

SSI2131

FATKEYS™ VOLTAGE CONTROLLED OSCILLATOR

The SSI2131 is a new-generation voltage controlled oscillator for high-performance electronic musical instruments and other systems requiring accurate audio-band waveform generation. The device offers unprecedented levels of temperature stability, exponentiality, waveform integrity, and ease of use. Buffered voltage outputs include triangle, sawtooth, and pulse with PWM control.

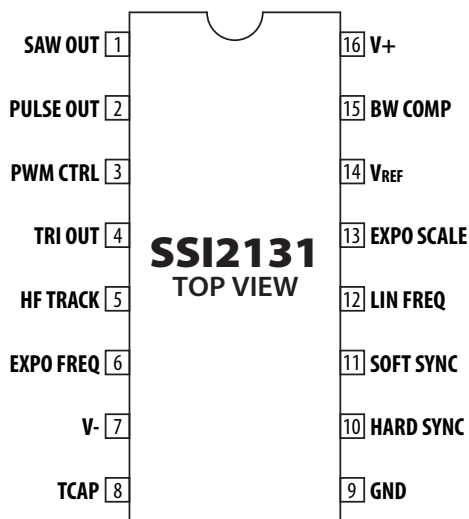
A precision analog multiplier provides temperature stability, and careful attention was paid to improvement of triangle and sawtooth waveform accuracy compared to previous generation VCO IC's.

Optional trims are possible for exponential scale and high frequency tracking which can be automated by CPU-calibrated systems. The SSI2131 requires an absolute minimum of external components and is available in an easy-to-use 16-lead SOP package.

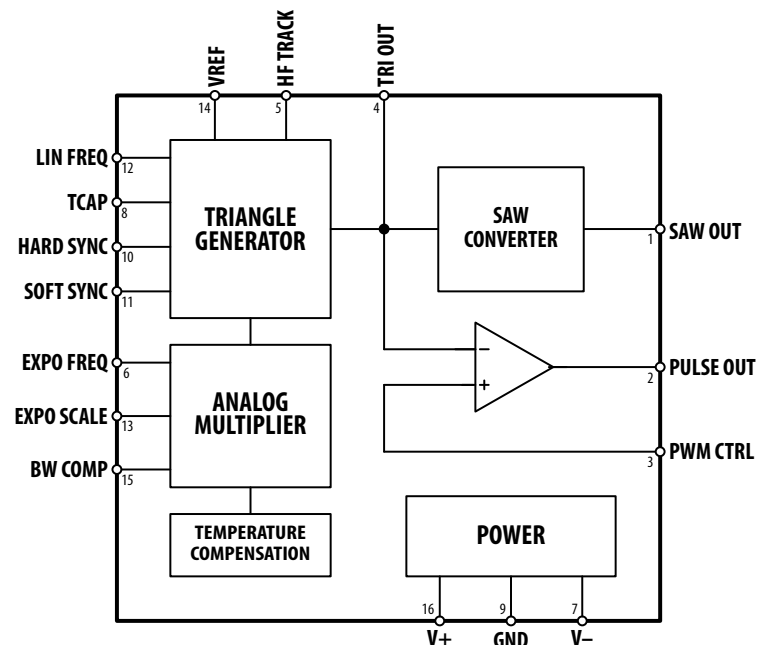
For equivalent VCO performance with more features, please see the SSI2130 which adds an integrated five-channel mixer, open-collector square output, sine wave generator, and through-zero FM/PM capability.

FEATURES

- High Performance Synth Voice Front-End
- Triangle, Saw, and Pulse with PWM Control
- Unprecedented Temperature Stability
- High-Integrity Waveforms
- Superb Exponential Response
- Buffered Waveform Outputs
- Extremely Low External Component Count
- Easy-to-Use 16-Lead SOP Package



PIN CONNECTIONS
16-LEAD SOP
(JEDEC MS-012-AC)



FUNCTIONAL BLOCK DIAGRAM

The SSI2131 is available exclusively from Sound Semiconductor and its authorized resellers

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

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SPECIFICATIONS ($V_S = \pm 5V$, $V_{REF} = 2.5V$, $f = 1kHz$, $T_A = 25^\circ C$; 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
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

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
SSI2131SS-TU	16-Lead SOP* - Tube	50
SSI2131SS-RT	16-Lead SOP* - Tape and Reel	4000

*SSI Package ID "PSL16"; Compliant with JEDEC MS-012-AC. Package outline drawing available at www.soundsemiconductor.com. Please order in full container multiples.

