an optional high-frequency trim (HFT) output that can be used to automatically compensate for this.

Fixed Trim

For low cost applications the scale trim can be replaced by a fixed resistor. If adopting the recommended approach of driving the SCALE pin from VREF, a 24.3kΩ fixed resistor provides a scale sensitivity typical for 20μA per octave.

Similarly, for HFT a simple network of a 4.32kΩ resistor from HF TRACK to GND and a 267kΩ resistor from HF TRACK to EXPO FREQ will provide adequate high frequency compensation for 20μA per octave sensitivity. This is shown in Figure 1.

Manual Trimming

For manual trim applications such as modular synthesizers, a bias voltage will be necessary to establish the 0V/octave point, for example 27.5Hz or MIDI note zero. Figure 7 shows a simple circuit to provide such a bias.

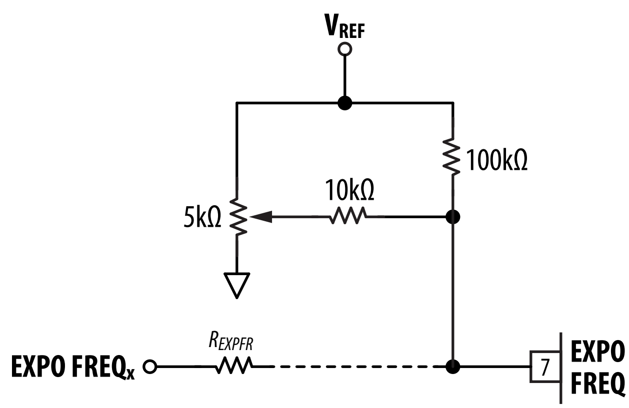


Figure 7: Expo Biasing Circuit for Manual Trim Applications

High frequency tuning is handled by the circuit shown in Figure 8, which is best performed using a precise 10-turn pot.

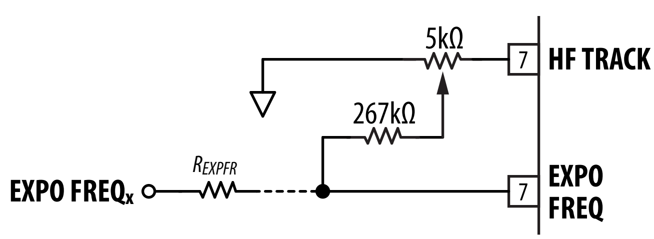


Figure 8: High Frequency Trim Circuit

Tuning Process

The SSI2130 requires tuning before it can be used in tonal-based musical applications. Described below is a single-pass tuning process which brings the SSI2130 into a good level of tuning. It is possible to repeat the process once or twice to achieve a tighter tuning but is not necessary in most cases.

SETUP

The following equipment is recommended:

- Precision voltage source, accurate to better than +/- 0.0008V, OR a settable voltage source and a 5.5-digit (or better) bench DMM (e.g., Agilent 34401A)
- Frequency counter to 6 digits or more (e.g., HP 5334A or 53131A)
- Calculator or spreadsheet

MEASURE

1. Apply CV of 1.000V to the control voltage input
2. Measure frequency = “FA”
3. Apply CV of 5.000V to the control voltage input; maintain for step 13
4. Measure frequency = “FB”

CALCULATE INTERCEPT

5. Let A = log2(FA)
6. Let B = log2(FB)
7. Calculate dy = B – A
8. Then let dx = 5 – 1
9. Finally, the intercept, I = A – dy/dx

CALCULATE TARGET FREQUENCY

10. The desired Slope = dx/dy = 1V/oct
11. From which Log Target, T = I + 5*Slope = I + 5
12. And so Target Frequency = 2^T
13. With control voltage input still set to 5.000V adjust the EXP SCALE trimmer until the SSI2130 is generating the Target Frequency.

HIGH FREQUENCY TRIM

14. Apply CV of 9.000V to the control voltage input
15. Calculate set frequency as 16 times the target frequency from step #12 of above
16. Adjust HF TRIM until the set frequency is reached.

A TUNING EXAMPLE

1. CV = 1.000V
2. FA = 30Hz
3. CV = 5.000V
4. FB = 522Hz
5. A = $\log_2(30)$ = 4.907
6. B = $\log_2(522)$ = 9.028
7. dy = B – A = 4.121
8. dx = 5 – 1 = 4
9. I = A – dy/dx = 4.907 –4.121/4 = 3.877
10. Slope = 1
11. T = I + 5 = 3.877 + 5 = 8.877
12. Target Frequency = $2^{8.877}$ = 470.157Hz

Automated Tuning

The SSI2130 is ideal for use in microprocessor-controlled synthesizers. Once a tuning cycle has characterized both the scale and high-frequency behavior the SSI2130 maintains its characteristics over a wide temperature range, thereby reducing the need for subsequent retuning cycles. The process described above can be readily automated. The falling edge of the SQUARE output will provide the lowest jitter for frequency measurement.

The high frequency trim is less sensitive to tuning variations. In some applications this can be left as a fixed trim, or manually trimmed. Applications requiring programmable HF trim can be achieved with an external VCA such as an SSI2164 connected between the HF TRACK output and the EXPO FREQ input as shown in Figure 9.

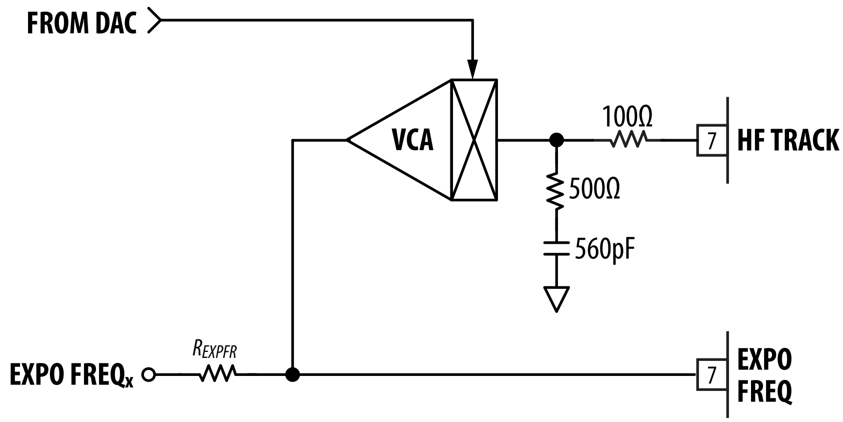


Figure 9: DAC Control of High Frequency Trim Using a VCA

PRINCIPLES OF OPERATION

Designing musical oscillators around the SSI2130 brings several benefits. Exceptional temperature-stable exponential conformance extends over ten octaves. Reduced external component count simplifies layout and lowers BOM costs. Enhanced functionality pulls in wave shapers and electronic mixing. Knowledge of the internal operation, presented here, is essential to getting the most out of the SSI2130.

