

THE LIGHTNING EMPIRICIST

Advocating electronic models, at least until livelier instrumentalities emerge

Volume 12, Numbers 3 and 4

July — October, 1964

MODULARITY, MEDIEVAL & MODERN

While Beauty and Modularity are not mutually exclusive, some of the most beautiful structures are only mildly modular. Among man-made structures the farmer's stone fence, of variegated boulders and rocks, perhaps partly tumbled, may speak with sufficient eloquence for all the others in this regard. In untrammelled nature herself, what with trees and rivers and mountains, still milder modularities are evident; yet she gets along wonderfully so, and we are more than content with her patterns and paces. But in the town the stone fences give way to brick walls, based on units more nearly the same size. On the sides of houses, the doors and sashes and window panes are as often as not interchangeable, if minor mismatches may be overlooked. Inside, modules of furnishings are increasingly irresistible to householders and designers. Phonograph discs, sheets of foolscap, lamp bulbs and no end of other sundries come in devoutly standardized dimensions. For many generations the trend has been manifest, to the despair of some who foresee its ultimate Procrustean influence on our selves and souls, and who seek relief in departures from such regularity. Houses, of course, are nothing as compared with hotels and hospitals and factories, where implements and machinery carry the trend to somewhere near its logical limits.

On a smaller scale, however, nature already outdoes us in modularity, for in the downward progression through cells, molecules & atoms to the fundamental particles themselves, the absolute extremes of sameness appear to be attained, accompanied by the policy of assemblage in integral multiples. Crystals could hardly be more modular. Electricity counts itself in discrete electrons: each one matching every other, except for certain chaotic indeterminacies of action. So don't blame engineers if their blocks are repetitious — if their practicality breeds monotony. They merely emulate the ultimate in natural fine-structure. While further you may privately feel that engineers should spurn Beauty, you will probably agree that they frequently achieve it accidentally. More to the point: handsome is as handsome does!

Most of this loose harangue has revolved about the modularities of dimension alone; there is also the modularity of function to consider. System people in general, and instrument people in particular, implicitly recognize this functional discipline in their block diagrams and informational flow graphs. It is central, in fact, to the operational philosophy of computation and synthesis that transformations both temporal and functional, and of any complexity, may be built out of a group of standardized basic operations arranged in sequences and loops. Minimizing the number of types of such modular operators is a big part of the game. Getting flexibility plus simplicity is the way to score. There is still room for several competing doctrines on just how this game should best be played, and on to what extent the modularity of dimension should interlock with that of function. It has been our belief for many years that the two should be carried along quite closely together. Our development programs have reflected this tenet, and they will most likely continue to do so.

It is evident in the evolution of analog machinery specifically, that such machinery is being applied to an ever

increasing variety of purposes: not just to computation and simulation in the design laboratory, but to testing and to monitoring of experiments, to manufacturing and to controls. The economies and the usefulness of this powerful methodology will be sharply augmented if its services are available in the framework of modular components which can serve *all* the above applications. Just as operational amplifiers are common to most analog instrumentation, and in fact partly for this reason, it follows that more comprehensive unit-operators, in standard modular forms, will soon be quite universally recognized as general purpose tools to be applied in appropriate combinations and arrangements to the growing list of jobs to be done.

In the electronic industry, notably in its large communications branch, a very well entrenched sort of modular doctrine has been in evidence since rather early days. This is the associative and structural convention embodied in the well-known *relay rack* assemblages: combining a standard 19-inch width and vertical multiples of 1.75 inches. While there are established variations on this dimensional convention, it is by far the commonest. Though trite, this doctrine of the rack will not soon disappear, even though thermionics yielded over completely to the solid state tomorrow. To overlook it in instrumental planning would

be foolhardy. Most bench-borne instruments, for example, seem eventually to spawn rack-borne equivalents, on customer demand. Recognition of this eventuality, in terms of compatible modularity, seems much the better part of valorous projection.

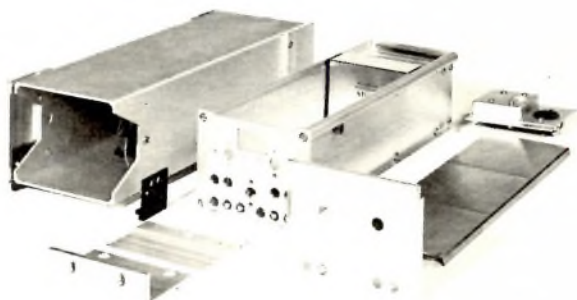
In a short-form catalog currently issuing, and in the remainder of this Lightning Empiricist, we are introducing a novel philosophy of modular packaging designed for the New Instrument Era. We shall apply the code designation "Q3" for this structural innovation, with appropriate qualifying and specializing suffixes and prefixes for individual modules. It is founded on a matrix of receptacles which may in principle extend to any desired height or width. The modular unit of height is 3.5 inches, which, taken together with the fact that four horizontal units fit neatly into the standard relay rack, permits complete compatibility with the latter structural convention — without at the same time being in any way restricted thereby. Thus we offer freedom under law, with an extremely rigid and rugged yet completely adaptable and flexible containing assemblage into which slide precisely the similarly rugged individual modules. Service connections, for power and so on, are automatically afforded by uniform pluggery at the rear. Signal connections may be made either at the back or on the modular front panels. Operating adjustments are enabled on the front of, or in some cases inside, the various modules.

