

Lawrence Berkeley National Laboratory

Recent Work

Title

AN ELECTRONIC ANALOG SYSTEM FOR KINEMATICAL ANALYSIS OF INTERACTION VERTICES

Permalink

<https://escholarship.org/uc/item/37k8g4rt>

Author

Murray, Joseph J.

Publication Date

1962-06-06

University of California

**Ernest O. Lawrence
Radiation Laboratory**

TWO-WEEK LOAN COPY

*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 5545*

 **Berkeley, California**

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

UCRL-10278

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

AN ELECTRONIC ANALOG SYSTEM FOR KINEMATICAL ANALYSIS
OF INTERACTION VERTICES

Joseph J. Murray

June 6, 1962

AN ELECTRONIC ANALOG SYSTEM FOR KINEMATICAL ANALYSIS
OF INTERACTION VERTICES*

Joseph J. Murray

Lawrence Radiation Laboratory
University of California
Berkeley, California

June 6, 1962

Typically, the majority of bubble chamber events that have been selected visually by simple topological criteria "fit" one or more of the common hypotheses associated with the topology. Usually, however, there is also a residue of events, amounting to perhaps 10% of the total number of events analyzed, which for more than trivial reasons do not fit any of the common hypotheses. These consist of rare reactions not considered among the common types, misinterpretations of the actual topology, and errors in calculation.

Existing analysis machinery is well adapted for processing large numbers of "successful events," but for reprocessing the "failures" it is cumbersome because of the relatively large delay in obtaining results of revised calculations. It would be a great advantage in treating the failures to have immediate feedback, so that a physicist could acquaint himself with a problem event and lay it to rest in a single operation.

An electronic analog of the KICK-GUTS part of the analysis system was conceived about a year ago as a means of providing such a facility, and a prototype is now nearing completion. It was named PEBL (momentum, energy balance). Inputs to the analog--momenta, angles and errors--are now obtained from the geometrical reconstruction programs. The inputs are inserted digitally in a decimal system by manual switching at present, with provision for semi-automatic insertion by a punched card or tape-reading machine, if such a procedure should prove desirable in the future. Output is obtained digitally in either visual or printed form, one quantity at a time or in groups, by automatic scanning of programmed formats. The system is a fully automatic steady-state analog requiring a few seconds to reach equilibrium. Very little specialized technical know-how is required to use the machine.

*This work was done under the auspices of the U. S. Atomic Energy Commission.

In principle the basis for the analog may be illustrated as follows. A set of measured values χ_i^m of variables with uncorrelated errors δ_i (a convenient but unnecessary restriction) is adjusted in a servo-system with integral feedback to produce a set of fitted values χ_i^f which satisfy the constraints of energy and momentum conservation. That is

$$\chi_i^f - \chi_i^m = \sum_{\lambda} C_{i\lambda} \epsilon_{\lambda}, \quad (1)$$

where $C_{i\lambda}$ are feedback coefficients to be determined, and the ϵ_{λ} are integrated errors, one corresponding to each constraint;

$$\epsilon_{\lambda} = \int_0^t F_{\lambda}(\chi_1^f \dots \chi_n^f) dt / \tau_{\lambda}, \quad (2)$$

where $F_{\lambda}(\chi_i^f)$ are the constraint functions, equal to zero when the system is in equilibrium. The τ_{λ} are the time constants of the integration.

Differentiate Eq. (2) and expand F to first order about the measured values χ_i^m

$$\tau_{\lambda} \dot{\epsilon}_{\lambda} = F_{\lambda}(\chi_i^m) + \sum_i (\chi_i^f - \chi_i^m) F_{\lambda i}, \quad F_{\lambda i} = \partial F_{\lambda} / \partial \chi_i,$$

and substitute for $\chi_i^f - \chi_i^m$ from Eq. (1),

$$\tau_{\lambda} \dot{\epsilon}_{\lambda} = F_{\lambda}(\chi_i^m) + \sum_{\Delta} \sum_i C_{i\Delta} \epsilon_{\Delta} F_{\lambda i}. \quad (3)$$