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SSI2131 PIN DESCRIPTIONS

Pin(s)	Pin Name	Description
1	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, and when TIME REVERSE is pulled to ground the sawtooth is slowly falling and quickly rising. This signal is also fed internally mixer.
2	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.
3	PWM CTRL	Input of the internal comparator. Input range is 0V to VREF.
4	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.
5	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.
6	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 20 μ A/octave, using a 50k Ω resistor to give the common 1V/octave response.
7	V-	Negative supply. Recommend a 100nF local decoupling placed as close to the package as possible with a low inductance trace to ground.
8	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.
9	GND	Ground.
10	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.
11	SOFT SYNC	Connects to an internal 5k Ω 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.
12	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.
13	EXPO SCALE	A ground-referenced current input. Current into the EXPO SCALE pin sets sensitivity (scale) of the EXPO FREQ pin. For a 20 μ A/octave sensitivity feed a current of 94.34 μ A into the EXPO SCALE pin.
14	VREF	Reference voltage input, which must be fixed at 2.5V from a low-noise low-impedance voltage reference.
15	BW COMP	Provides frequency compensation for the exponential converter. Connect a 270 Ω resistor in series with a 10nF capacitor to ground.
16	V+	Positive supply. Recommend a 100nF local decoupling placed as close to the package as possible with a low inductance trace to ground.

USING THE SSI2131

The SSI2131 is a compact and highly versatile analog voltage controlled oscillator subsystem for easy design of synthesizer voice front ends. Relevant inputs are ground-referenced currents 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 SSI2131, 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 pulse with PWM control waveforms, together with soft sync, hard sync, and three (or more) 1V/octave control voltage inputs.

The positive supply comes into the SSI2131 at pin 16, and the negative supply at pin 7. Both supplies require local 100nF decoupling capacitors. Ground connection is at pin 9. The reference voltage is connected to pin 14.

The exponential control voltages (CV's) are brought into the SSI2131 through external resistors into a current summing node at pin 6. The exponential converter requires a single scale adjustment set by a current flowing into the EXPO SCALE pin 13. The components as shown set the sensitivity to 20 μ A/octave, with the trimmer allowing for manual fine adjustment. For correct operation it is also required to set a linear control current into the SSI2131's LIN FREQ pin 12. If linear frequency modulation is not required this pin should be supplied with a constant current of about 5 μ A using a 499k Ω resistor from VREF.

Due to normal silicon properties, the exponential converter has high frequency tracking errors. Resistors on pin 5 compensate by injecting a small correction current into the EXPO FREQ pin 6. An optional trim (see "Exponential Converter Setup and Trimming") can further improve

