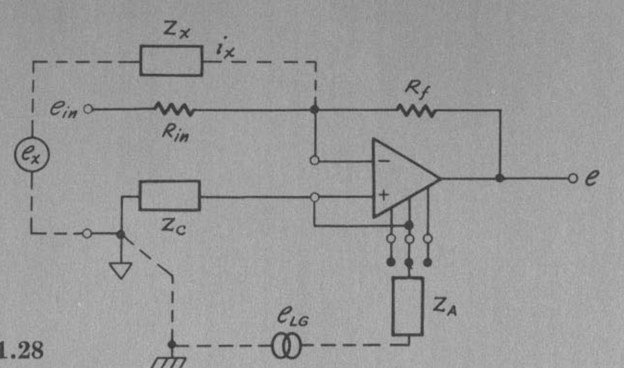
I.28 THE NEED FOR AN INTERFACE PHILOSOPHY. In the real and unyielding world of circuits that *work*, we must emulate the best physicians (who treat the *whole* man) and treat the *whole* amplifier, including its complete "circuit environment."

The innocent circuit drawn in solid lines may be prey to dozens of (curable) ills, two of which are shown in dashed lines. Another malady is shown in 1.29(a). Now then:

- In 1.28, if R_{in} is 2.0 megohms, and e_{in} is one volt, how much leakage coupling (Z_x) is required from a voltage source (AC or DC) of 100 volts (e_x) to produce a noise signal equivalent to 0.1% of the input signal? *Answer:* Z_x = *200,000 megohms.* (At 60 Hz AC, just about 0.01 pF will do it!)
- Again 1.28, if power supply common is coupled to the 60 Hz AC line (e_{LG}) with about a megohm (Z_A), how much common impedance (Z_C) must creep into the grounding connection to produce 1.0 μvolt more input noise? *Answer: About* 10 *milliohms.* (About 8 inches of #22 wire!)
- How much current must be returned through the power-common, from the load on amplifier #3, (1.29a) to create a 0.1 mV error between the reference grounds of Amplifier #1 and Amplifier #2, if Z_C is 50 milliohms? *Answer: Only 2 mA! The cures?* Read on!



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I.30
I.31
I.39

I.29 A POWER SUPPLY PHILOSOPHY. It is a common conception that operational amplifiers are, by nature, extremely tolerant of such power supply misbehavior as regulation, random fluctuations, long-term drift, hum, noise, ripple, and transients; some designers even suggest that an unregulated DC supply is adequate for all but the most critical applications. Though this is to a great extent true, experience—supported by logic—forces us to mention important qualifications.

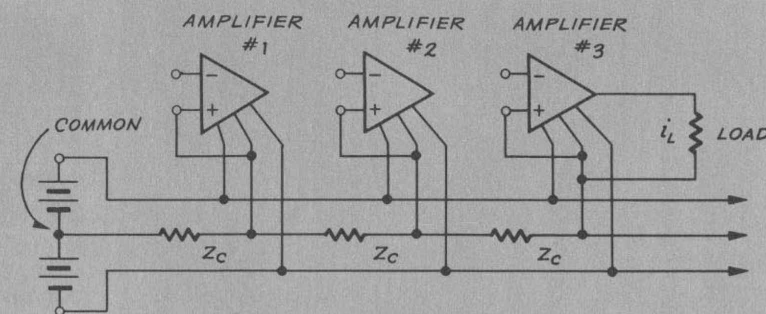
The influence of power supply *regulation and drift* may be small, but it is there; and, even in applications not requiring differential amplification with high CMRR, power-supply voltage variation is a potential source of common-mode error. Good tracking of the positive and negative supply voltages helps reduce it.

Any appreciable *internal impedance* in the supply and its leads provides unwanted coupling between and among amplifiers that share it. See 1.29(a).

