IN MEMORIAM

George A. Philbrick (1913–1974)

A Brief Personal Tribute

by H. M. Paynter[1]

The father of modern operational amplifiers and electronic analog computing has passed on to immortality. George Arthur Philbrick died of a cardiac arrest on December 1, 1974 at the age of 61, having been stricken suddenly at his home in Cotuit, Mass.

George was born in Belmont, Massachusetts, on January 5, 1913. His parents were both artists, and his family and forebears include many with scientific and technical bents as well. He grew up in Winchester, Massachusetts, attending public schools there.

George entered Harvard's engineering school in 1932, and received a bachelor of science degree in communications engineering in 1935, completing the program in record time, as a full-scholarship student. One of his influential teachers was George Washington Pierce and it is also interesting to point out that Jacob Den Hartog was then a young assistant whom he knew.

Shortly after receiving his degree, George went to work for the Foxboro Company, via one of its founding components, the Atlantic Precision Instrument Company. He had the good fortune to be teamed up with "Doc" Clesson E. Mason (1973 Oldenburger Medalist), who was undertaking a many-faceted program of applying rational and mathematical methods for better understanding of process control.

For about two years of this 1936–1942 period at Foxboro, George and Doc Mason were closeted in a small office in Boston, separated from all other distractions, where they worked out a complete mathematical analysis of process control (of pressure, flow, temperature, etc.), including the synthesis of appropriate new controllers, having reset, rate, impulse-rate and many other features.

As part of this program, George built in 1938 "Polyphemus": a one-eyed monster (whose eye was a CRT) which was the world's first high speed general purpose analog computer. This machine, now prominently displayed at the Smithsonian Museum of History and Technology in Washington, could represent both the process itself and a variety of conceivable controllers. Polyphemus used vacuum tubes in feedback amplifiers for activation of its circuitry. It was no doubt at this time that George was bitten by the "lightning empiricism" bug.

With the advent of war, George became, like so many others, a government scientist, a National Defense Research Council section member (1942–1945), and a chief technical aide and consultant in the Office of Scientific Research and Development (OSRD) from 1943 to 1945. During this hectic period, he worked primarily on fire control systems (work most of which remains classified even after 30 years!) but one responsibility of his NDRC Section 7.2 was oversight of the second Bush Differential Analyzer at MIT (Van Bush was science czar and directed NDRC and OSRD); the machine was an ingenious but low-speed mechanical device). George's OSRD oversight responsibilities also included the more novel and ultimately fruitful electronic analog computer at Columbia University's Project Cyclone, whose guiding genius was John Ragazzini. This machine used *operational amplifiers* for the first time in a computing configuration. (It is described in the *Palimpsest*[2] and elsewhere.) (This machine soon led to the first *commercial* analog computer, manufactured by the Reeves Instrument Company. However, it, also was a low speed device from the start.)

George A. Philbrick in 1951

After the war, George returned to the Foxboro Company, but now only as a consultant, having been inspired to enter MIT as a graduate student, with the intention of obtaining a doctorate, using the design and construction of a novel *high speed* electronic analog *computor*(sic) as a thesis project. Thus in 1946 while making plans, assembling and testing components, and writing preliminary material, he was approached by Bill Shaffer and others at the then Wright Aeronautical Corporation (later to become Curtis-Wright) to consider building a special purpose turbo-prop engine control simulator. For a target price of 22 thousand dollars, George accepted the challenge and postponed his graduate education, his thesis and his chance for a doctorate (for all time, as it turned out).

This computor, built in the bedroom of George's house on Scott Street in Cambridge, provoked the formation of George A. Philbrick Researches, Inc. (GAP/R) in 1946. Foxboro, through Ben and Rex Bristol, having been given the opportunity to build this machine and thus to go into the computor business, instead lent Arnold Beveridge to George as a part-time business

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[2]A palimpsest on the electronic analog art (H. M. Paynter, ed) GAP/R, Boston, 1955

