APPLICATION NOTE

AN1512
All-in-one: NE5230

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ABSTRACT

Recent improvements in low voltage operational amplifier design have resulted in novel applications formerly thought impossible. Design improvements include rail-to-rail operation at both the input and output, programmable bandwidth, full swing capability to ±0.8V with ±9V V_{CC} and availability in surface mount packages. These unique features combine to make possible applications such as voltage-to-current conversion down to zero; a low voltage, full-swing, instrumentation amplifier; a solar-powered, gated function generator; active filters and many more applications. A circuit for increased output power is also presented.

INTRODUCTION

The name of the game in low voltage op amps is: MAX HEADROOM. For a given range of voltage, how much of that voltage can be utilized by the op amp's output? Traditionally, not very much, especially on the positive side. Among other important concerns are input voltage range, drive capability, speed, input bias current and power supply current. Trade-offs are part of every design. But with each new design, fewer trade-offs are tolerated. For example, drive capability and speed were not available in the same amplifier. Now, they are not only offered together but expected in precision designs. And so it is with low voltage and input and output rail-to-rail operation. The NE5230 is the first to offer this combination. Moreover, the device offers power supply current programmability. This feature allows variable bandwidth, slew rate and, to some degree, input bias current. This unique combination of features makes the device useful in a great many applications. What this means to the user is outlined below.

INPUT AND OUTPUT RAIL-TO-RAIL OPERATION

Figure 1 illustrates input and output rail-to-rail operation. The amplifier's common-mode voltage includes both input rails, and its output swings up to both rails. The NE5230 is unique in this regard. Figure 1 demonstrates the usefulness of this feature. The voltage-to-current converter shown in Figure 2 can deliver current down to zero for a zero input voltage. With minor changes, this circuit can also be configured to sink as well as source current by simply using an NPN connected to the negative supply instead of the PNP connected to the positive supply. The output current is a function of the input voltage divided by the value of the load resistor. Selection of the resistor value is limited, on the one hand, by the maximum power capability of the amplifier, which is outlined in the data sheet. While many amplifiers can swing to the negative rail, no other can accomplish this at both output rails under load. Applications range from transducer interfaces to level-shift circuits.

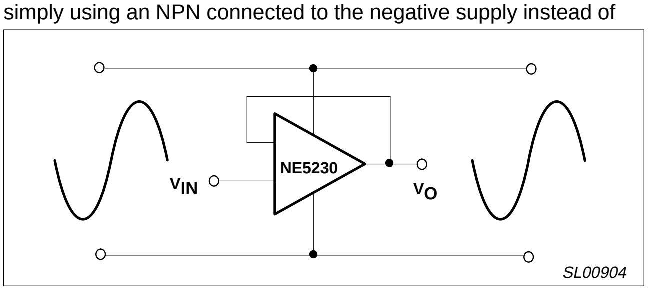

Figure 1. Rail-to-Rail Operation

INSTRUMENTATION AMPLIFIER

Another useful application for rail-to-rail operation is the instrumentation amplifier shown in Figure 3. Along with its other practical features of high common-mode rejection ratio, high input impedance, and low offset drift, this familiar amplifier's capability has now been enhanced. Signal swing beyond both input rails and swing up to both output rails is now possible. With equal value resistors, the gain configuration is a non-inverting gain of three. With the power supply voltage of ±2.00V, with no load at room temperature, the performance was predictable. The photographs in Figure 4 show the input and output of the waveforms of the circuit used. Among its other applications, remote transducers, portable precision instrumentation and any low voltage, low power application are included in this amplifier's repertoire.

