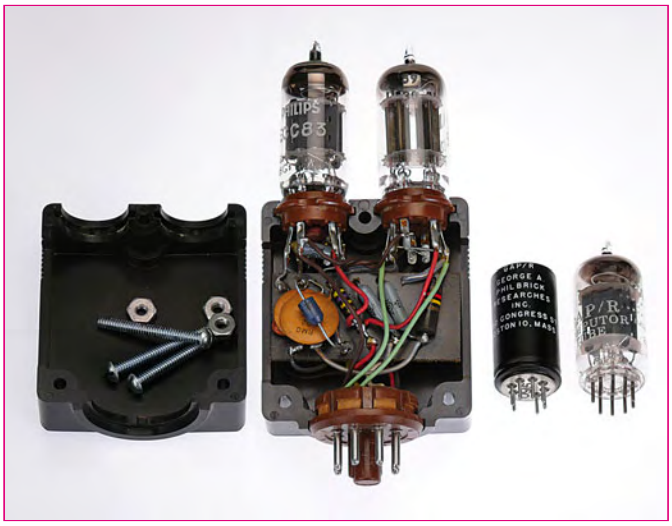
Philbrick K2-W, the mother of all op amps

GAP/R vintage K2-W, K2-X and K2-P op amps. (Author's collection)



Embree Electronics C/50 op amp (opened up for curiosity), GAP/R 'Computor' tube and GAP/R 'Airpax' A-175 DC-to-AC chopper. (Author's collection)

By Jan Didden (The Netherlands)

One popular belief among the all-transistor generation of electronics enthusiasts is that operational amplifiers (op amps) came after engineers learned to put many transistors on a chip carrier. In fact, op amps are much older.

As with many technologies, the development of op amps was initially strongly driven by military requirements. World War 2 saw developments in largely mechanical contraptions for mathematical problems like aiming anti-aircraft guns and calculating the optimum point to release bombs over enemy targets. Functionally, the devices consisted mostly of amplifiers, integrators and differentiators; very complex instruments comprising, for instance, gear wheels with logarithmically-arranged cogs. These were phased out gradually and replaced with electronic function blocks called operational amplifiers: amplifier blocks that could be configured to perform an operation: amplification, summing, differentiation and integration to name just the simplest ones. The first op amp type circuit design published was probably by Lovell and Parkinson of Bell Labs for the M9 anti-aircraft gun director built by Western Electric. Later on, Loebe Julie at Columbia University consulted for the George A Philbrick Researches company (GAP/R), to develop the electronic module for a bombing simulator which GAP/R was developing for the US Armed Forces. It was Philbrick who saw the commercial potential, and from 1952 GAP/R offered its op amps for commercial use as well. The first device was the K2-W shown in **Figure 1**. To this day the circuit configuration is the basis of many high-gain, balanced-input circuits including the balanced differential stage, cathode-coupled with a large cathode resistor acting as a current source. A differential-input signal unbalances the differential pair and causes a differential output signal at the anodes. The second pair buffers this signal with cathode-followers and provides a single-ended output. Later circuits improved on this with, for instance, a real current source to bias the input pair (which came to be known as a 'long-tailed pair') and differential outputs, see **Figure 2**. For amusement only, if you compare this to the circuit in **Figure 3** of an NE5532 op amp, the pedigree is clear.

