THE LIGHTNING EMPIRICIST

Advocating electronic models, at least until livelier instrumentalities emerge

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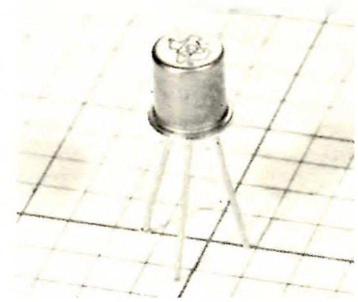
PHILBRICK & THE SEMICONDUCTOR REVOLUTION

SURELY it is a blatant *non sequitur*, though an American one, that we as big buyers of transistors and junction diodes are privileged to philosophize on semiconductors at a high technical level. Of course we have also bought our share of vacuum diodes and triodes and pentodes, and in fact are still doing so as heavily as ever. In the simpler days just past, with only conductors plus insulators plus vacuum, electrons as a tangible commodity, tangible at least in concept, offered a comforting unitary medium wherewith to understand and plausibly to explain substantially all the electronic phenomena one needed to be in business. Discussions transcended the split between the continuous and the discrete with little effort: we spoke pleasantly of a smooth stream of (negative) electricity, then listened to the passage of individual particles. But now — Great Caesar's Ghost! Any profound account of semiconductor behavior requires statistical and wave mechanics, quantum field theory, and a grasp of crystalline lattices just to get started. The experienced empiricist, of course, quickly takes refuge in the macroscopic variables, in terms of which to describe his component devices, but he frequently albeit privately yearns for the underlying simplicity of electrons *in vacuo*. Even regarding the electrical carriers themselves, we have in the solid state a reincarnation of the centuries old two-fluid theory of electricity, with ephemeral "holes" in a symmetrical relationship to electrons, but there are more than one kind of hole, and the ghosts are near to getting out of hand.



The vital fact in all this extravagance, as it applies in particular to the Analogy Racket, is that one finds it vastly harder now to see what is coming next. The limitations of primary semiconductor devices, as they relate to our amplifiers and other circuitry, have been pushed back much faster than anyone might reasonably have expected: except of course by hindsight. This is certainly due, at least in part, to the relatively greater obscurity of the fundamental processes, coupled with the massive, competitive, interdisciplinary attack on the practical problems involved. In six years, it is evident that the spread between existing and theoretically ideal junction devices has been reduced by a factor of 8 to 15. Six years ago, no one could have bought the sort of junction triode, or transistor if you insist, which now can be delivered from stock for a couple of bucks. This is Revolution, and it is unlikely to stabilize with new phenomena appearing on a monthly schedule.

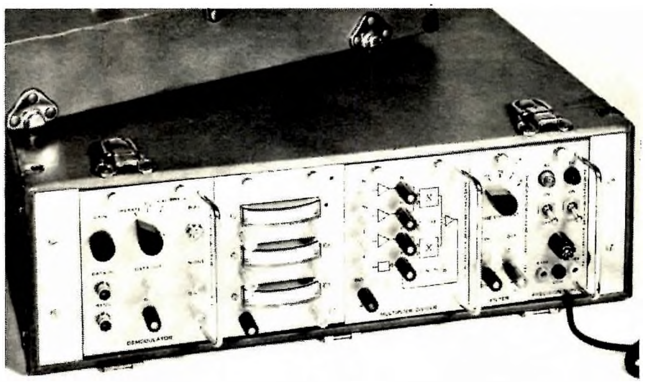
To return for a moment to the older two-fluid theory of electricity, one of the more recent proponents of this theory was a Harvard professor who died in 1938. Named after him was the well known Hall effect, which is fundamental to theory and experiment in semiconductive materials; but few who refer regularly to the effect can identify the man. He was Dr. Edwin Herbert Hall, from Gorham, Maine, and would he might have survived to hear everyone talking of holes and electrons in the solid state. The Hall effect, incidentally, though tempting as a manifestation of cross-products, is among the harder ways to multiply accurately. We threw in the sponge 13 years ago. Incidentally again, Glazebrook's Dictionary of Physics (Brit.) holds that Kelvin noticed the Hall effect 30 years ahead of Hall. Exactly like Lord Kelvin to have done a thing like that; he used analog integrators somewhat ahead of *us*.

Meanwhile, it is trite but true that in contrast to instruments which depend solely on vacuum or thermionic devices, those which are built out of the solid state variety can offer a full order of magnitude advantage in size, efficiency, and reliability. Prices, hitherto an order of magnitude to the bad, are now approaching a fully competitive position, especially if fair allowance is made for comparisons in maintenance, heat removal, and frangibility. Thus with these two cultures in conjunction, and with newer and still more accomplished semiconductive items parading onto the scene, our own lives are marvellously diverting. While this issue contains a number of the semiconductor products which are currently basic to our line, there are many more in the pipeline worth crowing about. Operational amplifiers to be sure, but more than these. Future issues may hold some surprises.