Temperature-Compensated Exponential Converter

The exponential converter takes a linear input current and produces an exponential charging current for the triangle oscillator. It is internally temperature compensated with on-chip PTAT (proportional to ambient temperature) current sources. The addition of a simple external high-frequency trim produces an exponential converter that can operate over a 10-octave range to within ±1 cent. A simplified diagram of the exponential converter is shown in Figure 10.

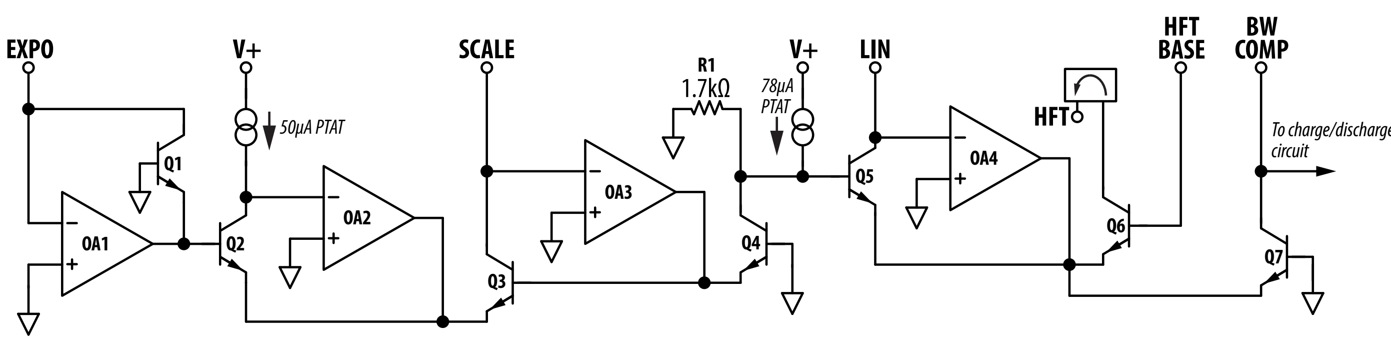


Figure 10: SSI2130 Simplified Exponential Converter

Opamp OA1 and transistor Q1 convert the linear current Iexpo into a logarithmic voltage, while OA2, Q2, and the first PTAT current source provide temperature compensation for the transistors in the exponential converter.

OA3 and Q3 set the amps-per-octave response based on the current fed into the SCALE pin. Q4 , R1 (1.7kΩ), and the second PTAT current source implement an exponential function which converts the logarithmic control voltage back into a linear control voltage. OA4, Q5, and Q7, implement the second exponential function to generate capacitor charging current for the oscillator core. The current into the LIN FREQ pin provides linear frequency control for linear FM musical effects.

Q6 and its current mirror generate a duplicate of the charging current. This is used for external high-frequency compensation trim ("HFT"). Output current "I_C" of the exponential converter is given by the following:

$$I_C = I_{LIN} e^{\frac{R}{V_T}\left(\frac{I_{EXPO} I_{PTAT}}{I_{SCALE}} - I_{ZERO}\right)}$$

V_T is the junction thermal voltage (given by kT/q), I_{LIN} is the current into the LINFREQ pin, I_{EXPO} is the current into the EXPO pin, I_{SCALE} is the current into the SCALE pin, I_{PTAT} is a current source that compensates for temperature, and I_{ZERO} is a current source that sets the output of the expo converter for $I_{EXPO} = 0$µA. As V_T , I_{PTAT} and I_{ZERO} are proportional to absolute temperature (PTAT), the output of the expo converter is independent of temperature. Re-scaling the exponent term to use the logarithm base of 2 (in octaves) produces:

$$I_C = I_{LIN} 2^{\frac{1}{\ln 2}\frac{R}{V_T}\left(\frac{I_{EXPO} I_{PTAT}}{I_{SCALE}} - I_{ZERO}\right)}$$

The scaling factor for the exponential control current is then given by the following expression:

$$I_{SCALE} = \frac{1}{ln2}\frac{R}{V_T} I_{EXPO} I_{PTAT}$$

Putting $I_{PTAT} = 50$µA, R = 1700 and $V_T = 26$mV derives the following simplified relationship:

$$I_{SCALE} = 4.717 I_{EXPO}$$

For example, for a 20µA/octave sensitivity I_{SCALE} needs to be 94.34µA. If using VREF then a 26.5kΩ resistor is required. A 24.3kΩ resistor and 5kΩ 10-turn cermet trimmer from the VREF rail would be a good design choice, and with 49.9kΩ EXPO input resistors.

A second example, for a 10µA/octave sensitivity I_{SCALE} needs to be 47.17µA. For the same VREF a 53.6kΩ resistor is required; use a 49.9kΩ resistor and 5kΩ 10-turn trimmer, and 100kΩ expo input resistors.

Current into the LIN FREQ pin, I_{LIN}, is a linear control of the oscillator frequency. For typical operation this is set to around 5µA (VREF through a 499kΩ resistor). The oscillator stops when the input is zero. The section below describes the relationship between frequency, I_{LIN}, and the timing capacitor.

Triangle Oscillator

The core of the SSI2130 is a triangle oscillator – see Figure 11. The charging current from the exponential converter is mirrored twice (Q1, Q2, Q3, OA1). The first current output, from Q2's collector, is mirrored and doubled by Q4-6. The second current output, from Q3's collector, charges the timing capacitor connected to the TCAP pin.

When SW1 is in the open position, the capacitor charges linearly at a rate set by the current through Q3. When SW1 is closed the doubled current is also connected to the timing capacitor, with the capacitor now being linearly discharged. Since the charge and discharge currents vary only in their sign the resulting voltage across TCAP is a highly linear triangle. Opamp OA2 buffers the capacitor voltage to drive internal circuits and TRI OUT pin.

Window comparators CP1 and CP2 compare the triangle waveform with GND and VREF. The outputs of the comparators drive the Set and Reset inputs of flip-flop FF1. The output of FF1 controls switch SW1. The output of FF1 also drives open-collector output SQUARE.

