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Boulder Laboratories

DATA REDUCTION INSTRUMENTATION FOR RADIO PROPAGATION RESEARCH

BY WALTER E. JOHNSON

U. S. DEPARTMENT OF COMMERCE
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NATIONAL BUREAU OF STANDARDS

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July 1961

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ABSTRACT

An approach is given to the overall problem of Data Reduction Instrumentation for Tropospheric Radio Propagation Research at the National Bureau of Standards. The need for early coordinated planning between those responsible for the data taking, data analysis, and data reporting is emphasized. A multi-channel, magnetic tape system is described as a successful solution to the data taking problem. Three special purpose computers are described as solutions to the data analysis problem: a Spectrum Analyzer, a Distribution Analysis System, and a Correlation Computer. Three computation aids are described as aids for the reduction of data not recorded on magnetic tape: the Refractive Index Computer, the Amplitude Distribution Analyzer and Chart Scaler, and the Punch Tape Data Translation System.

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DATA REDUCTION INSTRUMENTATION FOR RADIO PROPAGATION RESEARCH

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1. INTRODUCTION

The general subject of Data Reduction is pertinent to all basic and applied research programs. A complete treatment of this subject, however, would necessitate presenting the theory of operation of a range of data reduction devices varying from averaging voltmeters to general purpose digital computers. This report is not intended to cover all of the Data Reduction problems encountered in Radio Propagation Research. The intent of this report is to present a "customized" approach to the data reduction problem and to describe particular devices and systems developed for this purpose.

Customizing the data reduction process must start with the initial data recording and carry through to the final presentation. The theoretical results expected from a particular experiment should have a strong influence on the methods of analysis to be used and on the choice of recording systems. Conversely, advanced recording and analysis techniques can many times suggest experiments that would not have been feasible using older techniques.

Early coordinated planning is needed among those responsible for the data recording, data analysis and data reporting. The type and number of signals to be recorded should decide the choice of either a digital or analogue recording system. The method of analysis should dictate the choice of a time coding system and the calibration procedures. The desired final results should suggest analysis methods and set overall accuracy requirements.

2. THE DATA RECORDING AND REPRODUCTION SYSTEM

2.1 General Requirements

There are several general requirements which influence the choice of any particular data recording and reproduction system. The system selected must be capable of satisfying the experiment requirements for: number of simultaneous recording channels, total length of recording, expected bandwidth of the data, and type of data reduction planned.

The data from relatively simple short term experiments can be adequately recorded and analyzed using standard strip chart recorders. The majority of the experiments conducted in support of the Tropospheric Propagation Research Program at the National Bureau of Standards, Boulder Laboratories, however, demand a much more extensive system. In almost all cases these experiments, or recording programs, require the recording of from three to twelve simultaneous channels of information for continuous periods of time varying from one hour to several days. The data frequencies expected range from zero up to several hundred cps in some cases; in others, up to only a few cycles per second.

The type of data reduction being planned must have a strong influence upon the choice of the data recording and reproduction system. Planned compatibility between the data reproduction system and the analysis equipment can result in very large savings in both time and money. The system should also be capable of considerable flexibility with respect to the editing of the data before analysis. Editing raw field data is a very necessary part of most programs and results in great savings of analysis time.

All of the above considerations have contributed to the selection of multi-channel, FM magnetic tape recording systems as being an efficient means of recording Tropospheric Radio Propagation Research Data.

2.2 Magnetic Tape Data Recording System

The field recording equipment shown in figures 1 and 2 consists of: tape transport, recording oscillators, compensation generator, time code generator, and calibration equipment. The tape transport is generally the largest and most expensive component of the basic field recording equipment. The transports now in use are designed for either one-half or one-inch tape and are capable of recording either seven or fourteen simultaneous channels of data. Recording speeds are chosen so as to faithfully reproduce the highest expected data frequency. A recording speed of 0.6 ips is very commonly used where data frequencies up to 100 cps are expected. Recording speeds up to 6 ips are used where atmospheric disturbances may contribute data frequencies of several hundred cps.

The recording oscillator is, very simply, an oscillator whose frequency is varied by the incoming data signal and whose output drives one track of the recording head on the transport. The center frequency of the oscillator is set by the tape speed being used. A center frequency of 500 or 540 cps is used for 0.6 ips, while a center frequency of 5000 or 5400 cps is used with a tape speed of 6 ips. An input voltage variation of plus or minus 1.5 volts is required to effect the maximum modulation capability of plus or minus 40%.

