An IC Amplifier User's Guide to Decoupling, Grounding, and Making Things Go Right for a Change
By Paul Brokaw

"There once as a breathy baboon
Who always breathed down a bassoon,
For he said "It appears
that in billions of years
I shall certainly hit on a tune"
(Sir Arthur Eddington)

This quotation seemed a proper note with which to begin on a subject that has made monkeys of most of us at one time or another. The struggle to find a suitable configuration for system power, ground, and signal returns too frequently degenerates into a frustrating glitch hunt. While a strictly experimental approach can be used to solve simple problems, a little forethought can often prevent serious problems and provide a plan of attack if some judicious tinkering is later required.

The subject is so fragmented that a completely general treatment is too difficult for me to tackle. Therefore, I'd like to state one general principle and then look a bit more narrowly at the subject of decoupling and grounding as it relates to integrated circuit amplifiers.

. . . Principle: Think—where the currents will flow.

I suppose this seems pretty obvious, but all of us tend to think of the currents we're interested in as flowing "out" of some place and "through" some other place but often neglect to worry how the current will find its way back to its source. One tends to act as if all "ground" or "supply voltage" points are equivalent and neglect (for as long as possible) the fact that they are parts of a network of conductors through which currents flow and develop finite voltages.

In order to do some advance planning it is important to consider where the currents originate and to where they will return and to determine the effects of the resulting voltage drops. This, in turn, requires some minimum amount of understanding of what goes on inside the circuits being decoupled and grounded. This information may be lacking or difficult to interpret when integrated circuits are part of the design.

Operational amplifiers are one of the most widely used linear ICs, and fortunately most of them fall into a few classes, so far as the problems of power and grounding are concerned. Although the configuration of a system may pose formidable problems of decoupling and signal returns, some basic methods to handle many of these problems can be developed from a look at op amps.

OP AMPS HAVE FOUR TERMINALS
A casual look through almost any operational amplifier text might leave the reader with the impression that an ideal op amp has three terminals: a pair of differential inputs and an output as shown in Figure 1. A quick review of fundamentals, however, shows that this cannot be the case. If the amplifier has an output voltage it must be measured with respect to some point . . . a point to which the amplifier has a reference. Since the ideal op amp has infinite common-mode rejection, the inputs are ruled out as that reference so that there must be a fourth amplifier terminal. Another way of looking at it is that if the amplifier is to supply output current to a load, that current must get into the amplifier somewhere. Ideally, no input current flows, so again the conclusion is that a fourth terminal is required.
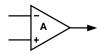

Figure 1. Conventional "Three Terminal" Op Amp

A common practice is to say, or indicate in a diagram, that this fourth terminal is "ground." Well, without getting into a discussion of what "ground" may be, we can observe that most integrated circuit op amps (and a lot of the modular ones as well) do not have a "ground" terminal. With these circuits the fourth terminal is one or both of the power supply terminals. There is a temptation here to lump together both supply voltages with the ubiquitous ground. And, to the extent that the supply lines really do present a low impedance at all frequencies within the amplifier bandwidth, this is probably reasonable. When the impedance requirement is not satisfied, however, the door is left open to a variety of problems including noise, poor transient response, and oscillation.

DIFFERENTIAL-TO-SINGLE-ENDED CONVERSION

One fundamental requirement of a simple op amp is that an applied signal that is fully differential at the input must be converted to a single-ended output. Single-ended, that is, with respect to the often neglected fourth terminal. To see how this can lead to difficulties, take a look at Figure 2.
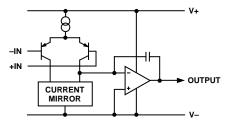

Figure 2. Simplified "Real" Op Amp

The signal flow illustrated by Figure 2 is used in several popular integrated circuit families. Details vary, but the basic signal path is the same as the 101, 741, 748, 777, 4136, 503, 515, and other integrated circuit amplifiers. The circuit first transforms a differential input voltage into a differential current. This input stage function is represented by PNP transistors in Figure 2. The current is then converted from differential to single-ended form by a current mirror that is connected to the negative supply rail. The output from the current mirror drives a voltage amplifier and power output stage that is connected as an integrator. The integrator controls the open-loop frequency response, and its capacitor may be added externally, as in the 101, or may be self-contained, as in the 741. Most descriptions of this simplified model do not emphasize that the integrator has, of course, a differential input. It is biased positive by a couple of base emitter voltages, but the noninverting integrator input is referred to the negative supply.

