The Lightning Empiricist

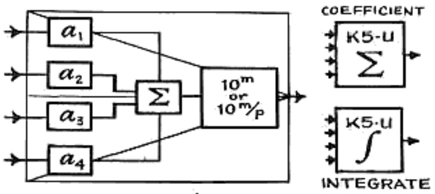
A journal for devotees of high-speed analog computation, those enthusiasts for the new doctrine of Lightning Empiricism, publishable aperiodically and distributed without charge by Geo. A. Philbrick Researches, Inc., 285 Columbus Avenue, Boston 16, Mass. and offering items of interest and value on such computational topics as applications, techniques, and new or improved components.

ISSUE No. 7 GAP/R March 1959

JUST TWIST THE KNOBS — GEORGE DOES THE REST

MODEL K5-U UNIVERSAL LINEAR OPERATOR

The governing equations and a block diagram of this versatile, stabilized component are as shown.



$$e = e_o + 10^m \sum_{i=1}^{4} a_i e_i$$

or

$$e = e_o + 10^m \int^t_0 [\sum_{i=1}^{4} a_i e_i]\, dt$$

$-50.0v < e_o < +50.0v$ IN STEPS OF 0.1 VOLT

$m = 0, 1, 2,$ or 3 AS DESIRED

$-11.10 < a_i < 11.10$ IN STEPS OF 0.01 VOLT

Some of the significant virtues of the K5-U are:

1. A single FORM switch to choose the circuitry for INT(egration) or COEF(ficient) and to select the value of "m". (See the equations.)
2. A MODE switch to provide Set, Run, Hold, and Command positions via plug-in relays. The Command position enables remote control for programming and group operation.
3. Four three-digit decade switch and resistor assemblies and four sense switches to establish **the** values and signs of "a_i" without the use of potentiometers.
4. A three-digit decade switch and resistor assembly and a sense switch to establish the value and sign of "e_0"
5. K2-W's, K2-P's, and plug-in relays for reliability.

K5-U (Cont. on Page 3)

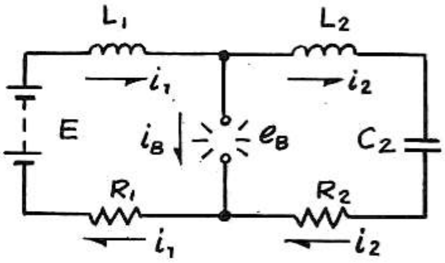
SIGNIFICANT APPLICATIONS OF THE K5-MODULES

A Dc Arc Circuit

The electrical arc - or arcing circuit - appears in many forms as:

a. Arc welding and cutting.
b. An arc light.
c. A cable or network short.
d. An insulator flashover.
e. An opening switch.

The conditions for controlling or preventing such arcing can readily be studied by analog techniques.

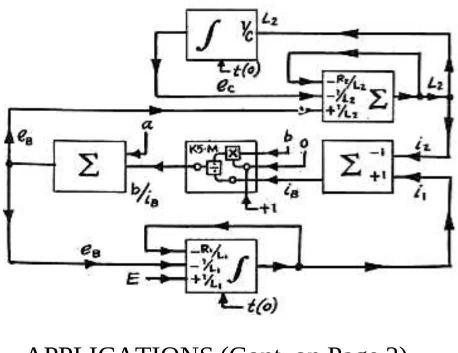


$$e_B = a - b/i_B \text{ (Ayrton's Equation)}$$

$$i_1 = (1/L_1) \int^t (E - e_B - R_1 i_1)\, dt$$

$$i_2 = (1/L_2) \int^t (e_B - e_C - R_2 i_2)\, dt$$

$$e_C = (1/C_2) \int^t i_2\, dt$$



APPLICATIONS (Cont. on Page 2)

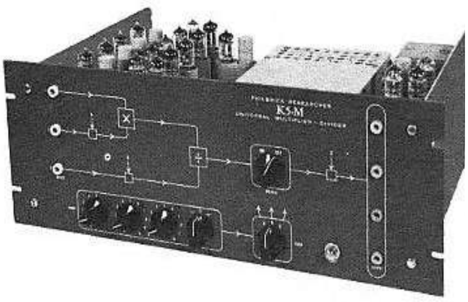
USA-3's REDESIGNED (See Page 4)

MODEL K5-M MULTIPLIER-DIVIDER

NEW NEW NEW

Another module that furthers the philosophy of Living Mathematics.