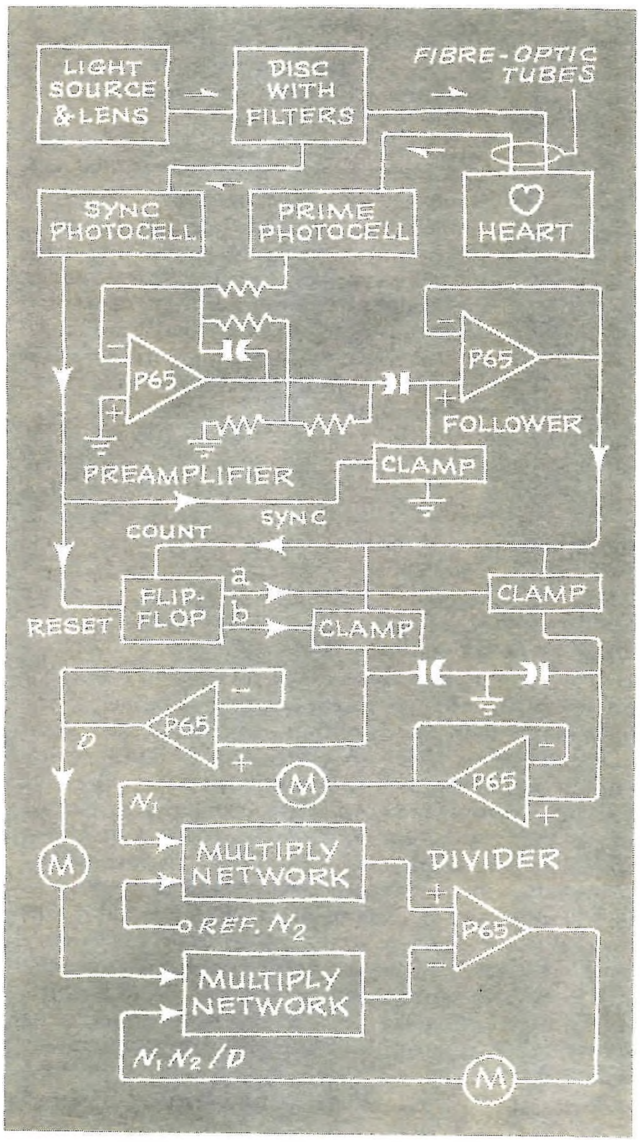
If we could possibly manage it, we would publish right away an issue of The Lightning Empiricist for some time in 1968. Short of that, we *can* mention some of the concoctions which are on the fire. In line with our professed enthusiasm for electronic modelling, attention somewhat overdue is being given to passive circuitry. Part of this concentration is logically on static networks, so called, for nonlinear relationships in considerable variety. Our earlier intensive period of activity in this branch of the art was prior to 1950, but the newer semiconductive primary tools are irresistible. Passive dynamic networks will come in for treatment, probably in the next forthcoming issue of The Lightning Empiricist, since a long term proprietary development has recently taken a practical turn, and a certain patent has issued.

What, no Hybrids? What, nothing beyond 10 volts? Patience — and Peace.

THE BELLEVUE INTRACARDIAC OXIMETER



The Instrument Assembled in Portable Case

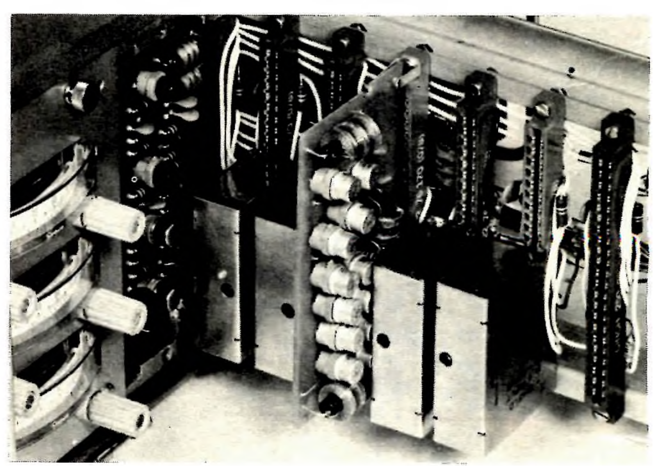


Block Diagram Showing Amplifiers

The rapid development and application of open heart surgery has placed ever greater demands on diagnostic tools. It is often desirable to measure the concentration of oxyhemoglobin or of dye within the blood at specific points in the circulatory system: particularly within the heart itself. Such an instrument should be compact enough to be introduced into the heart through an artery or a vein, and should respond with sufficient rapidity to observe fluctuations during the period of a single heart beat. A combination of fibre optics and analog computing techniques has resulted in a highly useful instrument. A light source shines a beam through an opaque disc containing two holes with optical filters of different wave lengths. The disc rotates at 30 revolutions per second. The resulting chopped beam is transmitted through a thin fibre tube to the measuring point and the scattered and reflected light is picked up by a second such tube and piped back to a photocell. The analog computer separates the signals from the background, samples them, stores them, and obtains their ratio. This quotient of the signal intensities (proportionate to the intensity of light reflected by blood at two wave lengths) is a linear function of the concentration of pigments, such as oxyhemoglobin or Indocyanic Green dye.