The Philbrick Q3 packaging development, which has been in preparation for several years, has a number of unique (and some surprising) advantages, which are already being exploited locally. It is expected to revolutionize custom apparatus, for example, and to enable us still better to serve those who have learned (in growing numbers) to come to us for understanding and sympathy and analog instrumentation.



THE Q3 MODULAR PACKAGING SYSTEM

Interestingly enough, this purely mechanical development, the Q3 modular packaging system, has been our most significant recent contribution to the electronic art. Although the Q3 development is in itself non-electronic, in an electronic system nothing so influences, so enhances system reliability as does mechanical design and construction. And certainly the same can be said for the flexibility found in modern analog systems. The trick is to make it strong and handsome, yet through ingenuity of design keep it economical in mass production. All this assumes, of course, that we have shown ordinary good horse sense in the design of the electronic circuits and purchase of their components so as to assure topnotch reliability. We take this for granted only because we work hard at it.



The basic Q3 package is a module which can be thought of as 13 in. long cell cut from rectangular extruded aluminum tubing (4.2 in. wide x 3.5 in. high) into which a standard Q3 chassis slides on 4 rails. These cells are extremely rigid and may be permanently joined together to form any desired sized honeycomb of rectangular cells for bench-top use. Also they can be stacked in locking fashion without being joined together. If, in the horizontal dimension, the honeycomb is 4 cells wide, it can be rack mounted, even if it is only 1 layer high. Each and every cell consists of solid aluminum shell cut from our own special extruded rectangular tubing into which the Q3 modular chassis slides on its 4 rails.

After a Q3 modular chassis is inserted into a Q3 shell, as it slides home, the two 24 pin hermaphroditic connectors on the rear mate with the two on the back plate of the shell. Each terminal can be wired separately, *then inserted* into the connector! Also it can be removed (with a simple hand tool) and replaced; best of all, the user need insert *only* those terminals he needs.

A concealed ball bearing latch locks each chassis into place automatically as it is pushed home; insertion force required is extremely small. Unlatching will automatically pop the chassis out almost an inch for easy access. The sweet operation of the hidden automatic latch mechanism is one of the delights of the Q3 system, especially considering that it does not diminish the available space on the Q3 chassis.

Explosion proof versions of Q3 packaged systems can be furnished on special order. However, on these, gaskets are provided and the latch mechanism removed; the Q3 chassis being retained instead by screws.

The degree of thermal, electrostatic, and magnetic shielding afforded by the honeycomb of solid aluminum

shells is one of the real joys of the Q3 system to the designer-user. Thermal conductivity through the honeycomb is so good that isothermal operation is approached for most practical purposes. Provision is also made for operating any honeycomb as an oven. Each cell's shell has concave corners on the 4 edges running its length to provide channels for the insertion of heating rods. This gives splendid distribution of heat input whenever it is desired to control the temperature.

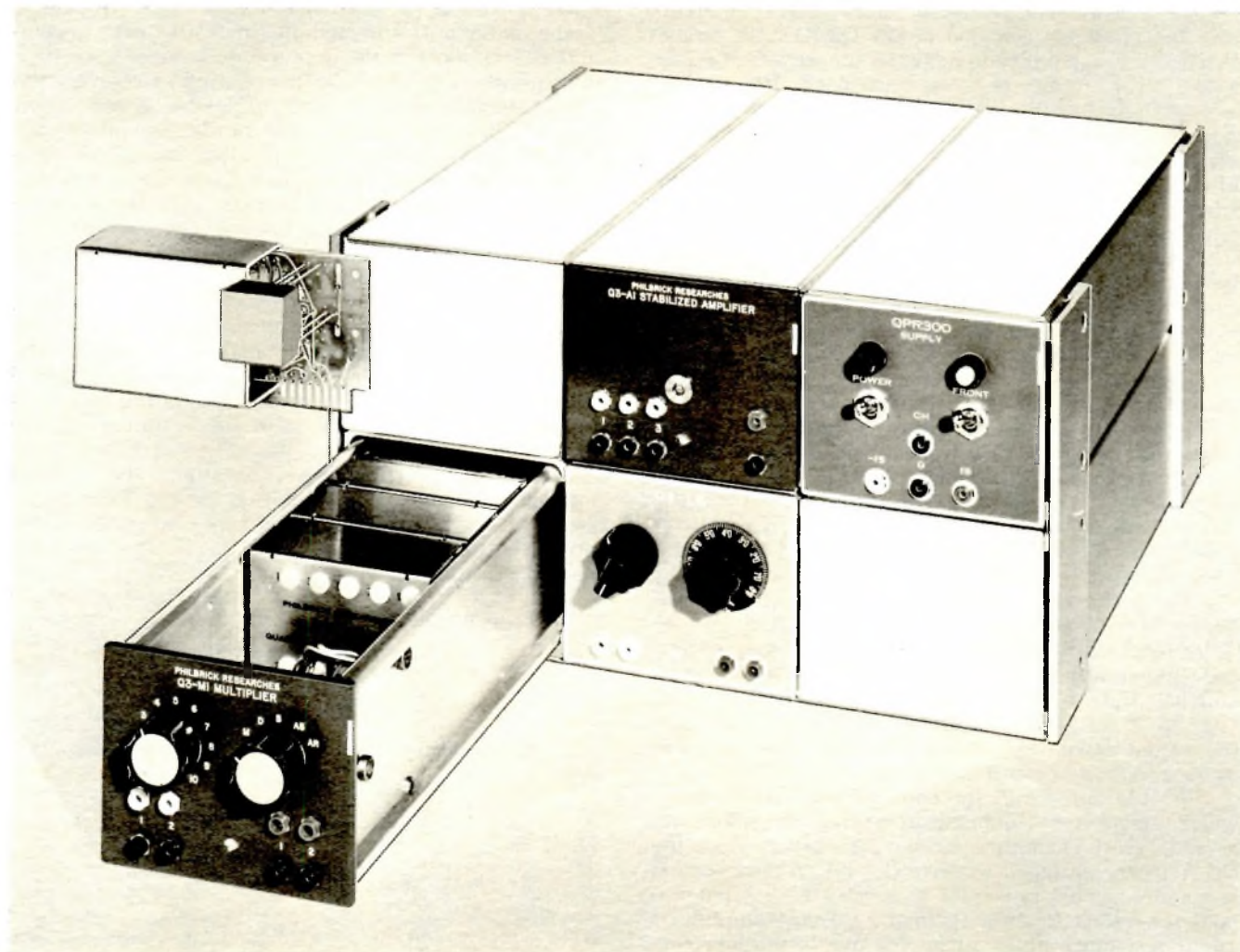
A very broad range of potential Q3 users now exists, from lone biologists assembling their own electronic instrumentation for an experiment all the way to hardened teams of engineers designing instrument systems for production. Useful to all as needs arise are the many Philbrick instruments in Q3 modules available from stock, e.g., the QPR-300, a reference grade 300 ma dual (± 15 vdc) power supply, or the Q3-M1P, a self powered, accurate wide band multiplier-divider-squarer-rooter, or the Q3-A1P self-powered universal amplifier, or any of a number of others. Equally important is the availability of many pre-packaged circuits mounted in our standard housing used for the SP656 amplifier. This is designed to fit exactly (height and width) crosswise into a Q3 chassis. For instance, the SPR-30, a 30 ma dual (± 15 vdc) power supply (transformer separate) is available; so also are the PSQ-N and PSQ-P, quadratic transconductors, and many others including electronic switches, log converters, groupings of 4 small operational amplifiers, etc. will soon be available.



