

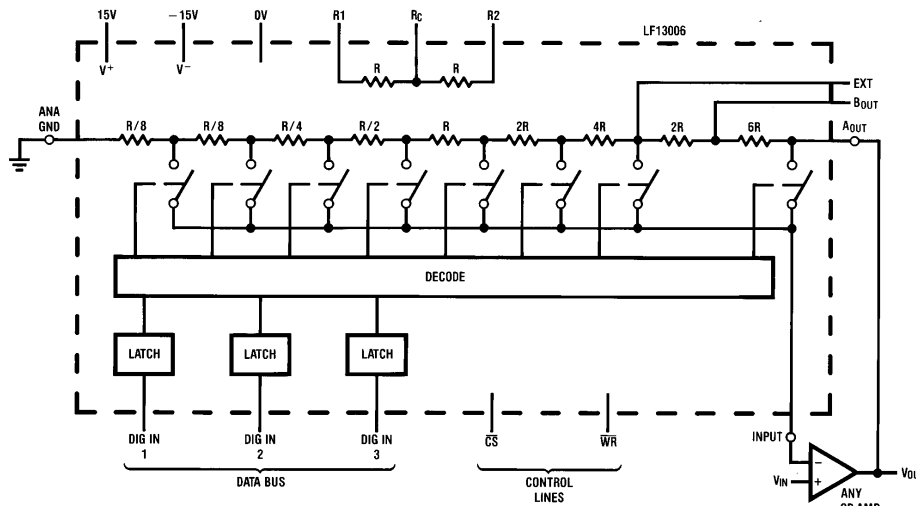
# LF13006/LF13007 Precision Digital Gain Set Applications

National Semiconductor  
Application Note 344  
March 1984



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

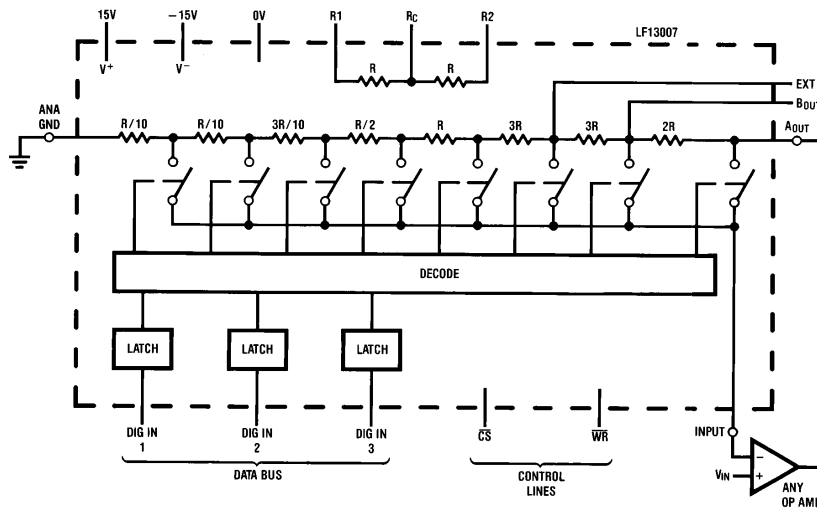
of closed loop gain. As shown, inverting and noninverting configurations are possible with several variations. Nearly unlimited values of gain can be realized using different combinations of outputs and/or the additional resistors at R1, R<sub>c</sub>, and R2 to modify an amplifier's input or feedback.



Note:  $1R = 15\text{ k}\Omega$

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

TL/H/5513-1



Note:  $1R = 15\text{ k}\Omega$

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

TL/H/5513-2

LF13006/LF13007 Precision Digital Gain Set Applications

AN-344

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.