The Model K5-M Multiplier-Divider is a precision analog computing component with improved long term stability based on a new all-electronic semiconductor network. It accepts three variable inputs e_1, e_2, e_3, and provides as output e_1, e_2/e_3. Accuracy as a multiplier, including drift, is better than 0.10v in all four quadrants.



The limiting values of the inputs are:

$-50v < e_1$, (or e_2,)$< +50v$

e_2 is positive up to +50 volts.

A three-digit precision voltage decade provides an adjustable INDEX voltage E (0 to ±50 volts in steps of 0.10 volt). E can be added to e_2, e_3, or e as desired. If, in any mode of operation, only two variables are involved, (e_2 or e_3 being zero) E must be used to replace the unused variable. This decade is constructed of fixed resistors of appropriate tolerances and a unique switching arrangement. No potentiometers are involved.

A BOUND circuit, inserted by the turn of a front panel switch, stabilizes operation when the output is fed back as an input, as in the case of the extraction of a square root or an absolute value. This circuit prevents operation when e_3 approaches zero or becomes negative.

The dynamic response of the K5-U is determined by a circuit controlled

K5-M (Cont. on Page 2)

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

PROLOGUE

Throughout this issue we wax enthusiastic about the virtues of the K5- Modules here represented by theK5-U and the K5-M components. These Modules extend and advance Philbrickian traditions of compatibility, economy, and simplification of function.

It is well known that the K2 Operational Amplifiers are the least expensive computor building blocks. With these, any rational empiricist can construct almost any desired circuit to combine and transform analog signals.

In fact - this is precisely what Philbrick has done to develop various compatible modular components.

For example:

The linear and nonlinear K3-Modules with which the maestro can explore a variety of computing, control, and instrumentation problems.

The CRM Central Response Component which creates the unique electronic graph paper:

The CS-2 Central Signal Component, which supplies step, clamp, ramp, and sweep signals.

The R-100A and the SR-400 Power Supplies:

The F2-V Function of Two Variables, which enables the study of the impact of two variables on the operation of a mechanism:

The FF Arbitrary Function Component, elsewhere described in this issue.

Now we announce the K5-U Universal Linear Operator and the K5-M Multiplier-Divider. These Modules contain stabilized amplifiers and an ingenious switching of resistors to supply adjustable coefficients and index voltages without benefit of potentiometers.

Philbrick never stands still. Further developments are even now in process. But the K5- Modules are already a major step forward.

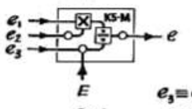
K5-M (Continued from Page 1)

by a three-position switch mounted on the top of the chassis. When this switch is in position 1, the system response is approximately Gaussian. The switch, in positions 2 and 3, inserts special lead networks into the circuitry to provide the desired phase and/or frequency characteristics. When the switch is in position 3, the phase shift is less than 0.5' at 500 cps.

The unit is mounted on a standard 7 inch rack panel. In addition to filament power at 115 vac, it requires 100 ma at plus and minus 300 vdc. The standard range of inputs and output is plus and minus 50v.

Typical applications include analog computation, correlation, precision modulation, and control. No external equipment is necessary to obtain products, ratios, squares, square roots, or absolute values.

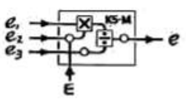
a. Multiplication



$e_3 \equiv 0$

$$e = \frac{e_1 e_2}{e_3 + E} = \frac{e_1 e_2}{E}$$

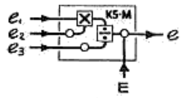
b. Division



$e_2 \equiv 0$

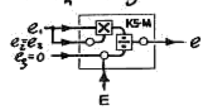
$$e = \frac{e_1(e_2 + E)}{e_3} = \frac{e_1 E}{e_3}$$

c. Multiplication & Division



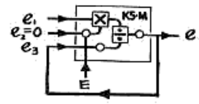
$$e = \frac{e_1 e_2}{e_3} + E$$

d. Squaring



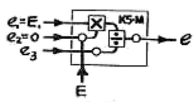
$$e = \frac{e_1^2}{E}$$

e. Square Rooting



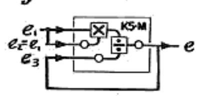
$$e = \frac{e_1 E}{e} = \sqrt{e_1 E}$$

f. Inversion



$$e = \frac{E E_1}{e_3}$$

g. Absolute Value

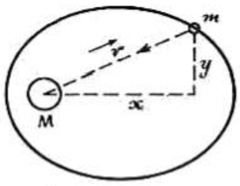


$$e = \frac{e_1^2}{e} = |e_1|$$

APPLICATIONS (Continued from Page 1)

<u>A Timely Problem In Satellite Orbits</u>

As we reflect upon the man-made satellites that orbit the earth - and those that don't - an elementary analysis of the dynamics of orbiting maybe of interest. Such an analysis is presented.