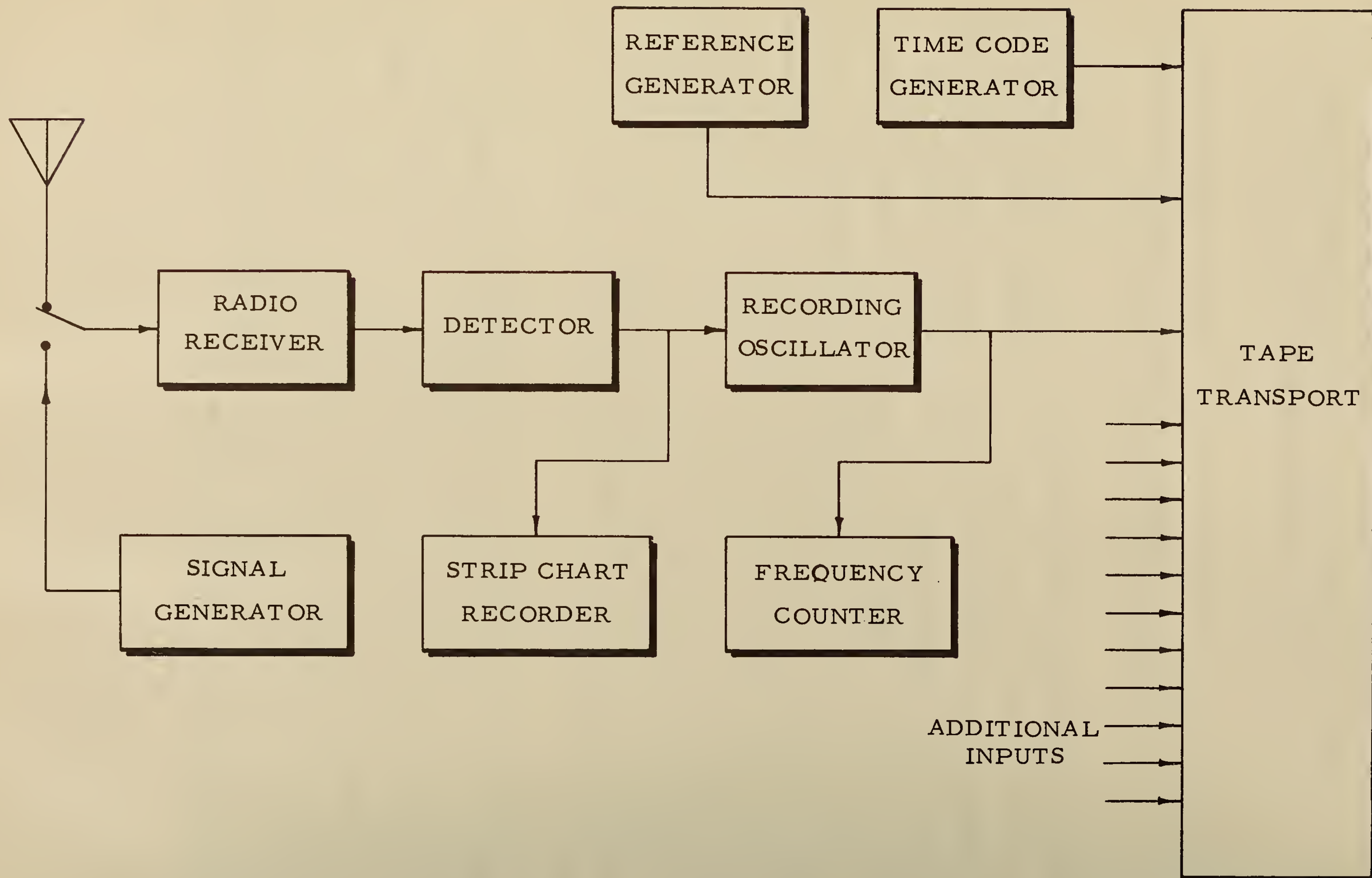

Figure 1. MAGNETIC TAPE DATA RECORDING SYSTEM

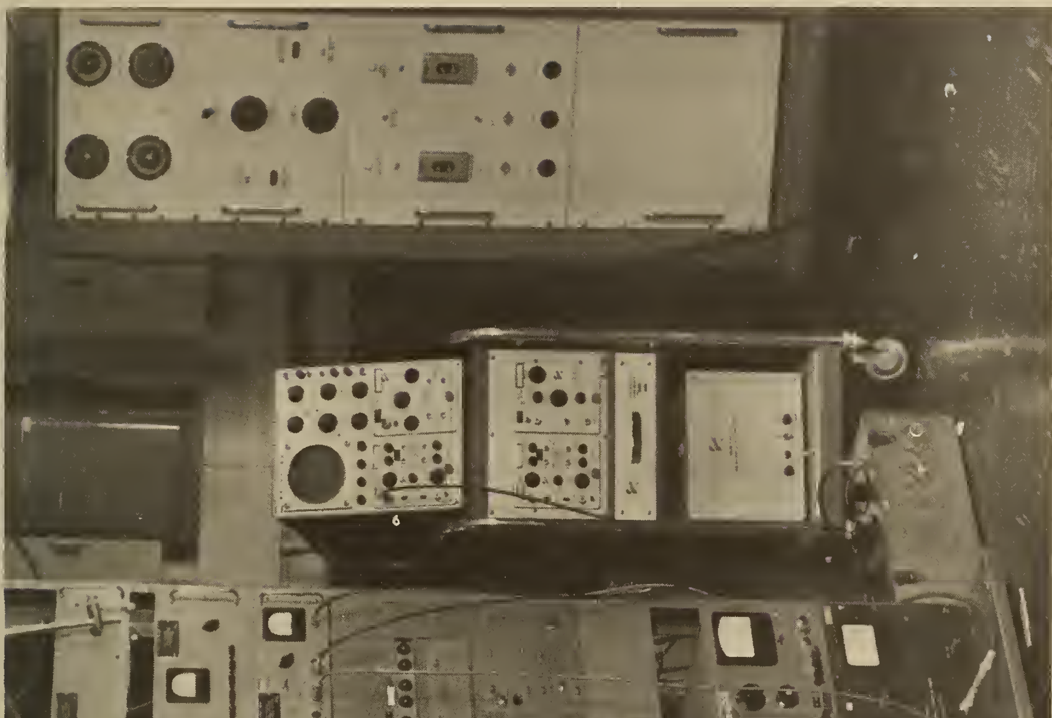

Figure 2. MAGNETIC TAPE DATA RECORDING SYSTEM

The compensation generator is merely a crystal controlled, fixed frequency oscillator whose output is recorded on a separate channel of the tape transport. Its frequency is set the same as the center frequency of the recording oscillators. This signal is used in the reproduction or playback process to compensate for wow and flutter variations introduced by the mechanical tape driving equipment.

A time code generator and a calibration system may be considered peripheral equipment to the data recording process but are nevertheless very vital to the overall objectives. A time code generator of some type should be included in the plans for all recording programs. Where data are recorded in the form of several ten minute blocks or samples per reel of tape, it may be satisfactory to merely identify the start of each block by a break or enhancement of the compensation signal. Generally, however, it is necessary to provide a much more extensive and precise time code. For this purpose, a time code generator is used which produces a complete hours, minutes, and seconds code each second. This code then provides the necessary information to the playback equipment for the selection and control of the data to the analysis equipment.

Data calibration is universally accepted as necessary. It is not always given the proper attention that it deserves. Individuals performing field calibrations must always be aware of the accuracy required and how the calibrations will be utilized in the reduction process. The method currently being used is to calibrate a simulated transducer input in terms of the frequency as recorded on the magnetic tape. In the case of a propagation signal, a signal generator voltage at the input to the radio receiver is calibrated in terms of the frequency output of the recording oscillator. The accuracy of this method can be made as high as desired. It also provides great flexibility to the reproduction process as the playback frequency is directly proportional to the tape speed.

2.3 Magnetic Tape Data Reproduction System

The data reproduction process, generally accomplished at a central facility in the laboratory, is much the reverse of the recording process. The laboratory equipment shown in figures 3 and 4, consists of: tape transport, FM signal discriminators, compensation discriminator, search and control unit, calibration equipment, and editing equipment. The transport used in the laboratory is in general very much the same as the one used in the field. It must be compatible in terms of tape width, tape speeds, and number of recording channels. In addition, it should have additional playback speeds and a fast forward or backward search speed. One of the units in use at NBS-BL is capable of nine speeds from 0.3 to 60 ips, either 12 or 14 channels on one-inch tape, and has a bi-direction search speed of 120 ips.

The discriminator units re-convert the tape signal to the originally recorded data signal. Data recorded at 0.6 ips and played back at 60 ips now have upper frequencies of 10 kc instead of the original 100 cps. The compensation discriminator output is zero except for the contribution of wow and flutter from the two tape transports. The data discriminator outputs contain both the data information and the wow and flutter contributions. Proper combination of these two outputs essentially cancells the effect of wow and flutter.

The search and control unit input is the tape signal recorded from the time code generator. Each second of record time is read and displayed by the unit regardless of playback speed. This information is used to control the transport while searching for information on a tape reel. Once the information is located, the unit automatically switches the transport to a pre-selected playback speed and provides an on-and-off signal to the analysis equipment.