It should be apparent that most of the voltage difference between the amplifier output and the negative supply appears across the compensation capacitor. If the negative supply voltage is changed abruptly, the integrator amplifier will *force* the output to follow the change. When the entire amplifier is in a closed-loop configuration the resulting error signal at its input will tend to restore the output, but the recovery will be limited by the slew rate of the amplifier. As a result, an amplifier of this type may have outstanding low frequency power supply rejection, but the negative supply rejection is fundamentally limited at high frequencies. Since it is the feedback signal to the input that causes the output to be restored, the negative supply rejection will approach zero for signals at frequencies above the closed-loop bandwidth. This means that high-speed, high-level circuits can "talk to" low-level circuits through the common impedance of the negative supply line.

Note that the problem with these amplifiers is associated with the negative supply terminal. Positive supply rejection may also deteriorate with increasing frequency, but the effect is less severe. Typically, small transients on the positive supply have only a minor effect on the signal output. The difference between these sensitivities can result in an apparent asymmetry in the amplifier transient response. If the amplifier is driven to produce a positive voltage swing across its rated load, it will draw a current pulse from the positive supply. The pulse may result in a supply voltage transient, but the positive supply rejection will minimize the effect on the amplifier output signal. In the opposite case, a negative output signal will extract a current from the negative supply. If this pulse results in a "glitch" on the bus, the poor negative supply rejection will result in a similar "glitch" at the amplifier output. While a positive pulse test may give the amplifier transient response, a negative pulse test may actually give you a pretty good look at your negative supply line transient response, instead of the amplifier response!

Remember that the impulse response of the power supply itself is not what is likely to appear at the amplifier. Thirty or forty centimeters of wire can act like a high Q inductor to add a high-frequency component to the normally overdamped supply response. A decoupling capacitor near the amplifier won't always cure the problem either, since the supply must be decoupled to somewhere. If the decoupled current flows through a long path, it can still produce an undesirable glitch.

Figure 3 illustrates three possible configurations for negative supply decoupling. In 3a, the dotted line shows the negative signal current path through the decoupling and along the ground line. If the load "ground" and decoupled "ground" actually join at the power supply, the "glitch" on the ground lines is similar to the "glitch" on the negative supply bus. Depending upon how the feedback and signal sources are "grounded," the effective disturbance caused by the decoupling capacitor may be larger than the disturbance it was intended to prevent. Figure 3b shows how the decoupling capacitor can be used to minimize disturbance of V– and ground buses. The high-frequency component of the load current is confined to a loop that does not include any part of the ground path. If the capacitor is of sufficient size and quality, it will minimize the glitch on the negative supply without disturbing input or output signal paths. When the load situation is more complex, as in 3c, a little more thought is required. If the amplifier is driving a load that goes to a virtual ground, the actual load current does not return to ground. Rather, it must be supplied by the amplifier creating the virtual ground as shown in the figure. In this case, decoupling the negative supply of the first amplifier to the positive supply of the second amplifier closes the fast signal current loop without disturbing ground or signal paths. Of course, it is still important to provide a low impedance path from "ground" to V– for the second amplifier to avoid disturbing the input reference.

