AN ABSTRACT OF THE THESIS

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Adapting man, as an organic link, to closed loop control systems, is increasingly presenting problems to designers of systems of any nature. Performance of the human in the systems is dependent upon a multitude of recognized factors, and many as yet unknown factors and variables.

In order to investigate the problem areas involved, a means of simulating real life conditions must be available. This study centers on the development of such a laboratory simulator system and its requirements.

The main area of interest selected is the human operator in tracking operations. This subject area is thoroughly researched and the major problem areas are briefly discussed. The tracking areas to be simulated include pursuit and compensatory tracking tasks, multi-dimensional tracking tasks as well as environmental control criteria for the subject,

the latter consisting of an environmentally controlled chamber. Facilities were selected, based upon previous tracking studies to vary some of the basic environmental conditions: illumination, sound pressure and temperature.

The tracking tasks available can be varied in type of input signal display media, operator control unit as well as waveform of the input signal, operator control response function and performance data collection. Timed, random and cumulative timed data collection features are designed into the system. In addition a chart recorder facility and interface is available for obtaining a hard copy of the actual tracking performance.

Complete circuit descriptions and diagrams are presented in the appendices of this thesis.

Actual conclusions on data obtained with the system are not included although a large data file has already been created. Numerous experiments are suggested however, and typical machine outputs are illustrated, interpreted and discussed. Because of the magnitude of possibilities to experiment and investigate using the simulator system, it is beyond the scope of this project to provide data and subsequent conclusions or observations.

# DEVELOPMENT OF A SYSTEM FOR MAN-MACHINE EXPERIMENTATION

by

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A THESIS

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Without the aid and reassurance of my wife, Helen, this task would not have been accomplished. Her efforts in maintaining a productive environment under difficult circumstances are very much appreciated.

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# DEVELOPMENT OF A SYSTEM FOR MAN-MACHINE EXPERIMENTATION

## CHAPTER I

## INTRODUCTION

Human Factors Engineering, a relatively new name for an old discipline, concerns itself with the adaptation of the human to the often monstrous creations by the same human, the Man-Machine System. (Figure 1-1).

In pursuing this task, Human Factors Engineering takes the format of a science as well as a technology, probing for solutions in a sequence of alternating both functions.

Consider a problem occuring in the preliminary design stages of a system in which the human has a function at some point. In this instance, the Human Factors Engineering Science is applied towards a solution, often system simulators are utilized in aiding to evaluate the problem, to dynamically measure adaptation of the human to the system as a function of system performance, output and reliability. In the course of this approach, Human Factors Engineering technology provides its input.

Ever since the development of increasingly complex man-machine systems, engineers have experienced difficulties in fitting the human in their products. Often their creations required from him too many hands, too many feet or even too