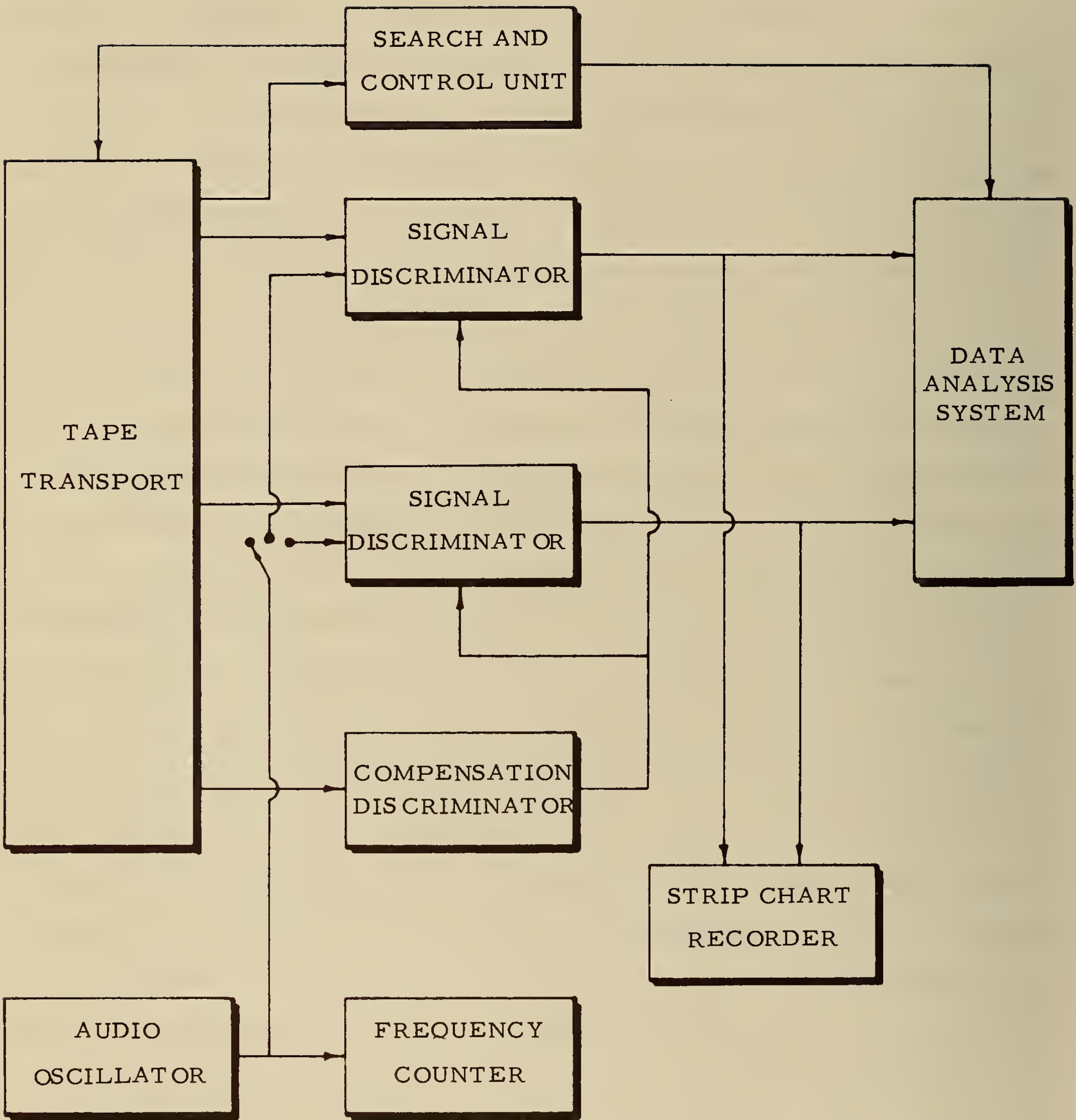

Figure 3. MAGNETIC TAPE DATA REPRODUCTION SYSTEM

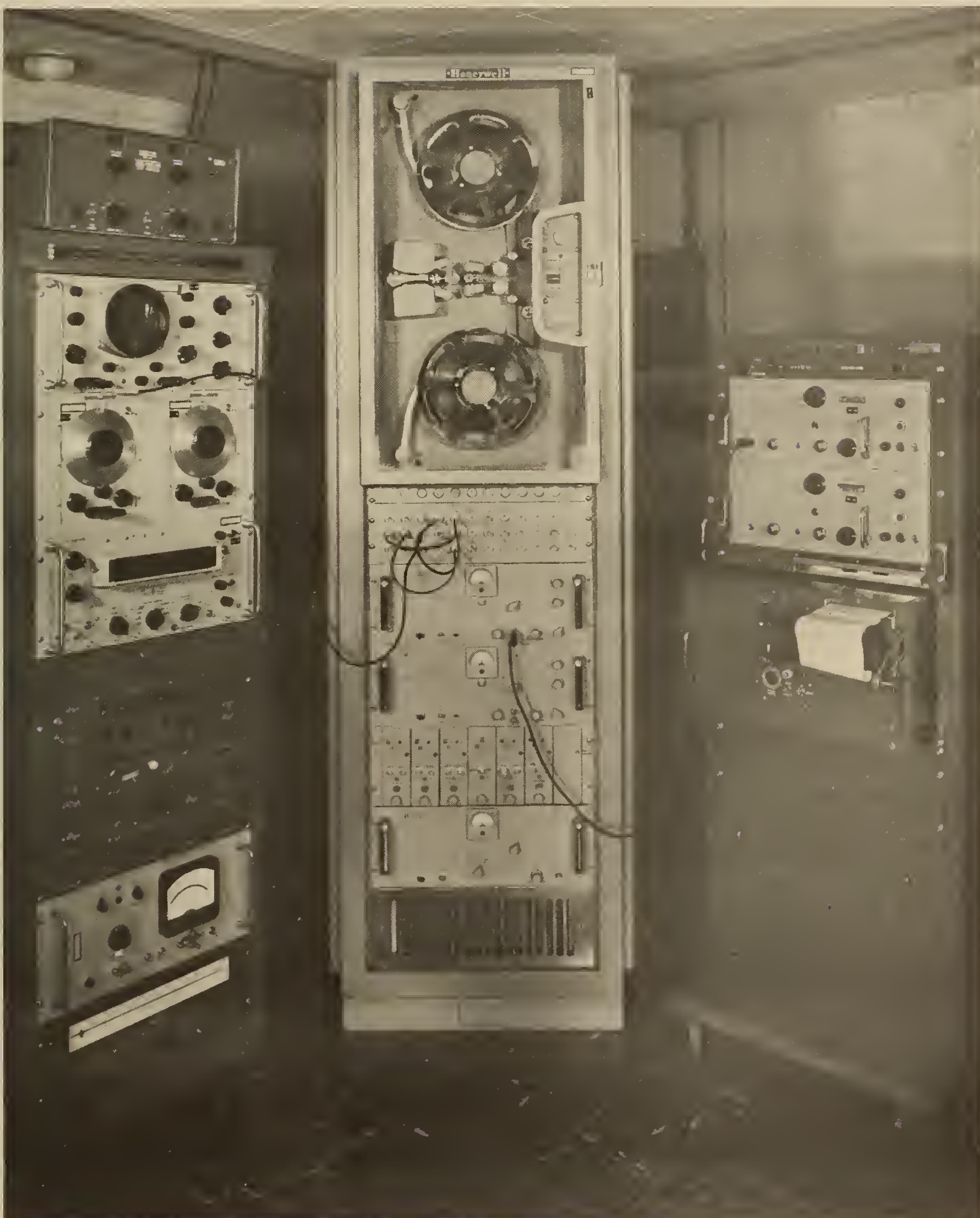

Figure 4. MAGNETIC TAPE DATA REPRODUCTION SYSTEM

Calibration and editing are accomplished with the help of the search and control unit and with the assistance of such additional units as a frequency counter, a signal generator, a strip chart recorder, and an oscilloscope. Calibration is accomplished by setting a frequency count into the discriminator and recording the associated output voltage. Editing is generally accomplished with the assistance of recorder log-book information and either an oscilloscope or strip chart recorder. Editing must be done so as to eliminate portions of the data tape that contain calibration information, equipment failures, interference signals, and tape drop-outs.

3. SPECIAL PURPOSE COMPUTERS

The use of special purpose computers is, in general, justified by the demand for a particular type analysis. Most research laboratories today either own or have available a high speed, general purpose digital computer. The cost in both time and money of translation, programming and analysis of field data on general purpose computers in many cases more than justifies the development of special purpose computers. These computers can be either digital or analog or combinations of both of the types and, in general, are developed for specific type input data. The following text contains a description of three of the special purpose computers currently in use.

3.1 Spectrum Analyzer

Spectral analysis is one of the most widely used methods of describing radio propagation data [Thompson, 1959]. The Spectrum Analyzer shown in figures 5 and 6, utilizes the heterodyne principle of mixing the output of a variable frequency oscillator with the data signals to obtain sidebands. The mixer is supplied with the data to be analyzed, together with the output of a variable frequency oscillator; thus, any component of the data can be made to produce sidebands. A tuned amplifier selects only those sidebands from the mixer that come within its passband. The bandwidth of the tuned amplifier is adjustable in two ranges from a fraction of a cycle per second to 45 cps.

The output from the tuned amplifier is rectified and applied as a d-c voltage to a potentiometric, strip-chart recorder which has a logarithmic response. The paper drive of the recorder may be coupled to the oscillator controller frequency dial drive with a synchro system so that the resultant record will be an accurate plot showing amplitude versus frequency. The accuracy of the frequency indication is improved through the use of identification marks made on the chart through the keying action of the frequency dial on the oscillator controller.

The variable oscillator is motor driven to sweep through the range of 3 kc to 5 kc, and the tuned amplifier will accept only 3 kc sidebands. Therefore, the spectrum analyzer will automatically analyze all signals from a lower practical limit of 3 cps to its maximum upper frequency of 2 kc, because these signals will produce a 3 kc sideband acceptable to the tuned amplifier. If a 2 kc component should appear in the input signal, the heterodyning will produce a low sideband of 3 kc and a high sideband of 7 kc when the variable oscillator reaches 5 kc. The 3 kc sideband, which is accepted by the tuned amplifier, now represents the 2 kc component in the input signal, and will vary in amplitude proportional to the 2 kc component.

A square-law network is incorporated as a portion of the rectifier circuitry and may be switched in as desired. In square-law operation, the square of the input voltage to the strip-chart recorder is recorded, and in linear operation the direct rms input voltage is recorded.