A P65 Amplifier is used to AC amplify the photocell output. A synchronized "clamp" sets the base line during the dark portion of the cycle to zero. Another P65, connected as a precise voltage follower, transforms this high impedance signal to a lower impedance signal with negligible voltage error. A synchronized flip-flop feeds the 60 signal pulses per second alternately to storage capacitors connected at the inputs of two P65 followers. The outputs of the followers are fed into a multiplier-divider (containing more P65's), which obtains the stepwise varying quotient. The synchronizing signals are obtained from another photocell whose output leads that of the data photocell.

The optical system for the Intracardiac Oximeter was designed for the Cardio-Pulmonary Laboratory of Bellevue Hospital by American Optical Company, and the sampling ratio computer was designed by Pastoriza Electronics, Inc., 285 Columbus Avenue, Boston 16, Massachusetts. This instrument is now being used at Bellevue by Dr. Yale Enson, of the Columbia University College of Physicians and Surgeons.



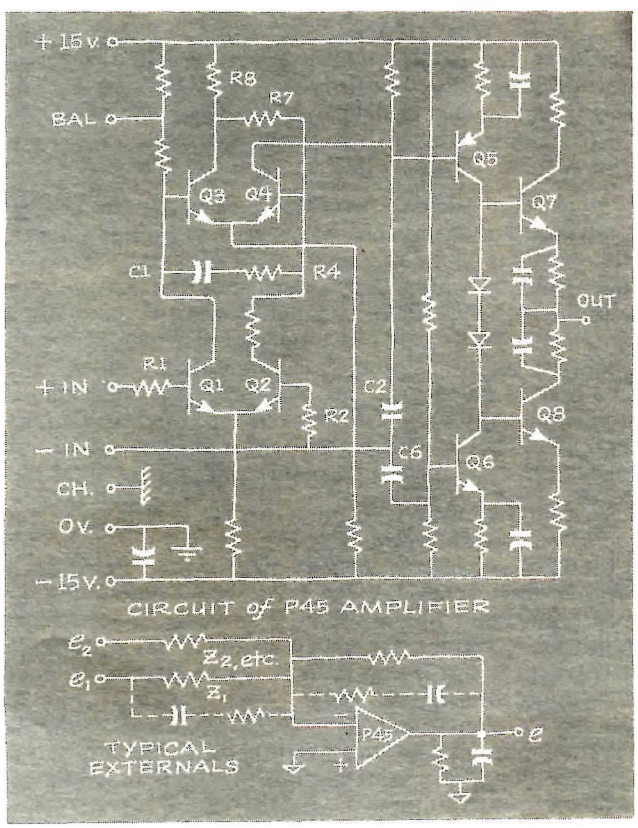
Modular Section of the Instrument Withdrawn Showing P65 Amplifiers in Place

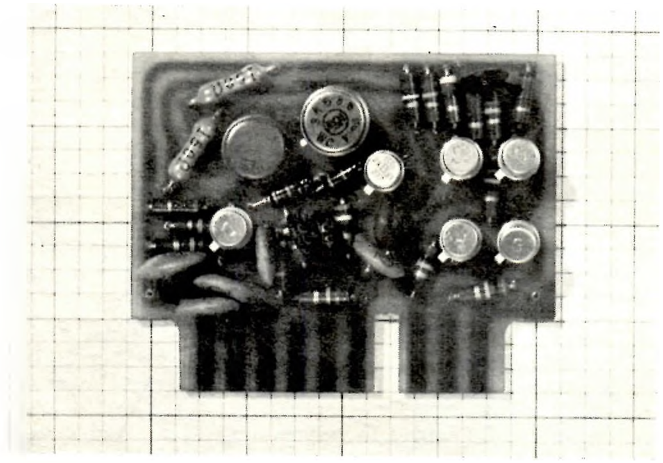
DESIGN OF A MODERN HIGH-PERFORMANCE OPERATIONAL AMPLIFIER

By Robert Allen Pease, Manager
Development Division
Philbrick Researches, Inc.

Essentially we wanted an operational amplifier capable of providing useful and accurate amplification at speeds faster by a factor of 10 to 1000 than familiar amplifiers could provide. Naturally solid state; hence the MODERN in the title. We wanted an amplifier with a good degree of versatility — one that would operate stably under all conditions of resistive feedback, as in bounded circuits, and as an integrator or differentiator. We wanted high voltage and current gain, and low voltage and current noise and drift. In addition to these theoretically essential features, many others are desirable for a practical amplifier. A practical amplifier ought to be tolerant of capacitive loading from output or summing point to ground; it should also be safe under overload or fault conditions such as output shorted to ground, and be able to cover a broad range of operating temperatures.

Obviously such an amplifier, having a fair number of transistors, involves compromises. Almost any characteristic can be traded for any other: current drift can be traded for voltage gain, power gain traded for bandwidth, dollars for current gain, et cetera. The task of the designer is to engineer the most profitable compromise, so that the essential features are obtained at the expense of a minimum of other desirable properties.





