The Lightning Empiricist

A journal for devotees of high-speed analog computation, those enthusiasts for the new doctrine of Lightning Empiricism, publishable aperiodically and distributed without charge by Geo. A. Philbrick Researches, Inc., 230 Congress Street, Boston 10, Mass. and offering items of interest and value on such computational topics as applications, techniques, and new or improved components.

ISSUE NO. 3 GAP/R APRIL, 1956

SALES AND APPLICATIONS

GAP/R, for the first time in its history, now has manufacturer's representatives within convenient distance of every significant industrial area in the United States. Thus, GAP/R customers now have available to them, on a relatively local basis, qualified personnel to discuss with them specific applications problems. These representatives, of course, will be backed up by GAP/R research engineers and application staff.

Our first National Annual Sales Meeting was held in Boston on March 15, 1956.

The Eastern Joint Computor Conference and Exhibition, held in Boston during November, was a very successful meeting and display. The flood simulation model, in which GAP/R modular components were used, created a considerable amount of interest.

In conjunction with our manufacturer's representatives, an integrated program of sales and applications engineering is being developed. GAP/R has in Boston an extensive demonstration computing center and conference room for our visitors.

We have published for general distribution a sixteen-page brochure which describes GAP/R's operation and includes a comparison chart of our four basic types of computor Components. The characteristics of K2, K3, and KS3 installations are compared.

A comprehensive survey of our customer's requirements has indicated the need for new products and a development of some of our previous concepts. Some of these new products have now been developed and are being announced in this issue of THE LIGHTNING EMPIRICIST. Watch for other announcements in succeeding issues.

With the advent of the projected KS3 Modules there has been some tendency to refer to the predecessor, and still very much used, K3 Modules as unstabilized. This is definitely a mis-

Concluded on Page 3

FUNCTIONS — STATIC AND DYNAMIC

FUNCTION OF TWO VARIABLES

We now have in production an Electronic Generator that produces an output voltage which is an adjustable function of two independent input voltages. That is, it represents the equation

$$z = f\,(x, y)$$

in the form

$$e_x = f\,(e_x\ e_y)$$

This Generator, which might be called an electronic three dimensional cam, provides, in effect, a developed surface with adjustable slopes throughout the surface and adjustable increments for each edge function.

Typical applications include the modeling of compressor maps, machine characteristics, and the thermodynamic states of matter. By the use of one or more such Generators, the behavior of an actual physical system can be modeled to a degree of precision heretofore in the realm of wishful thinking.

The principle of operation of this Generator is a generalization of the principle that governs the operation of the Model FFR Arbitrary Function Component. This method can readily be extended to the determination of a function of three or more variables; such Generators are presently under development.

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CONTENTS

DELAY LINE SYNTHESIZERS

We now have several models of Time Delay Components and Delay Line Synthesizers assembled as modular units.

One form of Time Delay Component samples input information and releases the same information in exactly the same form after a controllable time lapse. One unit has been built with a stepless delay range from 50 milliseconds to 5 seconds adjustable by a voltage signal, provided from either a fixed knob adjustment or an arbitrary signal. Modules with still longer delays are also available.

One of the most obvious applications of the Delay Line is that of phase shifting. The need for adjusting at will the time delay arises in problems that involve transport lags such as one in which the time delay depends upon the transport length divided by the transport velocity. If this velocity varies during the process, a variable time delay is involved and must be provided without loss of signal information.

The Delay Line Synthesizer is an integral feature of the GAP/R Time Delay Component. It can be used to represent substantially any process or operation in which superposition can be assumed to hold. Each unit is constructed of five sections. Each section contains an isolation amplifier so that succeeding sections do not constitute a load on the preceding sections. The output of each section can be adjusted at will and the outputs of all sections are added together. Modules can be cascaded to produce, in effect, a Synthesizer of any desired number of sections. The operation is such that the output is a synthesized response.