LOW VOLTAGE, GATED FUNCTION GENERATOR

Another useful application is as solar-powered, gated function generator. Although it can be powered conventionally, circuit performance is not significantly different with solar cells. This circuit uses a Wien Bridge sine wave oscillator. The Wien Bridge has been used since the vacuum tube era. It is simple, stable, and requires few external components. The circuit utilizes both positive and negative feedback to achieve balanced operation. The oscillator will stop working if too much negative feedback is used and will saturate in both states if too much positive feedback is used. In a practical implementation, some non-linear element must be employed to realize this stable condition. The gain of the amplifier must be large enough at the frequency of oscillation to make the input excursions small enough to be compensatable by this non-linear element. Diodes and FETs have beenused to accomplish this. One of the most popular is the lamp; small, inexpensive and readily available, its voltage variable resistance makes it an ideal candidate for this application. It works like this: as the negative feedback voltage increases across the lamp, its resistance increases, and thereby reduces the output voltage. When the output voltage decreases, the amount of negative feedback voltage across the lamp decreases, thereby decreasing the resistance of the lamp. This balancing act continues until a stable oscillation is achieved. It is important to note that the lamp resistance is changing due to the thermal effects caused by the changing voltage across it. The frequency of oscillation is determined by

$$f_{OSC} = \frac{1}{2 \pi RC}$$

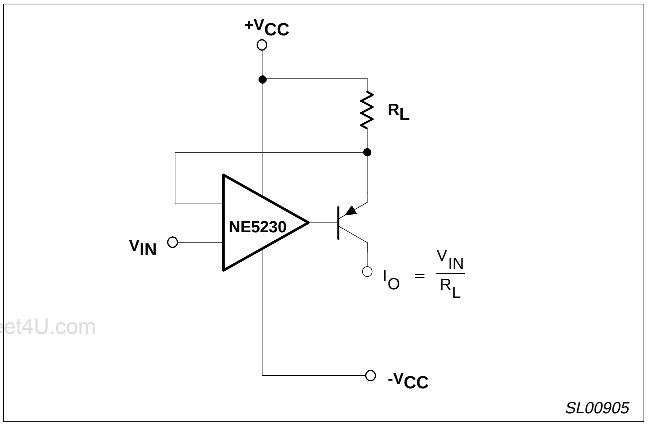

Figure 2. Voltage-to-Current Converter

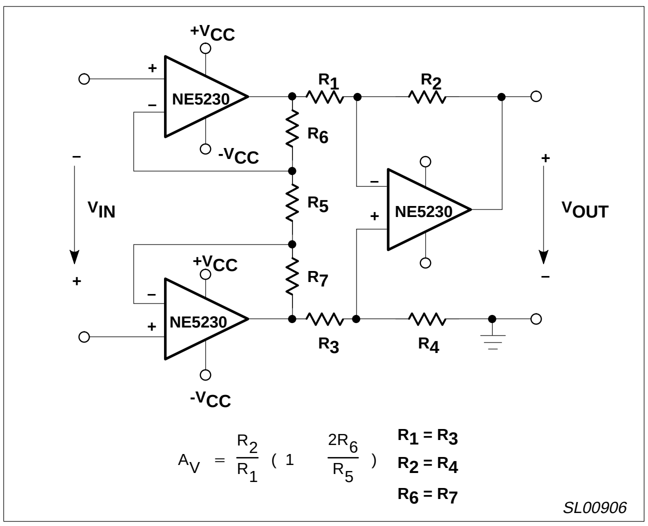

Figure 3. Rail-to-Rail Instrumentation Amplifier

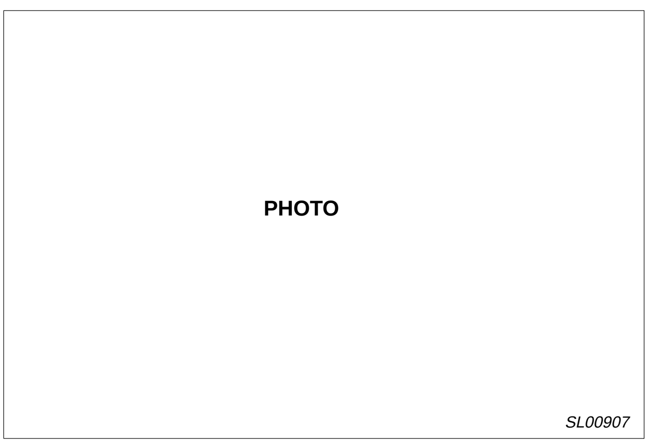

Figure 4. Input and Output Waveforms

Another classic oscillator uses a comparator and an integrator. The output of the comparator is fed back to the input of the integrator. The output of the integrator is connected to the input of the comparator. Upon application of power, the comparator goes into one state or the other. This comparator output voltage is fed back into the input of the integrator which begins ramping up or down, depending on the polarity of the first pulse from the comparator. When the voltage threshold of the comparator is reached, the output changes state. The cycle then repeats.