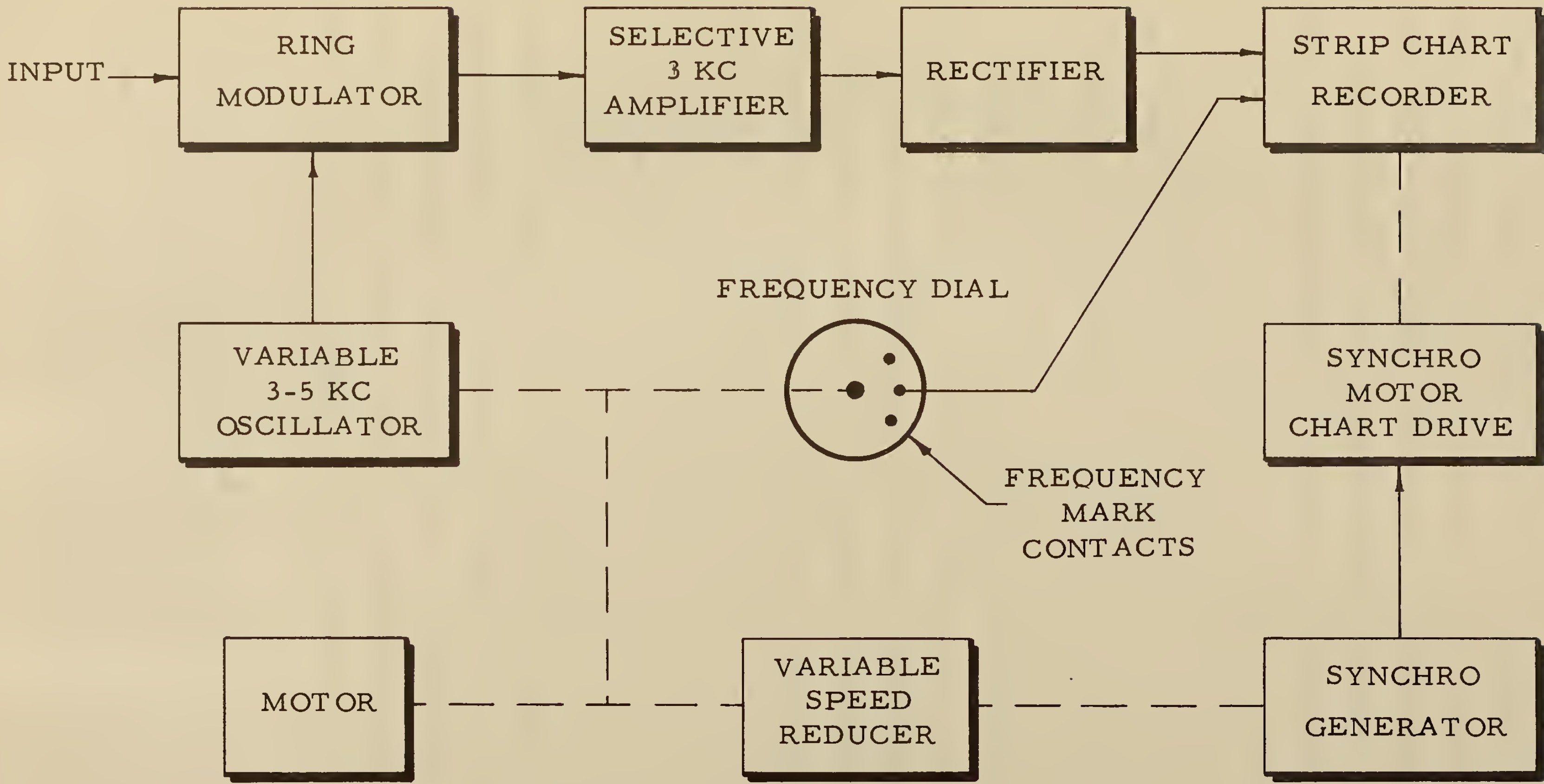

Figure 5. SPECTRUM ANALYZER

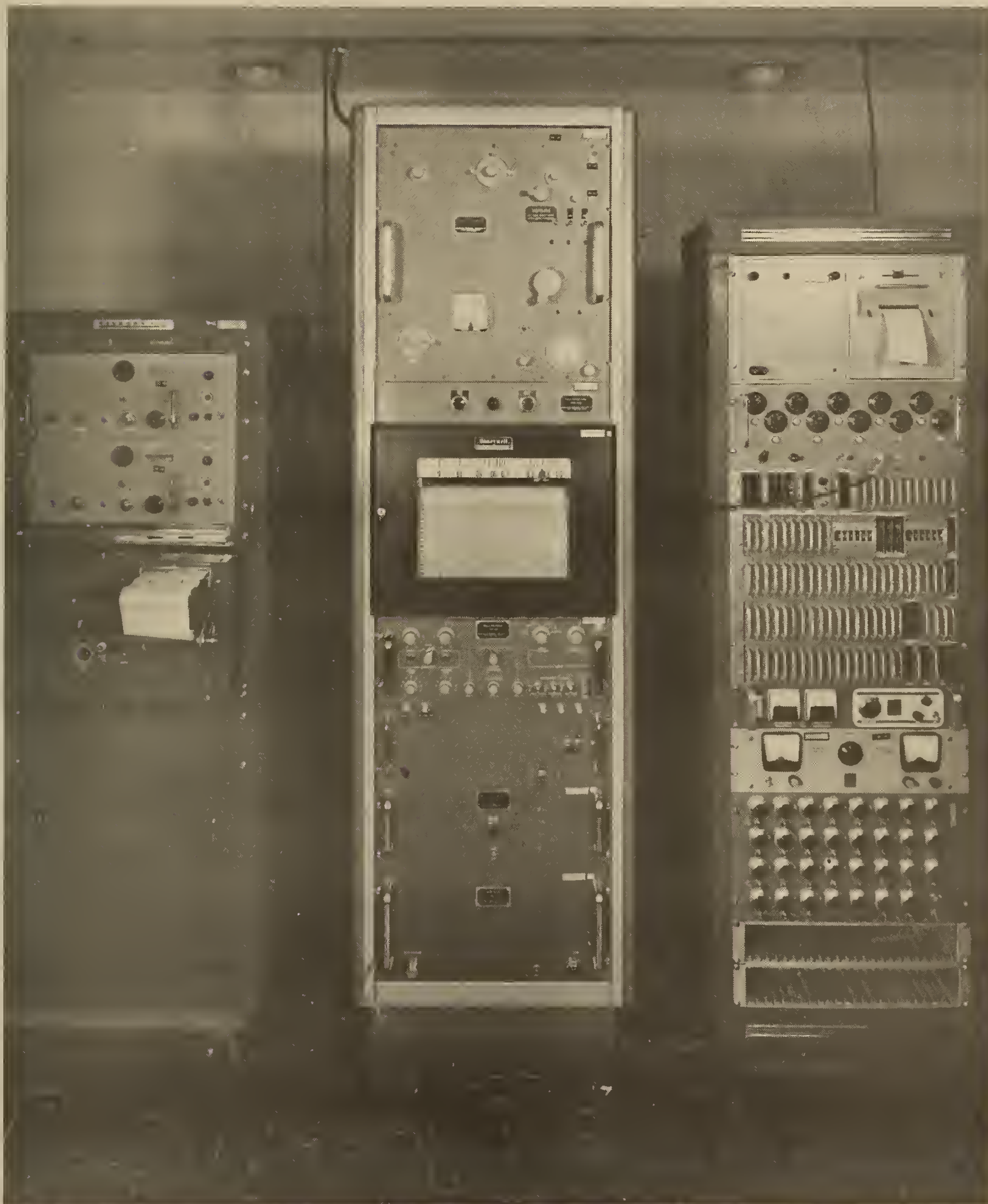

Figure 6. SPECTRUM ANALYZER

3.2 Distribution Analysis System

The Distribution Analysis System (DASY) shown in figures 7 and 8, is a special purpose computer designed to analyze time varying data recorded on magnetic tape [Norton, 1955; Crichlow, 1960]. The following statistical parameters are deduced from the data:

(a) Cumulative amplitude distribution

(b) Fade rate vs level

(c) Fade or enhancement duration distribution at specific data levels

(d) Distribution of the percent of time preset fade or enhancement durations are exceeded, at specific data levels.

The incoming data are sampled 20,000 times per second. These samples are compared to a reference voltage and two pulse trains are formed. One pulse train represents periods of time the data are above the reference; the other, periods when the data are below the reference. These two pulse trains contain all the necessary information to determine the four statistical parameters mentioned above.

With the 20,000 per second sampling rate, it is possible to analyze most field data when playing back the magnetic tape at one hundred times the speed at which it was recorded. The effective sampling rate, relative to record time, is then 200 samples per second. This provides a resolution of five milliseconds in measuring fade or enhancement durations.

The input data can vary between the limits of plus and minus 7.5 volts. The threshold sensitivity of the comparator circuit is plus or minus five millivolts or less; d-c drift in reference voltage is 3 mv or less in two hours. Thus, the threshold detection accuracy, relative to the full scale input voltage, is better than 0.1%.

A typical operation would be to calibrate the computer at ten reference voltages before starting the analysis. The reference selector is then set to the first reference voltage and the data analyzed relative to it. At the end of the analysis period, the resultant data are automatically recorded on a digital printer and the reference selector steps to the next reference voltage for a subsequent pass through the data. A complete analysis is performed about a reference level with each pass of the data.

3.3 Correlation Computer

The correlation computer shown in figures 9 and 10, is a special purpose analog computer designed to continuously perform the multiplication and integration or averaging required in solving the normal ized correlation equations [Florman, 1960]. The tape transport system, which will provide a dynamic delay feature, has not as yet been procured. The basic computer portion, however, is well developed and worthy of report at this time.

Two random input signals, x' and y', are first applied to the servo controlled signal conditioning amplifiers. The function of these amplifiers is to amplitude condition the incoming signals so as to equate their variances over the averaging time to be used in the computation. The two conditioned signals, x and y, are then applied to a sum and difference circuit and then to squarers followed by averaging circuits. This succession of circuitry produces the variance of the sum of the signals and the variance of their difference as follows:

$$\sigma^2_{x+y} = \sigma^2_x + \sigma^2_y + 2\sigma_{xy} = 2(\sigma^2_x + \sigma_{xy})$$

$$\sigma^2_{x-y} = \sigma^2_x + \sigma^2_y - 2\sigma_{xy} = 2(\sigma^2_x - \sigma_{xy})$$