Concluded on Page 3

GAP/R ALL-SPEED ELECTRONIC ANALOG COMPUTORS
The Lightning Empiricist

Again we ask — wish us luck. In issue No. 1 (June 1952) we did say that THE LIGHTNING EMPIRICIST would have only aperiodic publication, but our friends tell us that we have gone the limit in this direction. Without making a firm commitment (we must hedge somehow), we hope to release four issues during 1956. **This publication sets forth to be both a house organ and a customer organ. So that it will be read before filing, the contents must be of interest to all of our readers. We solicit requests for specific items and shall equally welcome contributions, particularly in the field of novel applications for GAP/R equipment. Such contributions can profitably include physical and electronic block diagrams as well as verbal descriptions.

**Our founder, George A. Philbrick, has now been released from purely administrative duties so that he can devote all his time and energy to creative effort in the field of electronic analog computors.

**Our present organization includes:

Administration
- Fred N. Philbrick, President
- Arnold Beveridge, V. Pres.
- John Dowd, General Manager

Research and Engineering
- Roger R. Noble, Chief Engineer

Sales and Applications
- John M. Embree, Director of Sales and Applications Eng'r'g.

Advertising
- Walter F, Nolan, Manager

Consultants
- George A. Philbrick
- Henry M. Paynter

This is a team of which we can be proud and which we are confident can answer all your questions about the application of GAP/R Modules and Modular Components to Electronic Analog Computor needs.

**The basic concept of GAP/R operational units is that they are modular components or modules. By assembling units, one can develop almost any desired Electronic Analog Computer or Operational Model. To emphasize this basic concept, we are even considering designating the units as Modules ( ) such as Module MU. What think you, dear reader?

K2 APPLICATIONS MANUAL

An *Applications Manual for GAP/R Series K2 Octal Plug-In Computing Amplifiers* has been published in response to persistent demands.

In addition to descriptions of the K2 Series of GAP/R modular components, the *Manual* contains circuit diagrams covering numerous applications of these components.

The circuits presented in the *Manual* by no means exhaust the possibilities; and it is anticipated that users will be aided and stimulated to develop applications and circuitry to meet their own problems. We welcome information and circuits of unusual applications for these useful modular components.

Copies of the *Manual* are available upon request.

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CONSOLE HOUSING

The standard relay rack commonly used to support GAP/R modular components is certainly functional. Some, however, prefer to house GAP/R modules in a setting that is both functional and also architecturally pleasing, especially when assemblies are of a permanent or semi-permanent nature.

A console housing has been found to meet the aesthetic as well as the functional requirements. Built of enameled sheet metal, it is sturdy, has pleasing contours, and is tailored to fit GAP/R modular components with little or no waste space.

Like the relay racks, these housings are sectional and as many as are needed can be assembled into a convenient arrangement. A special turret section is available to contain a 17 inch oscilloscope and to provide a writing shelf for the investigator.

Several manufacturers supply such housings. Names will be furnished upon request.

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KS3 STABILIZED MODULES

There has been a substantial demand among our customers for Operational Modules of the K3 series with a significantly lower drift rate than the present K3 Modules. The drift rate of the Operational Amplifiers K2-W and K2-X as used alone or in K3 Computor Components is of the order of 5 millivolts per day which is more than acceptable in a large majority of applications. There are certain applications, however, where a materially lower drift rate is necessary.

The projected KS3 Stabilized Modules will have a built-in scale accuracy of 0.1% or better; and drift will be held to a sub-millivolt level.

PRODUCT IMPROVEMENT

We at GAP/R are constantly seeking ways and means of improving our electronic analog computor modular units and components. Among the most recent of these improvements can be cited:

**The K2 Series of modular components is now appearing with natural tan mica filled bakelite bases instead of the black bases formerly used. We had had reports of "high grid current" in the K2-W and K2-X units. This current was found to be a leakage current (in the order of 10^{-7} amp) between pins 2 (amplifier input) and 3 (—300 v) which occurred when the amplifiers were used at above 55°C ambient temperature. The use of the new bases has reduced this leakage to the order of 3 X 10^{-9} amp even at ambient temperatures up to 85 °C.