To further encourage the diverse users of analog components to embark on Q3 adventures, particularly in terms of building their own analog circuits into Q3 modules, we are making all Q3 modular hardware available from stock, ready for immediate shipment at all times.

This includes all manner of pre-punched standard Q3 chassis and front panels as well as several designs of blank ones; naturally it includes all connector hardware, latches, brackets of all types, etc. Side panels and related hardware are interchangeable — no rights or lefts. All fastenings are vibration-proof, either by lock washers or "Nylok" screws. A variety of front

panels are available: blank, but pre-punched for such applications as mounting a small patch board; mounting a meter on about half the useable area; mounting up to 8 thumb-wheel operated rotary selector switches with numerical indication; and many others. In fact, Q3 parts and pieces are evolving steadily, a continuing development project.



MODEL Q3-A1P

The Q3-A1P is a uniquely flexible self-powered operational amplifier complete with a concealed, shielded "patch board" and it arrives ready to work. It can bring to life just about every circuit application, linear or non-linear, of which one dreams for an operational amplifier. As implied by its model number, it is wholly self-contained in one Q3 modular chassis, which includes its interconnection panel. This chassis, in turn, slides into a standard Q3 housing, which can be either a single bench top unit or one modular cell of many in a Q3 system. The outside dimensions of the standard Q3 housing are 4.2" w x 3.5" h x 13" l exclusive of control knobs protruding from the front panel.

The actual operational amplifier used in the Q3-A1P may be any of the SP series of plug-in amplifiers, but the SP656 is supplied as standard equipment. The

self-contained power supply is an adjustable Model SPR-30, capable of supplying 40 ma at ± 15 vdc. This leaves a substantial amount of current available for the user's other circuitry, the exact amount depending upon how the amplifier's output is employed. The space normally available for the user's components is $5\frac{7}{8}$ " l x $3\frac{3}{8}$ " w x $2\frac{1}{8}$ " h, a rather luxurious allowance for plug-in computing elements. In addition, the patch bay contains another edge connector, already wired to accept a number of standard circuits packaged identically to the SP656. A typical example of such packaged circuits is the PSQ-N Quadratic Transconductor, available from stock, also described in this issue. A fully-encased SP-size plug-in uses up about a quarter of the compartment; three quarters of the original space is still available for other components. Fitted out with a PSQ-N, the Q3-A1P is now ready to do high accuracy squaring or rooting, depending on where the user plugs in one jumper and one resistor.

As with all basic Q3 modules, two 24-terminal connectors are provided on the rear so that all inputs, outputs, and services can be handled there (with many spares). In addition, inputs and outputs are available through jacks on the front panel. All electrical circuits are floating, fully insulated from the chassis and housing so that physical ground can be tied in remotely, if desired, and even operated at a voltage different from the electrical common of the Q3-A1P. In larger systems, this capability is generally a necessity if noise in low level circuits is to be minimized. If isolation between physical ground and power ground is not wanted, physical ground can be connected to electrical common ground by inserting a standard shorting plug into a pair of jacks provided on the patch panel. Zero balance is accomplished by a front panel screw driver adjustment.