The key to understanding decoupling circuits is to note where the actual load and signal currents will flow. The key to optimizing the circuit is to bypass these currents

around ground and other signal paths. Note, that as in Figure 3a, "single point grounding" may be an oversimplified solution to a complex problem.
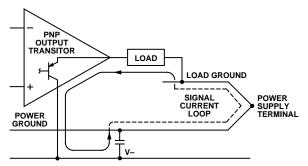

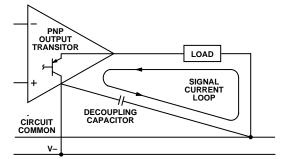*Figure 3a. Decoupling for Negative Supply Ineffective*

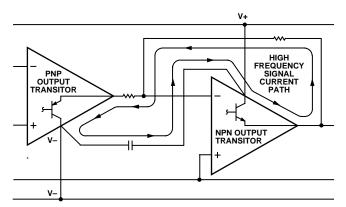*Figure 3b. Decoupling Negative Supply Optimized for "Grounded" Load*

Figure 3c. Decoupling Negative Supply Optimized for Virtual Ground" Load

Figures 3b and 3c have been simplified for illustrative purposes. When an entire circuit is considered, conflicts frequently arise. For example, several amplifiers may be powered from the same supply, and an individual decoupling capacitor is required for each. In a gross sense the decoupling capacitors are all paralleled. In fact, however, the inductance of the interconnecting power and ground lines convert this harmless-looking arrangement into a complex L-C network that often rings like the "Avon Lady." In circuits handling fast signal wavefronts, decoupling networks paralleled by more than a few centimeters of wire generally mean trouble. Figure 4 shows how small resistors can be added to lower the Q of the undesired resonant circuits. The resistors can generally be tolerated since they convert a bad high-frequency

jingle to a small damped signal at the op amp supply terminal. The residual has larger *low*-frequency components, but these can be handled by the op amp supply rejection.
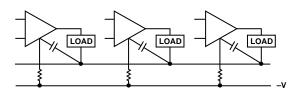

Figure 4. Damping Parallel Decoupling Resonances

FREQUENCY STABILITY

There is a temptation to forget about decoupling the negative supply when the system is intended to handle only low-frequency signals. Granted that decoupling may not be required to handle low-frequency signals, it may still be required for frequency stability of the op amps.

Figure 5 is a more detailed version of Figure 2, showing the output stage of the IC separated from the integrator (since this is the usual arrangement) and showing the negative power supply and wiring impedance lumped together as a single constant. The amplifier is connected as a unity gain follower. This makes a closed-loop path from the amplifier output through the differential input to the integrator input. There is a second feedback path from the collector of the output PNP transistor back to the other integrator input. The net input to the integrator is the difference of the signals through these two paths. At low frequencies this is a net, negative feedback. The high-frequency feedback depends upon both the load reactance and the reactance of the V– supply.
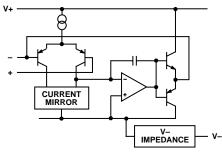

Figure 5. Instability Can Result from Neglecting Decoupling

When the supply lead reactance is inductive, it tends to destabilize the integrator. This situation is aggravated by a capacitive load on the amplifier. Although it is difficult to predict under exactly what circumstances the circuit will become unstable, it is generally wise to decouple the negative supply if there is any substantial lead inductance in the V– lead or in the common return to the load and amplifier input signal source. If the decoupling is to be effective, of course, it must be with respect to the actual signal returns, rather than to some vague "ground" connection.

POSITIVE SUPPLY DECOUPLING

Up to this point we have not considered decoupling the positive supply line, and with amplifiers typified by Figures 2

and 5 there may be no need to do so. On the other hand, there are a number of integrated circuit amplifiers that refer the compensating integrator to the positive supply. Among these are the 108, 504, and 510 families. When these circuits are used, it is the positive supply that requires most attention. The considerations and techniques described for the class of circuits shown in Figure 2 apply equally to this second class, but should be applied to the positive supply rather than the negative.