**The Model FFR Arbitrary Function Component is the successor to the K4-FF Function Fitter, Among the improvements are:

- Higher stability
- Greater range of gain adjustment
- Quadratic rounding of vertices to provide better fitting
- Self-contained power supply

The unit contains 10 segments, 5 positive and 5 negative, each adjustable from zero to 15 v. The slope of each segment is continuously adjustable from zero to plus or minus ten times the input slope so that other than monotonic functions may be fitted.

**The Duplex Multiplier has been revised so that its accuracy is in the order of 0.2% while the long term drift has been reduced to about 20 mv per day. A switch converts the Multiplier into a Divider. This new Multiplier is designated Model MU/DV and the price is as before.

**The Models HKR and MUR units are self-powered versions of Models HK (Operational Manifold) and MU/-DV (Duplex Multiplier).

**The Model CSR variable time base Central Signal Component is a self-powered version of the Model CS component. The Model CSR supplies an adjustable Ramp, an independent Oscilloscope Sweep, an adjustable Step, a Clamp, and an adjustable DC Voltage as in its predecessor. The display is continuously adjustable timewise from 50 millisec. to 50 sec., so that a system may be^ set up at high speed and then investigated in real time or in slow time or vice versa.

Concluded on Page 3

Sales and Applications (concluded)

nomer and a more appropriate description is the K3 Standard Modules. See elsewhere in this issue for a fuller discussion.

The title block of this publication describes it as a journal for "devotees of high-speed analog computation ..." However, we wish to emphasize the pan-celeric character of GAP/R components. Phi lb rick components are electronic analog operational units especially well suited to high speed repetitive operations; but they are equally useful at medium and slow speeds. Philbrick alone offers precise computation at all speeds from the slowest simulation to the fastest repetition.

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Delay Line Synthesizers (concluded)

One of the important applications of the Delay Line Synthesizer is the investigation of arbitrary variations in process or control modes.

An interesting application is in the field of traffic flow and control, such as the dispatching of trains over a single track road, with turnouts irregularly spaced, or the timing of a complicated system of traffic lights.

Problems of heat exchange, such as the dissipation of internally induced heat from a prime mover, can be readily investigated by an Analog Computer that includes a Delay Line Synthesizer.

A very important area is that of the control of continuous process plants, particularly in the adjustment of various inputs to satisfy programmed changes in output or to maintain a stable output. Analogous problems arise in equipment mortality and replacement scheduling. All of these problems imply the solution of integral equations.

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Product Improvement (concluded)

**Model RK Power Supply has been redesigned to improve its no-load to full-load transient characteristics and regulation against line variation. The redesign has resulted in reduced manufacturing costs and the price has been reduced to $320.00.

**Precision Resistors. Wherever possible, the deposited carbon precision resistors used in GAP/R equipment are being replaced with wire wound resistors to provide better reliability and performance at no additional cost to our customers.

NEW PRODUCTS

See also all Technical Data Bulletins.

Model R100

Compound Regulated Power Supply. Regulated output plus and minus 300 vdc at 100 ma; unregulated output 115 vac at 1 amp. Price, $130.00

Model HKR

Operational Manifold, Self Powered. Contains 10 K2-W Operational Amplifiers, and Model R100 Compound Regulated Power Supply. Price, $470.00

Model F2V

Function of Two Variables. An electronic generator to represent

$$z = f(x,y).$$

(See Page 1.) Price upon request.

Model FRR

Arbitrary Function Component. A self powered (Model R-100) Function Fitter. Price, $840.00

Model MU/DV

Multiplying / Dividing Component. Becomes a high speed Multiplier or Divider by the throw of a switch. (See Page 3.) Price, $600.00

Model K2-P

Stabilizing Amplifier. Used with the K2-X and K2-W Operational Amplifiers to reduce drift to a submillivolt level. Price, $55.00

Model DLS

Delay Line Synthesizer. Can delay signals without malformation and synthesize arbitrary responses of substantially any degree of complexity, provided superposition holds. (See Page 1.) Price upon request.