The Q3-A1P features an internal bound circuit to prevent driving the amplifier accidentally into voltage saturation. These bounds are set to permit the output to swing to $\pm 10\text{v}$ with no degradation of performance. However, when the output exceeds 10v the bound circuit begins to reduce the gain rapidly, reaching essentially zero gain after 11v is passed. In this way, the amplifier proper never reaches voltage saturation, hence the "recovery time from overload" is measured in microseconds. To warn the user that the unit is on the threshold of overvoltage, an indicator is provided in the form of a red flag which appears in the little arrow-shaped window in the lower middle of the front panel.

The performance specifications are essentially those of the SP656 (or other amplifier substituted for it). Gain bandwidth product is typically 3 megacycles, drift is generally under 1 microvolt at room temperature and less than 10 picoamps, average "dc", noise from "dc" to 10 kc is usually under 3 microvolts rms, and the output capability exceeds 15 ma at $\pm 10\text{v}$ with full swing capability of well over 10 kc.

In addition to all the conventional operations of which single-ended chopper stabilized amplifiers are capable, there is another unusual application which the Q3-A1P was designed to perform, and no modification is required. This is service as a very high input impedance voltage follower (gain of $+1.000000$ amplifier). Input resistance apparent is well over a million megohms, consisting primarily of the insulation leakage of the diallyl phthalate input jacks.

Q3-M1P MULTIPLIER

The literature of the analog art is strewn with partisan arguments proclaiming the virtues (?) of numerous analog multiplying schemes. Through the years we have been active in this controversy, pioneering both "quarter-square" and "triangular-wave" techniques. Quiet contemplation of this continuing dialogue forces us to one essential conclusion: the seemingly never-ending proliferation of new circuits demonstrate that the problem's solution has not yet arrived and, indeed, will not until "the state of the art" has advanced to stages now existing only as concepts. Rather than make a premature revelation of our own convictions of what that new state of the art will be, we are, in the Q3-M1P, refining a classical approach, the quarter-square technique, whose demonstrated

advantages are versatility, simplicity, accuracy, wide bandwidth and reliability.

The "quarter-square" multiplier is so named because it utilizes the algebraic identity:

$$xy = \frac{1}{4} [(x + y)^2 - (x - y)^2]$$

This identity could be exploited by connecting non-linear elements (e.g. PSQ-P and PSQ-N Quadratic Transconductors) and summing networks with uncommitted amplifiers in the appropriate manner each time multiplication or division is required. However, the usable performance of such a flexible arrangement depends not only on the skill of the assembler, but also on such *fortuitous*, and often *unreproducible*, factors as the relative location of the various elements, patchcord length and orientation, etc. In contrast, the Q3-M1P is a committed but still flexible structure, engineered for optimum static and dynamic performance without superfluous gadgetry, in a compact, portable and ready to operate package. Designed as one of a comprehensive series of modules oriented toward general and special-purpose analog computing, the self-powered Q3-M1P Multiplier is capable of accurate, high speed multiplication, division, squaring and rooting. It is equally at home as a single unit or as one module in a system.

Without patching or calibration, the desired mathematical operation is chosen by two front panel switches, one controlling the internal configuration, the other controlling the scaling voltage E. The functions performed are:

- (1) Multiplying (M)

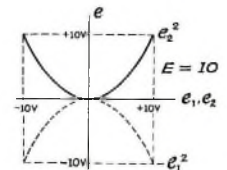
$$e = - \frac{e_1 e_2}{E}$$

- (2) Dividing (D)

$$e = - \frac{e_1 E}{e_2}$$

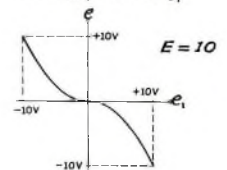
- (3) Squaring (S)

$$e = - \frac{e_1^2 - e_2^2}{E}$$



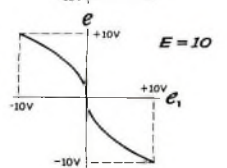
- (4) Ab-squaring (AS)

$$e = - \frac{e_1 |e_1|}{E}$$



- (5) Ab-rooting (AR)

$$e = - \frac{e_1}{|e_1|} \sqrt{|e_1| E}$$



where:

- e output voltage, $-10\text{ v} \leq e \leq 10\text{ v}$
- e_1 input one voltage, $-10\text{ v} \leq e_1 \leq 10\text{ v}$
- e_2 input two voltage, $-10\text{ v} \leq e_2 \leq 10\text{ v}$
- E arbitrary scaling voltage 0, 1 v, 2 v, . . . , 11 v

Model Q3-M1P is small in its demands and large in performance. Provide it with one or two input signals (anywhere between $+10$ v and -10 v) and small (under 5 watts) amounts of line power (115 v $\pm 5\%$, 50-400 cps), then tell it what to do (multiply, divide, square, ab-square or ab-root), and it will perform accurately (typically $\pm 0.1\%$ of F.S. as a multiplier at 25°C) over large dynamic (5 mv to 10 v at output), frequency (large signal: D.C. to 50 Kc/s; small signal: D.C. to 300 Kc/s for -3 db) and temperature ranges (T.C. ≈ 100 ppm/ $^\circ\text{C}$ from -25°C to $+85^\circ\text{C}$) while, at the same time, emancipating the operator from tangles of patch cords, plugs, pots, push buttons and similar paraphernalia that distract from the primary job of computing and controlling. In addition, it will do this without breaking either your bank book (\$995 — in small quantities) or your back (weight: 5.3 lbs. as a module, or 8.3 lbs. complete w/line cord and aluminum dress case).