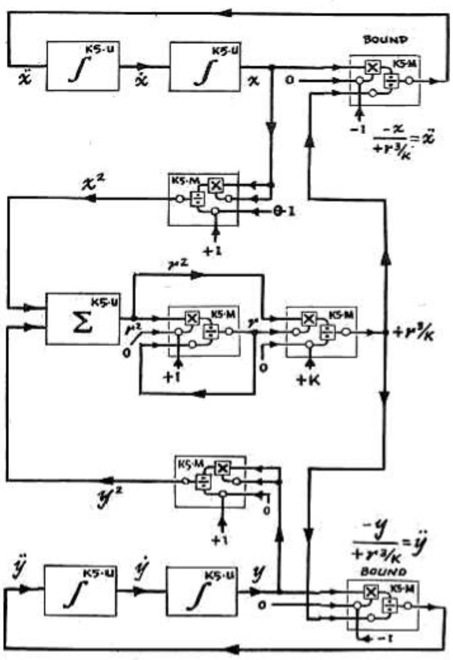


$$|F_g| = \frac{\gamma M m}{r^2}$$

$$\vec{F_g} = -\frac{\gamma M m}{r^3}\vec{r} = m\vec{a}$$

$$\gamma M = K \qquad a = \ddot{r} = \frac{-K}{r^2}$$

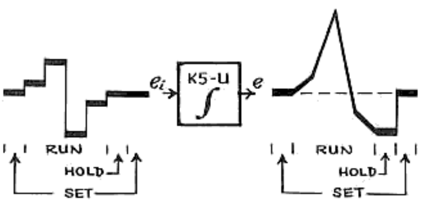
$$\ddot{x} = \frac{-K}{r^2} \cdot \frac{x}{r} \qquad \ddot{y} = \frac{-K}{r^2} \cdot \frac{y}{r}$$



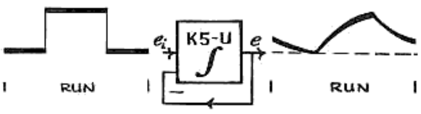
APPLICATIONS (Continued on Page 3)

K5-U (Continued from Page 1)

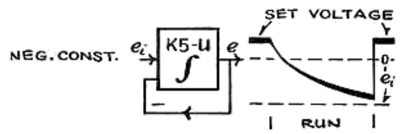
1. Panel switches to make operating changes - no internal patching needed.
2. Standard connectors, on rear of chassis for power and relay control connections.
3. Banana jacks on front panel for computing connections.
4. Standard 7 inch rack panel for mounting.



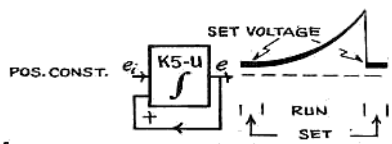
a. AS AN INTEGRATOR, OPEN LOOP



b. AS A UNIT LAG, STEP RESPONSE



c. AS A UNIT LAG, SET TO RUN



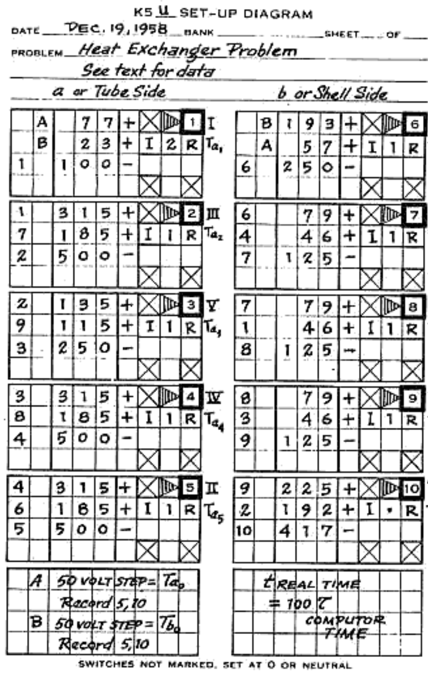
d. AS AN INCREASING EXPONENTIAL

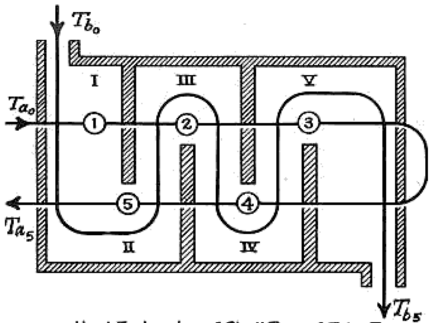
A Heat Exchanger Problem

Consider a heat exchanger having one shell pass and two tube passes.