FEED-FORWARD

A technique that is most frequently used to improve bandwidth is called feed-forward. Generally, feed-forward is used to bypass an amplifier or level translator stage that has poor high-frequency response. Figure 6 illustrates how this may be done. Each of the amplifiers shown is really a subcircuit, usually a single stage, in the overall amplifier. In the illustration, the input stage converts the differential input to a single-ended signal. The signal drives an intermediate stage (which, in practice, often includes level translator circuitry) that has low-frequency gain, but limited bandwidth. The output of this stage drives an integrator-amplifier and output stage. The overall compensation capacitor feeds back to the input of the second stage and includes it in the integrator loop. The compromises necessary to obtain gain and level translation in the intermediate stage often limit its bandwidth and slow down the available integrator response. A feed-forward capacitor permits high-frequency signals to bypass this stage. As a result, the overall amplifier combines the low-frequency gain available from three stages with the improved frequency response available from a 2-stage amplifier. The feed-forward capacitor also feeds back to the noninverting input of the intermediate stage. Note that the second stage is not an integrator, as it may appear at first glance, but actually has a positive feedback connection. Fed-forward amplifiers must be carefully designed to avoid internal oscillations resulting from this connection. Improper decoupling can upset this plan and permit this loop to oscillate.
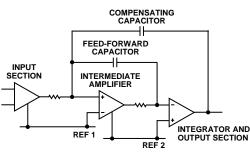

Figure 6. Fast Fed-Forward Amplifier

Note that the internal input stages are shown as being referred to separated reference points. Ideally, these will be the same reference so far as signals are concerned, although they may differ in bias level. In practice, this may not be the case. Examples of fed-forward amplifiers are the AD518 and the AD707. In these amplifiers, signal

Reference 1 is the positive supply, while signal Reference 2 is the negative supply. Signals appearing between the positive and negative supply terminals are effectively inserted inside the integrator loop!

Obviously, while feed-forward is a valuable tool for the high-speed amplifier designer, it poses special problems in application. A thoughtful approach to decoupling is required to maximize bandwidth and minimize noise, error, and the likelihood of oscillation.

Some fed-forward amplifiers have other arrangements, which include the "ground" terminal in inverting only amplifiers. Almost without exception, however, signals between some combination of the supply terminals get "inside" the amplifier. It is vital to proper operation that the involved supply terminals present a common low impedance at high frequencies. Many high-speed modular amplifiers include appropriate capacitive decoupling within the amplifier, but with IC op amps this is impossible. The user must take care to provide a cleanly decoupled supply for fed-forward amplifiers. Figure 7 shows a decoupling method that may be applied to the AD518 as well as to other fast fed-forward amplifiers such as the 118. One capacitor is used to provide a low-impedance path between the supply terminals at high frequencies. The resistor in the V+ lead ensures that noise on the supply lines will be rejected, and prevents the establishment of resonances with other decoupling circuits. The second capacitor decouples the low side of the integrator to the load.
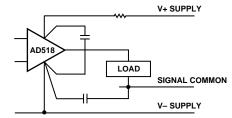

Figure 7. Decoupling for a Fed-Forward Amplifier

Alternatives include a resistor in both supply leads and/or decoupling from V+ to the load. In principle, the positive and negative supply should be tied in a "tight knot" with the signal return. To the extent that this cannot be done, there is a slight advantage to favoring the negative supply due to the high-frequency limitations of PNP transistors used in junction-isolated ICs.

OTHER COMPENSATION

While most integrated circuit amplifiers use one of the three compensation schemes already described, a significant fraction use some other plan. The 725-type amplifiers combine a V– referred integrator with a network the manufacturers recommend to be connected from signal ground to the integrator input. This makes the circuit extremely liable to pick up noise between V– and ground. In many circumstances it may be wiser to connect the external compensation to the negative supply, rather than to signal ground.

One more class of amplifiers is typified by the Analog Devices AD507 and AD509. In these circuits, a single capacitor may be used to induce a dominant pole of response without resorting to an integrator connection. The high-frequency response of the amplifier will appear with respect to the "ground" end of the compensation capacitor. In these amplifiers a small internal capacitance is connected between V+ and the compensation point. Unity gain compensation can be added in parallel and the pinout is arranged to make this simple. The free end of the compensation capacitor can also be connected either to V– or signal common. It is extremely important that the signal common and the compensation connect directly or through a low-impedance decoupling.