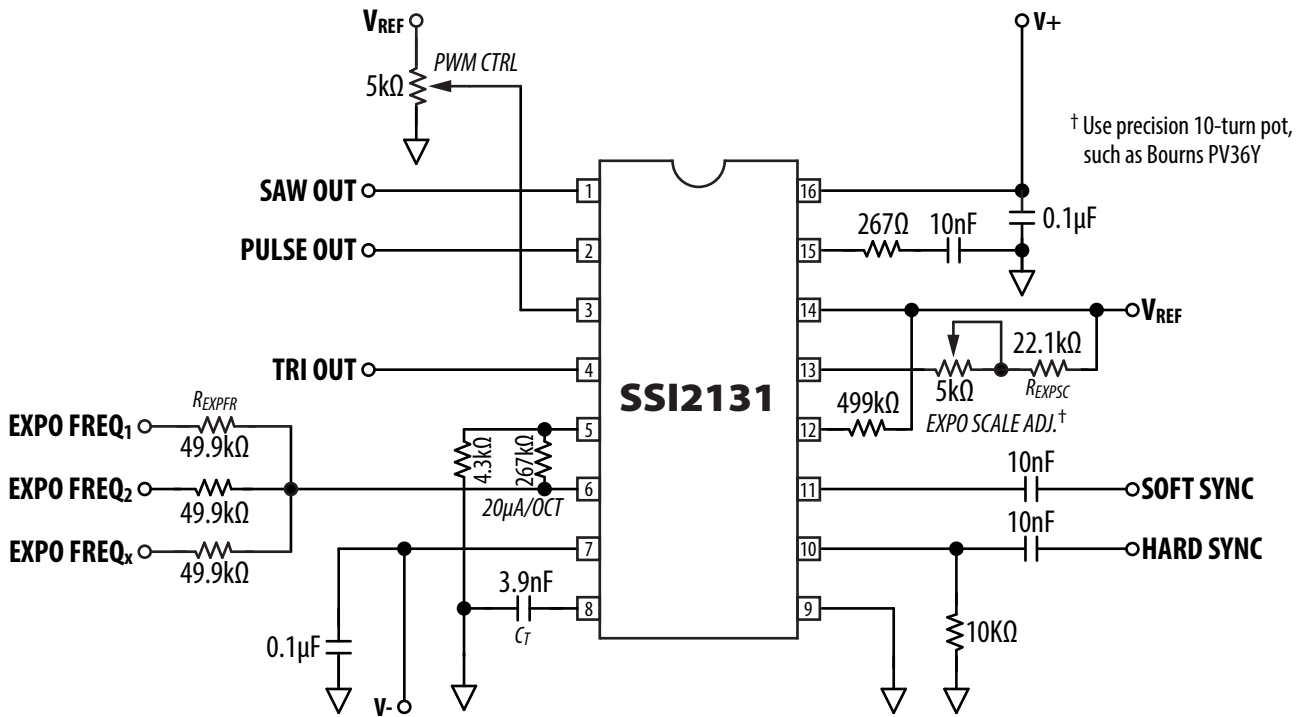


Figure 1: Typical Application Circuit

high frequency performance. The exponential converter also requires an external compensation network for stable operation, connected to pin 15, and the recommended values shown are suitable for a wide range of applications.

The SSI2131 supports several synchronization modes. SOFT SYNC (pin 11) requires a series 10nF capacitor for normal operation. HARD SYNC (pin 10) also requires a 10nF capacitor plus a 10kΩ resistor to ground.

The triangle oscillator requires a single high-quality timing capacitor connected to pin 8. The resulting voltage is then buffered and provided at the TRI OUT, pin 4. The SAW OUT (pin 1) 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 is connected internally to the buffered triangle output, while the second comparator input (pin 3) is connected to the wiper of a potentiometer or other voltage source to set pulse width.

Power Supplies and Grounding

The SSI2131 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 SSI2131 has ground connection on pins 9, which must be connected to ground using thick short traces or closely positioned vias to a ground plane.

Operating at these lower voltages allows the SSI2131 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.

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 which 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 SSI2131. Two key parameters are used to specify the VREF source: absolute tolerance and temperature coefficient.

The SSI2131 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:

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

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 SSI2131.

OUTPUT WAVEFORMS

The SSI2131 generates a triangle waveform, and internal processing blocks produce saw, sine and variable width pulse waveforms. See Figure 2.