The period of oscillation of the triangle core is the sum of the charge and discharge times. Since the charge and discharge currents are the same, the frequency of the triangle oscillator is:

$$f_{TRI} = \frac{I_C}{2V_{REF}C} Hz$$

C is the timing capacitor connected to the TCAP pin, VREF is the voltage at the VREF pin, and I_C is as shown above. Combining the two, and converting to octaves where a linear step increase in I_{EXPO} doubles the output frequency, derives an expression giving oscillator frequency, in Hz, from the exponential current input:

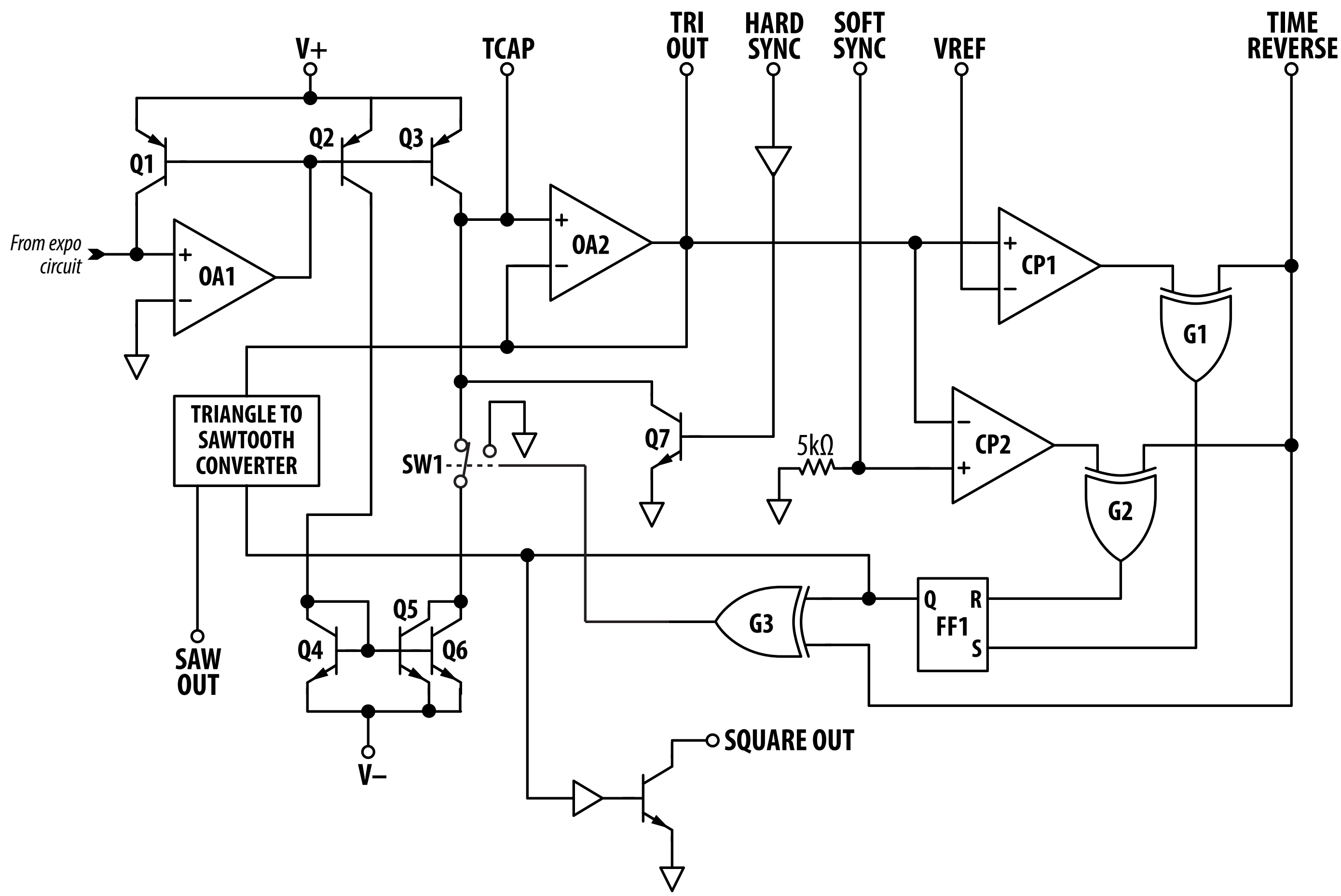


Figure 11: SSI2130 Simplified Oscillator Core

Triangle oscillator core can run forward or backwards depending on state of the TIME REVERSE input.

$$f_{TRI} = \frac{I_{LIN}\, 2^{\frac{1}{\ln 2}\frac{R}{V_T}\left(\frac{I_{EXPO} I_{PTAT}}{I_{SCALE}} - I_{ZERO}\right)}}{2 V_{REF} C}\, Hz$$

Soft sync shifts the threshold of the lower window comparator CP2. An AC-coupled impulse shifts the voltage at which the bottom of the triangle wave will trigger the comparator CP2 and reset FF1, causing the oscillator to change direction and start climbing up to VREF. Only the falling half of the triangle can be soft synced (when the capacitor is being discharged). The magnitude of the soft sync pulse determines how close to the normal reset point the oscillator will be synchronised.

Hard sync discharges TCAP to ground through Q7. This resets the oscillator to the start of its cycle irrespective of the phase of the oscillator. Internal circuits (not shown) ensure FF1 is also reset to guarantee the oscillator always returns to the start of its cycle.

The TIME REVERSE input, together with exclusive-OR gates G1-3, inverts the outputs of the window comparators and FF1. This has the effect of reversing the direction of the oscillator.

Sawtooth Wave Shaper

The triangle output, together with several other internal signals, is internally connected to the input of a sawtooth converter. The output of the sawtooth converter is a highly-linear sawtooth with substantially reduced glitches compared to other tri-to-saw converters.

The sawtooth converter works in conjunction with the TIME REVERSE pin to allow the selection of a rising or falling slope. When TIME REVERSE is high the sawtooth rises slowly, followed by a rapid descent back to zero. When TIME REVERSE is low, the sawtooth comprises a fast rising edge followed by a slow descent (sometimes called a ramp waveform).

In both modes of operation the sawtooth converter is also affected by both soft and hard sync. Because the sawtooth is derived from the triangle wave the same behaviour applies to the sawtooth: hard sync can occur at any point in the cycle, whereas soft sync can only occur during a small part of the cycle.

PWM Comparator

The SSI2130 provides a precision comparator (Figure 12). Its two inputs must be in the range 0V to VREF. Typically one input would be connected to an oscillator output, and the other input to a variable control voltage, for example a potentiometer between ground and VREF, to produce a pulse-width modulated (PWM) waveform.