LOOKING AHEAD

Watch this column for an announcement of a new Manifold Rack Shelf.

USE OF HIGH-SPEED MULTIPLIERS

With the advent of GAP/R Multipliers, enthusiasts of Lightning Empiricism have a precise and stable electronic Multiplier suitable for use in High-Speed Computors. Also some models, such as Model MU/DV, are equipped with a divider circuit so that the Multiplier is converted into a Divider by the throw of a switch.

Because this represents a significant departure from past history, we are reviewing a few of the numerous applications of this vital all-electronic tool.

Product of Two or More Variables

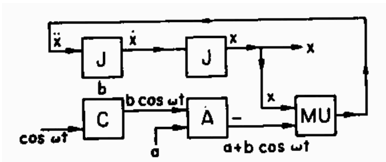
The simplest case of this type is, of course, the product of two variables, each of which can be introduced into the Multiplier as a variable voltage.

The investigation of an electrical circuit that includes a saturable inductance coil provides a typical problem. When such a coil is operated along the central portion of the saturation curve, the permeability is essentially a constant and is treated as such. When the core approaches saturation, however, the permeability and its related coefficient varies according to the degree of saturation so that a variable coefficient must be introduced instead of a constant. The performance of the magnetic amplifier is a case in point.

Another common problem is exemplified by the so-called Mathieu equation which is met frequently in the study of dynamic problems. This equation has the general form of

$$\ddot{x} + (a + b\cos\omega t)\,x = 0$$

This equation is found particularly in problems of communication and instrumentation where a system is driven or disturbed by the harmonic variation of one of its parameters. The circuit for this equation is shown in *Figure 1.*



$$\ddot{x} + (a + b\cos\omega t)\,x = 0$$

Figure 1. *Mathieu Equation*

Obviously the central role of the Multiplier in this problem is to enforce periodic variations in the restoring constant.

A third application in this area is in the use of the Multiplier as a precise instantaneous power meter. In this application, of course, the equation is of the form

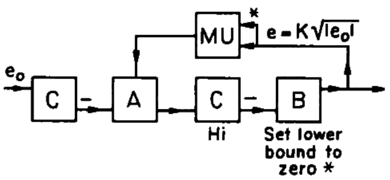
$$w = e(t) \cdot i(t)$$

Similar relations are cardinal in fluid, mechanical, and thermal power situations. In the abstract realm, such considerations give rise to correlation products, which will be considered in a later issue of The Lightning Empiricist.

Rational Powers of a Variable

An obvious application of Multipliers is the determination of integral powers of a variable.

Rational fractional powers are also readily obtained with the aid of the High-Speed Multipliers. The circuit for obtaining the square root of an input is shown in *Figure 2.*



*For ODD function rooting, insert K3-V Absolute Value Component in path indicated and release bound.

Figure 2. Square Root

A very simple application of the Multiplier in this area is again the determination of instantaneous power, this time from either of the equations

$$w = e^2 / r = ri^2$$

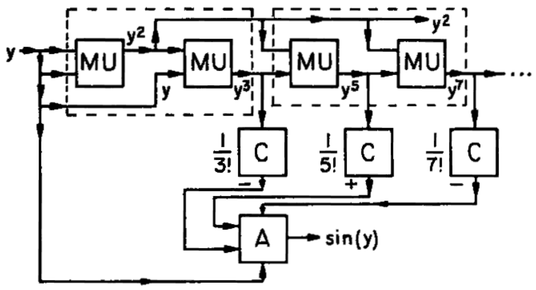
Another typical application is the measurement of the squared error in a simple servo or follower loop. As such, this procedure measures the power requirement of the servo. Also, if this squared error signal is integrated, its limiting amplitude is commonly used as a criterion or "figure of merit" for the servomechanism. Other criteria are easily instrumented by these means, *e.g.,* Integral — Time — Absolute — Error:

$$K = \int |e| \, t \, dt$$

The quality and reproducibility of the powers of the variables obtained by the high-speed Multipliers makes it entirely feasible to generate arbitrary functions through various expansion techniques. For example, a circuit to obtain the solution of an equation

$$x = \sin y$$

by means of the well known power series expansion, with terms up to the seventh power, is shown in *Figure 3.*



$$x = \sin y = y - \frac{y^3}{3!} + \frac{y^5}{5!} - \frac{y^7}{7!} + \ \ldots$$

Figure 3. Power Series Expansion

It is equally feasible to represent the same function by means of the product expansion, Legendre polynomials, or Tchebycheff polynomials, for certain classes of better fit.

Implicit Generation of Functions

Accurate high-speed Multipliers make possible integration with respect to an arbitrary variable. This is accomplished by employing the identity relationship

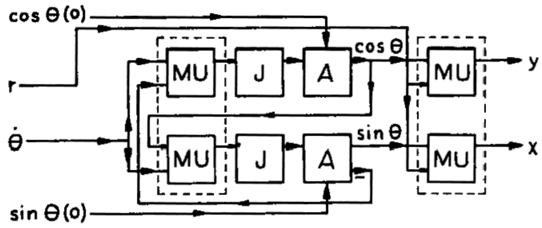
$$z = \int y \cdot dx \equiv \int y \cdot \frac{dx}{dt} \cdot dt$$

In many cases dx/dt is available elsewhere within the Computor Structure; otherwise differentiation with respect to time by a Differentiating Component will provide this signal.

A singularly interesting application of this type is to resolution and composition problems as indicated in the block diagrams of *Figures 4, 5.*

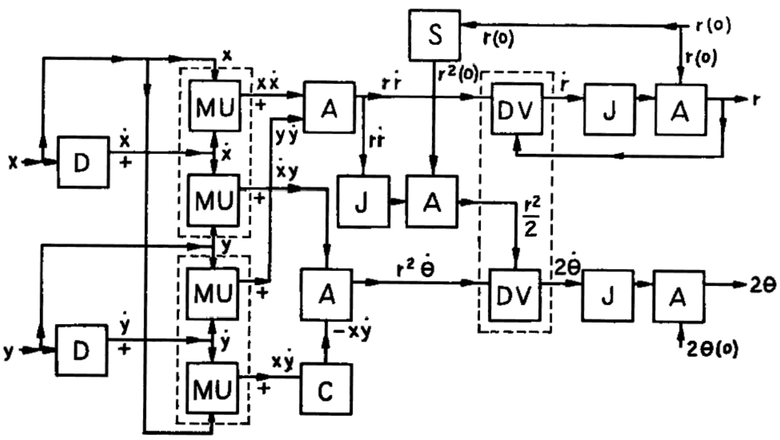
Generalizing along similar lines can produce many other classes of functions *implicitly.*

The foregoing constitutes merely a sampling of the almost innumerable problems that can be handled with the aid of high-speed Multipliers. GAP/R application engineers welcome inquiries about specific problems.



$$x = r \sin\theta = r \int (\cos\theta) \, d\theta; \qquad y = r\cos\theta = r \int (-\sin\theta) \, d\theta$$

Figure 4. Resolution



$$r = \int [(x\dot{x} + y\dot{y})/r] \, dt; \qquad \theta = \int [(\dot{x}y + x\dot{y})/r^2] \, dt$$