VCO

If an inversion in the feedback loop can be introduced and external energy applied at the right time, some interesting modifications of the previously described circuit will result – namely, a voltage-controlled oscillator. It works like this: the transistor inverts the output of the comparator. This voltage is presented to the inverting input of the integrator to begin the ramp cycle. When the comparator threshold is reached, the comparator changes state as before. This time, however, because the external applied voltage to the same inverting input is present, the amount of current available to the input is controlled by the external voltage and not by the feedback voltage. Once the component values are selected, the applied voltage, V_C, current available to the integrating capacitor determines the charging time constant and, therefore, the frequency. The more positive sets the frequency of oscillation because the the V_C, the more current is available and the higher the frequency of oscillation. The converse is also true with minor differences. It is interesting to note here that other low voltage op amps are not able to perform as well as the NE5230 in this circuit. This is because the NE5230 input voltage swing is able to exceed the rails by 250mV and still operate within its linear region. For a given set of conditions, then, the frequency range of the NE5230 is wider than conventional low voltage amplifiers. The frequency range of this circuit can also be changed by changing the value of the integrating capacitor. The smaller the value, the higher the frequency of oscillation for a given set of conditions.

The circuit in Figure 5 is the complete function generator. The measurements were taken at room temperature with only two AA batteries supplying the power. The outputs were loaded with 200Ω for the sine and triangular wave outputs and 50Ω for the square wave output. The output voltage for the sine wave was ±1V. The square wave output swung from rail-to-rail while the output voltage of the triangular wave varied with the input voltage, V_C. This was due, of course, to the voltage requirements of the transistor.

PERFORMANCE

The distortion of the Wien Bridge output was 0.015% at the lowest frequency and 0.09% at the highest. Using the different capacitor values, the frequency was varied from minimum to maximum using the ganged 10kΩ pot. The frequencies could be changed from 20Hz to 2.5kHz. It was necessary to include a 500Ω resistor in the positive feedback loop to prevent the complete saturation of the amplifier when the potentiometer was in one extreme of its travel. In addition, a small adjustment resistor was used in the negative feedback loop to adjust the gain and to compensate for the slow response of the lamp.

The maximum frequency obtained by the VCO was 9.7kHz with a V_C of 1.65V with +1.4V batteries. The frequency varied from 8.4kHz to 1.6kHz with ±1V (V_C) applied with 0.001μF integrating capacitor.

CONCLUSIONS: FUNCTION GENERATOR

The thermal time constant of the lamp was an inhibiting factor in the low frequency operation of the Wien Bridge. A diode or a FET will work better here. Extreme ambient temperature will change the operating point of the lamp and, therefore, the output amplitude. Some non-symmetrical output was seen when operating the VCO at the lower frequencies. This was due to influence of the transistor as described previously.