The triangle produces a pulse where both edges change as the reference voltage changes. The sawtooth produces a pulse where only one edge varies as the reference voltage changes - the other edge always coincides with the reset edge of the sawtooth.

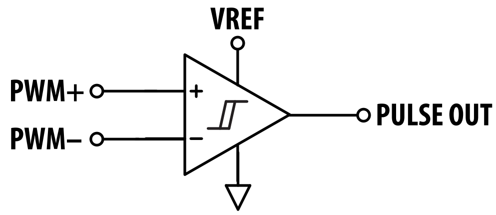


Figure 12: SSI2130 PWM Comparator
A little hysteresis goes a long way to making a great sounding PWM.

Sine Wave Shaper

The SSI2130 incorporates a high-quality temperature-compensated triangle-to-sine converter, as shown in Figure 13, primarily designed to convert the triangle output into a low-distortion sine wave. The converter has a differential input stage, allowing the designer to choose the phase relationship between the triangle input and sine output.

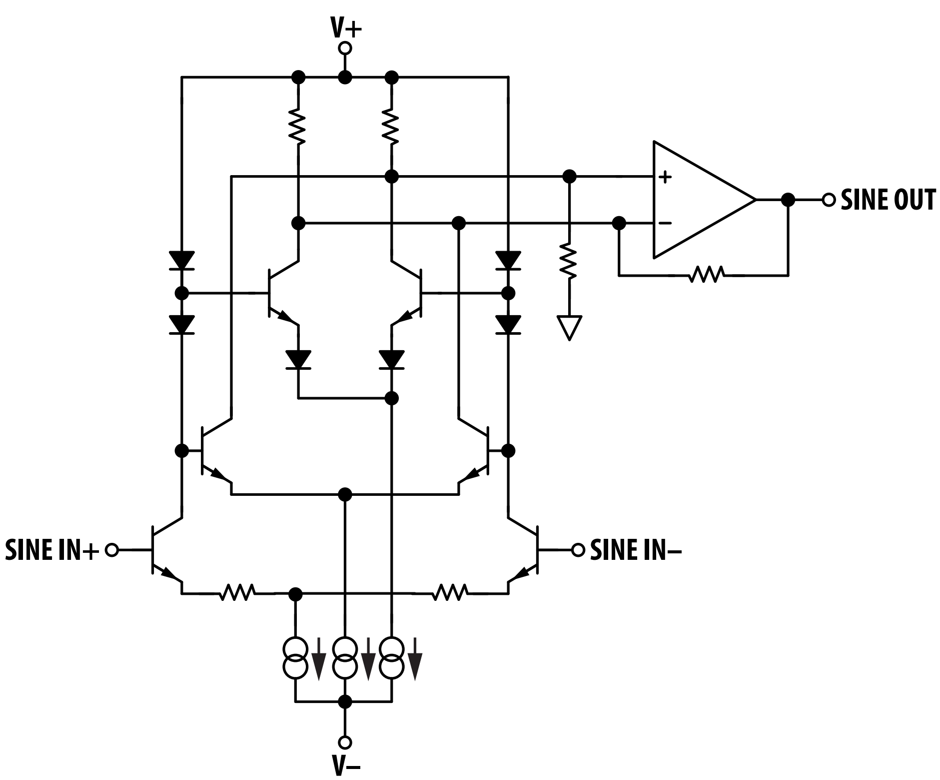


Figure 13: SSI2130 Triange-to-Sine Converter

The two inputs of the sine converter are ground-referenced voltage inputs. They require external 4.75kΩ bias resistors to GND. If the driving signal is connected to the SINE+ input (pin 2) the output of the sine converter (pin 24) is the same phase as the triangle waveform. To invert the phase of the sine output couple the triangle signal to the SINE- input (pin 3). To generate a half-sine waveform, the sine converter can be driven by the sawtooth output.

The voltage output of the sine converter is connected directly to pin 24. In a typical circuit this would be fed into one of the auxiliary inputs of the mixer.

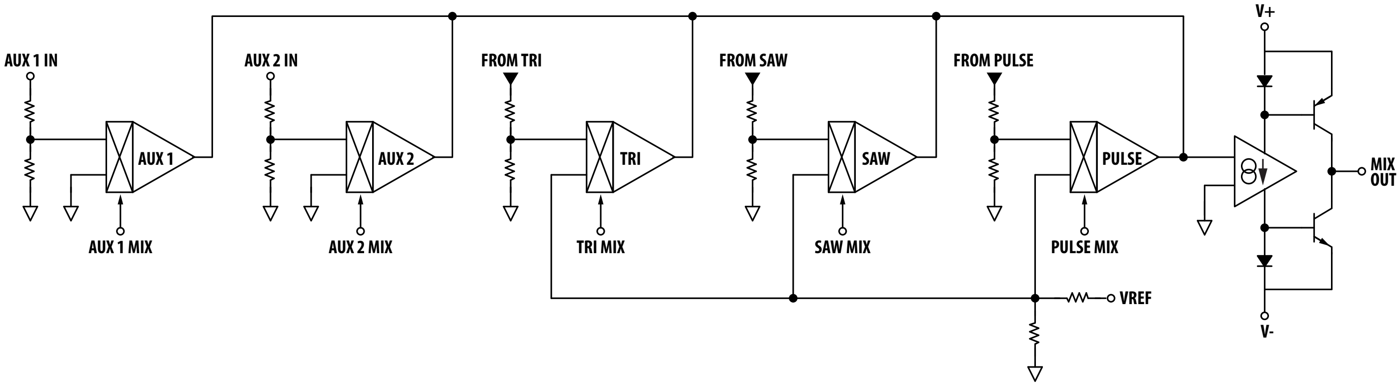


Figure 14: Mixer Section

Mixer

The SSI2130 generates several different waveforms. Bringing these together is a five-channel linear current-controlled mixer (Figure 14). Three channels are internally connected to the outputs of the triangle oscillator, the sawtooth converter and the PWM comparator. All three internal waveforms are shifted and scaled to remove the DC offset. The other two channels – AUX1 and AUX2 – allow external signals to be mixed into the output signal.

The gain of each channel is controlled by a current. An external series resistor is used to convert a control voltage into a control; the resistor sets the control range. For each channel:

$$I_{OUT} = g_m V_{IN}$$

where $g_m = I_{CTRL} K_{GAIN}$

I_{CTRL} is the control current into the channel's MIX pin, and K_{GAIN} is the gain coefficient. For the three internal channels this is 1.28; the two AUX channels 0.64. To accommodate higher signal levels the two AUX channels attenuate the input signal by a factor of 2, allowing signals up to $10V_{P-P}$ (±5V).