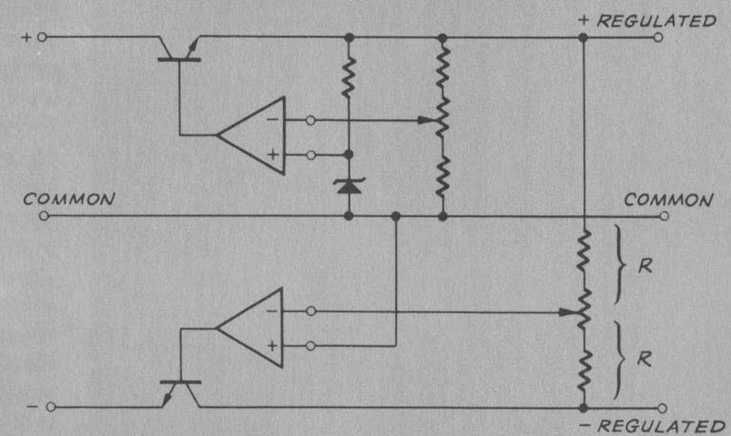
Power-supply changes that would go unnoticed if slow—and if used in large-signal circuits, can penetrate to a low-level pre-amplifier stage that is "rate-coupled" to the supply; hence, supply-voltage *transients* may not be ignored.

Hum and ripple are important *noise* components often found in the output circuits of poorly-supplied Operational Amplifiers; "refer" them to the input, if you will, but they probably originate not there, but in the supply . . . and that is where they should be scotched.

For the above reasons, Philbrick power supplies (highly recommended!) are all well-regulated, extremely-well-filtered, low-noise, dual-output designs, with the positive and negative outputs *inter-referenced* (as shown in the 1.29(b) diagram) for good tracking. Anything less than a high-performance supply is a disservice to most designs, and probably poor economy. Is a day of debugging worth an ounce of prevention?



1.29(a)



1.29(b)

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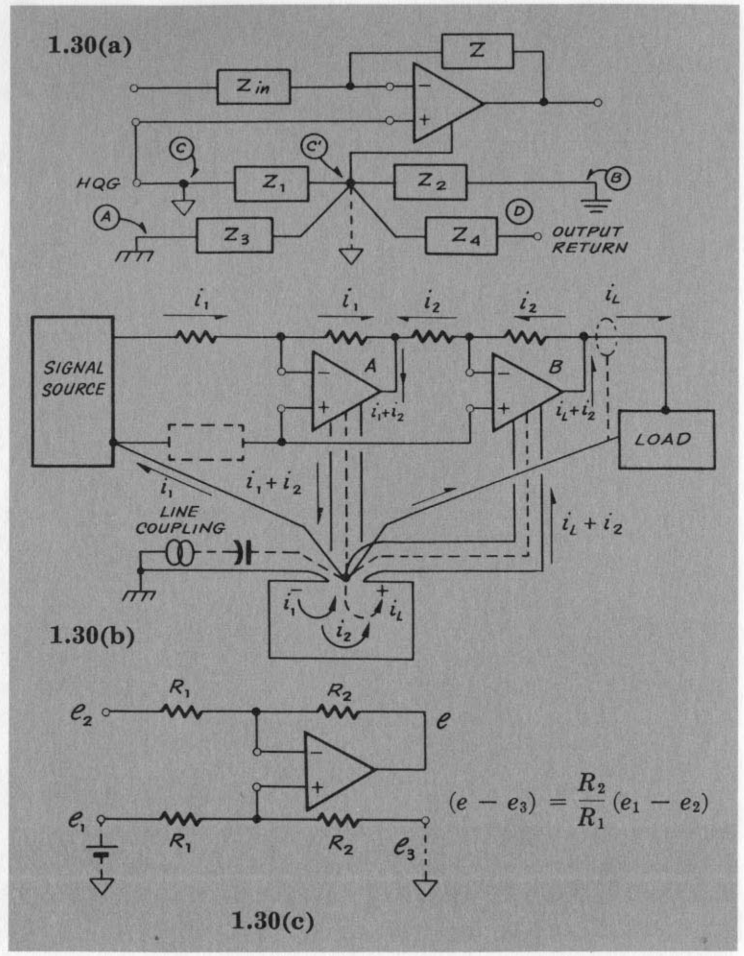
I.30 GROUNDING PHILOSOPHY. "Ground," in the ideal electronic amplifier, is a single point, common to all input, output, and power circuits. Practical amplifiers exhibit small but finite impedances in circuit returns—Z_1, Z_2, Z_3, Z_4 in (a)—and we accordingly designate three distinct grounds: *Chassis Ground*, *Power Common* (the DC-power-supply return), and *Signal Ground*, often designated "high-quality" ground, or simply HQG. Their symbols appear at A, B, and C, respectively. The point C′ is the "reference zero," and the object of any intelligent grounding technique is to minimize the potential differences between A, B, C, D, and C′.