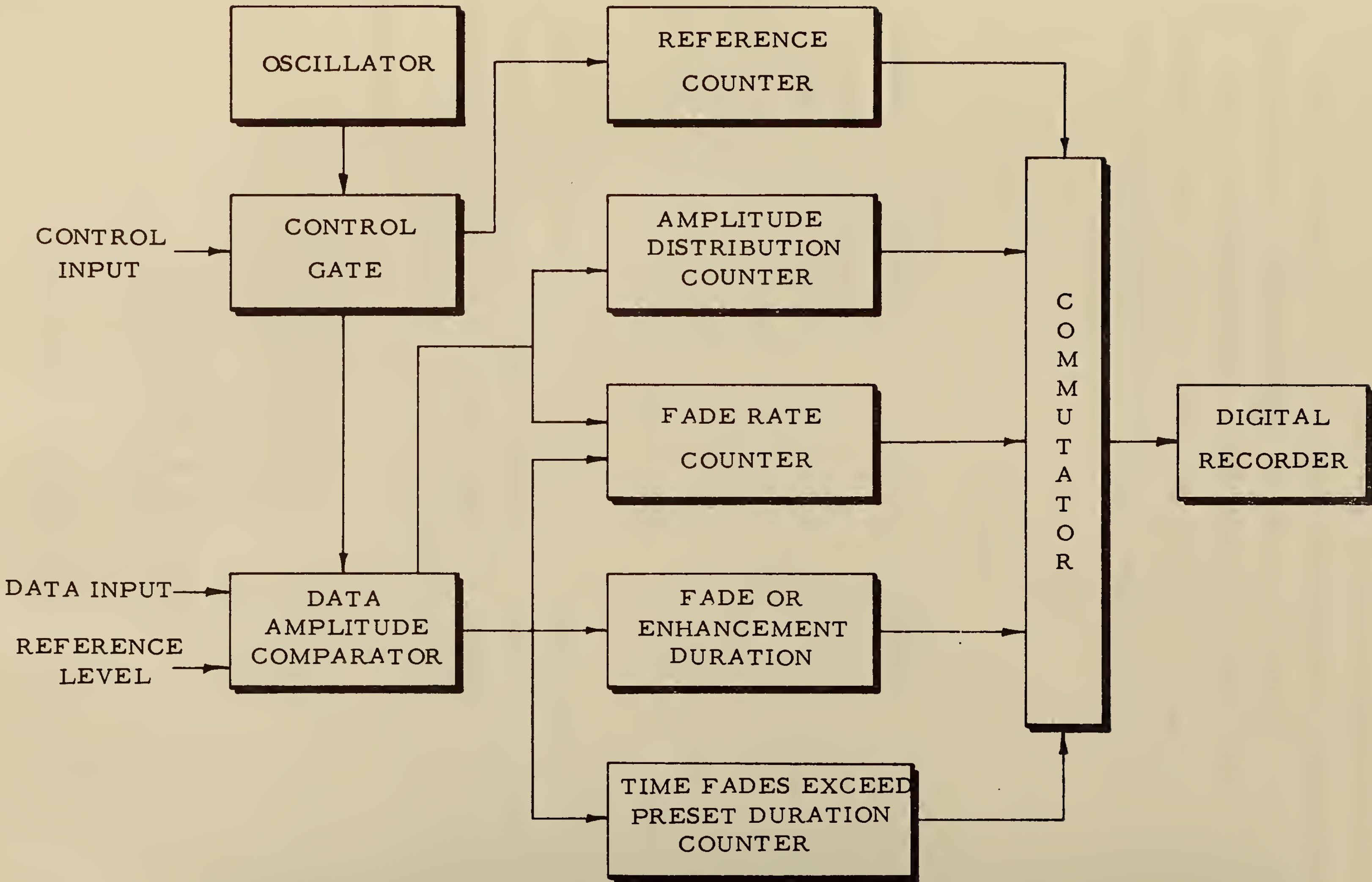

Figure 7. DISTRIBUTION ANALYSIS SYSTEM ($D\bar{A}SY$)

Figure 8. DISTRIBUTION ANALYSIS SYSTEM ($\bar{D}$ASY)

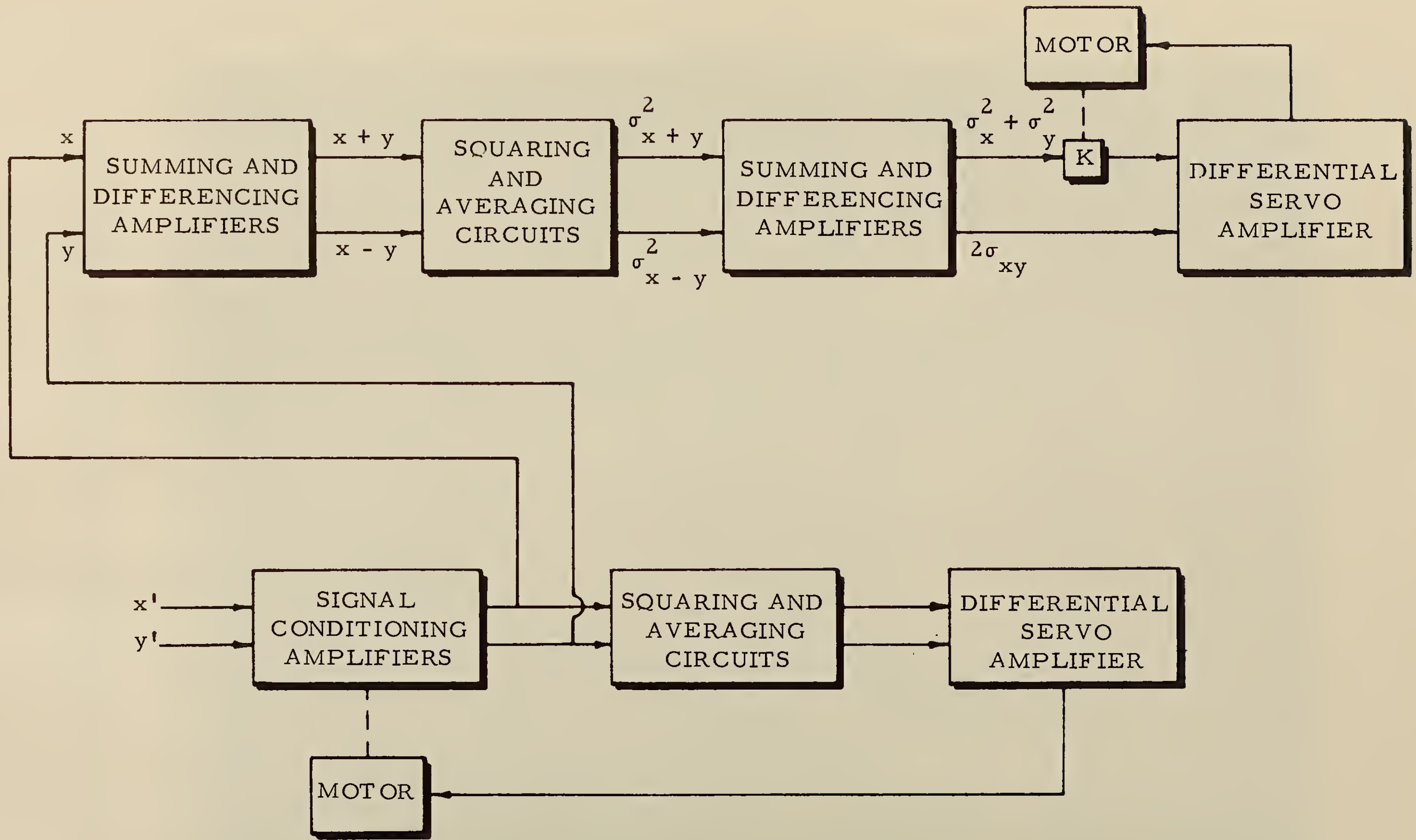

Figure 9. CORRELATION COMPUTER

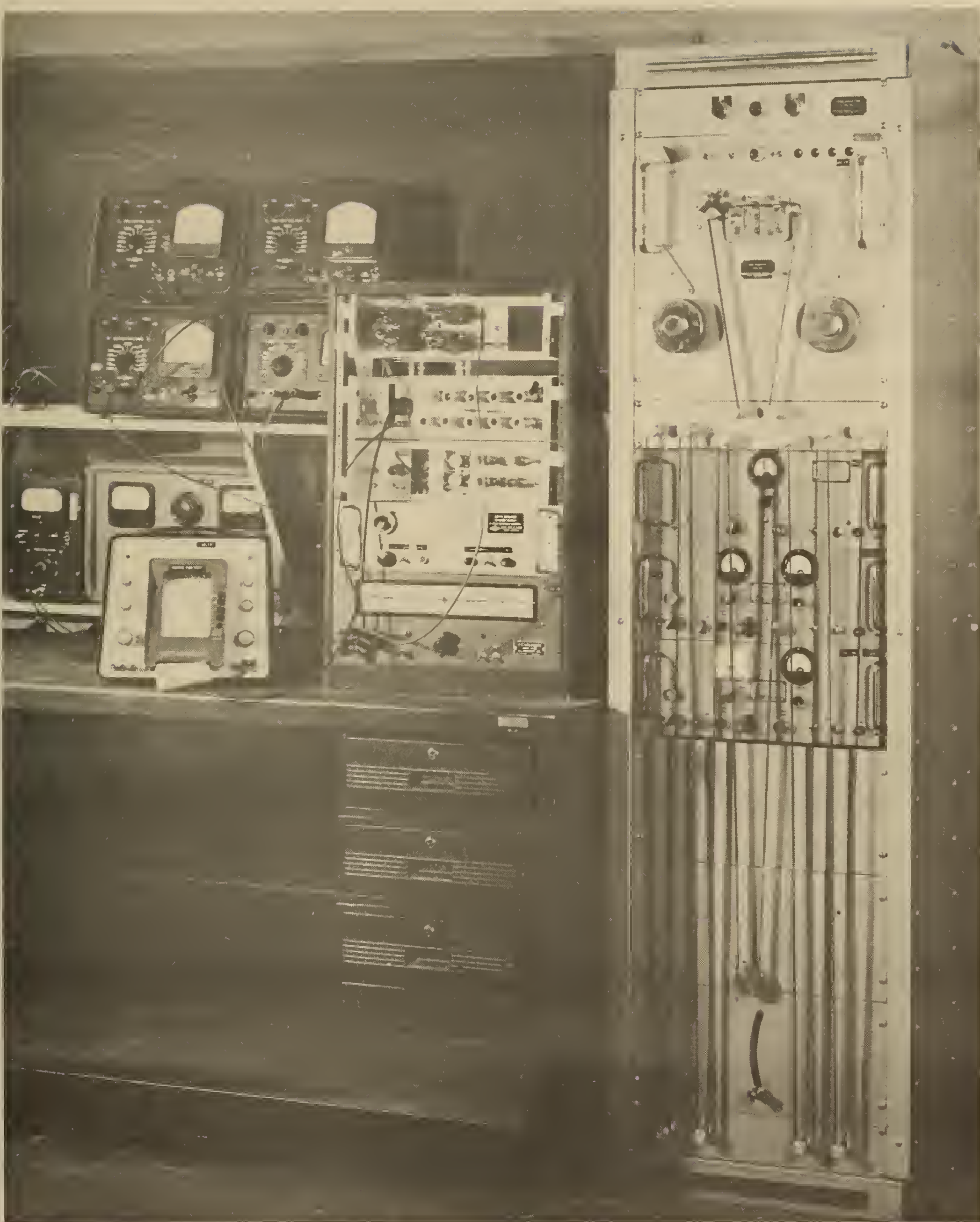

Figure 10. CORRELATION COMPUTER

By further taking sums and differences of the above equations we compute the covariance, σ_{xy}, and the sum of the variances, $\sigma_x^2 + \sigma_y^2 = 2\,\sigma_x^2$. If we are only interested in the covariance, this quantity may of course be recorded as an analog function of time for fixed delay (τ) or as a function of τ where this parameter is dynamically introduced by the tape loop transport system.