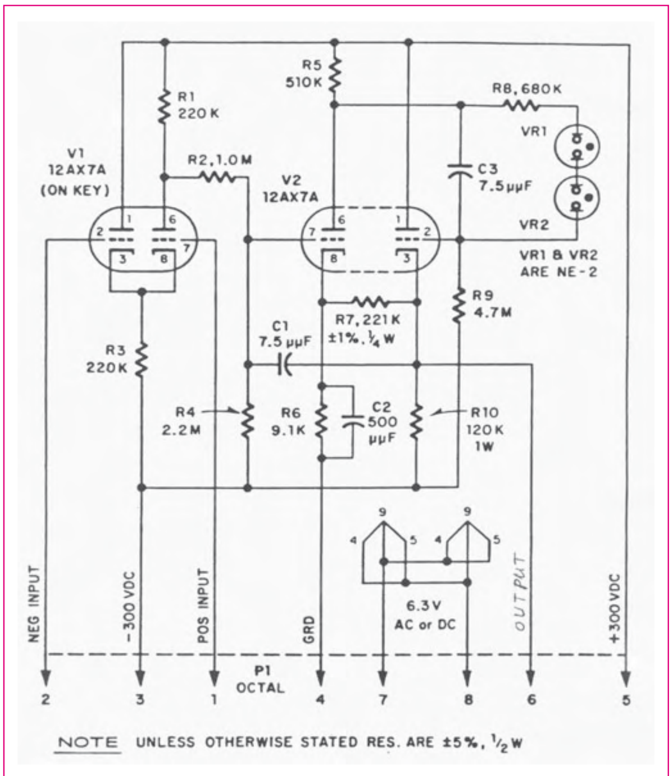


Fig 1. GAP/R K2-W opamp schematic diagram. You could easily build this yourself.

The K2-W used bipolar supplies of ±300 V. The output could swing about ±50V peak, and in this spec at least modern op amps are a big step backwards! Other specs were not so hot. The bandwidth was about 100 kHz with a 2 μs rise time, and an open-loop gain of 15,000. R_{out} was specified as about 1 kOhms.

But the specs itself were of lesser importance compared to the concept behind these units. K2-W's were built as plug-in units that could be configured for a specific function by the user: real operational amplifiers! They were generally not supposed to be used open-loop, but with a feedback circuit to obtain the desired transfer function. Just like today's op amps, several different versions were developed that had slightly different specs for different tradeoffs in the final product: after the K2-W came the K2-X, K2-XA and the K2-P. The K2-XA had double the speed, double the bandwidth, double the output swing and double the gain of the K2-W. These op amps all shared the same base socket connections and could be freely interchanged, similar to today's 'universal' op amp pinouts. The tubes used in the Philbrick units were dual triodes of the 12AX7, 12AU7 12AT7 (ECC83, ECC82, ECC81) family. There were also some specialised plug-in units like mechanical choppers that could take the place of the first double triode to make the unit into a DC amplifier. Philbrick also selected tubes for tighter specs and these were stamped with the company name and the indication 'Computor Tube'. GAP/R consequently used 'computor' in these days, not 'computer'. A wealth of information on these and other Philbrick products may be found at Joe Sousa's site [2].

With the success of these op amps, competitors tried to jump the bandwagon, of course. One outfit, Embree Electronics Corp. offered the C/50/BP, very similar to the Philbrick units, except that mechanically it was different, and it could be opened up for repair if necessary. Philbrick's units could not; apparently they had enough trust in their products to believe that repair would not be necessary over the lifetime of the unit, or maybe the price was low enough (for the military) to treat it as a consumable rather than a repairable item. Another similarity to modern IC op amps.

GAP/R took the concept one step further and developed a sort of universal unit that would take up to three op amp plug-ins plus an additional tube, the K3. This unit offered a higher level of integration and was actually called an 'analog computor', see [1].
With the development of the op amp, application notes and books on how to use them started to appear as well. One early GAP/R engineer, Bob Pease who until recently worked at National Semiconductor, wrote Philbrick's very first application note numbered 'R1'. Bob's stories about his early years at GAP/R can be found at [3].
Capt. Clarence L Johnson, an engineer with the US Air Force and Professor at the Department of Mathematics at the Air Force Institute of Technology, wrote "Analog Computer Techniques", published in 1956. This book gives a fascinating insight into the use of op amps to actually 'simulate' (as it was called) electromechanical problems, as well as their use in complex constellations of electromechanical servos and electronic op amps. **Figure 4** shows a simple circuit to generate a logarithmic function.