Figure (b) illustrates some recommended practices. First, a floating signal source for amplifier *A* is grounded to the power common. The amplifier reference inputs (which require insignificant current) may be connected either to power-supply common at the system tie point, or, as shown, to the signal-generator input. The voltage-difference "error" so introduced is only the (small) signal current, i_1, times the (low) ground-path resistance from signal-source to power supply. To assess its significance, compare the ground-wire and contact resistance with the input resistor of *A*, since they are in series. It is obvious that this error is probably negligibly small. *Significant* error could however arise if the *load* current, i_L, were to flow in the lead coupling the amplifier's reference input to signal ground. Note that amplifiers, computing interconnections do not require ground currents to flow unless ground appears explicitly as a network termination. Also, if either ±15 volts is to be used as a reference signal, it is best to run separate reference and power leads back to the supply. When supplying heavy load currents, or when the output contains large, rapid voltage transients, it may be wise to use a twisted or shielded pair. The load should be returned directly to the power-supply common. Multiple-power-supply systems often require that substantial computing current flow in the interconnecting ground bus. This bus should be heavy, short, flat, and highly conductive. Power-line and harmonically-related noise may be caused by insufficient electrostatic isolation of the primary and secondary of the power transformer, particularly if the power-supply-common is not tied to chassis (AC) ground at the supply. (This is done to avoid resistive coupling of power line currents producing ground system voltage errors.) In multiple power-supply systems, it may be necessary to tie each power common and chassis ground together and accept the resulting ground loops.

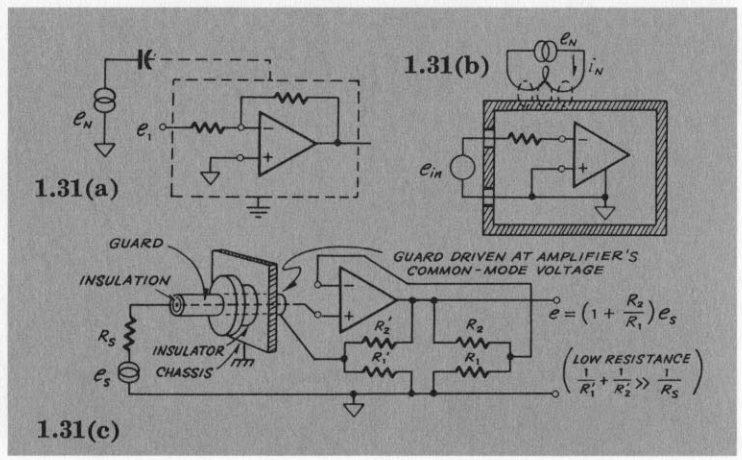
Circuit (c) is a difference amplifier capable of converting a signal referred to one ground system (denoted by e_1) to another (e_3) in such a way that it makes no difference which (if either) ground system is referenced to the power supplies.



$$(e - e_3) = \frac{R_2}{R_1}(e_1 - e_2)$$

I.30 I.28 I.29 I.31 I.39

I.31 SHIELDING AND GUARDING PHILOSOPHY. The amplifier input is as available to unwanted as it is to legitimate signals. We recommend that you choose one convenient path for signal entry, then make all of the rest inconvenient. When the unwanted signal, e_N, is capacitively coupled, as in (a), provide a correctly-grounded electrostatic shield for at least the input circuitry, and preferably for the whole amplifier. When the unwanted signal is introduced via inductive coupling, as in (b), such shielding should be ferromagnetic as well as conductive, thus adding electromagnetic isolation, by providing both a low-reluctance short-circuit path for the lines of flux of external magnetic fields, and a "shorted-turn" effect. Discontinuities in the shield must be avoided; when openings *are* necessary, minimize dimensions as well as area—i.e., prefer round holes to slits, areas being equal. High-permeability magnetic shielding is *very* well worth its cost, for shielding away signals under 100 Hz, but high-conductivity shielding (aluminum or copper) is the more effective means above 100 Hz. Both resistive and capacitive stray leakage paths, particularly those shunting high circuit impedances, may be interrupted by judiciously-arranged guard rings, as in (c), that lead the coupling to ground or to some other harmless (non-signal) path.



I.31 I.28 I.30 I.34 I.39