PIX Transposed

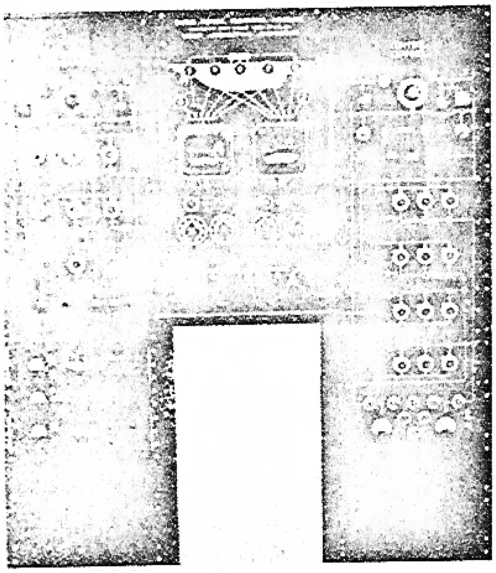


Fig. 1 Polyphemus in 1938

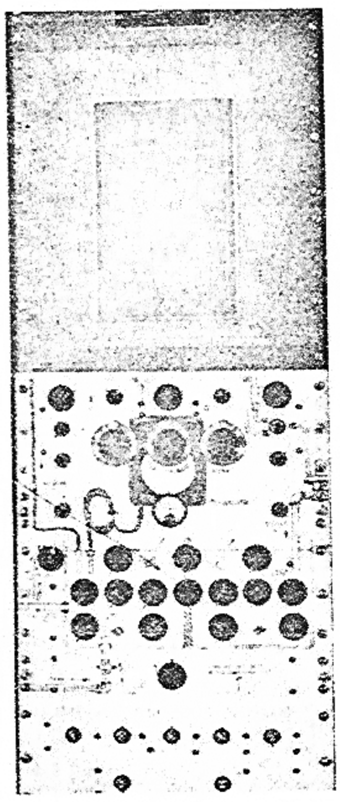


Fig. 2 The first GAP/R computor

advisor. (Arnie remained close to GAP/R for twenty years until it became Teledyne/Philbrick.) A second machine was built shortly after for the National Advisory Committee for Aeronautics (NACA). (This group was the antecedent of NASA.) For a change, this machine was built in younger brother Fred Philbrick's garage, Fred having become George's partner.

Thus was born GAP/R with its gospel of Lightning Empiricism: an organization which from these modest beginnings grew in a mere 15 years to a publicly-owned company with annual

(a.)

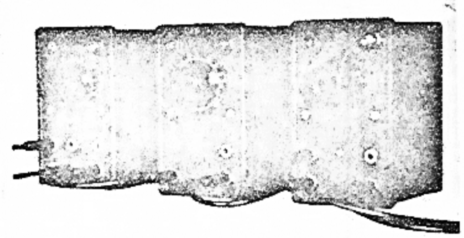


Fig. 3 The K3 series: GAP/R's realization of lightning empiricism

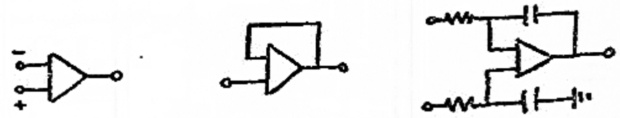
Fig. 4 The K2W: GAP/R's first differential op-amp

sales exceeding $5 million, to become in five more years Teledyne/Philbrick.

At this point this account must bring in my personal involvement. I was introduced to George by John Hrones in 1947. Very shortly after, I was one of the first proud possessors of those "little black boxes"—the wonderful K3s' (A, C, J, L, B, H, Z, etc.)—which brought the fruits of lightning empiricism to an increasingly large group of advocates. (They were staple products from 1948 to 1958, retired by K2 and K5; their widespread use and influence is documented in the *Palimpsest* of 1955.)

In 1950, George and I formed the Pi-Square Engineering Company (Π^2) as a partnership to exploit mutual interests and to do education, publication, research, development and consulting centered around analog computing. Among other Pi-Square activities was a computing center which ultimately became the American Center for Analog Computing on Clarendon Street, Boston.