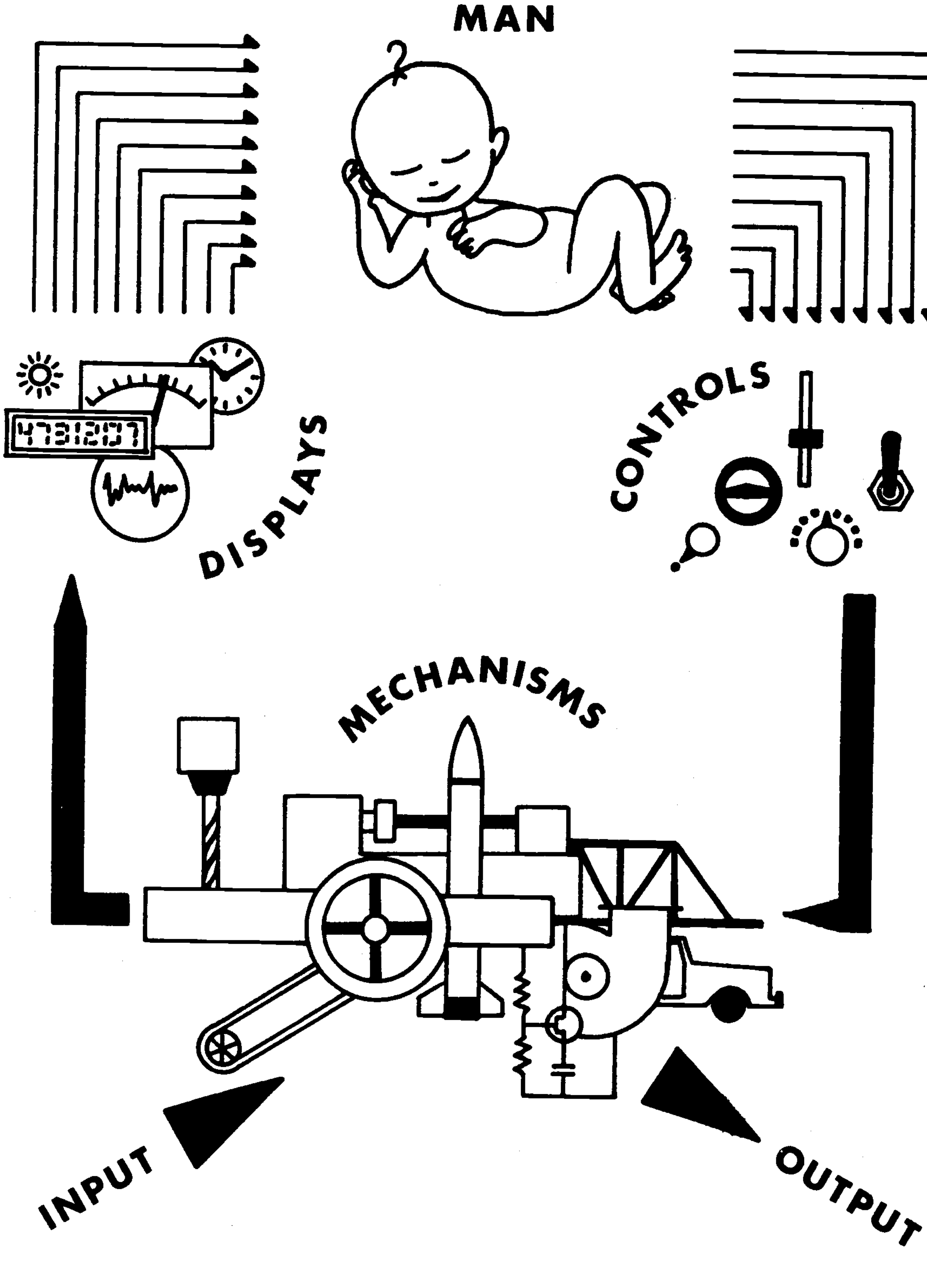


FIGURE 1-1 THE MAN-MACHINE SYSTEM

many heads. Human operators were called on to see targets which were close to invisible, read clusters of gauges blinded by perspiration running in their eyes, hear warning signals under conditions of deafening noise, track simultaneously in three coordinates with two hands, operate minuscule controls in sub-zero temperatures with shaking hands. At the same time, performing these functions required split second decisions, with zero allowance for error. On the other hand, such were the requirements with the human reaching a state of hypnotism (self or machine induced) through mere boredom. Obviously, the human failed in one or another of these tasks, often with disastrous results.

Because of these "human errors," designers, psychologists and engineers became increasingly involved in designing systems that required less of the human, and which, at the same time, exploited his special abilities to the fullest. This is the discipline variously called; human engineering, ergonomics, biomechanics, psycho-technology, engineering psychology, Human Factors Engineering or Industrial Psychology.

The man-machine system may be viewed as an automobile control system, a power plant control panel, the captains station on the bridge of his ship or a simple light switch. In essence, it represents the human operator as an organic data transmission and processing link, inserted between mechanical or electronic displays and controls of a machine. An input of some type is transformed into a signal which appears on a display. Perhaps in the format of a pointer reading, a pattern or color of lights, a shape on a cathode ray tube, in short, stimulating any of the human senses in a definite manner. Regardless of how presented, the information is read, processed mentally and transformed into some response or non-response. Whether it constitutes turning a dial, throwing a switch, pushing a button or stepping on a pedal, the control function signal, after transformation by the mechanism, becomes the systems output and subsequently acts upon the systems output as well, in the case of closed loop systems.

Considering the human in this fashion, it becomes obvious that, in order to design properly the mechanical components, the characteristics of the human, his capabilities and limitations, his functions in the system, must be taken into full account. The discipline Human Factors Engineering is concerned with just that aspect and to provide standards and assistance to all involving the human in their creations.

