LF13006/LF13007 Precision Digital Gain Set Applications

Some basic circuit configurations for using the LF13006 and LF13007 are shown in *Figures 1 through 4*. In each case only the Digital Gain Set and an op-amp are required, although in some instances the amplifier may need external compensation in order to maintain stability over wide ranges of closed loop gain. As shown, inverting and noninverting configurations are possible with several variations. Nearly unlimited values of gain can be realized using different combinations of outputs and/or the additional resistors at R1, Rc, and R2 to modify an amplifier's input or feedback.
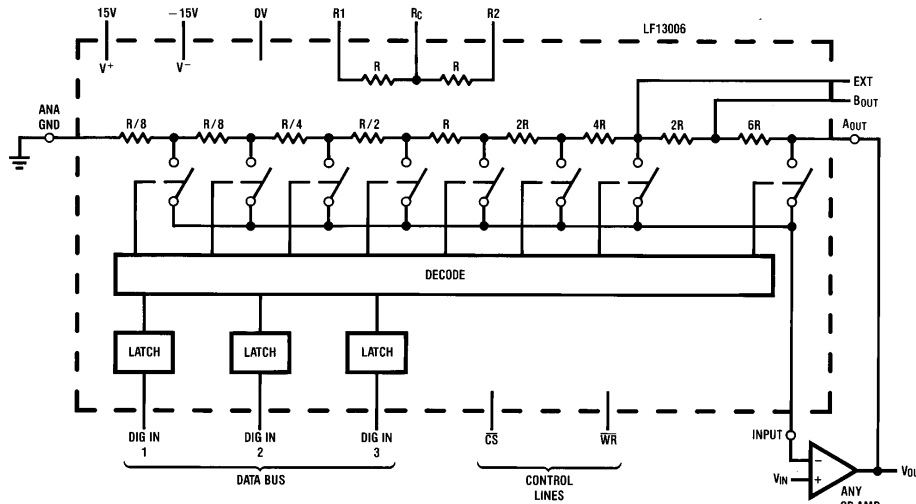
Note: 1R = 15 kΩ

FIGURE 1A. LF13006, GAIN = 1 to 128 in Binary Sequence

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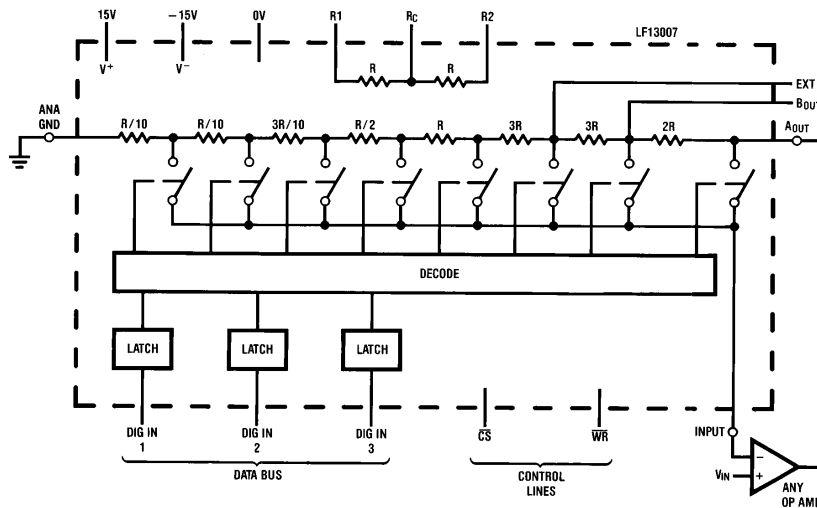
Note: 1R = 15 kΩ