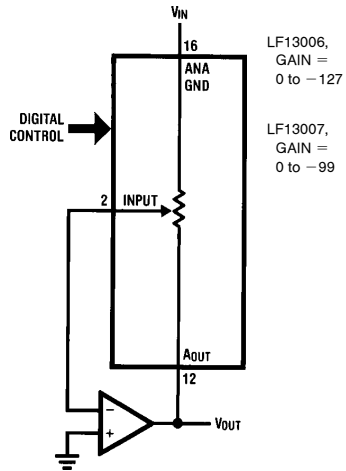


FIGURE 2. Inverting Mode

TL/H/5513-3

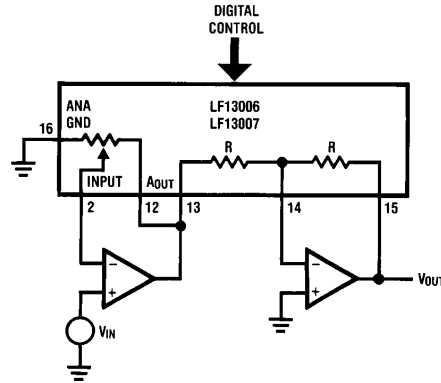


FIGURE 2A. High Input Impedance Inverting Mode

TL/H/5513-4

**GAIN (LF13006)**

- 9
- 1.8
- 1.29
- 1.125
- 1.059
- 1.029
- 1.014
- 1.007

**GAIN (LF13007)**

- 11
- 3.67
- 1.83
- 1.2
- 1.1
- 1.048
- 1.02
- 1.01

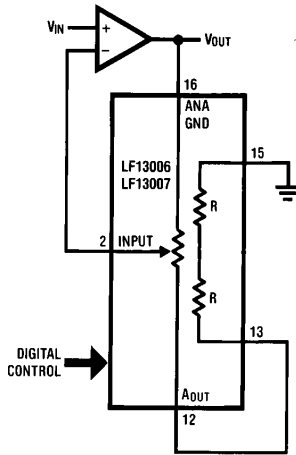


FIGURE 3. Variable Gains of Almost 1

TL/H/5513-5

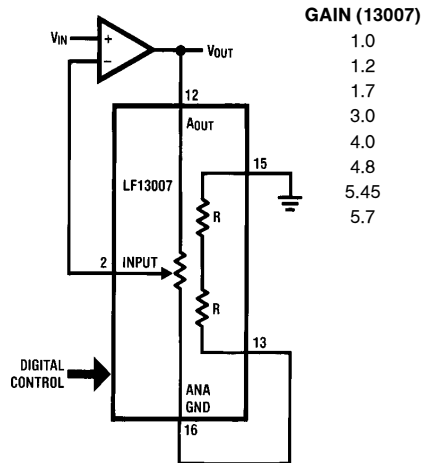


FIGURE 4. Altered Gain Range

TL/H/5513-6

**GAIN (13007)**

- 1.0
- 1.2
- 1.7
- 3.0
- 4.0
- 4.8
- 5.45
- 5.7

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  $R \times C_1$  to  $128R \times C_1$  can be programmed in binary 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.

Time Constant  $t = NRC_1$

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

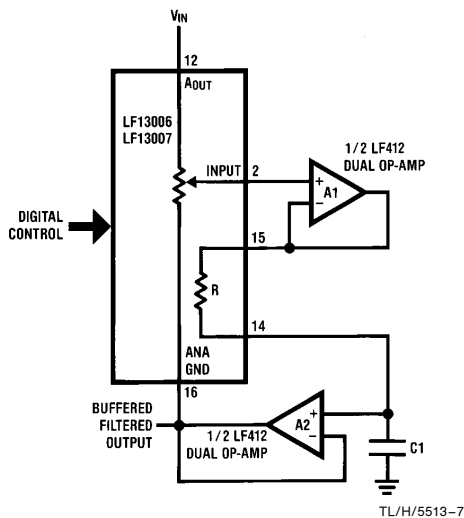


FIGURE 5. Variable Time Constant Filter

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 through 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.

$C_{\text{effective}} = C_1 N$

$N =$  GAIN of Fig 1

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

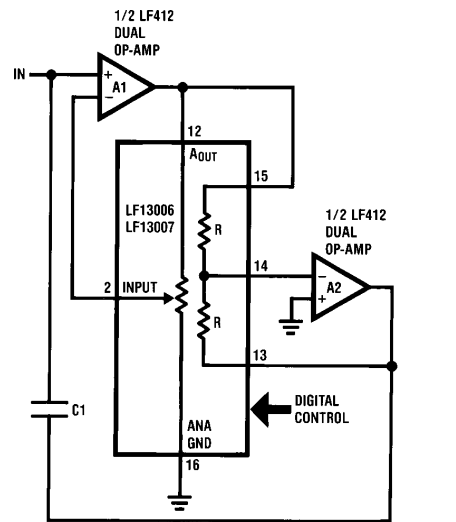


FIGURE 6. Variable Capacitance Multiplier

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<sub>OUT</sub>) 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.

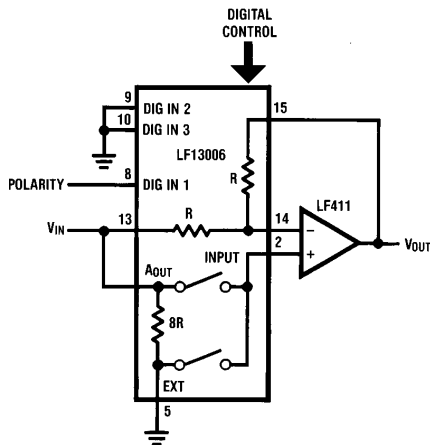


FIGURE 7. Switchable Gain of ±1

TL/H/5513-9

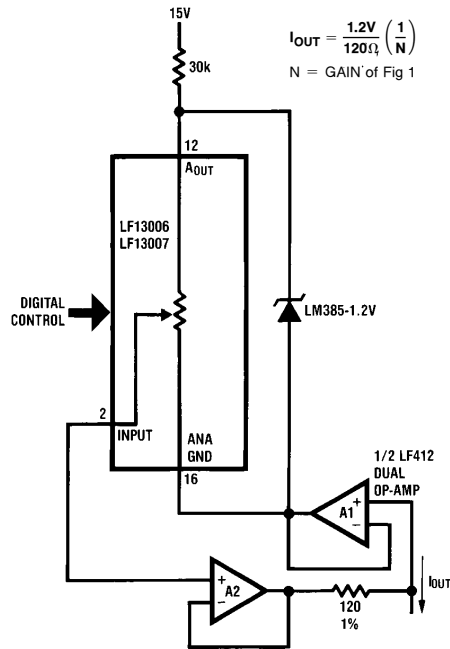


FIGURE 8. Programmable Current Source

TL/H/5513-10

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 3/4 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.