The development of a basic laboratory system, simulating many control functions found in man-machine systems forms the basis of this study. Taking into account the approaches in previous research, existing problem areas, system inadequacies and failures as well as all factors affecting human performance, the requirements for such a simulator are subject to many well known parameters as well as not-so-obvious elements.

Chapters two through four consist primarily of edited excerpts of the work of various authors who describe general principles relating to Human Factors Experimentation and the design of simulator systems. Chapters five through seven, augmented by the material in the appendices, constitute the documentation of the system developed by the author.

# CHAPTER II

## CURRENT RESEARCH: STANDARDS AND PROCEDURES[1/]

### Traditional and Original Systems

In scanning over the wide area of interest covered by Human Factors Engineering, the systems involved can be separated into two, overlapping general areas. Systems can be grouped by degree of complexity, novelty or uniqueness and human involvement: A continuum that stretches from the familiar or traditional, to systems without precedence (Figure 2-1).

In the case of traditional systems, engineering is of an evolutionary nature, each successive system being derived from an existing similar one. Experience obtained from the operation of that existing system reduces the research and experimenting required for the design of subsequent, usually improved versions. For new, original systems, the development process, particularly in its early stages, is to a large extent conceptual. New insights, approaches, techniques and data are required and analytical models must be developed and investigated prior to undertaking detailed design. These processes result in a longer development

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1/ "The substance of this chapter, exclusive of references to the simulator system described in Chapters IV through VII is contained in Kidd and Van Cott (1972), Van Cott and Warrick (1972), Frost (1972) and Adams (1971). In Chapter II these sources are quoted verbatim (hopefully not unjustly), for clarity sake and ease of presentation without benefit of quotation marks or literature citation."