For those interested in grand schemes, the Q3-M1P fits four abreast in a standard 19 in. rack, can be removed without disturbing adjacent modules either mechanically or electrically, needs no special ventilation, can be stacked to any height and oriented in any position. All input and output signal terminations are available on both front and rear panels via reliable connectors. Mating connectors are available as standard catalog items not only from Philbrick but from other nationally known manufacturers (Pomona and AMP). Also included on the rear panel connectors are line power input, signal grounds, and a signal from the output amplifier's bounding circuit suitable for driving a remotely located warning circuit.

The Q3-M1P output (source impedance is less than 1Ω at frequencies < 1 Kc/s) will drive anything from no load to full load (1 K Ω paralleled by 1,000 pF) over the entire specified frequency and voltage range with negligible changes in amplitude or phase shift (10° for F.S. output at 50 Kc/s). The combined use of a short circuit-proof amplifier and a load isolating resistor provide an output amply protected against catastrophic shorts to ground, ± 15 v power supply buses or similarly stiff points. In addition, input impedance is high enough (40 K Ω in parallel with 50 pF or 20 K Ω in parallel with 100 pF, depending on which input and/or mode is used) to allow parallel operation from a single source such as another Q3-M1P without buffers or power amplifiers.

The elegant packaging of the Q3-M1P is not intended as a trivial exercise in sophistication. All critical components are hermetically sealed or coated for maximum reliability and stability. With the exception of the front panel controls and a portion of the power supply, all components are then mounted on plug-in sub-assemblies which are further coated with a humidity sealant and then entirely enclosed for maximum electrical and thermal shielding. These are then plugged into connectors (featuring redundant electrical contacts) in the basic Q3 module which, when buttoned tight and inserted into its extruded aluminum shell, provide further protection. This combination of maximum reliability with maximum interchangeability thus provides welcome relief for those responsible for the maintenance of systems, large and small.

QPR300, etc.

Over the years, a cardinal point in the Philbrick philosophy of system design has been use of power supplies sufficiently precise to serve the system as its reference voltage as well as its source of power. A related point of long tradition in the Philbrick philosophy of circuit design is to place much emphasis on low current drain, low to a degree that is unusual compared to typical analog practice. This stems as naturally from our reluctance with regard to blowers as from the frustrations caused by temperature gradients in precise circuitry.

But we are just Yankee enough to observe also that the share of power supply cost for a given analog operation is generally low for Philbrick circuits in spite of the use of reference grade power supplies. Low current drain becomes an eminently practical area in which to invest much extra design effort: to reach for extra ingenuity. In the present solid state era, our pursuit of this objective appears even more important as performance goes up while size decreases dramatically, particularly size required for complex instrument systems. Finally, meeting the general requirement of 85°C intensifies this pursuit still further.

The QPR-300 is actually a PR-300 type supply built on a Q3 chassis. These supplies embody the foregoing philosophy, pursued to a degree which will delight the systems designer. First of all, rated output is 300 mA at ± 15 VDC, which is sufficient to power 8 Q3-M1 multipliers, or 25 type SP656 operational amplifiers in typical Q3 system service (or over 30 lightly loaded), or 50 small amplifiers of several types. At full load, placed alone by itself on a bench (with no chance to transfer its heat to a Q3 honeycomb framework), it still has only about 5°C temperature rise, just perceptible to the touch.

More important to many users is the QPR-300's degree of precision and freedom from noise of all types. In the PR-300 and QPR-300 the effects of line regulation, load regulation, ripple, and noise of all types, all combined, amount to roughly 10 parts per million. Furthermore, viewed at the regulating tie points, recovery from a 50 mA step change in load current requires only about 50 microseconds. They are capable of holding their output to within 0.01% day after day under typical laboratory conditions, which includes say a temperature range of 70° to 85°F . However, all Philbrick solid state supplies of recent vintage will operate satisfactorily over a range of -25°C (-13°F) to $+85^\circ\text{C}$ ($+185^\circ\text{F}$). Errors will, of course, be larger over such ranges, but even so the output voltage of the QPR-300, PR-300, etc. will typically vary less than $\pm 0.1\%$. These variations are due primarily to the reference diode.

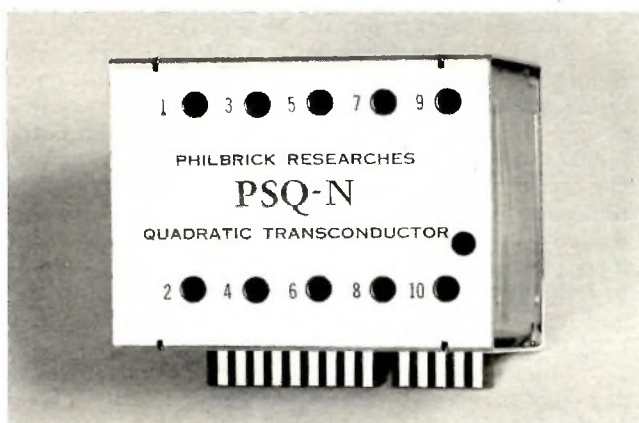
The recent use of these supplies by our own Standards Laboratory as the company's voltage standard may be of more than just passing interest, especially to those concerned with precise electrical measurements. Two PR-300's have been sent periodically to an outside independent instrument calibration laboratory maintaining direct traceability of their voltage standards to the National Bureau of Standards, certifiable to $\pm 0.004\%$ absolute for either the positive or the negative side of either PR-300. This project has been underway only a few months, but so far there is no evidence of a trend in the observations.