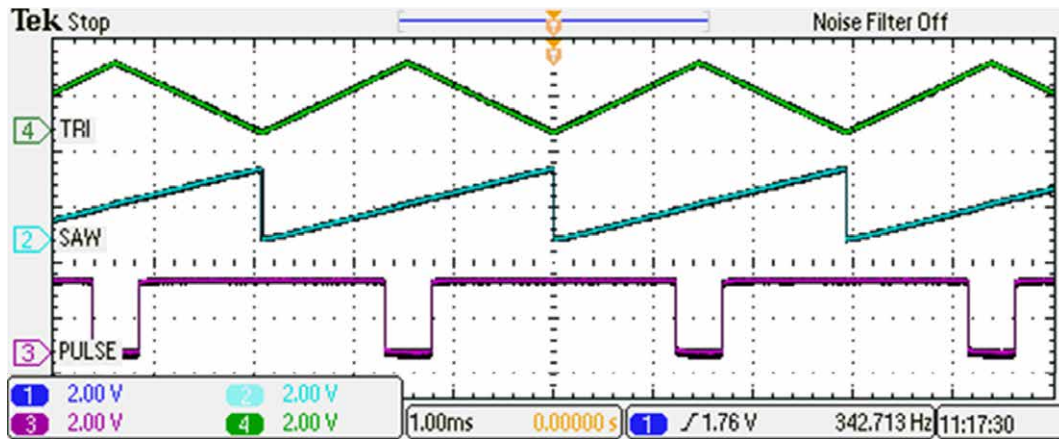


Figure 2: The SSI2131's Primary Waveforms

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 "Synchronization" for more detail.

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.

Variable Width Pulse (PWM)

An internal comparator in the SSI2131 is used to generate a variable-width pulse. This is most commonly used to generate PWM waves based on the triangle. 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).

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.

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 COG/NPO. 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 SSI2131 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, 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 SSI2131 supports two oscillator synchronization methods: soft sync and hard sync.

Soft sync synchronizes the SSI2131 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 11 unconnected if not used. See Figure 3.

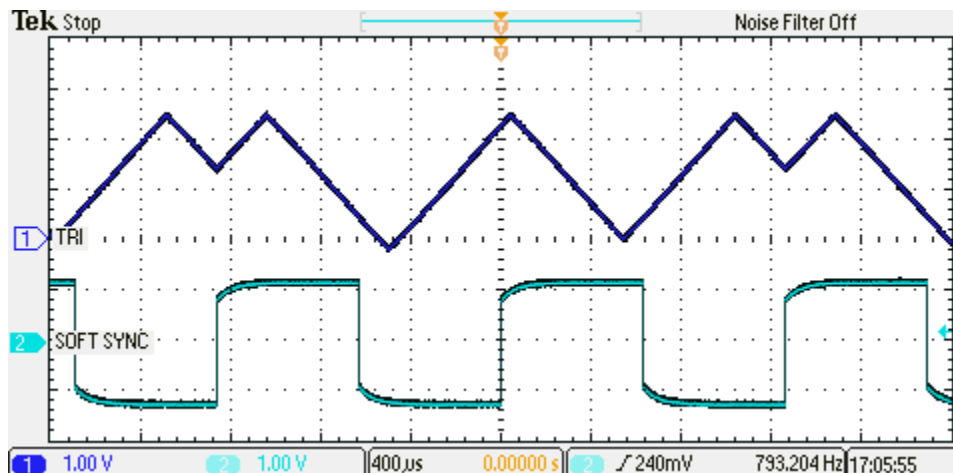


Figure 3: “Soft” Sync

Hard sync occurs at any point in the oscillating cycle and 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 SSI2131 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 4.