FIGURE 1B. LF13007, GAIN = 1 to 100 in "1, 2, 5" Sequence

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Of significant interest are circuits such as in *Figure 3*, which allow gain switching at values near one. These configurations can be useful where in-circuit trimming may be needed for small, narrow range adjustments. Also, by cascading two circuits, high resolution as well as wide gain range can be realized. For example, by using *Figure 4* in conjunction with *1A*, the programmed gains of 1.2 and 1.7 can be used to "fill in" between the binary steps supplied by *1A*. In audio applications, this particular arrangement would provide steps of 3 dB or less over a 46 dB range and slightly larger steps to 57 dB.
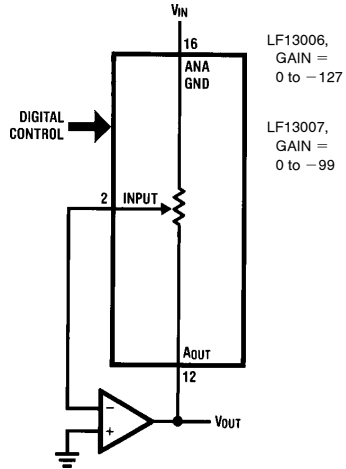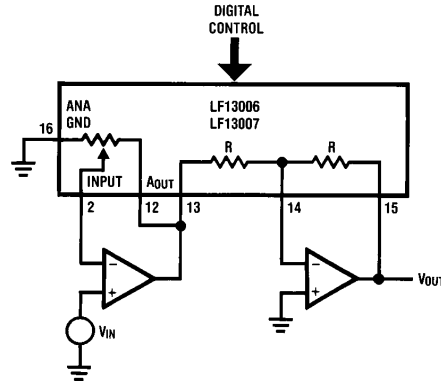

FIGURE 2. Inverting Mode

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FIGURE 2A. High Input Impedance Inverting Mode

GAIN (LF13006)	GAIN (LF13007)
9	11
1.8	3.67
1.29	1.83
1.125	1.2
1.059	1.1
1.029	1.048
1.014	1.02
1.007	1.01
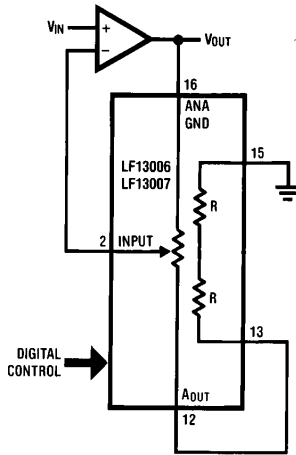
TL/H/5513–5

FIGURE 3. Variable Gains of Almost 1

GAIN (13007)
1.0
1.2
1.7
3.0
4.0
4.8
5.45
5.7
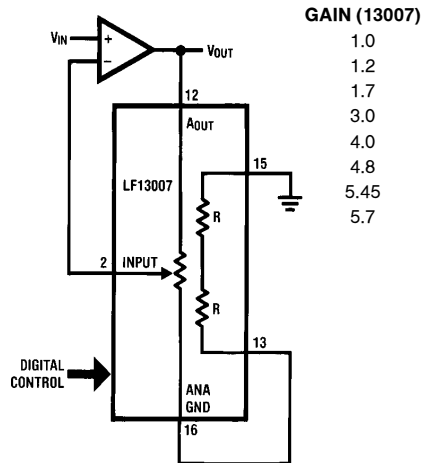
TL/H/5513–6

FIGURE 4. Altered Gain Range

Applications for these devices also include a wide variety of circuits besides those which simply switch op-amp gain. A simple digital "handle" on one or more other circuit parameters can do a great deal to enhance the capabilities of many analog designs. In circuits such as filters, precision references, current sources, and countless others, the addition of programming capability can be invaluable.