Channel	Control Pin	K_{GAIN}
TRI	9	1.28
SAW	10	1.28
PULSE	11	1.28
AUX 1	12	0.64
AUX 2	13	0.64

MIX OUT (pin 25) is a high-compliance current output with two possible operating modes. In "Voltage Mode" an external shunt resistor can be used to convert the output current into a voltage (see Figure 1), but note that the maximum voltage is ±3V, beyond which it will clip. In "Current Mode" the MIX OUT pin is summed into a virtual earth amplifier. The output voltage is then set by the feedback resistor and is not limited by the SSI2130 output compliance. It is also possible to mix together the current mode outputs of other SSI2130s, as well as SSI216x-family VCAs.

For example, to configure the mixer channel for unity gain for the an internal channel (±1.25V) with a control voltage of 5V, use a 100kΩ series resistor on the control pin to set the maximum control current to the recommended 50µA, and a 15.8 kΩ resistor from the MIX OUT pin to GND. It is important to configure the mixer to avoid clipping the MIX OUT pin. Careful attention to mix combinations and gain settings is essential to avoid distortion.

DESIGN AND APPLICATION NOTES

Numerous applications based on the SSI2130 are covered in this section. Excellent exponential tracking, high-quality waveforms, and the onboard mixer provide many circuit blocks for the designer to use. In addition, small size and low power support portable battery-powered applications. Linear and exponential frequency control allow a wide variety of musical and non-musical uses.

Pulse Width Modulation

An internal comparator produces a PWM waveform. It is designed to be directly driven by either the triangle or sawtooth outputs. To ensure the PWM output can be forced to always-high and always-low ends of operation the external threshold voltage should extend slightly beyond the 0V to VREF range.

The 10kΩ resistors pull the ends of the pot's range to just above VREF and just below ground. This gives full control of the PWM from 0% to 100%. See Figure 15.

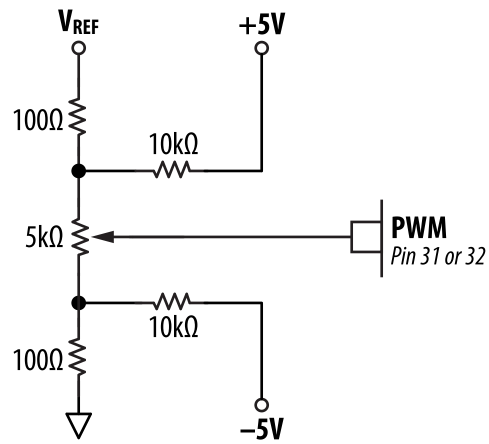


Figure 15: Ideal SSI2130 PWM Control Circuit

Exponential Control Inputs

The SSI2130 provides a single ground-referenced current input for exponential control (Figure 16). This greatly simplifies external circuitry for summing multiple control sources, including external control voltage inputs, manual fine and coarse tuning controls, auto-tune offsets, digital-to-analog converters, etc.

To maintain the SSI2130's excellent temperature stability, it is recommended to use very low temperature coefficient summing resistors and temperature-stable voltage references. If external summing op-amps are used, they should have very low offset drift to ensure that once tuned the oscillator does not drift appreciably as the instrument warms up or cools down.

Note that the circuit below is configured for a 20µA per octave response as shown by a 49.9kΩ control voltage resistor.

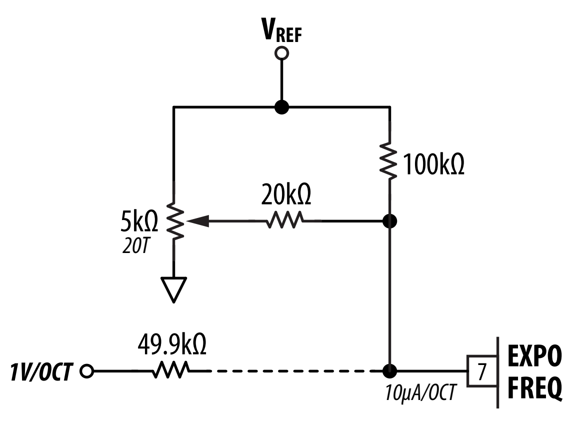


Figure 16: Ground-Referened Current Inputs Simplify Summing Multiple Control Inputs

Frequency Modulation: Through Zero And Beyond

Background

Angle modulation – the general term that covers both frequency modulation ("FM") and phase modulation ("PM")– is a relatively simple technique capable of producing waveforms rich in harmonic content. First proposed by John R. Carson in 1922, and originally developed for radio systems, it has been adopted by the electronic music community as a means of generating complex timbres with nothing more than a couple of oscillators. John Chowning, while at Stanford University in the 1970s, developed the musical application of FM synthesis which lead to develoment of Yamaha's DX7 digital FM synthesizer.

Mathematical analysis of FM and PM shows the harmonics generated are described by Bessel functions – a set of functions that look like damped sine waves which extend to infinity and beyond. This property produces complex timbres from simple circuit blocks. As the lower harmonics cross the zero frequency (DC), they effectively fold around from the negative region back into the positive frequency region with inharmonic components adding further richness to the sound.

Frequency Modulation

Frequency is the rate of change of phase: cycles (or radians) per second. An oscillator whose frequency can be directly varied, or modulated, by an external signal is a direct FM oscillator. The amount of change that the modulating signal can cause is called the "modulation index." For small modulation indexes any voltage-controlled oscillator can be used, and will result in a narrow-band output signal. A higher modulation index, where the frequency of oscillation can go to zero, and even negative in a mathematical sense, requires a special type of oscillator called a Through-Zero Oscillator.

The SSI2130 supports linear and exponential FM. Exponential FM is applied as an input to the EXPO FREQ pin, and varies the frequency of oscillation in a non-linear volts-per-octave scale. This produces a vibrato effect at slow modulation frequencies. The average pitch of the oscillator shifts with increasing modulation depth, and the side-bands are not harmonically-related to the fundamental.

Linear FM is achieved by varying the current into the LIN FREQ pin from the nominal level set during tuning. Linear FM varies the frequency of oscillation in a linear scale, and produces harmonic side-bands that are linearly related to the fundamental frequency. Figure 17 shows a simple scheme for adding manual vibrato to the SSI2130 using a low frequency oscillator ("LFO").