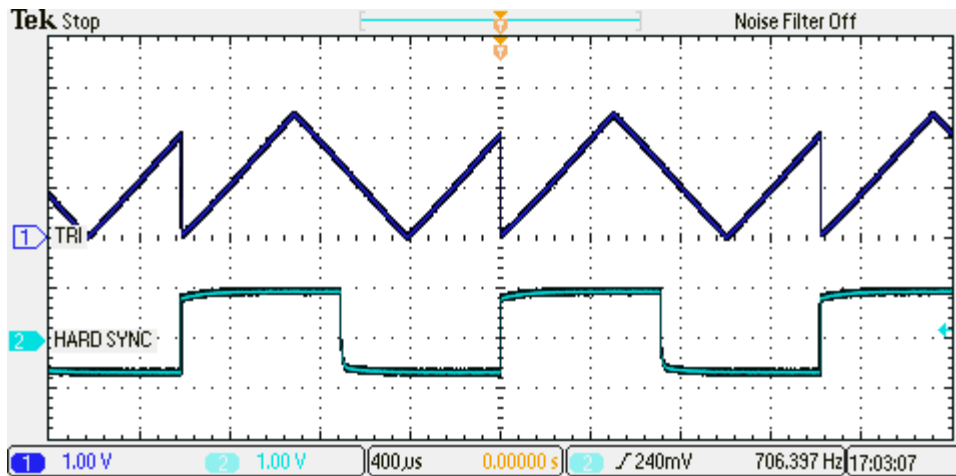


Figure 4: “Hard” Sync

TEMPERATURE COMPENSATION

All transistor-junction-based exponential converters are sensitive to thermal effects, which is a fundamental property of semiconductor physics. The SSI2131 incorporates automatic temperature compensation circuits to ensure stable tuning over a wide range of thermal drift. Note that the SSI2131 itself is a very low power device which minimizes self-heating effects. Any temperature changes are mainly due to the operating environment.

The SSI2131 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 SSI2131 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/NPO, 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 SSI2131 should have low temperature coefficients, ideally 100pm/°C 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 SSI2131 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 SSI2131. 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 expo scale and high-frequency. 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 SSI2131's frequency range the effects of parasitic resistance in exponential converter transistors results in the oscillator running slower than desired. The SSI2131 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 5 shows a simple circuit to provide such a bias.

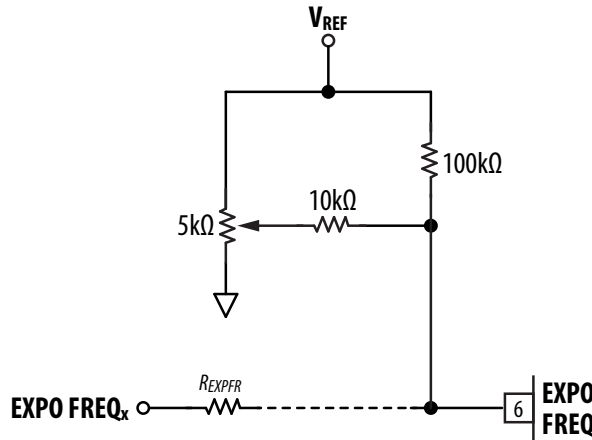


Figure 5: Expo Biasing Circuit for Manual Trim Applications

High frequency tuning is handled by the circuit shown in Figure 6 which is best performed using a precise 10-turn pot.

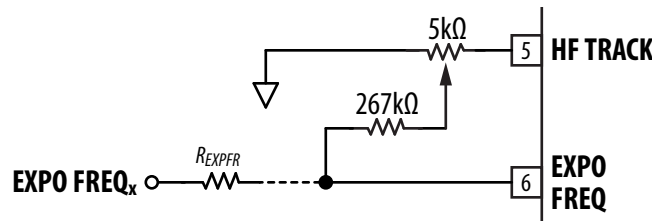


Figure 6: High Frequency Trim Circuit

Tuning Process

The SSI2131 requires tuning before it can be used in tonal-based musical applications. Described below is a single-pass tuning process which brings the SSI2131 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 $A = \log_2(FA)$
6. Let $B = \log_2(FB)$
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 SSI2131 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 SSI2131 is ideal for use in microprocessor-controlled synthesizers. Once a tuning cycle has characterized both the scale and high-frequency behavior the SSI2131 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 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 7.

PRINCIPLES OF OPERATION

Designing musical oscillators around the SSI2131 brings several benefits. Exceptional temperature-stable exponential conformance extends over ten octaves. Reduced external component count simplifies layout and lowers BOM costs. Knowledge of the internal operation, presented here, is essential to getting the most out of the SSI2131.

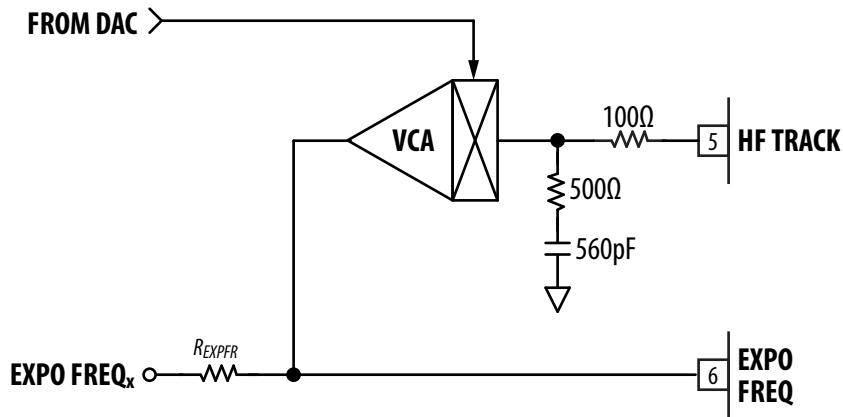


Figure 7: DAC Control of High Frequency Trim Using a VCA

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 8.