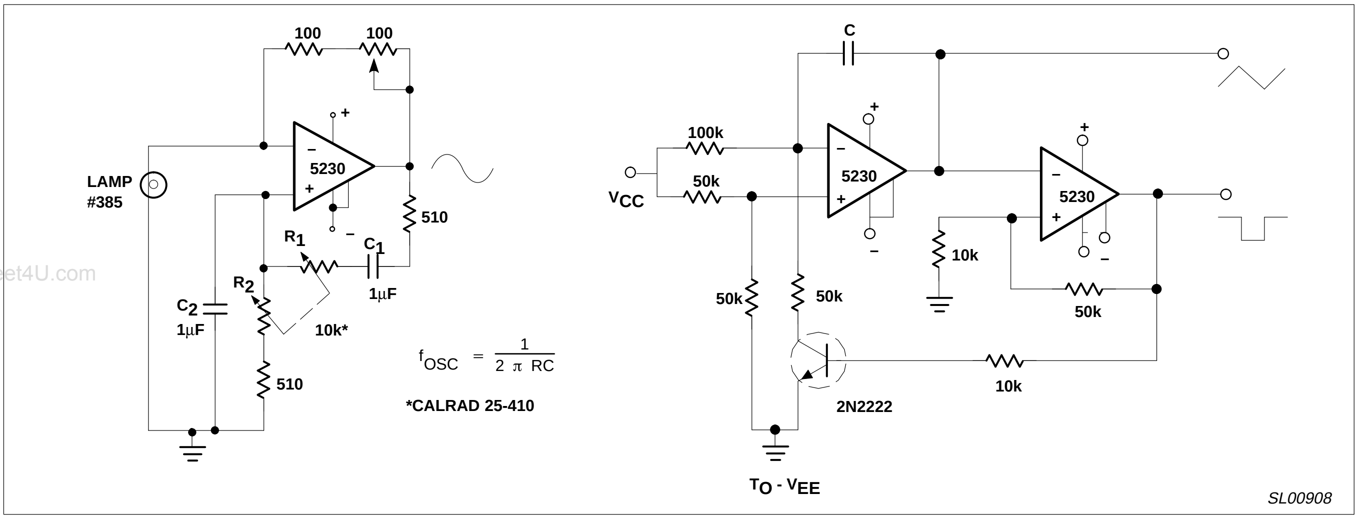

Figure 5. Gated Function Generator

BIAS ADJUST PIN

The NE5230 has another feature: the bias adjust pin. This pin is intended to control the power supply current. The power supply current is controlled by decreasing the internal bias current of the op amp. When the bias current is decreased, the transconductance (g_M) of the input stage is reduced; this, in turn, lowers the -3dB bandwidth. In addition, this pin can be used to turn the op amp on or off. If the voltage at the bias adjust pin is moved to 50mV above the voltage at the V_{EE} pin, the output becomes severely attenuated. The op amp, for all intents and purposes, is off. If, on the other hand, the bias adjust pin is moved to 50mV below the voltage at the V_{EE} pin, the bandwidth and slew rate are increased. The user should exercise care when doing this.

Utilized as a frequency-controlling element, this pin can be employed as a filter for upper band suppression. By carefully selecting the value, a single resistor connected to the $+V_{CC}$ pin can be used to determine the upper cutoff frequency of this filter. Values below 1.0MΩ should not be used because the total power approximately 100kΩ. This is an unconventional way to use this pin and this method of using the pin is not characterized. The user is cautioned to use care when employing the pin as outlined. The portion of supply current is too low for useful operation. The drive capability of the output is limited to the band which lends itself to this use is approximately the top half of the audio range. Below and beyond that range some problems become apparent. For the lower frequencies, the amplifier is operating far below its designed operating values and is not optimum in its performance. See Figure 6. For example, the drive capability of the amplifier is severely limited. The common-mode rejection ratio, power supply rejection ratio, as well as the input parameters go out of the data sheet-specified values at the higher frequencies; the slope of the suppression is less than desirable. At the frequencies in question, however, the method is unsurpassed in simplicity and ease of use.

AUDIO EQUALIZER

A useful application which takes advantage of the bias adjust pin is an audio equalizer circuit in Figure 7. An audio equalizer is a circuit which divides the audio frequency spectrum into equal parts. Adjustments of the frequency response of each band are possible. The equalizer circuit replaces a tone control in conventional audio equipment. Used in conjunction with a series capacitor filter, the NE5230 can be configured as a band pass filter. With one amplifier for each band, significant cost savings can be realized. The RC network in front of the circuit is used to remove the out-of-band response beyond the audio spectrum.

LOW FREQUENCY

These circuits are unity gain Sallen-Key filters. For the lower frequency band, the NE5230 can be configured to attenuate all but the lowest frequencies. Because the input parameters are compromised to the point where system performance is severely affected, the aforementioned unconventional method of upper band suppression is not used for the lowest frequency range of the equalizer. Instead, the upper end of this frequency band is attenuated using a second-order unity gain low-pass filter. The lower end is DC. The upper end cutoff was chosen to be about 1000Hz.