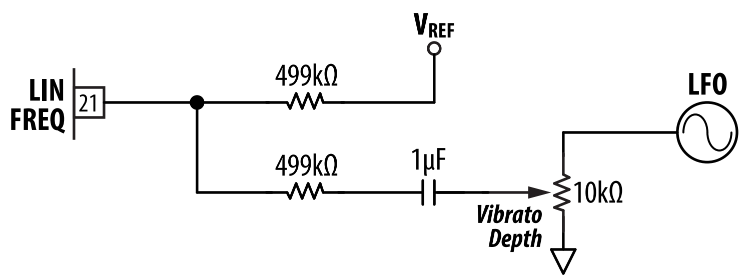


Figure 17: Linear Vibrato Keeps the Oscillator in Tune

The current into the LIN FREQ pin linearly scales the frequency set by the exponential converter. The sensitivity, often expressed as µA/Hz, depends on the output of the exponential converter: sensitivity increases with higher exponential currents, and decreases with lower exponential currents. For example, if the SSI2130 is oscillating at 500 Hz with a current of 5µA into LIN FREQ (the recommended nominal value), the sensitivity is 10nA/Hz. However, at an octave higher, the linear sensitivity becomes 20nA/Hz.

At extreme modulation depths linear FM requires an oscillator that can reverse the polarity of the neutron flow to allow it to go backwards through zero (DC) and into negative frequencies. The SSI2130, with a few additional external components, fully supports this mode of operation. This simple method produces harmonically-rich yet musical tones at very low cost.

The circuit shown in Figure 18 adds the necessary external components to implement through-zero FM ("TZFM"). A linear modulating signal is fed into the IN_{TZFM} point. The first opamp adds VREF to ensure stable operation when no modulation is applied. The LM311 compares the modulating signal against 0V and both drives the TIME REVERSE pin of the SSI2130 and also switches the second op-amp from non-inverting to inverting. This ensures the current into the LIN FREQ pin is always positive, and reverses the oscillator when the control is negative. For the circuit shown, IN_{TZFM} should be in the range $\pm$5V.

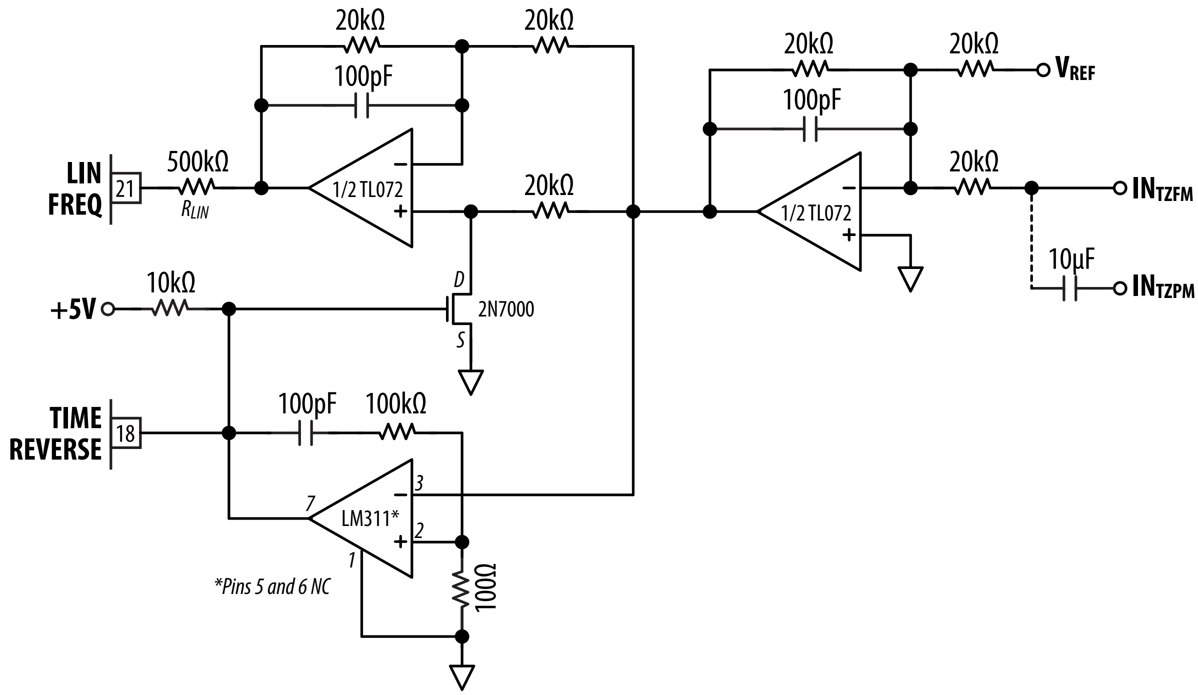


Figure 18: A Handful of Passive Makes TZFM and TZPM a Low Parts-Count Reality

Phase Modulation

While most analog through-zero oscillators implement FM, it is quite straightforward to support through-zero PM ("TZPM"). When the modulation waveform is a sine wave the result is the same for FM and PM. But when the modulating signal is not a sine wave the results are different, ranging from slightly different to very different depending on the modulation waveform and the modulation index.

The IN_{TZPM} input to the circuit in Figure 18 is used for phase modulation. Frequency is the differential (rate of change) of phase, so to modulate the phase of an oscillator the modulating signal must be differentiated. This is done electronically by adding a capacitor to the modulation input. FM is commonly found on musical VCOs, is well known, and used in many synthesizers. However, because the modulating signal is DC coupled, any offset results in the VCO being out of tune by introducing a constant frequency shift. PM removes the DC offset, keeping the VCO in tune.

Four-Quadrant Modulation

A second modulation scheme that is easily implemented with the SSI2130 is the four-quadrant product modulator, often called a "Ring Modulator" after the popular diode ring circuit invented by Frank Cowan in 1934. It is able to generate very harmonically-rich sounds from simple waveforms - while the name is given by the ring of diodes in the original invention it can easily generate clangorous bell-like ringing tones from just a couple of sine waves.

With the addition of an external op-amp and two of the auxiliary mixer channels (Figure 19) it is possible to implement a four-quadrant product multiplier producing classic "ring-mod" style audio effects.