Figure 5. Composition

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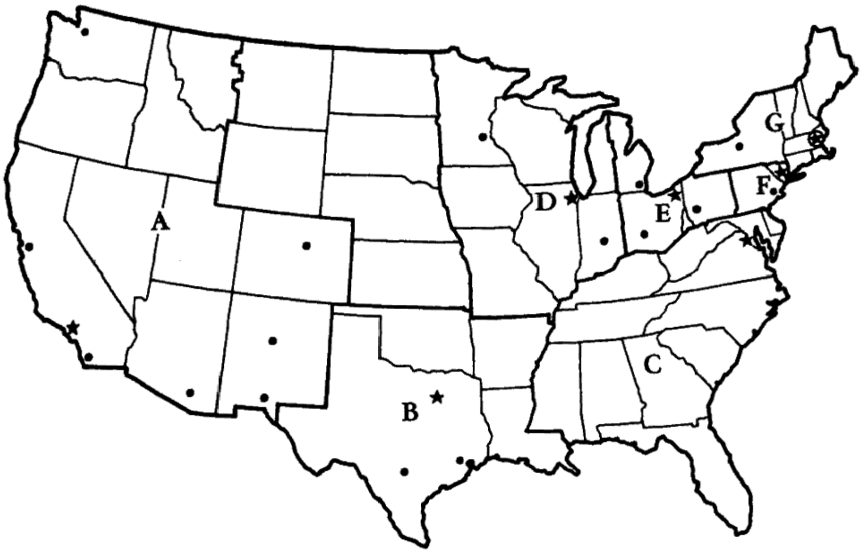

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* Refers to or describes GAP/R products.

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COMPUTOR SYMPOSIUM

A Symposium on the Applications of Analog Computors to the Problems of Industry and Management was held at the Midwest Research Institute on April 10 and 11, 1956. Among the speakers known to Empiricists were Drs. H. M. Paynter and Rufus Oldenburger.

OUR PALIMPSEST

A Palimpsest on the Electronic Analog Art — being a collection of reprints of papers and other writings which have been in demand over the past several years. Edited by H. M. Paynter, ScD., RPE.

This collection contains thirty-five significant papers, each dealing with some phase of the utility of electronic analog computor operational modules. The papers have been included with little or no revision so that they retain their historical flavor and significance. At the same time, each is pertinent to the subject and has been selected for its historical interest, soundness of doctrine, authentic novelty, or pedagogical value.

Several hundred references, scattered among the articles, form a substantial, keyed bibliography of the art.

The Palimpsest is available at one dollar a copy plus postage and handling.

CIRCUITS & BLOCK DIAGRAMS

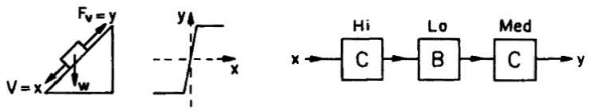
Users of GAP/R Components are invited to contribute descriptions and diagrams of novel applications. Here are some more aged samples:

* * * * * *

1. Coulomb Friction

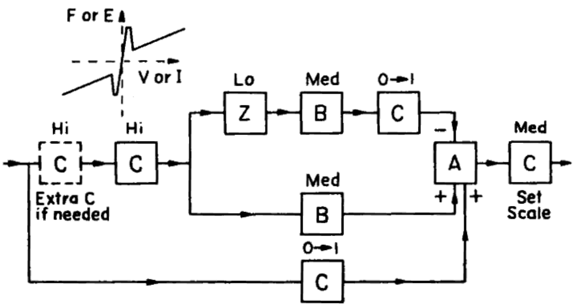
A realization of the *Signum* function of mathematical analysis.

Many obvious applications will occur to the reader, including the modification shown in 2.

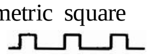


2. Stick-Slip Friction (or Gas Tube Resistance)

Frictional force has a finite yield point followed by a sharp drop to a sliding force which increases with velocity. The diagram shown features separate adjustments, for yield force, slip force, and resistance constant. The title indicates one of many analogs.



3. Pulse Time Modulator

Becomes either an asymmetric square wave generator (e_m, fixed) 
or a pulse timer (e_m variable) 
work can serve as an analog-digital converter.