Although the main signal path of these amplifiers can be compensated in a variety of ways, some care is required to ensure the stability of internal structures. It is always wise to use extra care in decoupling wideband amplifiers to avoid problems with the output stage and other subcircuits that are similar to the main integrator problem illustrated by Figure 5. An effective compensation and decoupling circuit for the AD509 is shown in Figure 8. This arrangement is similar to Figure 7, and one of these two circuits is likely to be suitable for many types of wideband amplifier. Depending upon the power distribution, a small (10Ω to 50Ω) resistor may be appropriate in both of the supply leads to reduce power lead resonance and interference both to and from circuits sharing the power supply.
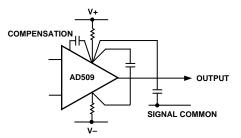

Figure 8. Decoupling a Wideband Amplifier

GROUNDING ERRORS

Ground in most electronic equipment is not an actual connection to earth ground, but a common connection to which signals and power are referred. It is frequently immaterial to the function of the equipment whether or not the point actually connects to earth ground. I prefer some distinguishing name or names for these common points to emphasize that they must be *made* common. The term "ground" too often seems to be associated with a sort of cure-all concept, like snake oil, money, or motherhood. If you are one of those who regards ground with the same sort of irrational reverence that you hold for your mother, remember that while you can always trust your mother, you should *never* trust your "ground." Examine and think about it.

It is important to have a look at the currents that flow in the ground circuit. Allowing these currents to share a path with a low-level signal may result in trouble. Figure 9 illustrates how careless grounding can degrade the performance of a simple amplifier. The amplifier drives a load that is represented by the load resistor. The load current comes from the power supply and is controlled by the amplifier as it amplifies the input signal. This current must return to the supply by some path; suppose that points A and B are alternative power supply "ground" connections. Assuming that the figure represents the proper topology, or ordering of connections along the "ground" bus, connecting the supply at A will cause the load current to share a segment of wire with the input signal connection. Fifteen centimeters of number 22 wire in this path will present about 8 mΩ of resistance to the load current. With a 2k load, a 10-volt output signal will result in about 40 microvolts between the points marked "ΔV." This signal acts in series with the noninverting input and can result in significant errors. For example, the typical gain of an AD510 amplifier is 8 million so that only 1 1/4 μV of input signal is required to produce a 10 volt output. The 40 μV ground error signal will result in a 32-times increase in the circuit gain error! This degradation could easily be the most serious error in a high-gain precision application. Moreover, the error represents positive feedback so that the circuit will latch up or oscillate for large closed-loop gains with R_f/R_i greater than about 250k.
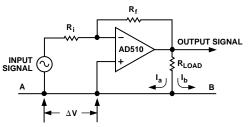

Figure 9. Proper Choice of Power Connections Minimizes Problems

Reconnecting the power supply to point B will correct the problem by eliminating the common impedance feedback connection. In a real system, the problem may be more complex. The input signal source, which is represented as floating in Figure 9, may also produce a current that must return to the power supply. With the supply at point B, any current that flows in additional loads (other than R_i) may interfere with the operation of the amplifier shown. Figure 10 illustrates how amplifiers can be cascaded and still drive auxiliary loads without common impedance coupling. The output currents flow through the auxiliary loads and back to the power supply through power common. The currents in the input and feedback resistors are supplied from the power supply by way of the amplifiers as previously illustrated in Figure 3c. The only current flowing in signal common is the amplifier's input current, and its effect is generally negligibly small.
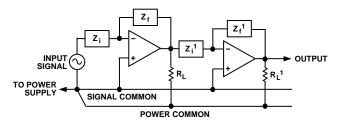
Figure 10. Minimizing Common Impedance Coupling