The unmodified sine wave is fed into AUX 1. A second, inverted, sine wave is fed into AUX 2. Both control inputs are biased to the half-way point, and the modulating signal (V_{MOD}) capacitor coupled into the control port of AUX1. Using the component values shown the output of the mixer is then given by:

$$V_{OUT}(t) = \frac{V_{SIN}(t)V_{MOD}(t)}{2}$$

When V_{MOD} is zero, both sine inputs are mixed in equal amounts and so cancel. When V_{MOD} goes positive, more current feeds into AUX1's control port, increasing the amplitude of the non-inverted sine wave. Likewise, as V_{MOD} goes negative the amplitude of the non-inverted sine wave decreases and so V_{OUT} takes on the inverted sine wave.

The input capacitor AC-couples the modulating signal into the ring modulator. The capacitor can be removed if modulation down to DC is required, but note any offset will introduce side-carrier interference in the modulator output.

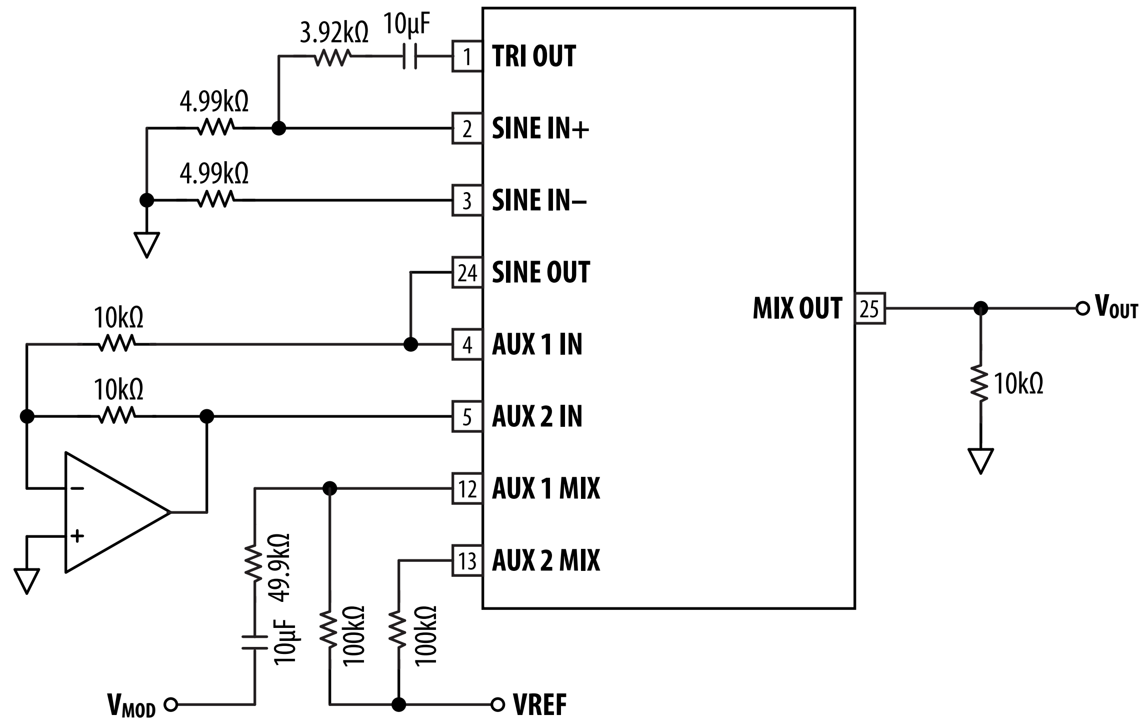


Figure 19: Just One Op-Amp is Needed to Build a Four-Quadrant Multiplier

Three-Way Cross Fader

With only three op-amps it is possible to crossfade between the internal waveforms using the internal mixer. The circuit in Figure 20 takes a zero to 1V control voltage and generates three control signals for connecting to the triangle, sawtooth and pulse mix controls through 20kΩ resistors.

A single -1V offset ("V_{OSV}") is required, which could be generated either from an inverted copy of VREF (change the resistor to 50kΩ), or with a low-cost shunt reference such as the TL431.

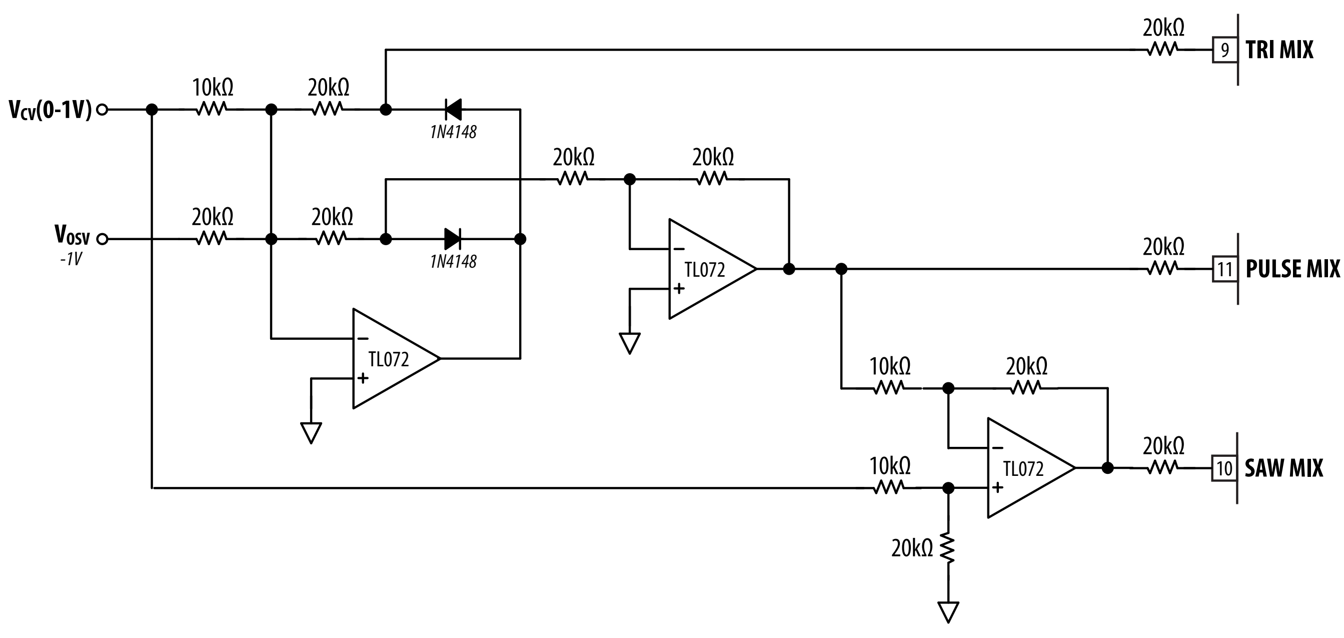


Figure 20: Triangle-Saw-PWM Cross Fader

Quadrature Sine Generation

A sine VCO is ideal for constructing frequency shifters. However most frequency shifters require both sine and cosine signals. In radio communications systems this is often done with RC polyphase filter networks which are only effective over an order of magnitude frequency range (e.g, 300 Hz to 3 kHz). More complex filters can extend this range but add cost.