CHARACTERISTICS and APPLICATIONS of STANDARD NONLINEAR TRANSCONDUCTORS

IMPEDANCE AND ADMITTANCE TRANSFORMATIONS using Operational Amplifiers

II. Standard nonlinear transconductors

Used with an operational amplifier, a nonlinear Transconductor produces at the summing point a current that bears a functional relationship to one or more applied input voltages. The Transconductor may be used in the forward path to produce an output dependent on the function embodied, or it may be fed back to obtain the inverse function. Transconductors of the type discussed here are generally *single-valued* with respect to the amplifier output, but there is no conceptual limitation on the use of somewhat more sophisticated Transconductors for multivalued outputs when the natural phenomenon simulated is itself multivalued.



The Transconductors discussed here are considered to be passive, because they do not contain operational amplifiers (but — looking ahead — it is interesting to speculate on the great versatility possible in the next generation of genuinely active transconductors). The nonlinearity of these Transconductors, simulative of smooth analytic functions, is achieved through the by now well-known technique that the Publisher pioneered originally, *piecewise linear approximation*, using biased diodes. By reversing polarity of the diodes and all voltages and currents, the *negative complement* of a function is obtainable. Elementary circuit details and examples of complementary functions are shown in the figures on this page.

The following types of standard nonlinear Transconductors are now in, or about to enter production: Quadratic (for squaring and rooting), Exponential (for logarithms and exponentials), Sinusoidal (for sines, cosines, and arcs), and Arbitrary. Most Transconductor types have built-in adjustable parameters; the range of adjustment is narrow for the fixed-purpose units, broad for the Arbitrary unit. Special fixed-purpose monotonic functions such as might be used to linearize outputs of thermocouples, bridges, or other transducers, or to provide predictable nonlinear time functions (when stimulated by predictable linear time functions) are easy modifications of the standard approach.

Exemplary Type — the Quadratic Transconductor

Containing all hermetically-sealed silicon semiconductors, these Transconductors are securely housed in exoskeletal packages similar to that used for SP656.

Shown in Figure 1 is Model PSQ-N Quadratic Transconductor, which embodies the relationship:

$$\frac{i}{5 \times 10^{-4}} = - \left[\frac{\Omega(e_1, e_2, 0)}{10} \right]^2$$

Its complementary partner, Model PSQ-P, embodies the relationship:

$$\frac{i}{5 \times 10^{-4}} = \left[\frac{U(e_1, e_2, 0)}{10} \right]^2$$

A circuit using PSQ-N as the input element and 20 K as the feedback element, with zero-centered push-pull signals applied to e_1 and e_2 , will yield the true square of the input voltage, scaled to 10 volts: (see Figure 1)

$$\frac{e}{10} = \left[\frac{e_i}{10} \right]^2, \text{ or } e = \frac{1}{10} e_i^2$$

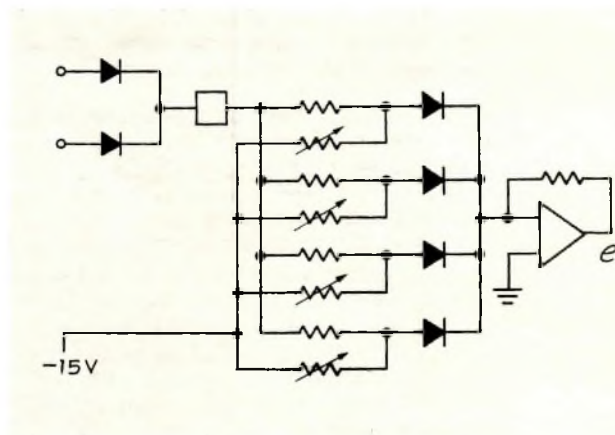


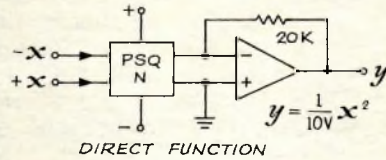
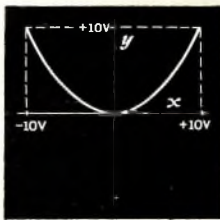
Fig. 1 Simplified Schematic
of Model PSQ-N Quadratic Transconductor

With ± 15.000 volts applied to its reference input terminals, the output of the Quadratic Transconductor squaring circuit will be within ± 10 millivolts of the true square of the input signal. The variation with temperature will be approximately 0.01 per cent (or ± 1 millivolt) per degree Centigrade, and over the range -25°C to $+85^\circ\text{C}$ the error is typically less than ± 100 millivolts. The scaling coefficient variation with power supply voltage is less than 0.01 per cent per millivolt. When $15\mu\mu\text{f}$ of capacitance is used in parallel with the 20 K feedback resistor, in circuits employing the ultrafast P45 operational amplifier, small-signal frequency response is determined entirely by the network characteristics, i.e., 45° phase shift at 500 kcps; and 10 volt square waves settle exponentially to within 10 per cent of final value within 1 microsecond.