Having given an example of a simple "grounding error" and its solution, I will now get back on my soap box and say that grounding errors result from neglect, based on the assumption that a ground is a ground is a ground. Some impedance will be present in any interconnection path, and its effect should be considered in the overall design of a system. Quantitative approaches are quite useful in specialized applications. In fast TTL and ECL logic circuitry, the characteristic impedance of interconnections is controlled so that proper terminations can reduce problems. In RF circuitry, the unavoidable impedances are taken into account and incorporated into the design of the circuit. With op amp circuitry, however, impedance levels do not lend themselves to transmission line theory, and the power and ground impedances are difficult to control or analyze. The most expedient procedure, short of difficult and restrictive quantitative analysis, seems to be to arrange the unavoidable impedances so as to minimize their effects and arrange the circuitry to overcome the effects. Figures 9 and 10 illustrate the sort of simple considerations that can substantially reduce practical ground problems. Figure 11 illustrates how circuitry can be used to reduce the effect of ground problems that cannot be corrected by topological tricks.
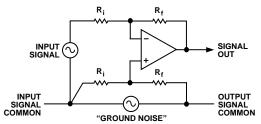

Figure 11. Subtractor Amplifier Rejects Common-Mode Noise

GETTING AROUND THE PROBLEM

In Figure 11 a subtractor circuit is used to amplify a normal mode input signal and reject a ground noise signal which is common to both sides of the input signal. This scheme uses the common-mode rejection of the amplifier to reduce the noise component while amplifying the desired signal. An important aspect of this arrangement, which is often overlooked, is that the amplifier should be powered with respect to the output signal common. If its power pins are exposed to the high-frequency noise of the input common, the compensation capacitor will direct the noise right to the output and defeat the purpose of the subtractor. It is just this kind of effect that makes it important to use care in grounding and decoupling. A subtractor

or dynamic bridge, like Figure 11, will be ineffective in correcting a grounding problem if the amplifier itself is carelessly decoupled. In general, an op amp should be decoupled to the point that is the reference for measuring or using its output signal. In "single-ended" systems it should also be decoupled to the input signal return as well. When it is impossible to satisfy both these requirements at once, there is a high probability of a noise or oscillation problem or both. Frequently the difficulty can be resolved with a subtractor, like Figure 11, where a network like the single-ended feedback network (which need not be all resistive) joins the input and output signal reference points and provides a "clean" reference point for the noninverting input of the amplifier.

A problem with the subtractor is that it uses a balanced bridge to reject the common-mode signal between the input and output reference points. The arms of the network must be carefully balanced, since to the extent they don't match, the unwanted signal will be amplified. Although even a poorly matched network will probably eliminate oscillation problems, noise rejection will suffer in direct proportion to any mismatches. An easier way to reject large "ground noise" signals is to use a true instrumentation amplifier.

INSTRUMENTATION AMPLIFIERS

A true instrumentation amplifier has a very visible "fourth terminal." The output signal is developed with respect to a well-defined reference point that is usually a "free" terminal that may be tied to the output signal common. The instrumentation amplifier also differs from an op amp in that the gain is fixed and well defined, but there is no feedback network coupling input and output circuits. Figure 12 shows how an instrumentation amplifier can be used to translate a signal from one "ground reference" to another. The normal mode input signal is developed with respect to one reference point which may be common to its generating circuits. The signal is to be used by a system that has an interfering signal between its own common and the signal source. The instrumentation amplifier has a high-impedance differential input to which the desired signal is applied. Its high common-mode rejection eliminates the unwanted signal and translates the desired signal to the output reference point. Unlike the dynamic bridge circuit, the gain and common-mode rejection do not depend on a network connecting the input and output circuits. The gain is set, in Figure 12, by the ratio of a pair of resistors that are
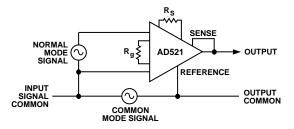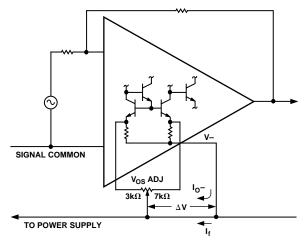

Figure 12. Applying an In-Amp

connected inside the amplifier. The amplifier has a very high input impedance, so that gain and common-mode rejection are not greatly affected by variations or unbalance in source impedance.
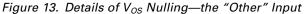
Since instrumentation amplifiers have a reference or "ground" terminal, they have the potential to be free of the power supply sensitivities of op amps. In practice, however, most instrumentation amplifiers have internal frequency compensation which is referred to the power supply. In the case of the AD521, the compensation integrator is referred to the negative supply terminal. The decoupling of this terminal is particularly important, and it should be decoupled with respect to the output reference terminal, or actually to the point to which this terminal refers.