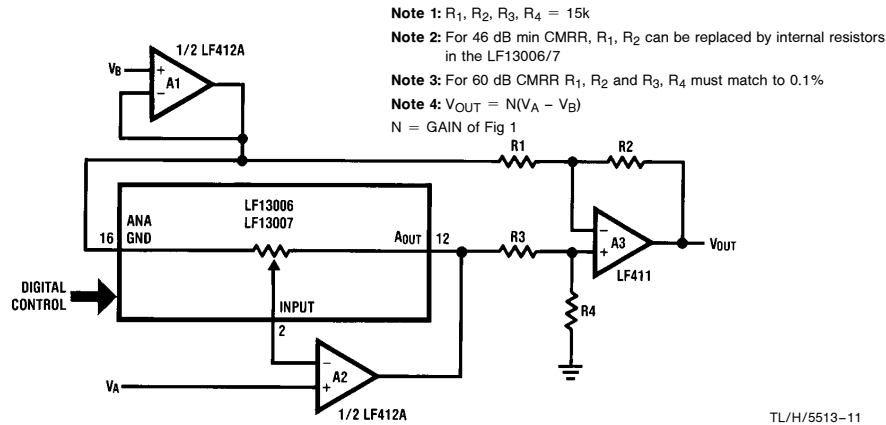


FIGURE 9. Programmable Instrumentation Amp

TL/H/5513-11

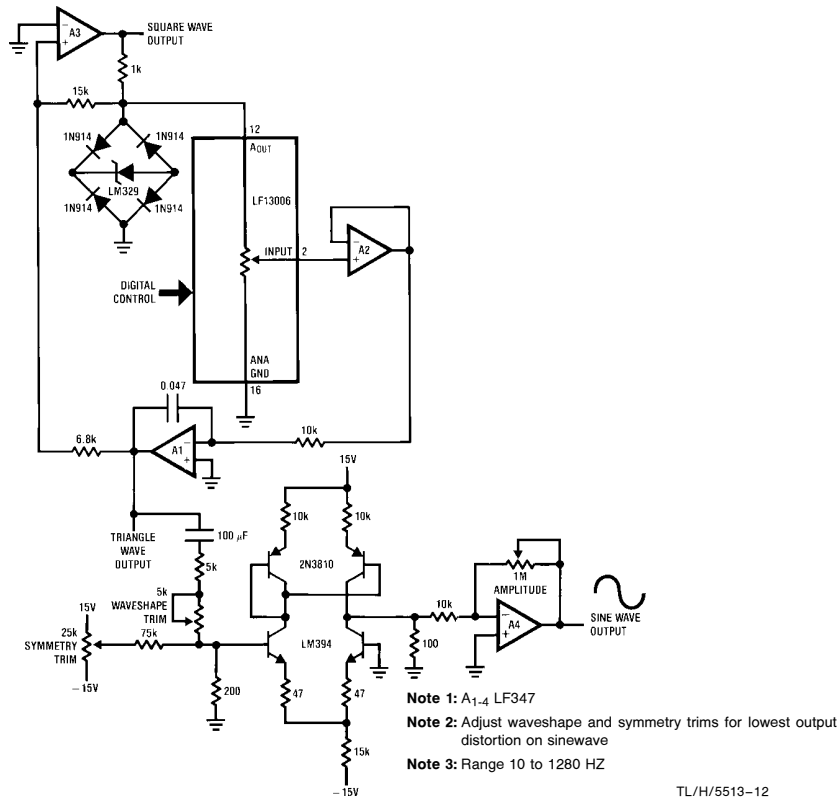


FIGURE 10. One Octave per Bit Function Generator

TL/H/5513-12

**LIFE SUPPORT POLICY**

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



**National Semiconductor Corporation**  
 1111 West Bardin Road  
 Arlington, TX 76017  
 Tel: 1(800) 272-9959  
 Fax: 1(800) 737-7018

**National Semiconductor Europe**  
 Fax: (+49) 0-180-530 85 86  
 Email: onjwge@tevm2.nsc.com  
 Deutsch Tel: (+49) 0-180-530 85 85  
 English Tel: (+49) 0-180-532 78 32  
 Français Tel: (+49) 0-180-532 93 58  
 Italiano Tel: (+49) 0-180-534 16 80

**National Semiconductor Hong Kong Ltd.**  
 19th Floor, Straight Block,  
 Ocean Centre, 5 Canton Rd.  
 Tsimshatsui, Kowloon  
 Hong Kong  
 Tel: (852) 2737-1600  
 Fax: (852) 2736-9960

**National Semiconductor Japan Ltd.**  
 Tel: 81-043-299-2309  
 Fax: 81-043-299-2408

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and National reserves the right at any time without notice to change said circuitry and specifications.