One good example of such versatility is shown in a digitally adjustable low pass filter in *Figure 5*. Applications for this function include variable bandwidth front-ends for data acquisition and "smart" filters for DC signals which combine fast settling with high noise rejection. This can be done by increasing bandwidth in the presence of a large input-to-output differential at the filter, and then cutting back as the output gets close to its final level. The corner frequency is easily set via the 3-bit code input to an LF13006 or 7. When using the LF13006, time constants from RxC1 to 128RxC1 can be programmed in binarily weighted steps. The same function performed with a conventional CMOS DAC would need more bits to cover the same range and would still not be able to maintain the precision of setting at its limits of operation.
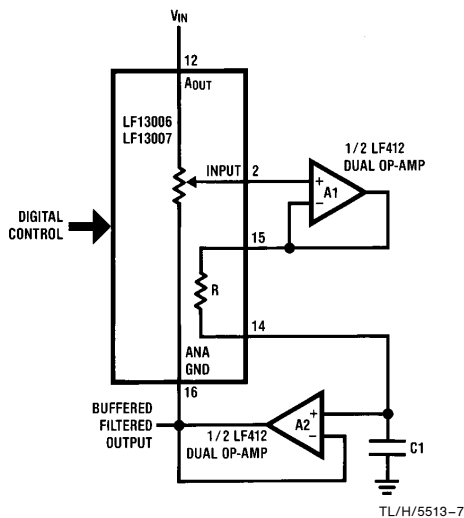
Circuit operation of the variable low pass is very straightforward. The LF13006 Network along with an LF412 dual op-amp form a resistance "multiplier" in which a settable fraction of the input voltage is used to determine the charge or discharge current though R into C1. One half of the dual amplifier (A1) is used to buffer the LF13006's "output" (Input, pin 2) and provide charging current for C1, while the second op-amp (A2) allows the resistor ladder to float on C1. In addition, the ratio of the selected time-constants will be very precise since these will be proportional to the LF13006's gain accuracy.

To a similar end, a classical capacitance multiplier can be made programmable with the circuit of *Figure 6*. The Digital Gain Set controls what is in effect a high input-impedance inverting amplifier which is used to drive the lower side of C1. The value of the "virtual" capacitor seen at the circuit's input will be C1 multiplied by the programmed gain. A drawback of this scheme is that the signal swing at A1's output can be large and may cause amplifier saturation. Thus for high capacitance multiplication factors, the input swing must be kept small in order to prevent clipping.

Time Constant $t = NRC_1$

N = Set gain in basic configuration (N = GAIN of Fig 1)

$C_{effective} = C_1N$

N = GAIN of Fig 1

Note: Output swing at input op amp is multiplied by set gain. Signal range may be limited.

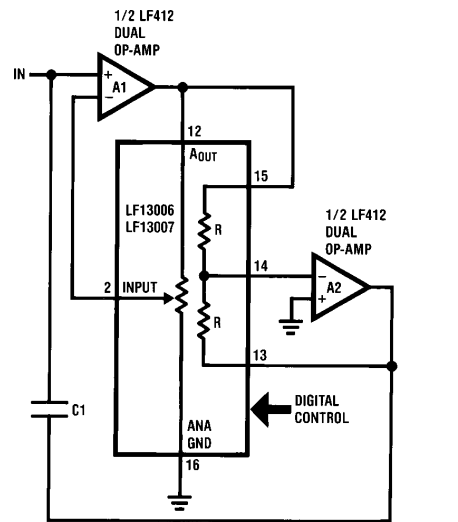FIGURE 5. Variable Time Constant Filter

TL/H/5513–7

TL/H/5513–8

FIGURE 6. Variable Capacitance Multiplier

In *Figure 7*, an LF13006 is used to switch a single amplifier's gain but not quite in the conventional sense in this case. The LF411 op-amp can be flipped from a follower to an inverter using no additional parts and only the "Dig. In 1" input (pin 8) of the gain network. This "two part" approach can be used in precision rectifier and synchronous modulator/demodulator circuits as well as for polarity inverters in front of A to D converters.

The two extra matched resistors that are provided at R1, R2, and Rc (pins 13, 14, 15) are used to set the inverter gain while two of the internal switches are configured to switch the op-amp's noninverting input. The 8R resistor (approximately 120K) which exists from the circuit input to ground is not actually needed but is an unavoidable result of this particular switch connection.

In another example, a precision current source can be given direct digital control by using the simple scheme shown in *Figure 8*. Here, the current source's reference is "floated" on the load terminal (I_{OUT}) by using one half of a Bi-Fet dual op-amp (LF412, A1) as a buffer for the output. This provides a current return path for the gain set's resistor ladder and the circuit's reference (LM385-1.2) which doesn't interfere with the main output. The other half of the Bi-Fet dual (A2) is used to supply the output current via the sense resistor, R1. The current source's output is varied by changing the fraction of the reference voltage which will be forced to appear across R1. With this scheme, the output current is governed by the equation; $I_{OUT} = V_{REF}/(R1 \times \text{Set Gain})$.