THE "OTHER" INPUT
Most IC op amps and in amps include offset voltage pulling terminals. These terminals generally have a small voltage on them and by loading the terminals with a potentiometer the amplifier offset voltage can be adjusted. While their impedance level is much lower than the normal input, the null terminals can act as another differential input to the amplifier. Although the null terminals are not generally looked at as inputs, most amplifiers are quite sensitive to signals applied here. For example, in 741-family amplifiers the output voltage gain from the null terminals is greater than the gain from the normal input!

An illustration of the type of problems that can arise with the "other" input is shown in Figure 13. The figure is an op amp circuit with some of the offset null detail shown.

Figure 13. Details of V_{OS} Nulling—the "Other" Input

As it is drawn, the V_{OS} null pot wiper connects to a point along a V– "clothesline" that carries both the return current from the amplifier and currents from other circuits back to the power supply. These currents will develop a small voltage, ΔV, along the conductor between the amplifier V– terminal and the null pot wiper. If the null pot is set on center, the equal halves will form a balanced bridge with the resistors inside the amplifier. The effect of the voltage generated along the wire is balanced at

the V_{OS} terminals and will have little effect on the amplifier output. On the other hand, if the null pot is unbalanced, to correct an amplifier offset, the bridge will no longer balance. In this case, voltages developed along the "clothesline" will result in a difference voltage at the V_{OS} terminals. For instance, suppose that a 10k null pot balances out the op amp offset when it is set with 3k and 7k branches as shown in the figure. In a 741 the internal resistors are about 1k so that the difference signal at the V_{OS} terminals will be about 1/8 ΔV. The gain from these terminals is about twice the gain from the normal input, so that the disturbance acts as if it were an input signal of about 1/4 ΔV. Using the same assumptions as in the discussion of Figure 9, the current i_{O}– will result in a 10 microvolt input error signal. In this case, however, the error will appear only when the amplifier load current comes from the negative supply. When the load is driven positive the error will disappear. As a result, the V_{OS} input signal will result in distortion rather than a simple gain error!

An additional problem is created by If, a current returning to the power supply from other circuits. The current from other circuits is not generally related to the op amp signal, and the voltage developed by it will manifest itself as noise. This signal at the null terminals can easily be the dominant noise in the system. A few milliamps of V– current through a few centimeters of wire can result in interference that is orders of magnitude larger than the inherent input noise of the amplifier. The remedy is to make the connection from the null pot wiper direct to the V– pin of the amplifier, as shown in Figure 14. Some amplifiers, such as the AD504 and AD510, refer the null offset terminals to V+. Obviously, the pot wiper should go to the V+ terminal of this type of amplifier. It is important to connect the line directly to the op amp terminal so as to minimize the common impedance shared by the op amp current and the null pot connection.
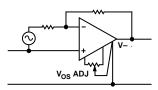

Figure 14. Connecting the Null Pot for Trouble-Free Operation

The considerations for op amp null pots also apply to the similar trimmers on almost all types of integrated circuits. For example, the AD521 in amp null terminals exhibit a gain of about 30 to the output. Although this is much less than in the case of most op amps, it still warrants care in controlling the null pot wiper return. Table I lists the integrated circuits manufactured by Analog Devices, including some popular second-source families, and indicates how internal conversions from differential-to-single-ended are referred. That is, the signals are made to appear with respect to the terminal(s) listed.

Table I.