Following techniques used by Dr. H. M. Paynter and his colleagues at M.I.T., the dot in the matrix indicates the input conditions denoted by subscripts (j-l) and (k-1) for the subdivisions whose outputs and parameters are indicated by the subscripts j and k. A lumping arrangement is employed whereby thermal energy is stored at the lump exciting condition (as in a well mixed stage) but the heat transfer between fluids is computed from the inlet temperatures with the heat transfer coefficients properly corrected. (For further details, contact Mr. P. D. Hansen, Mechanical Engineering Dept., M.I.T.)

This model will yield both static and transient performance data.





Heat Exchanger – 1 Shell Pass; 2 Tube Passes

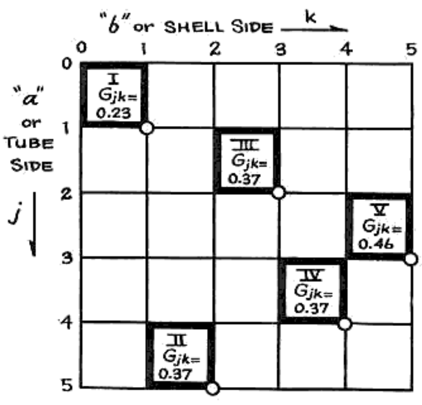
$$T_{a_j} = \frac{1}{\tau_{a_j}}\int^t \left[(1-G_{jk})\,T_{a_{j-1}} + G_{jk}\,T_{b_{k-1}} - T_{a_j}\right]dt$$

$$T_{b_k} = \frac{1}{\tau_{b_k}}\int^t \left[(1-G_{jk})\,T_{b_{k-1}} + G_{jk}\,T_{a_{j-1}} - T_{b_k}\right]dt$$

GOVERNING EQUATIONS

EXCHANGER SUBDIVISION	j	τ_{aj}	k	τ_{bk}	G_{jk}
I	1	1	1	4	0.23
II	5	2	2	8	0.37
III	2	2	3	8	0.37
IV	4	2	4	8	0.37
V	3	4 / 11 Sec	5	24 / 52 Sec	0.46

TABULATED DATA



HEAT EXCHANGER MATRIX

APPLICATIONS
(Continued from Page 2)

Generation of Probability Distributions

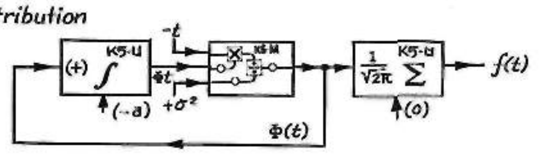
Current technical literature is replete with discussions of the utility of random and probability distributions in the study of system performance, witness several articles cited in the bibliography.

Useful techniques for the generation of Gaussian symmetrical and asymmetrical probability distributions are presented.

a. Symmetrical or Gaussian Distribution

$$f(t) = \phi(t) = \frac{1}{\sqrt{2\pi}}\,\epsilon^{-t^2/2}$$

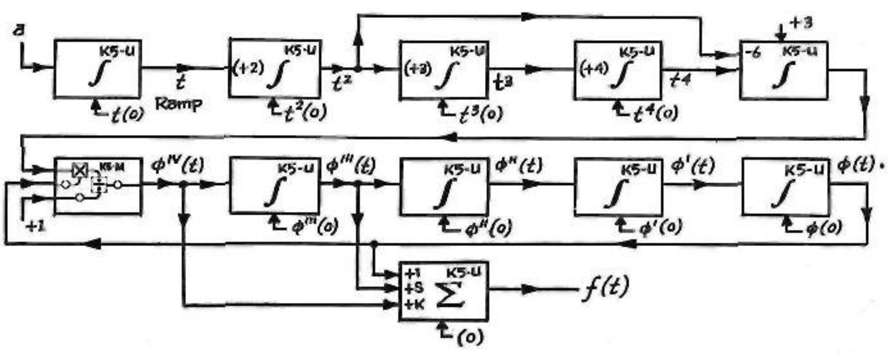
$$\phi'(t) = -t\,\phi(t)$$



b. Four Parameter Skewed & Kurtic Distribution (Gram-Charlier Expansion)