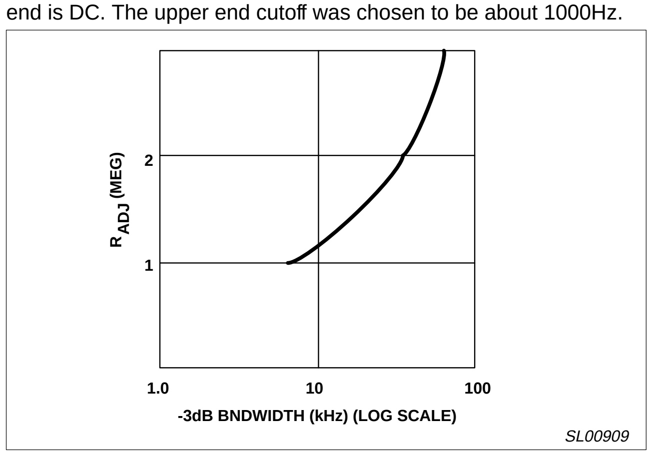

Figure 6. R_{ADJ} vs Bandwidth

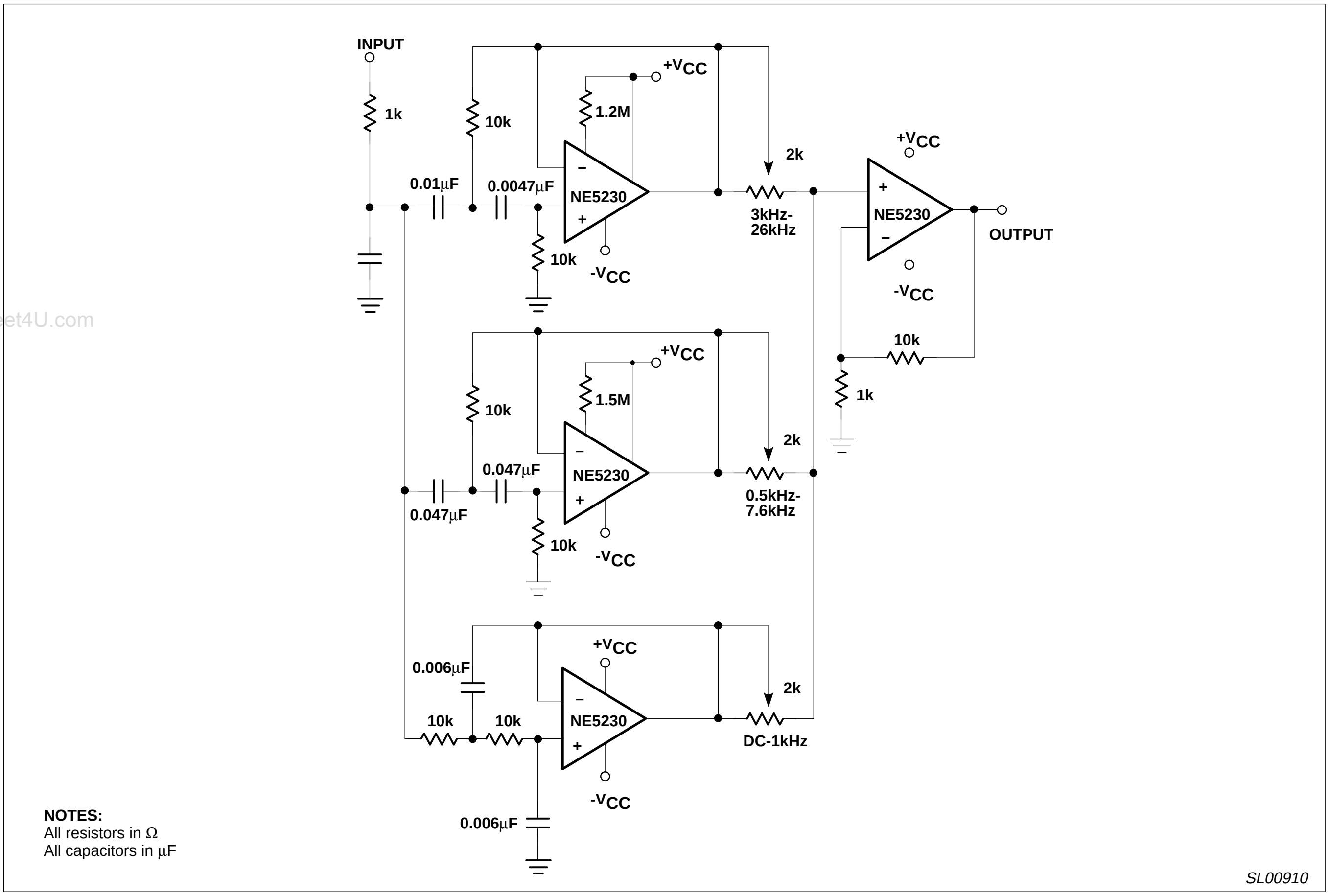

Figure 7. Audio Equalizer

MIDBAND FREQUENCY

The midband frequencies can be selected as described earlier. The upper frequency of this band can be determined by connecting a resistor from Pin 5 to Pin 4. The value of this resistor can be determined by using the graph shown as Figure 6. The lower end of this frequency is selected by using a second-order high-pass filter with the upper band suppression done by using the bias adjust pin. The lower end frequency was chosen to be about 500Hz and the upper band was selected to be about 7.6kHz.

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UPPER BAND FREQUENCY

The upper band lower frequencies were tailored using the same filters. The upper band upper frequencies can be tailored by using the bias adjust pin in the unconventional manner described earlier. The lower end cutoff frequency was chosen to be about 3kHz and the upper end band was selected to be about 26kHz.

PERFORMANCE

Clearly one other band could have been used to bolster the response between the lowest and midband frequencies. See Figure 8. The outputs of each of the circuits were fed into a summing amplifier. The photograph shows the composite bandwidth of the three circuits. The potentiometers are intended to serve as an interfacing adjustment element and not as a gain adjustment. However, some interaction was seen when adjusting these potentiometers. Adjustment of one changes the relative attenuation of the