	Internal Integrator Referred to:	Comment
AD OP 07/ 27/37	V+, V–	Internal Feedforward Cap V+ to V– and integrator V– to Output
AD380	V+	
AD390	V–	Output and Reference Amplifier
AD394/AD395	V–	Output Amplifiers
AD396	V–	Output Amplifiers
AD507	–	External Cap to Signal Common or V+
AD508	–	External Cap to Signal Common or V+
AD510	V+	
AD517	V+	
AD518	V+, V–	Internal Feedforward Cap V+ to V–I and Integrator V– to Output
AD521	V–	Output Amplifier Integrator
AD524	V–	Output Amplifier Integrator
AD526	V–	Output Amplifier Integrator
AD532/AD533	V+	Multiplier Output Amplifier Integrator
AD534/AD535	V–	Output Amplifier
AD536A	V–, V+ Common	External Integrator to V+, Internal Feedforward V– to Common
AD538	V–	Internal Amplifiers
AD542/AD642	V–	
AD544/AD644	V–	
AD545A	V–	
AD546	V–	
AD547/AD647	V–	
AD548/AD648	V–	
AD549	V–	
AD557/AD558	Common	Output Amplifier and DAC Control Loop Integrator Referred to Common
AD561	V–, Common	DAC Control Loop Integrator and Ref. Amp Referred to Common and Ref. Bias Amplifier Referred to V–
AD565A/ AD566A	V–	DAC Control Loop Integrator Referred to –V. Reference Input Common to Control Loop Isolated from DAC Output Common
AD568	V+	Reference Amplifier
AD580	V–	Output Amplifier
AD581	V–	Output Amplifier
AD582	V–	Output Amplifier
AD584	V–	Output Amplifier
AD586/AD587	V–	Output Amplifier
AD588	V–	Output Amplifier
AD624/AD625	V–	Output Amplifier Integrator
AD636	V–, V+, Common	External Integrator to V+, Internal Feedforward V– to Common
AD637	V–, Common	Internal Feedforward V– to Common
AD645	V–	
AD650/AD652	V+	Internal Amplifier
AD662	Common	DAC Control Loop Integrator and Reference Amplifier Referred to Common
AD664	V–	Output Amplifiers
AD667	V–, Common	Output Amplifier Referred to V– and Reference Amplifier Referred to Common
AD668	V+	Reference Amplifier

	Internal Integrator Referred to:	Comment
AD688	V–	Output Amplifier
AD689	V–	Output Amplifier
AD704/AD705/ AD706	V+	
AD707/AD708	V+, V–	Internal Feedforward Cap V+ to V– and Integrator V– to Output
AD711/AD712/ AD713	V–	
AD736/ AD737	V–, Common	External Integrator to V– Internal Feedforward V– to Common
AD741	V–	
AD744/AD746	V–	
AD766	V–	Output and Reference Amplifier
AD767	V–, Common	Output Amplifier Referred to V– and Reference Amp Referred to Common
AD840/AD841/ AD842	V+, V–	
AD843	V+, V–	
AD844/AD846	V+, V–	
AD845	V+	
AD847/AD848/ AD849	V+, V–	
AD1856/AD1860	V–	Output and Reference Amplifier
AD1864	V–	Output and Reference Amplifier
AD2700/AD2710	Common	Output Amplifier
AD2701	V–	Output Amplifier
AD2702/ AD2712	V–, Common	Output Amplifiers
AD7224/AD7225	V–	Output Amplifiers
AD7226/AD7228	V–	Output Amplifiers
AD7237/ AD7247	V+, Common	Reference Amplifier to Common Output Amplifier to Both V+ and Common
AD7245/ AD7248	V+, Common	Reference Amplifier to V+ Output Amplifier to Both V+ and Common
AD7569/AD7669	V–	All Amplifiers
AD7769	Common	All Amplifiers
AD7770	Common	All Amplifiers
AD7837/AD7847	V+	All Amplifiers
AD7840	V+, Common	Output Amplifiers to V+ Reference Amplifier to Common
AD7845	V+	All Amplifiers
AD7846	V+	All Amplifiers
AD7848	V+, Common	Output Amplifier to V+ Reference Amplifier to Common

This collection of examples will not solve all your potential grounding problems. I hope that it will give you some good ideas how to prevent some of them, and it should also give you some of the "inside story" on the ICs, which you can put to work in very practical ways. There is no general grounding method that will prevent all possible problems. The only generally applicable rule is attention to detail, and remember that you can always trust your mother, but . . . .