The correlation coefficient is obtained through the use of a second servo system which computes the ratio (K) of the covariance to the variance σ_x^2.

$$K = \frac{2\,\sigma_{xy}}{\sigma_x^2 + \sigma_y^2} = \frac{\sigma_{xy}}{\sigma_x^2} = \rho = \frac{\sigma_{x'y'}}{\sigma_{x'}\,\sigma_{y'}}$$

4. COMPUTATION AIDS

In some cases, field data are not recorded on magnetic tape or are not recorded in a form suitable for direct analysis by special purpose computers. In other cases, an analysis is to be performed that is sufficiently complicated or rare so as to not justify the development of a special purpose computer. In this latter case, the data from the magnetic tape equipment is digitized onto punched paper tape and programmed for analysis on the high speed, general purpose digital computer.

In the cases where field data is not recorded in the proper form, several computation aids have been developed to either compute or assist in the reduction of the data. The following three examples serve to illustrate the equipment which has been developed to satisfy this portion of the data reduction problem.

4.1 Refractive Index Computer

The Refractive Index Computer [Johnson, 1953] shown in figures 11 and 12, is a special purpose digital computer designed to solve the following equation for the radio refractive index [Smith, 1953].

$$N = (n-1)\, 10^6 = \frac{K_1}{T} \left(p + K_2 \frac{e_s}{T} RH\right)$$

In general, the data to be applied to this solution are in the form of tabulated numerical values and as such are not readily adapted to a continuous or automatic type data reduction process.

Fig. 11 is a complete circuit diagram of the computer, and serves to illustrate the simplicity of the circuit. The three independent variables of pressure, temperature, and relative humidity are introduced as dial settings by the operator. A fourth dial permits the operator to rebalance the bridge circuit, and the desired value of N is read directly from this dial. The circuit constants and dial calibrations have been adjusted so that the variables may be introduced directly in terms of their recorded values. The units for pressure are millibars, for temperature-degrees Centigrade and for relative humidity-percent.

A unique feature of this computer is the modification of a linear ten-turn portentiometer so that its output to input voltage ratio vs rotation equals the curve of the saturated water vapor term in the refractive index equation. Mechanical coupling of this element to the main temperature element effectively eliminates the term $\frac{e_s}{T}$ as a variable in the equation.