So it was that I was in on the birth of the K2W op-amp in the very early 1950's when GAP/R was on the fourth floor of the Western Union Building at 230 Congress Street in Boston. This first commercial *full-differential unstabilized* operational amplifier exploited the unique properties of the twin-triode, common heater 12AX7 (remember it?). Thus was born with much ceremony its twin, the circuit symbol indicated below, together with such typical full-differential or positive input circuits as those shown:



There are no doubt many tens of thousands of people around the world who were introduced to active circuits via K2W's and/or the manual which accompanied them.[3] (Only Heathkit could

[3] Applications manual for octal plug-in computing amplifiers [GAP, HMP (and others)] GAP/R, Boston, 1956.

price-compete and that only by using a single-sided, regenerative and driftable amplifier!) Moreover, the "graduates" of GAP/R and Π^2 went on to become principals in many organizations now prominent in this field (besides Teledyne/Philbrick) such as EAI, Burr-Brown, AD, and many others. How many universities, professors and students were exposed to lightning empiricism in this way will never be known. Thus few will dispute that while Ragazzini, Lovell, and certain others properly can be considered as contributing instrumentally to the development of the early "operational amplifier" and its solid-stateprogeny, it was George Philbrick who sired the modern "op amp": the ubiquitous solid state d.c. differential amplifier which is now the first stage of nearly all instrumentation circuits.

Besides the K2, a novel switch-programmable analog computor was developed, first marketed as the K5-series in 1958. However, even by that time dollar sales of amplifiers were steadily outstripping sales of analog computing systems and elements. Unfortunately the world at large never had the opportunity (that I and a few privileged others had) to use some of George's prototype and developmental equipment, such as the remarkable K7 series (never marketed). These machines were not only marvelous to use—they were also beautiful to look at!

As if all the above were not enough accomplishments for one man, George also did pioneering work in the following fields among many others:

(1) consistent advocacy of spelling: computor;
(2) all-electronic multipliers/dividers and other nonlinear circuits;
(3) bucket-brigade electronics;
(4) ultra-high-speed analog computing;
(5) active non-inductive circuitry;
(6) continuum logic and analog functions of many variables;
(7) use of positive/negative feedback in active circuits;
(8) use of active analog elements for control synthesis and realization;
(9) computor parameter optimizations/sensitivity determinations;

George was one of the founding fathers of our division (from its very beginning as the Industrial Instruments and Regulator Committee (IIRC) and was particularly influential in its continuing commitment to scientific principles. He published a number of significant papers on control in the ASME TRANS. and elsewhere, including the following:

1 "Automatic Control in the Presence of Process Lags," (with C. E. Mason), TRANS. ASME, Vol. 62, May 1940, pp. 295–308.
2 "Mathematics of Surge Vessels and Automatic Averaging Control" (with C. E. Mason), TRANS. ASME, pp. 589–601.
3 "Unified Symbolism for Regulatory Controls," TRANS ASME, Vol. 69, 1947, pp. 47–67.
4 "Electronic Analog Studies for Turboprop Control Systems" (with W. T. Stark and W. C. Schaffer), *SAE Quart. Trans.*, Vol. 2, No. 2, Apr. 1948.
5 "Designing Industrial Controllers by Analog," *Electronics* June 1948.
6 "The High Speed Analog as Applied in Industry," (ASME Spring Meeting, New London, May 1949).
7 The Electronic Analog Computor as a Lab Tool (with H. M. Paynter) *Industrial Laboratories*, May 1952.

Besides the always colorful but ever informative writing in "aperiodic" issues of the *Lightning Empiricist*, George finally managed to get published a few chapters of his masterful book on The Operational Amplifier. Unfortunately, this work was never finished as an enterprise; perhaps enough remaining manuscript can be found to bring a reasonable conclusion. However, that which has been already published sets a standard for technical exposition not likely to be soon equalled!

He also was granted a sizable number of patents on his work for Foxboro, for the U. S. Government, and for his own company.

As to family, George married his late wife Laurette in 1936 and is survived by his daughter Penelope who lives in Washington, D.C.

Some of us who were George's close friends and associates are now making plans for a testimonial/organizational meeting leading ultimately to suitable notice and publication of his work and to a proper resting place for his books and papers. Let this notice serve to bring you into contact with us if you can help in this worthy effort.