For $m = 0$, $\sigma = 1$

$$f(t) = \phi(t) + S\,\phi'''(t) + K\,\phi^{IV}(t);\ \phi(t) = \frac{\epsilon^{-t^2/2}}{\sqrt{2\pi}};\ \phi^{IV}(t) = (t^4 - 6t^2 + 3)\,\phi(t)$$



BIBLIOGRAPHY

Bates, M. R., Bock, D. H. and Powell, F. D.: Analog Computer Applications in Predictor Design. IRE, Vol. EC-6, No. 3, September 1957. (The analog computor was found to be very useful both in the design and in the final check of the design.)

Beck, C.5 Treating Transfer Functions on Analog Computers. Electrical Manufacturing, Vol. 62, No. 4, October 1958. (An illustration of the ease with which analog computing can model a system via the Laplace transform of its equations.)

Boffi.L.V. and Haas, Jr., V.B.: Analog Computer Representation of Alternators for Parallel Operations. AIEE Communication and Electronics, No. 30, May 1957, Paper No. 57-150. (The conceptual problems of adapting the basic equations for a single aircraft alternator, with an approximate saturation correction, to the condition of parallel operation.)

Boggs.W.E. Computer Clips Balancing Time. Control Engineering, Vol. 5, No. 6, June 1958. (A demonstration of the value of inexpensive analog components for the balance testing of turbine wheels in terms of "where" and "how much correction".)

Frick, R. K.: The Role of Analog Computers in Propeller Control Design. AIEE Applications and Industry, No. 33, November 1957. (The analog computor is applied to an aircraft design problem.)

Goodman, T. P. and Hillsley, R. H.: Continuous Measurement of Characteristics of Systems with Random Inputs. A Step Toward Self-Optimizing Control. ASME Transactions Paper No. 58—IRD-5, Vol. 80, No. 8, November 1958. (Novel use of high speed analog components to determine impulse moments of time variable systems.*)

Hainsworth,B.D.,Tivy, V. V. and Paynter, H. M.: Dynamic Analysis of Heat Exchanger Control. ISA Journal, June 1957. (Use of Lightning Empiricism in the purest sense for exploring process response and regulation.#*)

Herschel, Von R. and Kettel, E.: Das Problem derNormierung bei der Answendung von Analog-Rechenmaschinen zur Behandlung regelungstechnischer Aufgaben. Regelungstechnik, 6 Jahrgang 1958, Heft II. (An important contribution to our understanding of the problems and principles of scaling analog computors.*)

Hochschild, E. F.: Dynamic Study of an Experimental Pneumatic Process-Pressure Transmitter. ASME Transactions, Paper No. 57--IRD-7, Vol. 80, No. 2, February 1958. (A provocative demonstration of the utility of the combined analytic-computor-test process.)

Horn, R. E. and Honnell, P. M.: Matrix Programming of Electronic Analog Computers. AIEE Communications andElectronics, No. 38, September 1958, Paper No. 58-66. (The authors simplify scaling and model construction by the use of matrix algebra and concepts. Our colleagues, Dr. Paynter and Mr. Sheingold then discuss how sets of K5-U may aptly realize the resultine matrices.#*)

Jaeger, Charles: Contribution to the Stability Theory of Systems of Surge Tanks. ASME Paper No. 57—A-65, Vol. 80, No. 7, October 1958. (A signal advance toward the general solution of an important and intricate problem. Dr. Paynter has contributed further simplifications and general results via K5-U representation.#*)

Leiby, D. W.: Dual-Cycle Boiling-Water-Reactor Nuclear Power Plant. AIEE Communication & Electronics, No. 35, March 1958, Paper No. 57-684. (An analog computor study of the transient performance of a complex nonlinear system.)