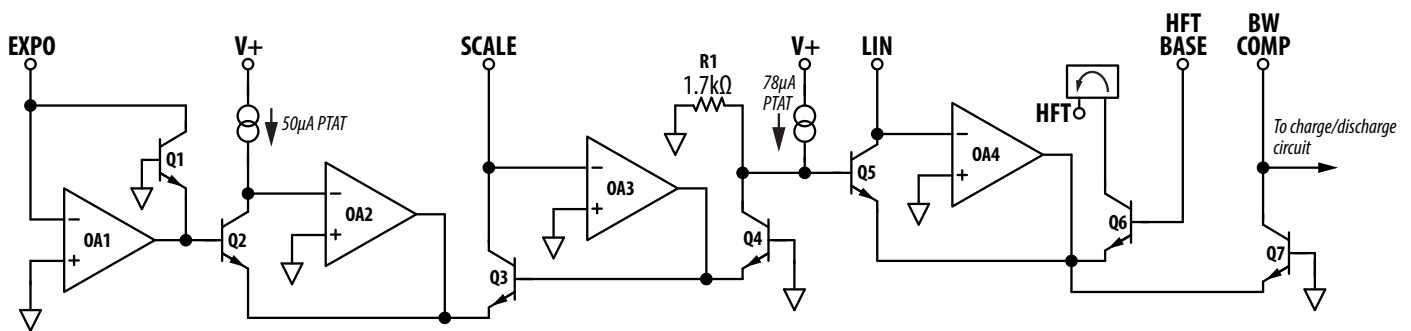


Figure 8: SSI2131 Simplified Exponential Converter

Opamp OA1 and transistor Q1 convert the linear current I_{EXPO} 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 $I_{EXPO} = 0\mu A$. 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:

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

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

$$I_{SCALE} = \frac{1}{\ln 2} \frac{R}{V_T} I_{EXPO} I_{PTAT}$$

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

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

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

A second example, for a $10\mu\text{A}/\text{octave}$ sensitivity I_{SCALE} needs to be $47.17\mu\text{A}$. For the same V_{REF} a $53.6\text{k}\Omega$ resistor is required; use a $49.9\text{k}\Omega$ resistor and $5\text{k}\Omega$ 10-turn trimmer, and $100\text{k}\Omega$ 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 $5\mu\text{A}$ (V_{REF} through a $499\text{k}\Omega$ 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 SSI2131 is a triangle oscillator – see Figure 9. 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.