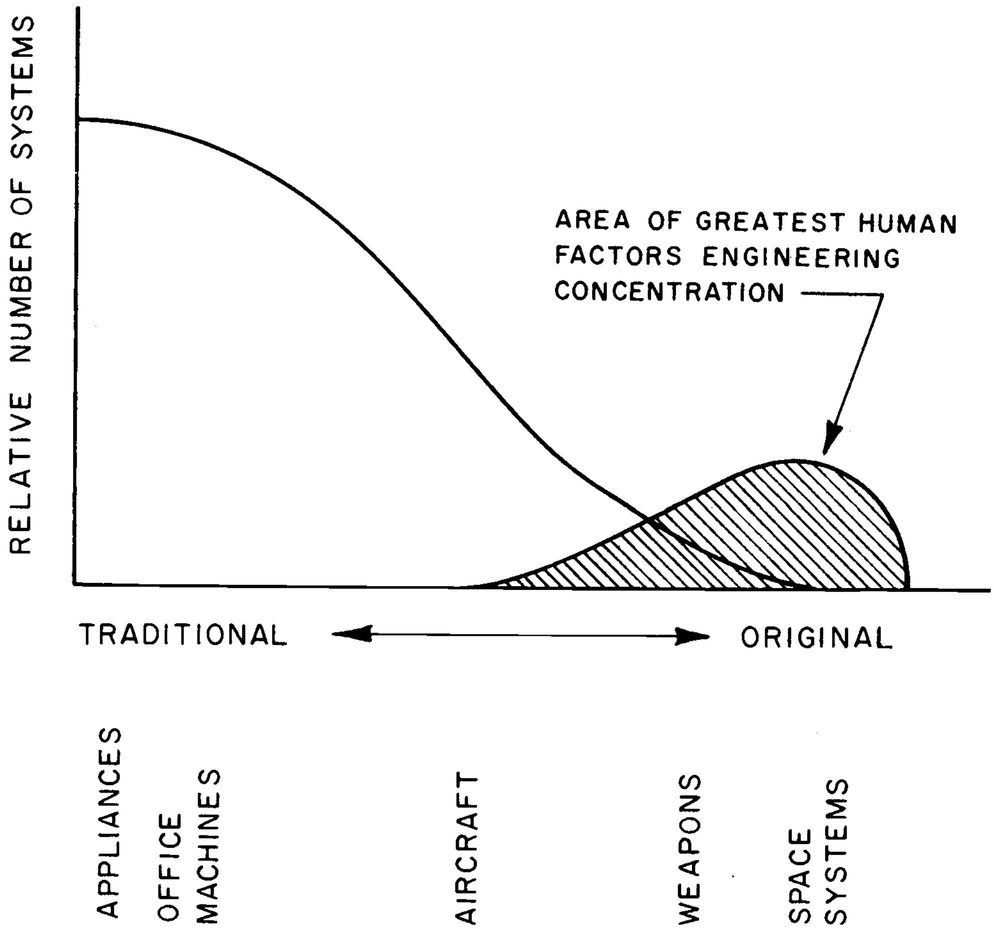


FIGURE 2-1  TRADITIONAL AND ORIGINAL SYSTEMS

cycle. The effort or input provided by the Human Factors Engineer depends on the classification or nature of the system. If it is a traditional one, an appliance, typewriter keyboard or an automobile, his emphasis tends to be on the welfare of the user. In case of a new, unique system, emphasis shifts to a concern for the performance demanded of the human by the system; his accuracy, speed and reliability of his overall performance as a part of that system as a function of time. In the first area, design considerations are human oriented; in the latter, system oriented. The key difference may be that in traditional system design, the Human Factors Engineer's function is largely one of improvement or optimization, while where new, unique systems are involved, the Human Factors Engineer is less concerned with achieving an optimum man-machine interface than with the design of an interface which is operable and supports the performance required of man by the system. The Human Factors Engineering approach will vary depending on whether his concern is with a traditional or an original system. (Table 2-1). While methods vary less in emphasis than in kind, it might be said that in the case of a new system, the Human Factors Engineer is concerned with conceptually synthesizing a total system, with determining the role that human performance will play in such a system, and then with designing the environment and man-machine interface to make that performance possible. Mission, function and task analysis methods can be of use in the Human Factors Engineering of new systems, because they allow the

| Goals | Traditional Systems Improvement | Original Systems Operability |
|---|---|---|
| Criteria | Comfort<br>Safety<br>Consumer Acceptance | Reliability<br>Accuracy<br>Efficiency |
| Emphasis | User Welfare | Human Component Performance |
| Approach | Man-Oriented | System-Oriented |
| Method | Analytic-Experimental | Synthetic-Analytic |

TABLE 2-1 TRADITIONAL AND ORIGINAL SYSTEM

development of a conceptual framework within which human performance and performance constraints can be studied, and they are the best way of understanding the complete system. In the case of traditional systems, where the rcle of man has largely been defined by past systems, there is little emphasis on mission and function analysis. Task analysis is used less to construct the performance required of man than to analyze his performance to determine how it might be improved through equipment redesign. In both instances, the design of parameters of a system simulator include all of the goals listed in Table 2-1.

## System Analysis

Functions provided by a system simulator should provide answers to all questions raised in the process of analyzing the sequence of events or operations within that system. The following general purposes of systems analysis can be identified:

1. Scheduling. In the development of a complex system, system analysis is necessary to identify all of the requirements and the logical and sequential order in which they must be completed. It is therefore, an important input to design, production and test schedules as well as to system management in defining the resources, the skills and money needed to produce a fully operational system.
2. Identifying Limiting Factors. System analysis enables the designer to determine the factors that potentially limit or constrain the performance of a system. These may include environmental limitations, hardware factors, information acquisition, flow factors, personnel problems and costs.
3. Establishing System Performance Criteria. System analysis provides the criteria which must be met by the several interrelated functional elements of a system. These criteria thus became standards both for design as well as for test and evaluation.
4. Identifying and Explicating Design Options. Through explicit comparison of expected performance with criteria, system analysis enables the designer to better the utilization of men and machines. Each

stage of a conceptual sequence of operations can be the instance for a check of design decisions. Insofar as functional requirements suggest or compel the survey of options, system analysis is often the instigator of invention.

5. Evaluation of Systems. System analysis is a prerequisite to the test and evaluation of systems. Performance measures of the system and its subsystems are needed to find out how a system can be expected to perform under actual operating conditions or whether one system can be expected to be better than another. These measures can be selected intelligently only from the criteria of performance furnished in a system analysis.