Paynter, H. M.: Generalizing the Concepts of Power Transport and Energy Ports for Systems Engineering. ASME 1958 Annual Meeting, IRD Educational Committee Session, Paper No. 58-A-296. (A generalized analysis of the reticulation of basic engineering systems into "multiport" systems at the boundaries of which power is transmitted only through a finite number of facets or "energy ports" so that most commonly used standard components can be catalogued into a relatively small set of elements in the form of one-ports, two-ports, and three-ports.*)

Paynter, H. M.: On an Analogy between Stochastic Processes and Monotone Dynamic Systems.,Regelungstechnik, Tagungs Bericht.,1956, Moderne Theorien und ihre Verwendbarkeit, Verlag R. Oldenbourg, Munchen 1957. (Routing a signal through a cascade of generally different linear operators bears a strict correspondence to drawing random samples from different statistical distributions; this analogy yields many benefits to studies of dynamics and control.#*)

Paynter, H. M.: Ordering and Selection Processes and Ultra-Reliable Systems. AAAS, Paper presented at the Session on General System Theory, Washington, D.C., 2'i December 1958. (An analysis and synthesis of systems and generalized mathematical logic through "auctioneer" and "shopper" operations.#*)

Paynter, H. M. and Ezekiel, F. D.: Water Hammer in Nonuniform Pipes as anExample of Wave Propagation in Gradually Varying Media. ASME Transactions, Paper No. 57--A-107, Vol. 80, No. 7, October 1958. (Some general conceptions permitting sounder computor representations of practical geometrics.#*)

Rose, Harold; Modular Units for Automatic Test Systems. Automatic Control, Vol. 9, No. 4, October 1958. (Flexible test equipment for the automatic checkout of various designs and modifications of missiles, at minimum cost and maximum accuracy. Logically, Philbrick modules are used in its construction.*)

Sasseen, J. H.: An Electronic Analog Cross Correlator for Dip Logs. IRE-EC-6, No. 3, September 1957. (Data from the dip-meter ranges from highly to poorly coherent information. The extraction of reliable information from these data is ably handled by simple analog components.)

Schwartzenberg, J. W.: A Simulator for Nuclear Reactor Operator Training. ISA Journal, Vol. 4, No. 9, September 1957. (A training simulator using Philbrick K2-X's,a real console activated by the simulator circuit, and a mock-up of a reactor, was found to make the training realistic.*)

Van Home, T. B.: An Analog Method for the Solution of Probability of Hit and Related Statistical Problems. IRE-EC-6, No. 3,. September 1957. A technique, applicable to many probability problems.)

*Refers to Philbrick products.
#Reprints available upon request.

USA-3's REDESIGNED FOR IMPROVED SELF-VENTILATION

When a real performer like the USA-3 appears, the temptation to refine it is irresistible and some excuse is sought. We tried on this unit, but the frequency response was (and is) so good and the noise and drift so low, that the project to improve its performance stalled. Nor could we seem to figure out a smaller package. However, one very persistent engineer studied the ventilation requirements and found the excuse.

In the previous model, resistors were operated well within their ratings, but most mountings starve the air flow around them,so that forced ventilation is needed.

After extensive empiricizing it proved possible to reduce these hot-spots greatly without altering the performance specifications. Now it is possible in many applications to dispense with forced ventilation.

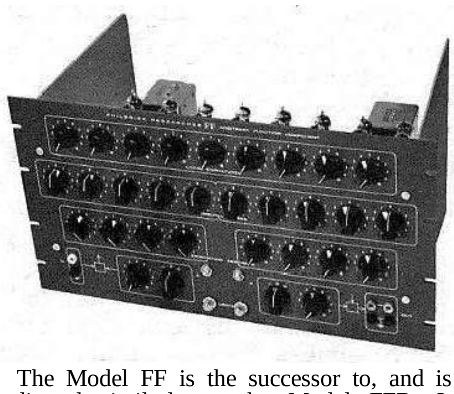
Following up on this improvement, a JAN version, designated the USA-4J has been developed to meet military standards as well as to feature greatly improved performance.

The foregoing activities naturally have had their impact on our stand-bys so that now a JAN version of the K2-W, designated the K2-WJ,is starting in production. JAN versions of the K2-P and the K2-X will follow.

MODEL FF ARBITRARY FUNCTION COMPONENT

This unit is a necessity for introducing arbitrary and adjustable static functions of a voltage into an instrumental system or model. Within its range of ±50 volts, you can design the functional relation involved as a continuous curve for which the slope of the segments does not exceed ± 10 volts per volt.

That is: $y = y_0 + f(x - x_0)$



The Model FF is the successor to, and is adjusted similarly to the Model FFR. It has substantial advantages:

1. Stabilized output amplifiers.
2. Twice the range available on both the X and the Y shifts.
3. Banana jack connectors.
4. Reference marks and numbers on the adjustment knobs to enable resetting within calibration range.
5. Cooler and more reliable in operation because it uses an external power supply.