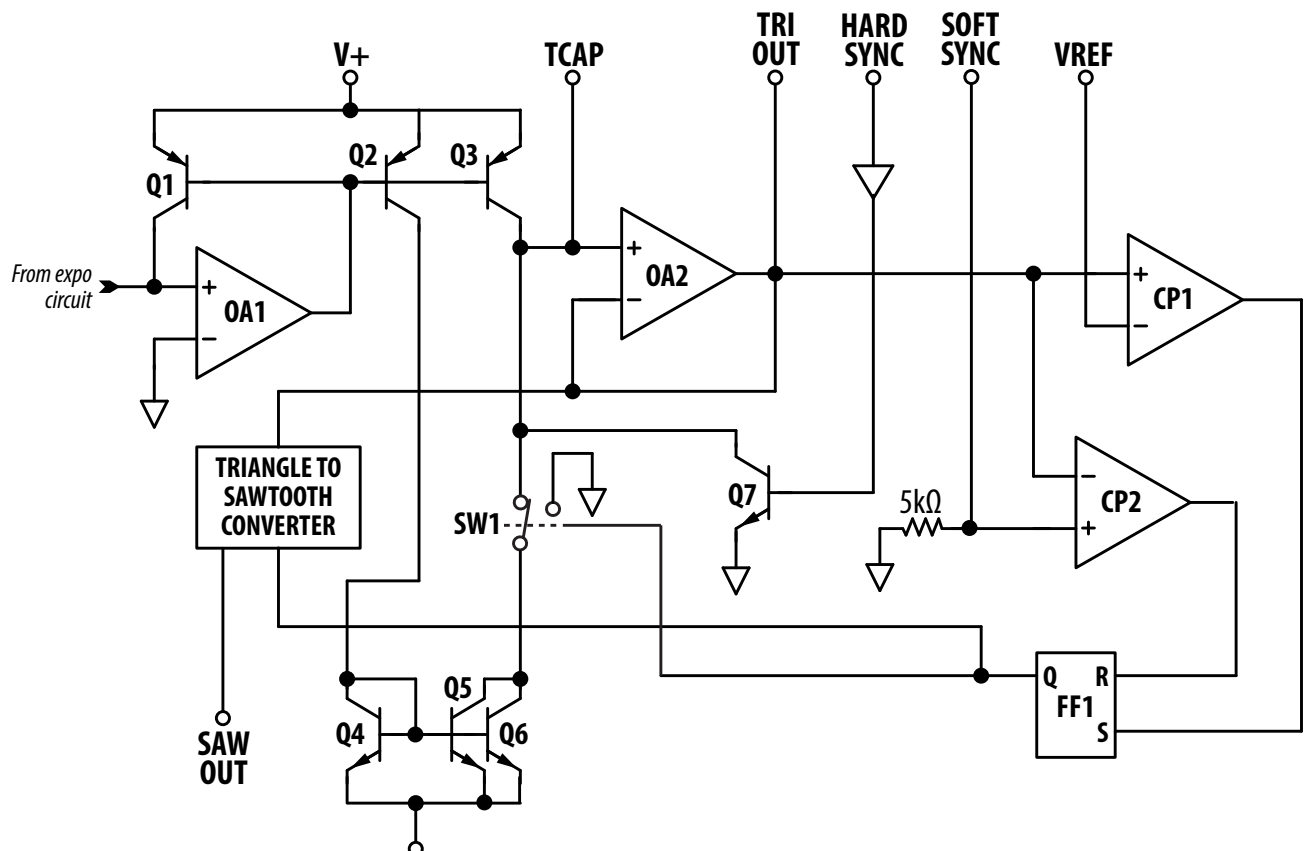


Figure 9: SSI2131 Simplified Oscillator Core

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:

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

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:

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

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.

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 is 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 SSI2131 provides a precision comparator (Figure 10). Its two inputs must be in the range 0V to VREF. One input is connected to the 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.

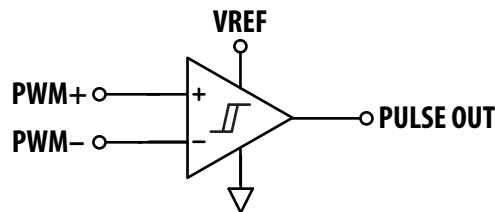


Figure 10: SSI2131 PWM Comparator

A little hysteresis goes a long way to making a great sounding PWM.

DESIGN AND APPLICATION NOTES

Numerous applications based on the SSI2131 are covered in this section. Excellent exponential tracking and high-quality waveforms 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 internally connected to the triangle output. 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 11.

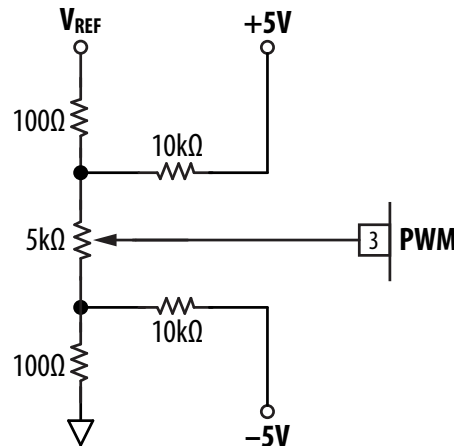


Figure 11: Ideal SSI2131 PWM Control Circuit

Exponential Control Inputs

The SSI2131 provides a single ground-referenced current input for exponential control, as shown previously in Figure 6. 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 SSI2131'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.