Circuit Board, Component Side

Static Gain

May I refer to the adjacent schematic? In the first stage, Q1 and Q2 are a closely-matched pair operating at moderately low collector currents, so as to provide high input impedance, low drift, and yet good current gain. In the second stage, Q3 and Q4 contribute to the current gain (still virtually no voltage gain!), which is further boosted by a conservative factor of 4 to 8 by means of the positive feedback comprising R7 and R8. As with the previous stage, the operating conditions of Q3 and Q4 are well balanced so as to minimize drifts.

The single-ended output of the second stage drives into the base of Q5, the main DC voltage driver, operating in a Class A configuration. Since Q6 acts as a current source, the voltage gain of Q5 is typically greater than 1,000.

Q7 and Q8 act a push-pull emitter follower, operating in a Class AB mode. They are responsible for the gratifying efficiency with which loads from 1 to 20 milliamperes may be driven.

The total DC gain generated by these 4 stages of amplification may be observed as a voltage gain of from 20,000 to one million depending on load, a current gain of 5 million, and a transconductance of 40 mhos: these figures actually running out to at least 100 cps.

Dynamics

Starting from DC and from the front end of the amplifier, R1 and R2 isolate the summing point from the input capacitance between the bases of Q1 and Q2; together with that capacitance they provide a low pass filter for the "DC" signal path. Then R4 and C1 roll off the gain of Q3 and Q4 to a low but "stiff" value. Then C6, the feed-forward to the base of Q6, begins to roll the gain down to an even lower but stiffer value.

Later yet, C2 begins to feed forward to the base of Q5; this must take place after the gain of Q1 through Q4 has decreased considerably, lest feedback through the aforesaid capacitor provoke instability. After a while, the effective capacitance from the collector of Q6 to ground causes the gain to roll off, further stiffening the output impedance against load capacitance. Lastly, the current gains of Q5 through Q7 roll off also.

Meanwhile, the low input impedance at high frequency, looking "right into" the bases of Q5 and Q6, makes the P45 (this amplifier, recently so designated) unusually tolerant of stray capacitance from summing point to ground.

The effect of all these dynamic tinkerings is to roll off the voltage gain, nominally 20,000 from DC to 1 kcps, at 6 (+1, −2) db per octave until it passes through unity at about 100 megacycles.

Some Applications

The P45 was designed expressly for operation as a negative-gain amplifier at low impedance levels. With 1 kilohm external resistors, the risetime is typically 20 nanoseconds small signal and 100 nanoseconds full swing: 20 volts peak-to-peak. If resistors of the order of 1 megohm are used, the response will degrade somewhat unless small r and c shunts are connected as shown. Even in cases where such networks would load down the signal source too heavily, special circuits may be recommended which will provide extremely fast amplification at high impedance levels.

The differential inputs of the P45 were designed primarily to provide low drift and to permit the use of a DC offset or slowly varying voltage as a reference. Thus the positive input lacks the gain and bandwidth character of the negative input. Nonetheless, the P45 can perform some positive-input functions with creditable speed and accuracy. For instance, when connected as a gain-of-plus-100 amplifier, a bandwidth of nearly 1 mcps is attained, while the input impedance of the combination is still very high.

By way of comparison, the P45 is approximately equal to a P65 plus a P66 (see further) with respect to noise, drift, gain, efficiency, reliability, compactness, and price. Its bandwidth, however, is 10 to 100 times faster.

Finished P45 Amplifier, in case now standard for several Philbrick plug-ins. (Hole at top optional.) Actually, this protective and form-fitting design carried off one of last year's Wescon prizes. (Another was taken by Philbrick's Model SK2-V Amplifier. See the January 1, 1963 issue of the Lightning Empiricist.)

SOLID STATE POWER SUPPLIES

While Philbrick semiconductor products will function with power supplies made by other manufacturers (including the very simple ones obtainable from Burgess, Mallory, Gulton, and Eveready!), they quite understandably prefer to be served by supplies which have the same corporate background.

MODEL PR-150 COMPOUND REGULATED POWER SUPPLY, FOR PLUS & MINUS 15 VOLTS DC

The Model PR-150 Power Supply, shown here at the left, is at present the principal regulated supply in the Philbrick line. It is conservatively rated at 150 milliamperes at each of the two outputs: for +15 volts and −15 volts with respect to a common reference. The input is from 105-125 volts AC, at 50-400 cps.

Binding posts on the front panel offer the positive and negative output polarities, a common zero, and an independent chassis ground. A DC switch (and cooperating indicator lamp) furnishes the two voltages simultaneously and in parallel to the plus and minus posts. For testing or other purposes, a pair of banana jacks on the front panel are permanently connected to the regulating tie points inside. An AC switch (and its indicator lamp) manages not only to turn on the power supply itself, but controls the appearance of output voltages at the last-named tie points and jacks.