other bands. Because of this, it may be desirable to include a buffer with gain for each band. Certainly more than three bands can be designed using this technique. In this case, cascading would be required to increase the slope of each band to provide better separation.

BRIDGE-TIED LOAD

One of the concerns found when using low voltage op amps is deliverable power to the load. Although the NE5230 has excellent drive capability, the Bridge-Tied Load (BTL) configuration can be used to increase the output power of the NE5230. Figure 9 shows the outputs arranged in a push-pull configuration; output power can thereby be doubled. This circuit finds applications in the audio field where low distortion power is critical. A 0.1% THD was measured with a 1kΩ load at 10kHz at room temperature. The single NE5230 amplifier is specified to drive a 10kΩ load. While a lighter load will improve the distortion figures, the intention here is to demonstrate the concept.

CONCLUSIONS

The NE5230 is a versatile precision, low voltage op amp. Its rail-to-rail capabilities coupled with its low voltage operating range and power supply current programmability make this op amp stand out among the competition. While other op amps have individual features which, on paper, seem to be better, the NE5230 shines on its combined merits. Its unique combination of features makes it the new leader in low voltage op amps.

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Figure 8. Equalizer Bandwidth

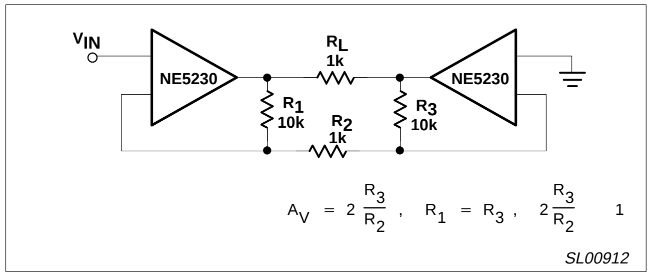

Figure 9. Bridge-Tied Load