Applications for the above circuit include bias sources for programmable amplifiers, linear ramp generators, and variable current limiters. For greater output currents, R1 can be reduced and an external pass transistor can be added to A2's output.

A common need in data acquisition systems is for a differential input amplifier, or instrumentation amplifier, with easily adjustable precision gains. Normally this can't be done without using several precision resistors and switches or employing expensive modular products that have this capability already built in. In *Figure 9*, a differential gain can be varied by using one Digital Gain Set in one version of a three op-amp instrumentation amp circuit. The amplifier's front end uses an LF412A precision dual op-amp as a follower (A1) and also as a variable gain inverter (A2), both which drive the inputs of a fixed gain difference amp (LF411). The instrumentation amp's common-mode performance will directly depend on the four external resistors. For designs where common-mode rejection is critical, close matching of resistor pairs R1, R2 and R3, R4 are required, i.e. 60 dB DC CMRR requires 0.1% matching. However, reasonable rejection can still be achieved (54 dB typ) if only two external resistors are used and the gain set's uncommitted resistors serve as R1 and R2.
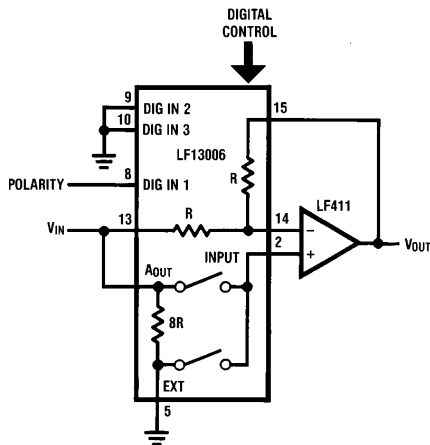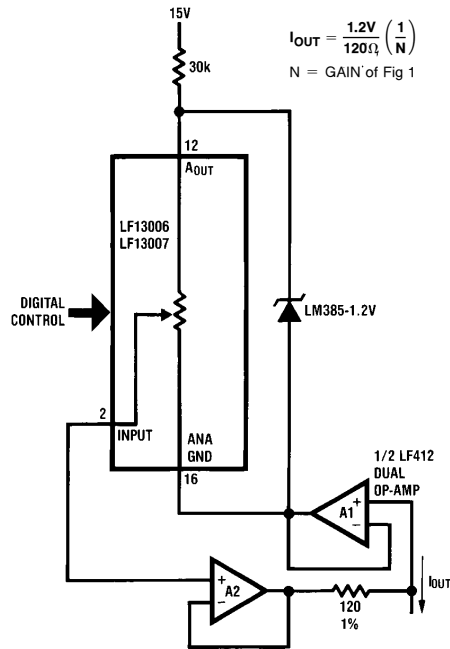

TL/H/5513–9

FIGURE 7. Switchable Gain of ±1

$$I_{OUT} = \frac{1.2V}{120\,\Omega}\left(\frac{1}{N}\right)$$

N = GAIN of Fig 1

TL/H/5513–10

FIGURE 8. Programmable Current Source

In *Figure 10*, the programmable function generator shown will shift its operating frequency one octave for each LSB change in the program code. Triangle square-wave and sinewave outputs are available over an eight octave range. If an LF13007 were to be used rather than the 13006, the 1, 2, 5 sequence would provide ideal scaling for horizontal sweep or other scanning circuits.