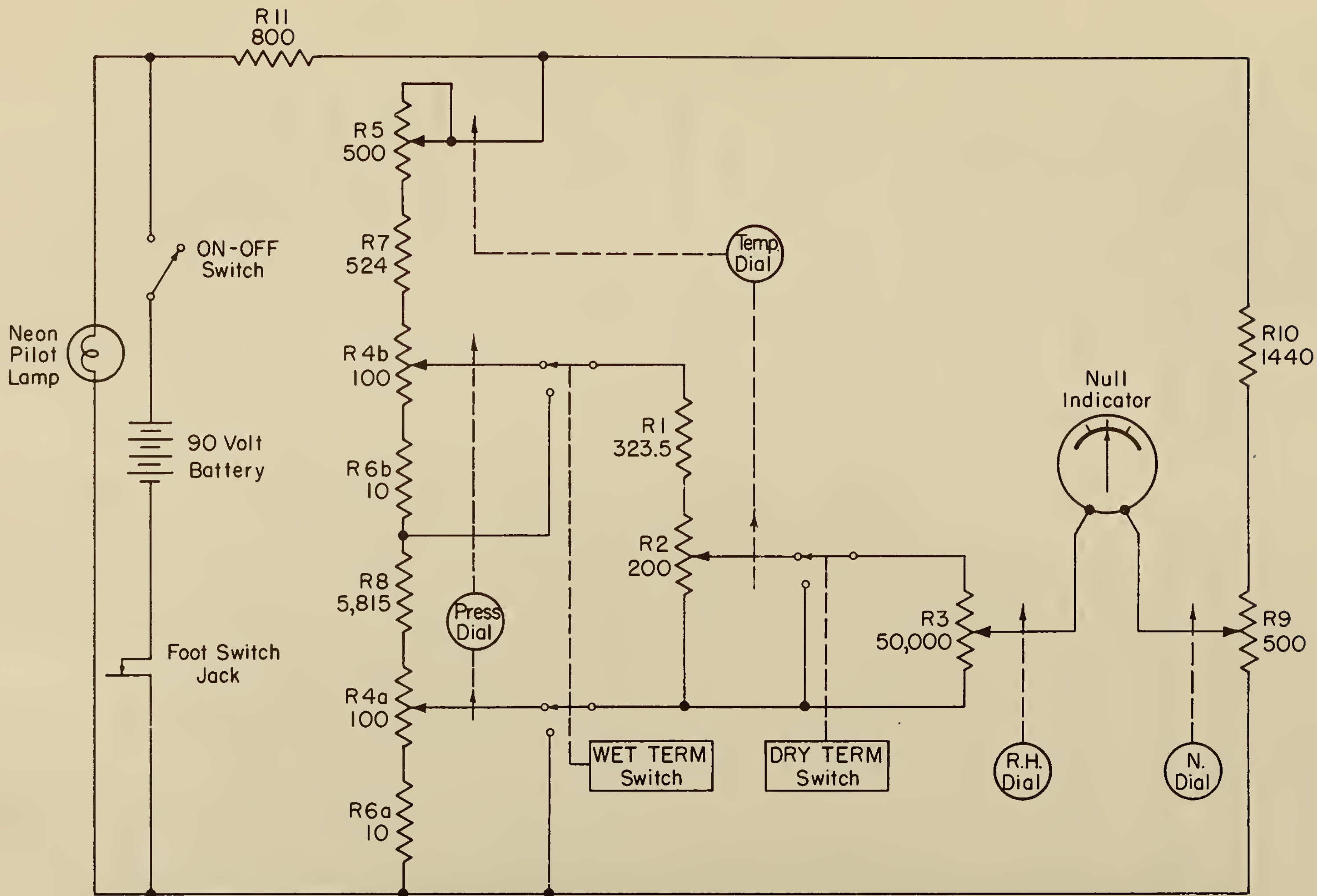

Figure 11. REFRACTIVE INDEX COMPUTER

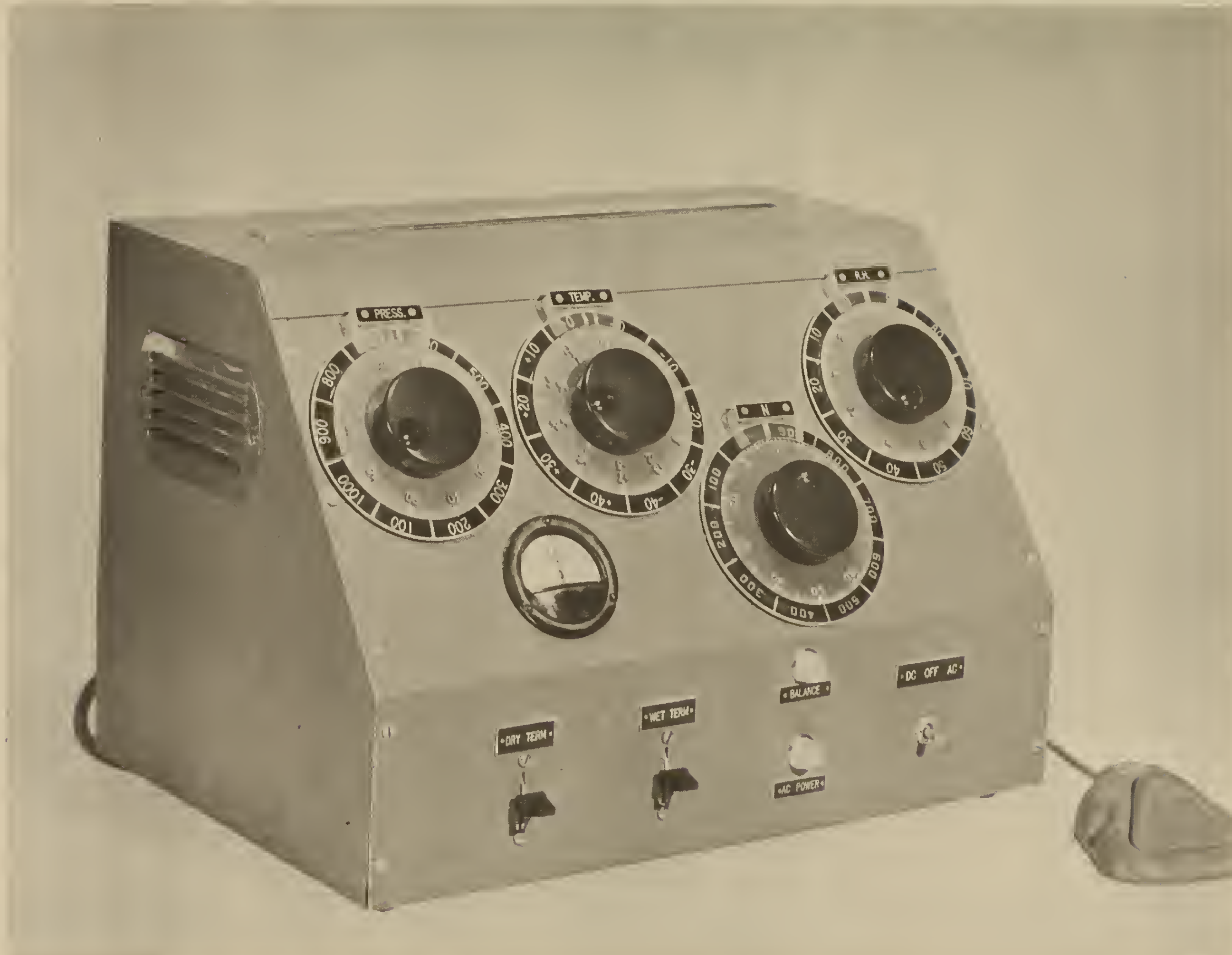

Figure 12. REFRACTIVE INDEX COMPUTER

The refractive index equation may be considered as being composed of two parts: a wet term, equal to $\frac{K_1}{T}$ ($K_2 \frac{e_s}{T}$ RH), and a dry term, equal to $\frac{K_1}{T}$ p. Many of the applications which require the solution of this equation also require the individual values of the wet or dry contributions to N. Two switches are incorporated into the final circuit which permit the computer to solve for either contribution and thereby greatly increase its usefulness.

4.2 Amplitude Distribution Analyzer and Chart Scaler

Strip chart records continue to be the primary recording medium for certain short term, low budget programs. The Amplitude Distribution Analyzer and Chart Scaler (ADIACS) shown in figures 13 and 14, was developed to assist in the analysis of this type of record. The analyzer consists basically of a chart scaler or follower, digital converter, code conversion matrix, numerical distribution totalizer, and a sampling system.

The chart scaler is essentially the chart drive mechanism from the same strip chart recorder as was used to record the field data. The scaling pointer has the same radius as the original recording pen. As the operator moves the pointer, following the recorded data, a mechanical digitizer attached to the pointer shaft rotates so that a full scale trace of the chart produces a 100 count output from the digitizer. This output is connected to a relay diode matrix which senses the level of the retraced signal in terms of a two-digit decimal number. Ten discrete levels may each be set by means of two selector switches. They, in turn, are connected to the drive coils of ten impulse counters. This arrangement causes the counters to register, at the sampling rate, whenever the signal exceeds the particular pre-set level. The sampling rate is controlled by a photo-cell sampling disk connected directly to the chart drive mechanism. The sampling rate may be varied by changing the number of holes in the sampling disk. The chart drive speed and the sampling rate are determined by the requirements of the particular data and the desired reduction accuracy.

The cumulative amplitude distribution for any desired sample length is determined by plotting the ratio of the reading in any counter to the total sample count versus the level position of the particular counter.

4.3 Punch Tape Data Translation System

Punched paper tape is a very useful medium in both the data recording and data analysis processes. Several different codes and formats are used in the preparation of these tapes, however, and it is essential that the data reduction program have equipment available capable of performing a variety of different data translation operations.

The Punch Tape Data Translation System shown in figures 15 and 16, includes the following major components: tape reader, removable patchboard type code conversion matrices, electrical input-output typewriter, and tape punch. There are a variety of modes of operation possible, capable of performing several different translation operations.

Perhaps the simplest mode of operation is direct copying of data tapes. This operation involves only the use of the tape reader and punch and certain driving circuitry. Another relatively simple mode of operation is the preparation of data or programming tapes from tabulated data.

In this mode, the typewriter is used to drive the tape punch through a code conversion matrix. A third mode of operation utilizes the tape reader, a code matrix, and the typewriter. In this mode, it is possible to verify or tabulate in typewriter output format the data punched on paper tape.

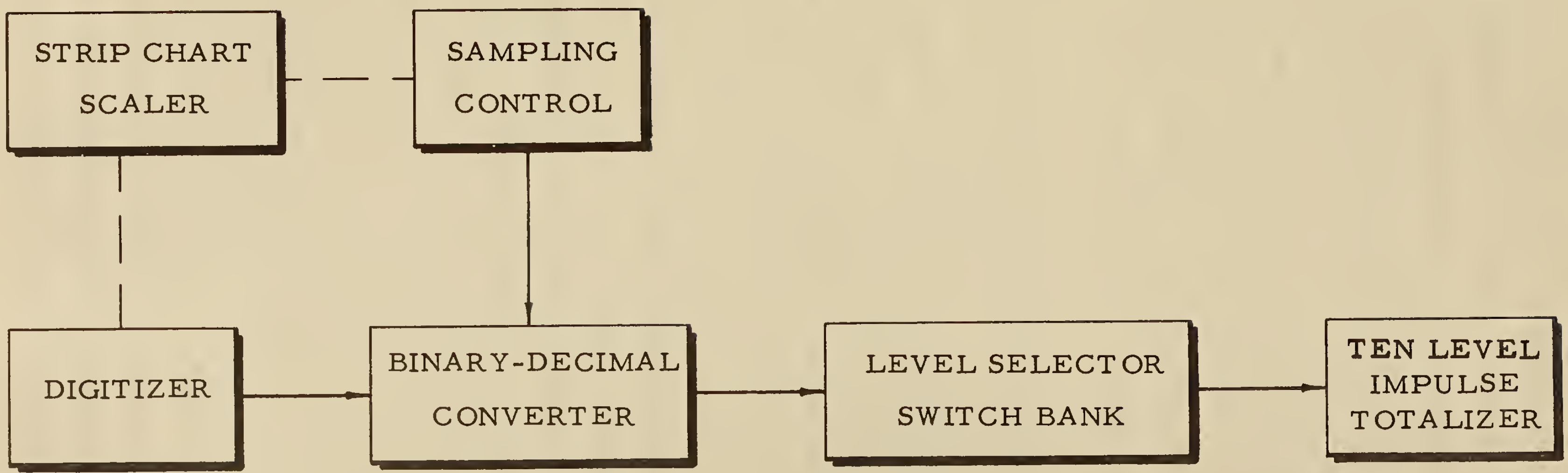

Figure 13. AMPLITUDE DISTRIBUTION ANALYZER AND CHART SCALER (ADIACS)

Figure 14. AMPLITUDE DISTRIBUTION ANALYZER AND CHART SCALER (ADIACS)