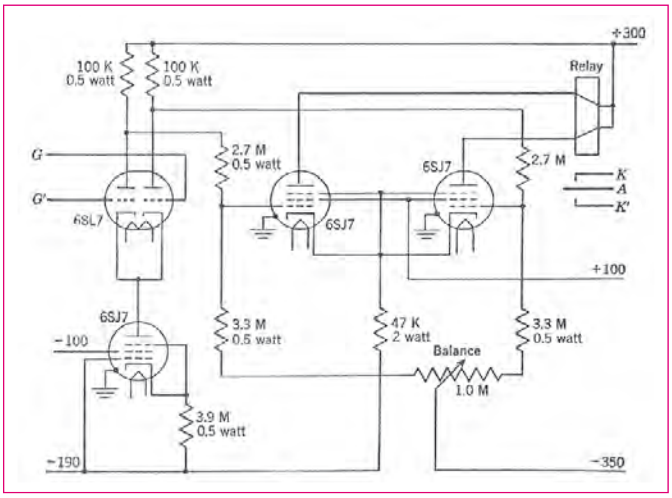


Figure 2. Tube-based 'long tailed pair'.

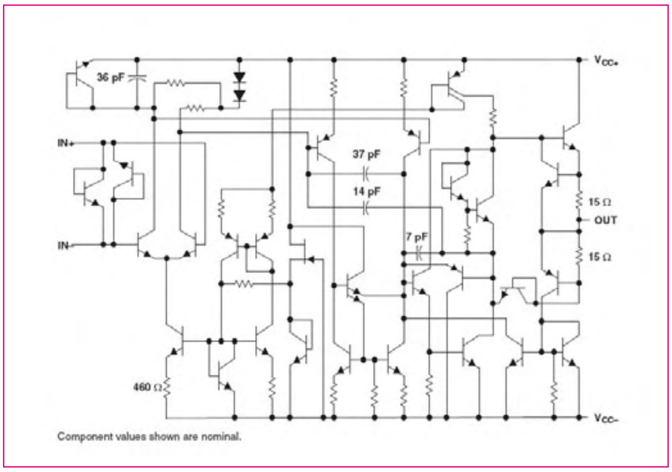


Figure 3. Internal schematic of the industry standard NE5532 monolithic opamp.

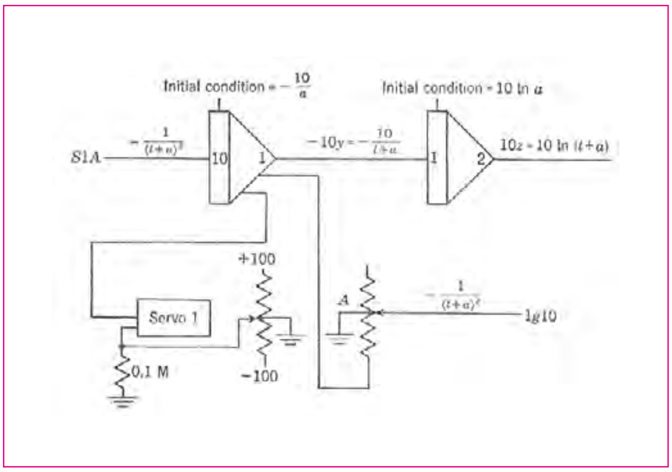


Figure 4. Using op amps to obtain the logarithmic of an input signal.

While the military prompted the developments of tube op amps, they could also be relied on to keep using them for a long, long time. The Nike anti-aircraft missile system used tube op amps and wasn't scrapped from NATO inventory until the late 1990s. I found some NOS K2-W's gathering dust at a military depot/repair unit that finally got rid of their stock in 2003.

We often see the monolithic opamp as a revolution in electronics. But with the concept of operational amplifiers firmly rooted in vacuum tube technology on the one hand, and the rapid development of the transistor and the integrated circuit on the other, monolithic op amps were just the next logical step in a technological evolution, and perhaps less than a conceptual breakthrough.

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Internet Links

[1] www.philbrickarchive.org/k3_series_components.htm

[2] www.philbrickarchive.org/

[3] www.national.com/rap/

Author email:
jandidden01@gmail.com

Further Reading

Analog Computer Techniques,
Clarence L Johnson,
McGraw-Hill, 1956

Retronics is a monthly column covering vintage electronics including legendary Elektor designs. Contributions, suggestions and requests are welcomed; please send an email to editor@elektor.com