This particular function generator employs ¾ of a quad op-amp as an integrator, comparator, and buffer. The integrator (A1) is driven from a controllable source which is simply the Digital Gain Set used as a passive voltage divider, and buffered by A2. The triangle output from A1 is used to drive a sine shaping circuit consisting of the last quarter of the LF347 (A4) and two dual transistors. Sine distortion can be reduced to 0.5% by trimming the symmetry and waveshape adjustments provided. The circuits' frequency range as shown is from 10 to 1280 Hz.
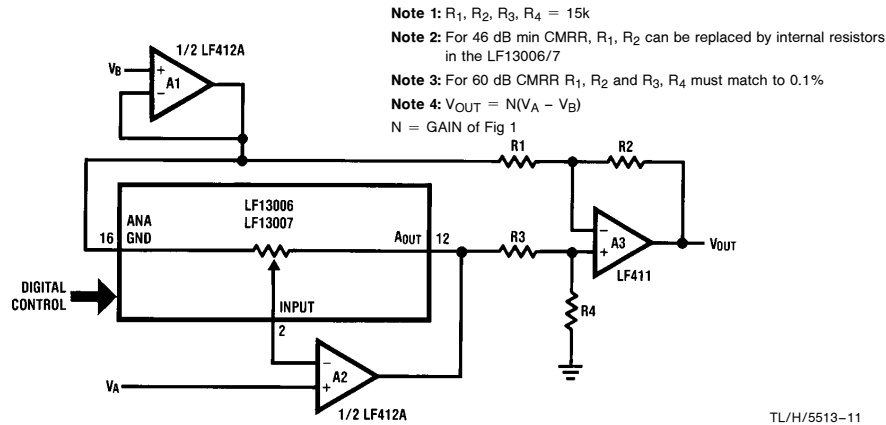
Note 1: R_1, R_2, R_3, R_4 = 15k

Note 2: For 46 dB min CMRR, R_1, R_2 can be replaced by internal resistors in the LF13006/7

Note 3: For 60 dB CMRR R_1, R_2 and R_3, R_4 must match to 0.1%

Note 4: $V_{OUT} = N(V_A - V_B)$

N = GAIN of Fig 1

FIGURE 9. Programmable Instrumentation Amp

TL/H/5513–11

Note 1: A_{1-4} LF347

Note 2: Adjust waveshape and symmetry trims for lowest output distortion on sinewave
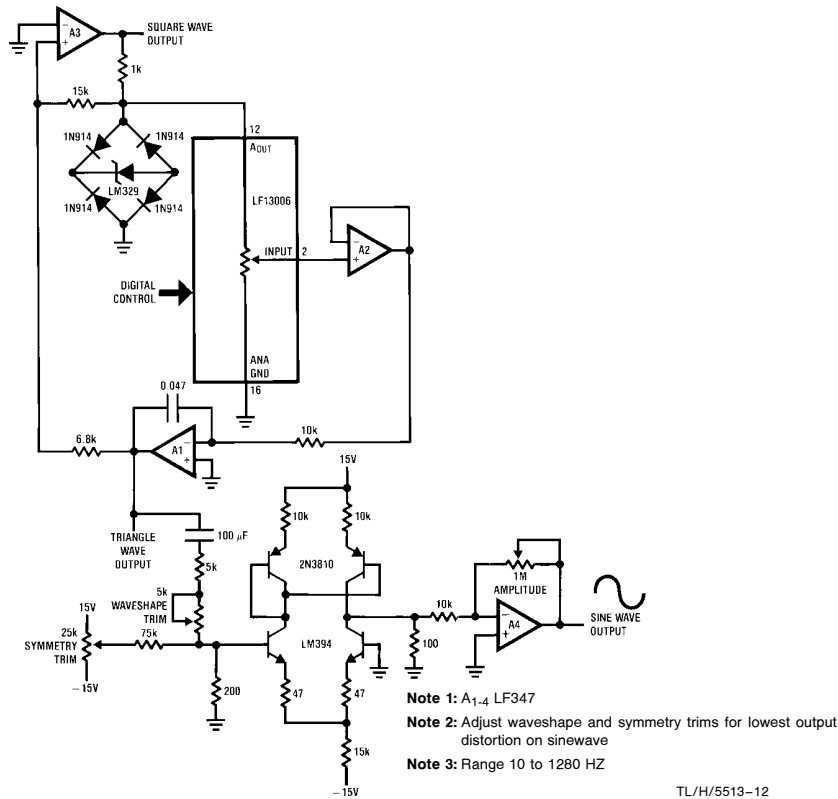
Note 3: Range 10 to 1280 HZ

TL/H/5513–12

FIGURE 10. One Octave per Bit Function Generator

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