Stability over a 24 hour period is 2 millivolts or better, depending on which of two types of regulating circuit is ordered. Hum and noise are on the order of 75 microvolts rms. Load regulation, for zero to 100 per cent, is about 150 millivolts. Suddenly applied load (full load) induces only a 10 millivolt transient, which decays in a millisecond. The line regulation is below 200 microvolts for the range of input voltage from 105 to 125. Maximum output impedances are 10 milliohms at the binding posts, and 2 milliohms at the internal tie points. The high frequency impedance is that of a 500 microfarad capacitor.

The PR-150 Supply is designed to recover automatically after an overload or short circuit; Under the latter circumstance the maximum output current is 300 to 600 milliamperes.

Dimensions are $5\frac{13}{16}$ wide by 4 high by $8\frac{1}{2}$ deep, in inches.

One additional point: the absence of overshoot when the PR-150 is turned on is deemed a desirable feature, acting to protect equipment which may have critical upper voltage limits.

MODEL PR-150C COMPOUND REGULATED POWER SUPPLY (Chassis Version of the PR-150)

For those who are prone to build assemblages of amplifiers and other equipment, and who want an integral or self-contained power supply, the Model PR-150C is offered as being adapted to this purpose. It differs from the PR-150 Supply principally in mechanical features, but in particular: No switches or lamps are provided. Instead of binding posts and jacks, an 8-terminal Blue Ribbon outlet connector carries the three output regulated points and chassis ground, plus the AC line input for downstream services, fused along with the normal supply but more permissively than the PR-150. The dimensions are $3\frac{3}{8}$ by $3\frac{1}{4}$ by 9 inches. See figure at right.

ADDITIONAL REMARKS Note that any of these supplies will serve as 30 volt sources, since they electrically "float." Obviously any multiple of 15 volts is available. Note further that these supplies, and in particular Models PR-150 and PR-150C, are intended as reference voltage sources as well as just power plants. Their 15 or 30 volt values may be converted to such lower values (as 10 volts) as may be desired, through operational amplifiers fed back for stiff outputs. Alternatively they may yield accurate currents to summing points simply by the interpolation of accurate resistors. 3 millivolts in 15 volts amounts to 0.02 per cent.

SMALLER SOLID STATE POWER SUPPLIES

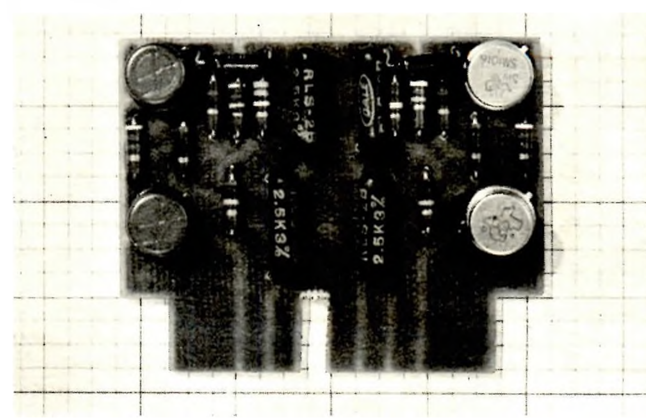
MODEL PR-30 & PR-30C COMPOUND REGULATED POWER SUPPLIES

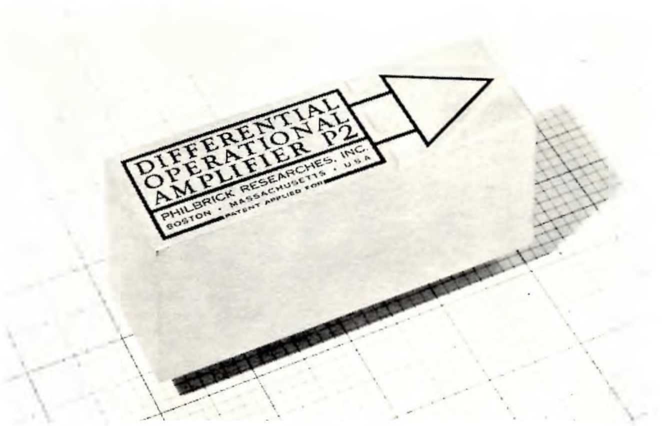
These are junior versions of the PR-150 Supply, having more modest capabilities, reflecting specifically in capacity and cost, but convenient for single operational amplifiers and associated circuitry. For example, it will comfortably supply an SP656 Stabilised Operational Amplifier, or 7 Model P65 Amplifiers, et cetera. The rating is 30 milliamperes nominal maximum at both plus and minus 15 volts DC. Direct short circuits of brief duration will lead to little if any harm.

There are no adjustments for the output voltages, these being factory preset to 1 per cent. Regulation is also 1 per cent, for zero to full load, or for $\pm$ 10 per cent on the 115 volt AC line. Noise and ripple are 15 millivolts at worst, and 5 millivolts rms typically. The internal impedance is about 5 ohms. Dimensions are $4\frac{7}{16}$ by $2\frac{3}{8}$ by $3\frac{1}{8}$ inches.