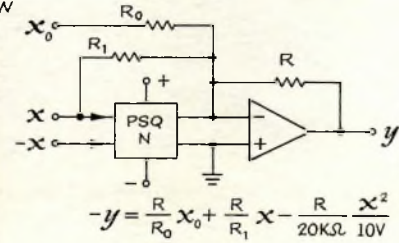
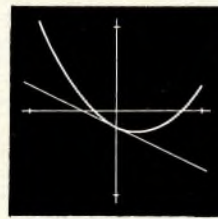
Because of the excellent accuracy and stability, fast response, and low temperature coefficient — which are typical of this entire Transconductor family — the PSQ is appropriate for nearly all applications employing squaring or rooting at less than radio frequencies. Such applications include quarter-square multiplication and division, squaring and ab-squaring, rooting and ab-rooting, vector operations, power series approximations, integrated-square, mean square, and root mean square computations.

Sales Manager's note: Model PSQ will be found to be reasonably priced. For best all-around performance, it should be teamed up with Model P45 Operational Amplifier and Model PR-300 reference-grade ± 15 volt dual Power Supply. For applications in which economy is paramount and performance specifications tolerant, the Model P65AU economy amplifier and compact PR-30 Power Supply will be found peerless.

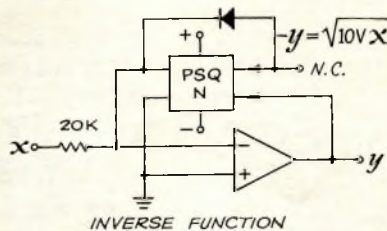
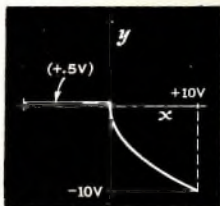
ABSOLUTE VALUE SQUARE



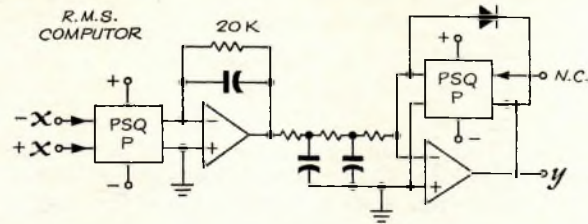
SERIES APPROXIMATION



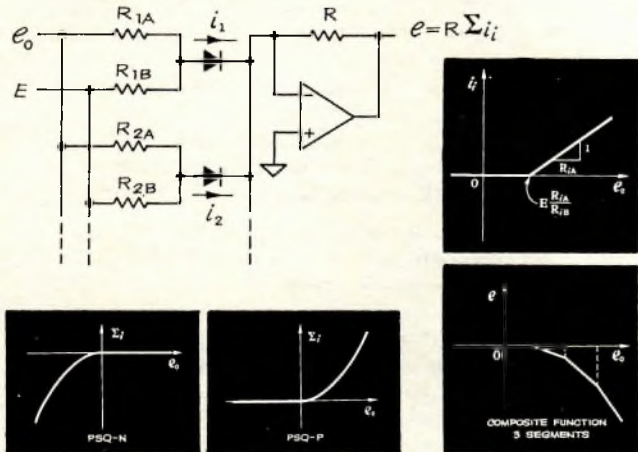
SQUARE ROOT



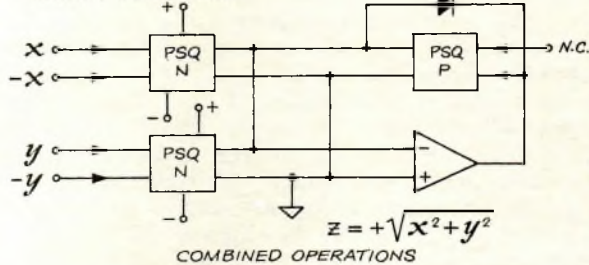
R.M.S. COMPUTER



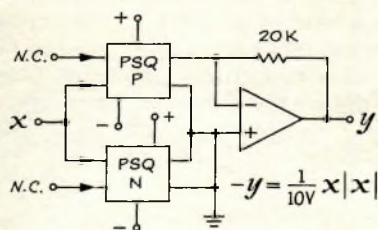
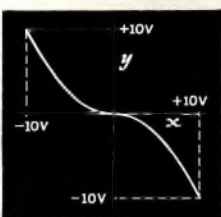
PIECEWISE LINEAR APPROXIMATIONS
PRINCIPLE DEMONSTRATED, ASSUMING IDEAL DIODES



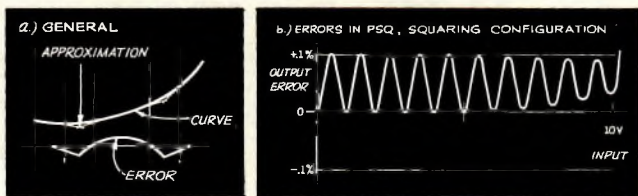
VECTOR COMPOSITION



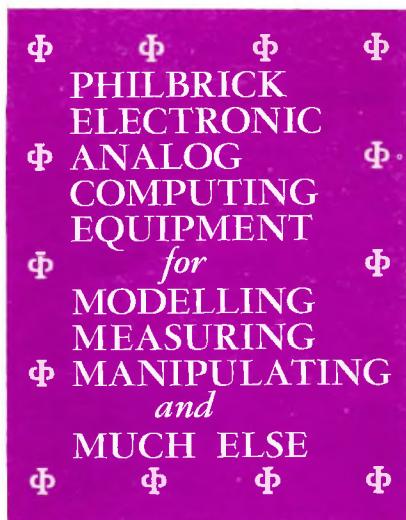
ODD VALUE SQUARE



ERRORS IN SIMULATING SMOOTHLY VARYING FUNCTIONS
BY PIECEWISE LINEAR APPROXIMATIONS (EXAGGERATED)



Some typical applications of PSQ Quadratic Transconductors



This is the cover of Philbrick Researches' new short form Catalog. You are welcome to write to our Sales Department for your copy.