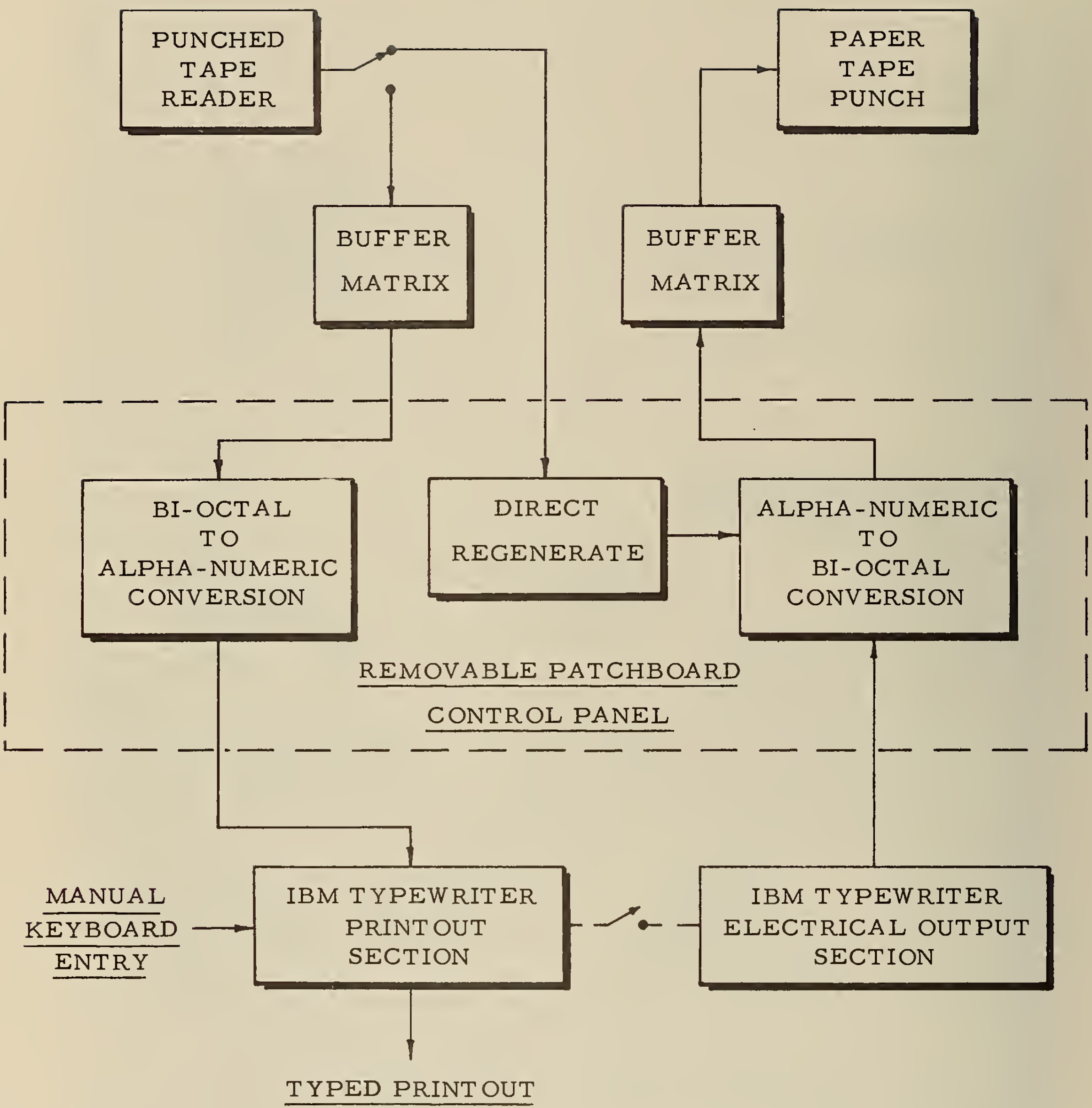

Figure 15. PUNCHED TAPE DATA TRANSLATION SYSTEM

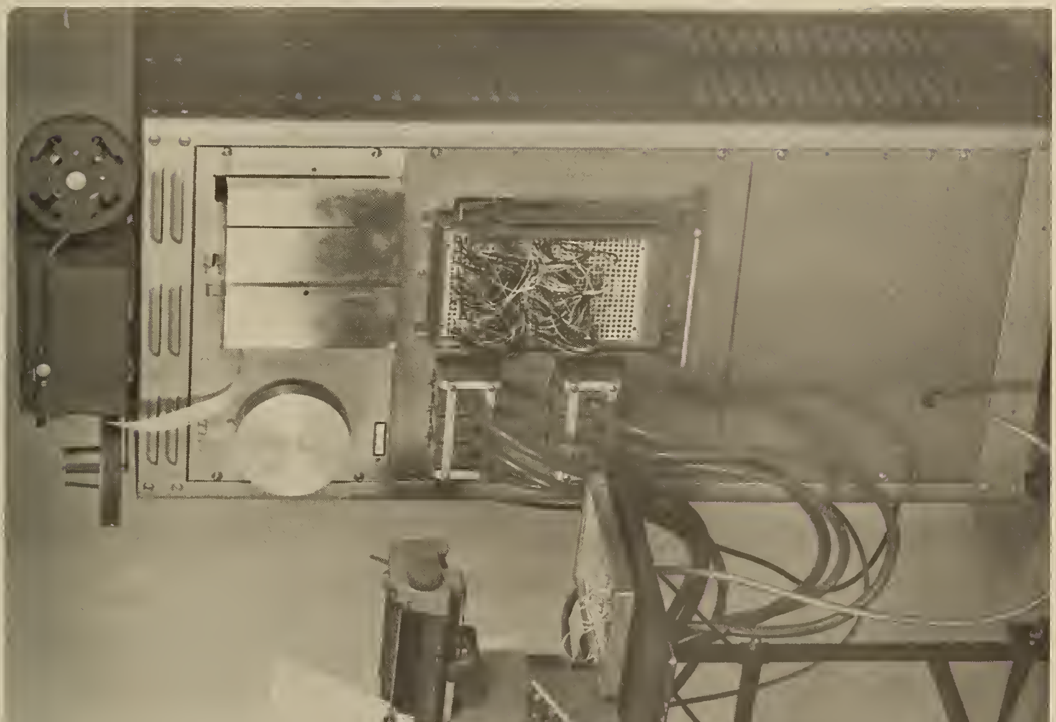

Figure 16. PUNCH TAPE DATA TRANSLATION SYSTEM

The complete mode of operation utilizes all of the components shown on the diagram. In this mode, tape data is read by the reader, converted for typewriter entry by a matrix, and typed out by the typewriter. Simultaneously, the typewriter signal is applied to another code conversion matrix. This, in turn, drives the tape punch. Control flexibility allows the operator to manually introduce programming commands at various points in the preparation of the new tape.

5. CONCLUSION

All of the equipment described in this report is currently in use within the Radio Propagation Engineering Division of the National Bureau of Standards, Boulder Laboratories. There are several sets of Magnetic Tape Data Recording Systems in use at various field locations. The Magnetic Tape Data Reproduction System and the Special Purpose Computers are operated as the Division's Data Reduction Facility. The Computation Aids are generally developed for particular projects, and are operated at any location by personnel responsible for the particular reduction for which they were designed.

It has been the intent of this report to continually emphasize the need for coordinated planning between those responsible for data taking, data analysis, and data reporting. It is hoped that the techniques and systems described here have served to adequately describe a successful solution to the general problem of "Data Reduction for Tropospheric Propagation Research".

6. ACKNOWLEDGEMENT

The development of certain equipments described in this report has been the responsibility of certain individuals in the Data Reduction Instrumentation Section. The author wishes to acknowledge the following contributions: Mr. P. I. Wells and Mr. D. V. Glen for the Distribution Analysis System; Mr. R. W. Hubbard and Mr. J. V. Cateora for the Correlation Computer; Mr. J. A. Sykes for the Data Reduction Facility; and Mr. R. A. Blumenhein for the Amplitude Distribution Analyzer and Chart Scaler, and the Punch Tape Data Translation System.

REFERENCES

Crichlow, W. Q., C. J. Roubique, A. D. Spaulding, and W. M. Berry, Determination of the amplitude-probability distribution of atmospheric radio noise from statistical moments, J. Research NBS 64D, (Radio Prop.), No. 1, 49-56 (Jan. 1960).

Florman, E. F., and R. W. Plush, Measured statistical characteristics and narrow-band teletype message errors on a single-sideband 600-mile-long ultrahigh-frequency tropospheric radio link, J. Research NBS 64D, (Radio Prop.), No. 2, 125-133 (Mar. 1960).

Johnson, W. E., An analogue computer for the solution of the radio refractive index equation, J. Research NBS 51, No. 6, 335-342 (Dec. 1960).

Norton, K. A., P. L. Rice, H. B. Janes, and A. P. Barsis, The rate of fading in propagation through a turbulent atmosphere, Proc. IRE 43, No. 10, 1341-1353 (Oct. 1955).

Smith, E. K. and S. Weintraub, The constants in the equation for atmospheric refractive index at radio frequencies, Proc. IRE 41, No. 8, 1035-1037 (Aug. 1953).

Thompson, M. C., Jr., and H. B. Janes, Measurements of phase stability over a low-level tropospheric path, J. Research NBS 63D, (Radio Prop.), No. 1, 45-49 (July 1959).

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Metrology. Photometry and Colorimetry. Refractometry. Photographic Research. Length. Engineering Metrology. Mass and Scale. Volumetry and Densimetry.

Heat. Temperature Physics. Heat Measurements. Cryogenic Physics. Equation of State. Statistical Physics.

Radiation Physics. X-ray. Radioactivity. Radiation Theory. High Energy Radiation. Radiological Equipment. Nucleonic Instrumentation. Neutron Physics.

Analytical and Inorganic Chemistry. Pure Substances. Spectrochemistry. Solution Chemistry. Analytical Chemistry. Inorganic Chemistry.

Mechanics. Sound. Pressure and Vacuum. Fluid Mechanics. Engineering Mechanics. Rheology. Combustion Controls.

Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.

Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics*

Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Crystal Growth. Physical Properties. Constitution and Microstructure.

Building Research. Structural Engineering. Fire Research. Mechanical Systems. Organic Building Materials. Codes and Safety Standards. Heat Transfer. Inorganic Building Materials.

Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.

Data Processing Systems. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Applications Engineering.

Atomic Physics. Spectroscopy. Radiometry. Solid State Physics. Electron Physics. Atomic Physics.

Instrumentation. Engineering Electronics. Electron Devices. Electronic Instrumentation. Mechanical Instruments. Basic Instrumentation.

Physical Chemistry. Thermochemistry. Surface Chemistry. Organic Chemistry. Molecular Spectroscopy. Molecular Kinetics. Mass Spectrometry. Molecular Structure and Radiation Chemistry.

* Office of Weights and Measures.

BOULDER, COLO.

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.

Ionosphere Research and Propagation. Low Frequency and Very Low Frequency Research. Ionosphere Research. Prediction Services. Sun-Earth Relationships. Field Engineering. Radio Warning Services.

Radio Propagation Engineering. Data Reduction Instrumentation. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Propagation-Terrain Effects. Radio-Meteorology. Lower Atmosphere Physics.

Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. Radio and Microwave Materials. Atomic Frequency and Time Interval Standards. Electronic Calibration Center. Millimeter-Wave Research. Microwave Circuit Standards.

Radio Systems. High Frequency and Very High Frequency Research. Modulation Research. Antenna Research. Navigation Systems. Space Telecommunications.

Upper Atmosphere and Space Physics. Upper Atmosphere and Plasma Physics. Ionosphere and Exosphere Scatter. Airglow and Aurora. Ionospheric Radio Astronomy.

NBS