The regulator circuit itself of the PR-30, exclusive of transformer, rectifiers, and filters, is built on a plug-in board, uniform in size with that of the P65 and other amplifiers. This subassembly, called the TR-30, (shown at right, below) is available separately and may be used to convert coarsely regulated $\pm$ 30 volt DC sources to $\pm$ 15 volt steadiness.

Also shown in the photo at left is a chassis-mountable version of the PR-30 unit, the PR-30C, for building into amplifier assemblages, as with the PR-150C. It has no lamp or switch or binding posts. An 8-terminal Blue Ribbon connector provides for electrical inputs and outputs. Dimensions are essentially the same as for the PR-30 Supply.





MODEL P2
DIFFERENTIAL OPERATIONAL AMPLIFIER

The unique and reliable P2 Amplifier is now entering its fourth year of production, still paralleled by a continuous and continuing program for improvement. It is still without peer, attaining input isolation, low common mode response, and minuscule input currents through the use of a special parametric circuit and rigidly controlled manfacturing procedures.

This potted assemblage with its rigid and robust cast aluminum case, though originally designed for laboratory applications in a modest range of temperature, has nevertheless served in considerably severer factory environs, for example, and has furthermore operated in the depths of oceans and has even soared through space. To stay on solid ground for the moment, however, it is relevant that P2 Amplifiers are now performing at the heart of process control instruments and computors manufactured by firms whose names would be readily recognised, but whose diffidence we honor.

In addition to its monolithic metal case, the P2 Amplifier is thoroughly sealed up, offering glass-to-metal solder terminals in a thick header plate. It is thus clearly intended for permanent installation, as has indeed proved warranted.

Although it will perform many of the operations of conventional operational amplifiers, the unusual characteristics of the P2 Amplifier have enabled the accurate measurement and processing of quite small (and ordinarily inaccessible) electrical currents: such as those from flames, ion chambers, and photomultipliers. Not too surprisingly, it has been used to measure leakage currents on other sorts of solid state structures than itself. As an integrate-and-hold amplifier, it challenges the best capacitors. As a differentiator of slowly changing variables, it challenges the cleanest signals. As a subtracting amplifier, for example, it can distinguish rational data out of the most tormented of common mode frenzy, and is even undismayed by hundreds of volts in such mode (± 200 volts rated).

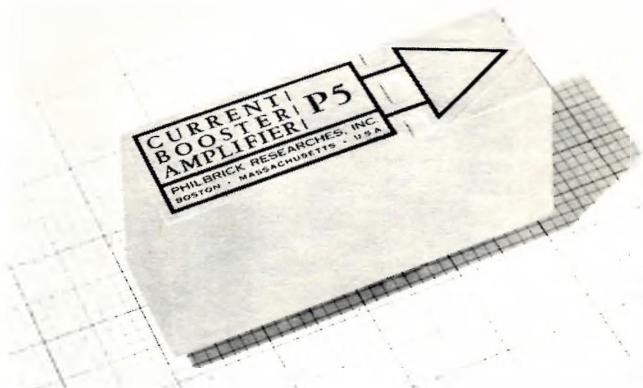
The differential DC input impedance of the P2 Amplifier is above 100 megohms for small signals; the impedance from either input to ground is about 100,000 megohms, even for large signals. In closed-loop, or feedback operation, of course, the differential input is automatically small, but the open-loop common mode rejection ratio itself is greater than 1 million: without adjustments. The input error current is below 50 micromicroamperes, and is *typically 5 times* smaller.

The DC voltage gain of the P2 Amplifier is at least 30,000, is nominally 80,000, and is actually adjustable. Its output potency is ± 1 milliamperes at ± 10 volts, and its output impedance is approximately 3.9 kilohms for open loop.

The relatively rather modest pass band of this amplifier is typically 75 kcps for small signals and 800 cps for full output swing. In applications requiring greater speed, recourse may be had to AC amplifiers operating in parallel paths to a common output.

An internal adjustment is provided for the DC input voltage offset. This offset remains below 5 millivolts in the temperature* range from 20° C to 45° C. The isothermal offset drift is 20-50 microvolts for ½ hour, and typically 100 microvolts per diem. Noise referred to the input is normally 1-3 microvolts peak-to-peak, and less than 1 micromicroampere peak-to-peak, for the range from 0.1 to 2 cps. Full load power requirements are 16 milliamperes at 15 volts, and 12 milliamperes at −15 volts DC.

(*) In production testing, each unit is cycled twice daily for at least five days through the temperature range from 65° C to −10° C. There is now good reason to believe that alternative versions of the P2, based on the same distinctive principle, can be produced for extended ranges of temperature, as well as for higher speeds and powers, etc., so that it may pay to keep in touch. Philbrick will be delighted to hear of specific needs for such other ranges and capabilities.



MODEL P5 CURRENT BOOSTER AMPLIFIER

Heavier output loads may be driven by the P2 Amplifier described above, through the interpolation of the P5 Booster between the P2 Amplifier output and its intended load. In such instances it is customary and heartily recommended to derive the feedback voltage from the Booster output rather than from the P2 output directly.