The SSI2130 can be used to generate a low-distortion sine wave. A SSI2164 is then used to build a tracking all-pass filter to provide the 90 degree phase shift to generate the cosine wave (Figure 21). Because the SSI2164 control response is already exponential, it is only necessary to scale and shift a standard 1V/octave control voltage in order to accurately track the SSI2130 VCO. The prototype implementation was shown to operate over a wide frequency range from 50 Hz up to 15 kHz covering the majority of the audio range.

As only one gain cell is used it is possible to choose from the SSI2161, SSI2162 or SSI2164 for the all-pass filter element. The only change to this circuit to support these variations is in the choice of compensation network component values. Please refer to the datasheets of the relevant parts for design information.

To set up this circuit requires the following four steps:

1. Apply 0 to +5V triangle to CV input
2. Observe SIN and COS on scope in XY mode
3. Adjust TRACK until steady ellipse on scope
4. Adjust OFFSET until ellipse is circle

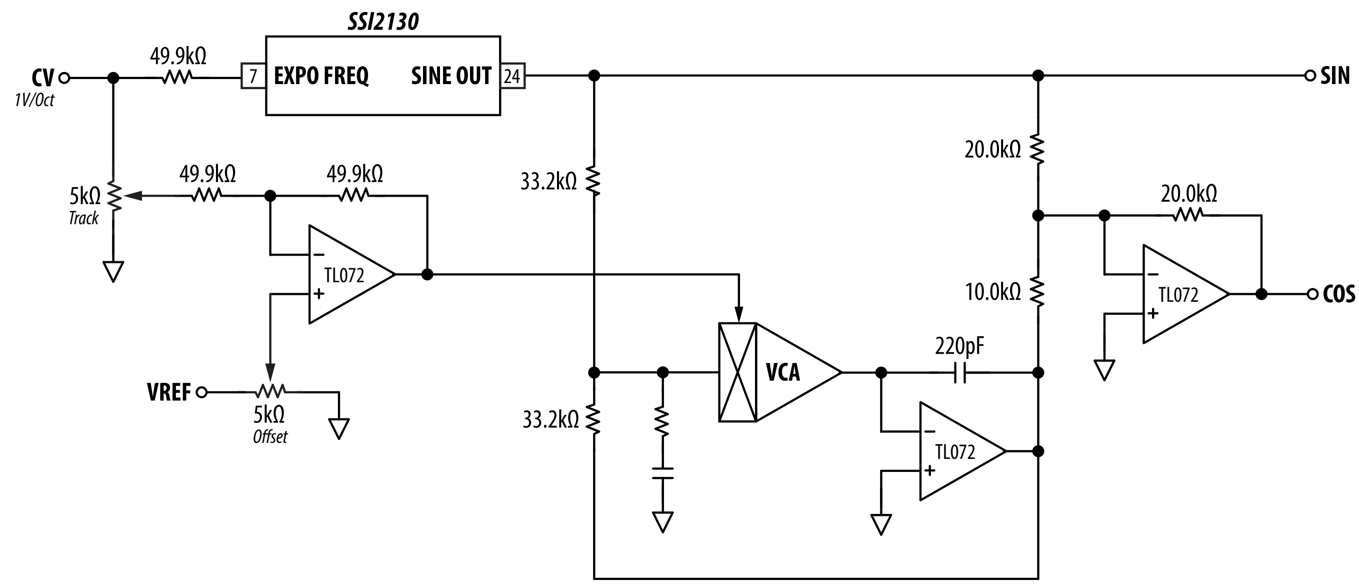
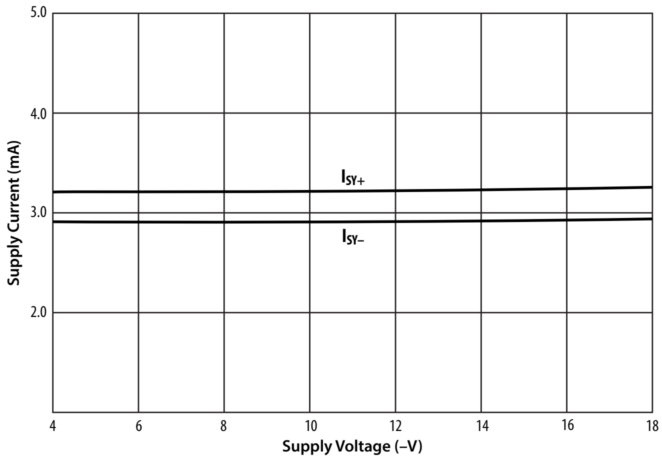
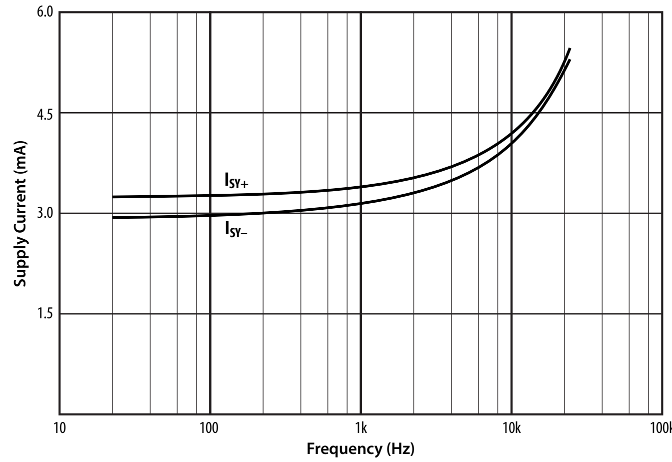


Figure 21: A sine VCO and a tracking APF makes for Quadrature Oscillator
Note VCA compensating component values are not shown as they depend on which variant of the SSI216x is used

TYPICAL PERFORMANCE GRAPHS



Supply Current vs. V– Supply Voltage
V+ = +5V, f = 20Hz, Figure 1 Circuit



Supply Current vs. Frequency
V+ = +5V, V– = -15V, Figure 1 Circuit