Frequency Modulation

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 led to development 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.”

The SSI2131 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 12 shows a simple scheme for adding manual vibrato to the SSI2131 using a low frequency oscillator (“LFO”).

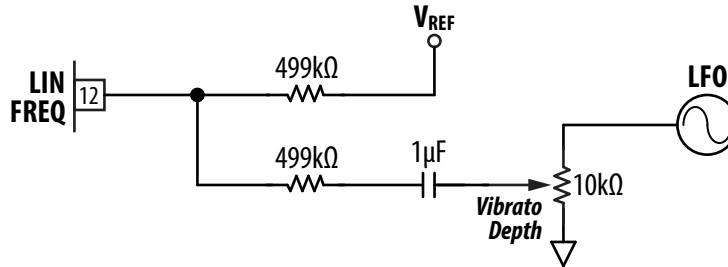
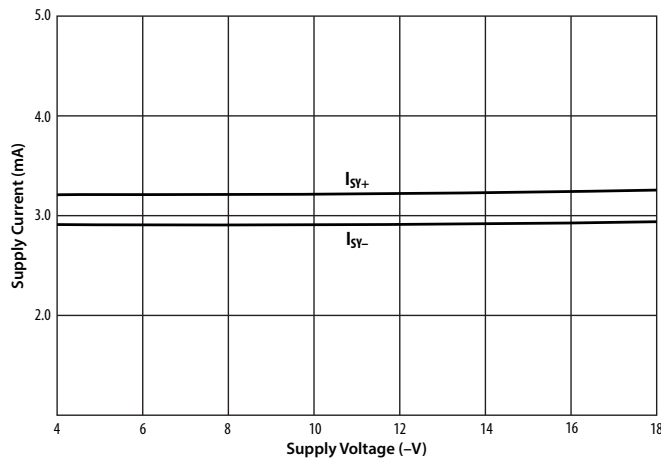


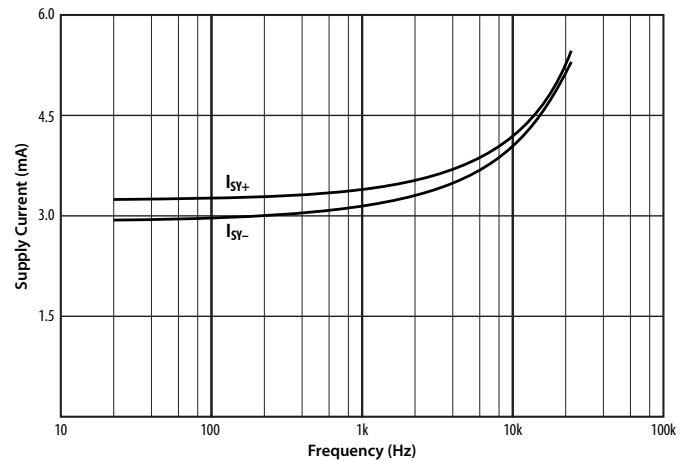
Figure 12: Linear Vibrato Keeps the Oscillator in Tune

The current into the LIN FREQ pin linearly scales the frequency set by the exponential converter. The sensitivity, often expressed as $\mu\text{A}/\text{Hz}$, depends on the output of the exponential converter: sensitivity increases with higher exponential currents, and decreases with lower exponential currents. For example, if the SSI2131 is oscillating at 500 Hz with a current of $5\mu\text{A}$ into LIN FREQ (the recommended nominal value), the sensitivity is $10\text{nA}/\text{Hz}$. However, at an octave higher, the linear sensitivity becomes $20\text{nA}/\text{Hz}$.

TYPICAL PERFORMANCE GRAPHS



Supply Current vs. V- Supply Voltage
 $V+ = +5\text{V}, f = 20\text{Hz}$, Figure 1 Circuit



Supply Current vs. Frequency
 $V+ = +5\text{V}, V- = -15\text{V}$, Figure 1 Circuit