The P5 Booster Amplifier will comfortably supply ± 20 milliamperes at ± 10 volts, or ± 10 milliamperes at ± 11 volts. Its current gain is 50-100 times, and it will reproduce an input voltage to within 5 per cent or better at its output. Thus it can make the impedance of any load look 30 to 100 times larger as seen by the output of any amplifier being assisted or augmented by the boost.

Ordinarily the P5 Booster introduces negligible phase shift or other adverse dynamics into the local computing loop of the P2. Conversely it will not speed up the operation of a P2 Amplifier working within its rating into a resistive load, but the Booster will obviously enable faster charging of a capacitive load.

MODEL P65
DIFFERENTIAL OPERATIONAL AMPLIFIER

The octal plugs and sockets of the Age of Thermionics are giving way inexorably to the edgewise connectors of circuit boards which carry semiconductors. Receptacles for such connectors have beome widely standardised and reliable. For the Model P65 Amplifier and its companions, Philbrick's Design Department furnished the plated steel casing shown above.

Simplicity, versatility, and reliability are claimed for the Model P65 Amplifier. Built entirely of silicon transistors, it operates successfully from −25° C to 85° C, and offers wide bandwidth, low voltage noise, low power consumption, and low selling price.

The DC open loop voltage gain is characteristically 20,000, and minimally 10,000, with a 10 kilohm load. At room temperature, the DC current gain is typically 400,000. Those who care for such facts may enjoy knowing that the transconductance of the P65 is greater than 1 mho, or 2 mhos typically.

At small signal amplitude, the unity gain bandwidth exceeds 1 mcps. For full output signal, the upper limit is about 10 kcps, corresponding to 600 millivolts per microsecond.

The nominal output range of the P65 is ± 11 volts and more than 1 milliampere may be delivered at ± 10 volts. The nature of the output is that of a current source.

A multiturn potentiometer, accessible through a small hole in the top edge of the case, permits adjustment of the input voltage offset to zero, or to some other point near zero if desired. Drift of this offset in time is below 10 microvolts for ½ hour, and below 50 microvolts per day. Typically the change in offset over the full operating temperature range is 3 millivolts, and assuredly below 10 millivolts. The input current offset is below 0.1 microampere for either input at room temperature. This changes with time by less than 0.001 microampere in ½ hour, and less than 0.01 microampere in a day. Over the temperature range, it may change 0.15 microampere.

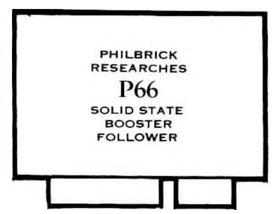
The common mode input impedance is nominally 10 megohms, and the differential input impedance about 150 kilohms. A generous ± 10 volts is permitted for the common mode range of freedom, and the input mismatch of common mode error over this range is 0.1 per cent. As to noise, the room temperature voltage contingent thereof is under 10 microvolts.

Power supplied to the amplifier should be ± 15 volts, and should of course preferably derive from a good regulated supply such as those shown on a previous page, although the amplifier is not terribly fussy. Batteries are feasible also, since each amplifier takes only 4 milliamperes at most. Parallel operation of many amplifiers presents no problem.

Physical dimensions are 2¼ by 1½ by ¾ inches, not including the protruding edge connector. A standard receptacle is normally supplied. The weight of the amplifier is 2½ ounces.

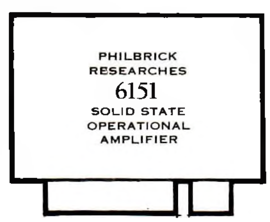
A great many customers have already applied a great many P65 Amplifiers in a great variety of operations for measuring, computing, and process controls. A number of forms and philosophies of assemblage might also be enumerated, of which only one example is seen in the description on page 2.

You can use the P65 to isolate, add, scale, integrate, and amplify. As an instance in the nonlinear realm, it will serve as a bounded voltage-comparator, with or without hysteresis. Used in pairs and triplets, it will enable "open circuit" differential measurements, converting either to single ended or differential readouts for further processing. Although it will not match the input impedance of the P2 Amplifier or its common mode indifference, the P65 will run hotter and is not as dear. No harm in asking Philbrick about your problems and plans.



MODEL P66 CURRENT BOOSTER This companion piece plays a role for the P65 Amplifier precisely like that played for the P2 by the P5, affording up to 20 times the output power. Electrically, the P5, P66, and PP66 are identical.

MODEL 6151 DIFFERENTIAL OPERATIONAL AMPLIFIER This Amplifier, built in the form of the P65, is similar in concept and function but is relatively refined as to input impedance, current gain, and current drift, sacrificing to some extent the voltage gain and the input voltage precision. It is aimed at applications such as low-current measurement, integration, and isolation, not completely matching the P2 in these regards but being smaller, faster, more economical, and more heat resistant.