BOOK REVIEW

"Generalized Instrumentation for Research and Teaching —

A Primer in the Art of Using Operational Amplifiers in General Utility Instrumentation" by Charles F. Morrison, Jr., Ph.D. Copyrighted first edition published by Washington State University Press Pullman, Washington, U.S.A. 1964 (104 Pages, Illustrated)

With increasing frequency scientists are crossing man-made "interdisciplinary lines", and the resulting hybrid technologies often succeed in advancing the "State of the Art" by orders of magnitude. This book, written by a Research Chemist, describes the application of the techniques of electronic circuits, feedback, and analog computing to chemical instrumentation and automated measurement. The author's prolog describes the scope of the work encompassed in the report:

For the past 30 months the National Science Foundation, through its Course Content Division, has supported the development of a generalized analytical (chemical) instrument. This document is a report on that development, along with an organized collection of facts and simple explanations, which we hope will enable you to discover how generalized instrumentation might aid your instrumentation program. Although the applications discussed are taken primarily from the field of chemistry, the techniques and principles could be of interest to persons in any field in which scientific instrumentation plays a part. We have attempted to: 1) reduce instrumentation to common functional blocks; 2) show ways by which these blocks may be conveniently, accurately, and inexpensively generated using operational amplifiers; and, 3) indicate how from these functions practical instruments may be synthesized for use in teaching and research.

The following Table of Contents may convey an idea of just how much ground the author essays to cover in the book's 104 pages and 185 illustrations.

TABLE OF CONTENTS

- I. PROLOG
- II. BASIC CIRCUITS — *Operational Amplifiers and What They Can Do*; Operational Amplifiers, Negative Feedback, and High Impedance Circuits.
- III. TECHNICAL CONSIDERATIONS; Offset, Drift Stabilization, Stabilized Follower, Current Booster Amplifiers, Accuracy, Open Loop Gain, Loop Gain, Frequency Response, Output Impedance, Noise, Integrator Errors, Stability of Operational Amplifier Circuits, Derivative Circuit Stability, and Bounding and Input Protection.
- IV. FUNCTIONAL BUILDING BLOCKS; Direct Coupled Amplifiers, A.C. Amplifiers, Adders and Subtractors, Integrators, Differentiators, Isolators and Followers, Switches, Signal Generators, and Current Drivers.
- V. THE DEGRADATION AND SYNTHESIS OF CHEMICAL INSTRUMENTS; A Generalized Look at Chemical Instrumentation and Choosing and Combining Analog Building Blocks.
- VI. A GENERALIZED INSTRUMENT; The Basic Concept, Circuit Philosophy, Construction Details, and Auxiliary Equipment.
- VII. TYPICAL APPLICATIONS; Potentiometric Titrators, Polarographic Circuits, Conductance Monitors, and Optical Applications.
- VIII. POSTLOG

Naturally one would not expect an exhaustive treatment of the subject in these few pages, but the author succeeds in making the reader aware of both the opportunities and pitfalls inherent in the application of analog technology, and in describing actual working instruments in sufficient detail to construct them. The book is written in an easily readable style, is commendably concise and to the point, and wastes little time (sometimes to our regret) with exploration of mathematical abstractions. It is as successful a general introduction to the application of analog techniques in chemical instrumentation and teaching as we have seen, and it is a "must" for the reference shelf of anyone interested in instrumentation for analytical chemistry, as well as the library of the analog enthusiast.

The author, Dr. Charles Morrison, is a Research Chemist with Granville-Phillips Company, Boulder, Colorado. The work described in the book was performed by him and his graduate students at Washington State University, Pullman Washington. The book is available at no charge to interested persons from the Granville-Phillips Company. Copies are also available through the Editor of *The Lightning Empiricist*.

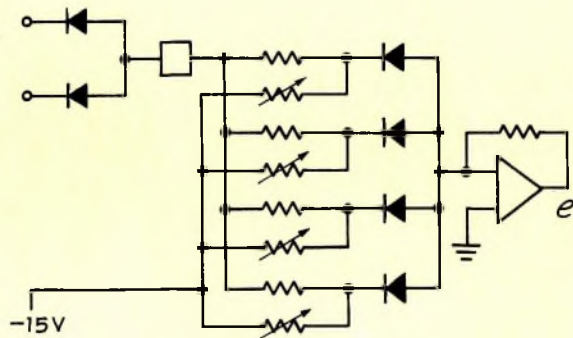
THE LIGHTNING EMPIRICIST

This is the third 1964 issue of *The Lightning Empiricist*, which is published at quarterly intervals by Philbrick Researches, Inc., at 127 Clarendon Street, Boston, Massachusetts 02116, and printed in the U.S.A. Comments and contributions are always welcome and should be directed to the Editor, *The Lightning Empiricist*.

Errata: The Lightning Empiricist Vol. 12 Nos. 3 and 4

Accuracy is a matter of passionate devotion at Philbrick, but sometimes the flames of passion seem to flicker momentarily. Two figures in this issue are incorrect as shown and should be replaced as follows:

1. For Fig. 1 on page 6, substitute the correct simplified schematic of PSQ-N shown below



2. For "Odd Value Square" on page 7, substitute the correct sketch shown below