This coupled set of differential equations determines the temporal behavior of the analog system if the τ_{λ} are large enough so the contribution from subloops in the feedback are negligible. In equilibrium we have $\dot{\epsilon}_{\lambda} = 0$. Solving the corresponding set of algebraic equations (3) for the ϵ_{λ} , and inserting the result in Eq. (1), gives

$$\chi_i^f - \chi_i^m = - \sum_{\lambda} C_{i\lambda} \left\{ \sum_{\Delta} F_{\Delta}(\chi_i^m) \frac{A^{\Delta\lambda}}{|A|} \right\}, \quad (4)$$

where $A_{jK} = \sum_i C_{ij} F_{Ki}$, and A^{jK} is the corresponding cofactor. If the constants are given the values $\delta_i^2 F_{\lambda i}$, Eq. (4) becomes the solution that minimizes

$$\chi^2 = \sum \frac{(\chi_i^f - \chi_i^m)^2}{\delta_i^2},$$

for the case of uncorrelated errors, hence the basis for the analog system. The \mathcal{E}_λ are analogs of the Lagrangian multipliers sometimes introduced in solving the problem of minimizing χ^2 .

From a design standpoint, the system consists of the following major sections:

(a) Input switching logic to generate the χ_i^m and the variance factors in convenient units;

(b) Subsystems duplicated for each track, which compute (1) the derivatives of the constraint functions F_{λ_i} (one per variable), (2) the fitted values of the variables, and (3) the energy.

(c) Subsystems duplicated for each vertex which (1) generate the constraint functions F_λ , and (2) compute the integral feedback \mathcal{E}_λ .

(d) Read-out devices to measure, scan, and display system variables in convenient units.

It has been found generally convenient to use two-dimensional vector technique in a steady-state AC ($f = 1$ kc) analog in which momentum components are represented by magnitudes, and azimuth and dip by phase angles of AC variables. With this technique all required computations (aside from linear addition and multiplication by a constant) have been reduced to two basic two-dimensional vector operations: (a) resolution of a vector into components with respect to an arbitrary reference, and (b) rotations, usually to obtain a reference phase. Both operations are performed in closed subloops in which the basic nonlinearity is always a rectification. A typical example is the calculation of total energy E , given the total momentum p and mass m . By the manner in which it is obtained, the signal representing p has an arbitrary phase. It is therefore first rotated or rephased into quadrature with the signal representing m . Addition of the two signals so prepared then gives a signal of magnitude E and phase angle with respect to p equal to $\cos^{-1} \beta$. The latter condition is useful in another connection. That is, one of the factors in the F_{λ_i} associated with the integral feedback from the energy constraint, \mathcal{E}_E , is β . The \mathcal{E}_E is therefore generated in quadrature with m and its component with respect to E is resolved, the result having a magnitude $\beta \mathcal{E}_E$. Operational techniques are used extensively. Both the rephasing and resolving operations require four operational amplifiers. About 65 amplifiers are needed for each track. The system is completely

transistorized, however, including all choppers. An amplifier occupies 1/4 or 1/6 of a 5×8 in. plug-in board, depending on whether it is chopper-stabilized or not. The circuitry exclusive of amplifiers associated with a resolver or rephaser occupies one such board. Exclusive of read-in decades, a track requires a total of 25 boards. The prototype, a 4-track 1-vertex system, occupies three standard 5-ft-high racks, including one rack reserved exclusively for readout equipment such as a digital voltmeter, scope, or scanning device. All subsystems have been reduced to printed circuitry, so that expansion to a system with more tracks and vertices will mainly involve copywork. Provision has been made to accommodate simultaneous 2-vertex fits.

To date the system has been operated under realistic conditions successfully, so far as basic performance is concerned; that is, it finds correct solutions, is stable, etc. Evolution and modification are at present so rapid, however, that neither exhaustive tests nor application to real problems in physics have been undertaken. The effective level of inaccuracies inherent in the analog is suggested by the fact that spurious χ^2 values obtained with test problems (exact solutions), with errors set to ≈ 2 or 3 MeV on all variables, have been ≤ 0.1 or 0.2 in typical situations. It has been the goal to achieve reliable accuracy of one part in 10^3 of full scale for all significant variables. Accuracy of perhaps a half or third of this has been achieved to date, but is being improved.

ACKNOWLEDGMENTS

The importance of the extensive contribution of my coworker, Seth Shepard, in the development and construction of this device cannot be over-emphasized. We very much appreciate the assistance received from members of our data analysis section in the preparation of input data.

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

- A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
- B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.