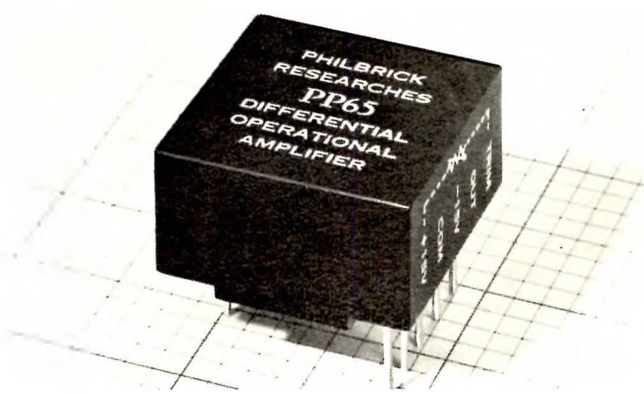


The nominal voltage gain of the 6151 Amplifier is 10,000 (at least 5,000) with a 10 kilohm load. Its current gain, however, is typically 10 million at room temperature. The transconductance is 1 mho typical and 0.5 mho minimum.

Voltage drift of the 6151, referred to the input, is less than 50 microvolts per hour, and less than 250 per day. Temperature over the full operating range affects this voltage error by less than 20 millivolts. The room temperature input current is below 0.05 microampere, and changes at most 0.0001 microampere per half hour, or 0.001 microamperes per day. Over the operating temperature range, this current varies 0.015 microampere.

The input impedance is characteristically 2 to 4 megohms differentially, and more than 100 megohms in common mode.

Otherwise the 6151 is very much like the P65 Amplifier.



MODEL PP65
DIFFERENTIAL OPERATIONAL AMPLIFIER

Take the basic circuit of the popular P65 Amplifier described above, imbed it in a rectangular block of epoxy resin as pictured here, and it may be wired directly, as an integral component, onto etched circuit boards of any variety. This unit weighs under an ounce, and occupies less than $\frac{4}{5}$ of a cubic inch of space.

The resistive input voltage trim adjustment is not made internal to the PP65, but is intended as an external (or even remote) feature in cases where it is required at all. Such treatment of the trim is, in fact, preferred by many users in the interests of flexibility and reliability.

The tinned connecting leads, which are shown clipped off in the above portrait, are spaced on a standard 0.1-inch grid pattern. An approved step construction, also visible above, alleviates the tolerances on board drilling or punching, affords same-side test points, and eliminates capillary moisture build up.

Among the indirect advantages of this form of packaging, aside from indestructability and close packing, is the notable reduction in thermal influences under operating conditions. This is traceable to the quite evident thermal isolation as such, and to a marked reduction in temperature differentials from external causes.

Temperatures up to 85° C are feasible; they may fall to minus 25° C for operating, and to −55° C for storage. The nominal voltage gain exceeds 10,000, with a differential input impedance of 200 kilohms, and an output capability of ± 1 milliampere at ± 11 volts. The common mode range is ± 10 volts, and the common mode input impedance is above 10 megohms. Input voltage offset over the temperature range is below 10 millivolts, whereas at constant temperature it is less than 50 microvolts over 8 hours. In the same interval the input current variation is less than 0.01 microamperes.

The gain-bandwidth product of the PP65 exceeds one mcps for small signal, while full output swing obtains up to 10 kcps. Maximum power required is only ± 4 milliamperes at ± 15 volts, so that even portable use is convenient.

If more output current is required, up to 20 milliamperes of either polarity, a booster unit (called Model PP66) is available in a matching package. This latter unit is *electrically identical* to the P66.

MODEL SP656 CHOPPER-STABILIZED
OPERATIONAL AMPLIFIER

This brand new model is offered to supply the demand for a compact, single-ended, chopper-stabilized amplifier. The corresponding vacuum tube models are Philbrick USA-3 and USA-4JX, which have served very successfully in the conventional 100-volt categories. With all silicon semiconductors, its temperature range corresponds to those of the P65 and PP65 amplifiers. Over the working temperature range, the input offset is less than 50 microvolts, while the 8-hour drift is less than 1 microvolt. The DC voltage *gain exceeds* 50 million, and is more typically 200 million. In the low frequency band, from 0.1 to 2 cps, the input noise peak-to-peak is about 20 microvolts, dropping to 10 microvolts above 2 cps, while the input shunt resistance varies from 440 kilohms at DC down to 100 kilohms. The DC input current at balance is below 10 micromicroamperes.

The SP656 Amplifier will drive loads up to ± 15 milliamperes at ± 10 volts with good efficiency, the quiescent demands being about 6 milliamperes on the ± 15 volt supplies.

Mechanical protection is afforded by a larger version of the special exoskeletal case which is characteristic of the P65 and other amplifiers described above. A 15-terminal edge connector mates with a standard type of receptacle, normally supplied. Optionally available is a special combination socket and hold-down which will permit either horizontal or vertical installation.

This amplifier is looking forward *expectantly to* service in a number of crucial instrument and computing applications. Its dimensions are $3\frac{3}{16}$ by $2\frac{3}{8}$ by $1\frac{1}{2}$ inches.

THE LIGHTNING EMPIRICIST

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