It is these general purposes that will ultimately decide the format and capabilities of the simulator system. It will have to be able to identify and evaluate each and every variable within its own processes before any conclusion of the performance level of the human link in that system can be legitimatly drawn. Having met all these requirements, system analysis is comprised of the following steps:

1. The explication of system requirements and constraints.
2. The description of system functions.
3. Detailed descriptions of operational event sequences.
4. Identification and evaluation of environmental factors.
5. Detailed descriptions of component processes.

Being independent steps, normal procedures allow them to be followed in any sequence most suitable in each individual case. A system may already have been partially designed, or time limitations may alter the sequence. Regardless, they form a conceptual structure, helpful to understanding the relationships of human factors engineering to the total system engineering process.

Operator Centered Analysis

Previous practical experience with system design has indicated the value of specifying the performance characteristics of the tasks to be accomplished by human operators. Such specification covers the psychological aspects of the indication to be observed (stimulus and channel), the action required (response behavior, including decision making), the skills and knowledge required for task performance, and probably characteristic human errors and equipment malfunctions. The gathering and organization of such information is called task analysis. Information developed through task analysis is of the nature of data that will be obtained from a simulation system. It forms the basic "building blocks" for the overall human engineering analysis. The development of this information through task analysis can be divided sequentially into two major parts: (a) subtask derivation and (b) skill and knowledge analysis. In subtask derivation, information pertinent to the entire subtask is obtained, including the location at which it is performed, and its relationship to existing tasks. To find out which skills and knowledge are required involves an examination of the various steps or parts of the subtasks. This analysis results in a statement of the psychological requirements of the task, the kinds of discriminations that must be made, the decision-making, motor and other skilled responses required. The nature of information that subtask derivation may include are:

1. A statement of the task, as derived from the personnel function. The statement should contain an action verb and indicate the purpose of the task in terms of a system goal or subgoal, an example would be the words "actuate power switch."
2. The category of task should be noted, i.e., whether it is an operator, maintenance, or support task.
3. The location in which the task is performed. This separates tasks performed in such separate places as the maintenance shop, supply area, manufacturing plant, on board ship, at the wheel of an automobile, etc.

The task may be peculiar to one or more segments of a work cycle or mission, as identified by mission analysis. The segment in which it falls should be named. The task may be discontinuous and readily divisible into discrete subtasks frequently encompassing procedures such as checking. Or it may be a continuous control action that affects a continuously varying stimulus, as in steering an automobile. Each task should be identified as one of these types. The frequency of task occurrence should be estimated, if the task is periodic. If performance of the task depends on the occurrence of malfunctions, human errors, or contingencies, the probability estimate may be revised as operational evidence becomes available. Operational data based on experience or obtained from a system or subsystem task analysis provide a measure of system requirements, environmental factors, human performance and equipment performance, and other mission data should provide a basis for anticipating possible non-routine situations. The basic requirements of a system or subsystem simulator are thus determined. The following questions should be answered by data experimentally obtained from either the actual system, prototype or simulator:

1. Relative Performance Measure. Just as the "right man" in the "right job" with the "right tools" is likely to be a productive worker, so the man with the "right assignment," the "right task," the "right equipment," and the "right environment" is likely to be an efficient operator. The qualitative measure "right" can be obtained by comparison of methods and equipment in the pursuit of identical tasks.
2. Adaptation of the Human to the Task. A human needs less training to operate a device when both the device and operational procedures are properly engineered for human use. Speed, accuracy and reliability of operator performance provide a

measure of how the human fits the device and the device fits him.

3. Improvement of Manpower Utilization. Tasks and equipment are optimally human engineered when they minimize the need for special skills or high aptitudes in the human operator. Performance measurements will indicate limitations in task complexity.

4. Limits of Task Complexity as a Function of Reliability. Poor equipment design or choice of equipment for selected tasks, or requiring several parallel operating functions will lead to system failure. Determining the limits will allow human resources to be used with utmost effectiveness.

Selecting the Area of Concentration

Viewing the human in man-machine systems as an information processing link (Figure 2-2), four subsystems can be identified: (a) sensing, (b) information processing, (c) memory or storage, and (d) responding. The human sensing subsystem detects and encodes energies from the physical environment. The information processing subsystem acts upon stored and sensed inputs, discriminates signals from noise, recognizes information patterns, makes decisions, and selects appropriate responses from among available options. It also controls regulatory and reflective processes for survival and adaptation. The memory subsystem

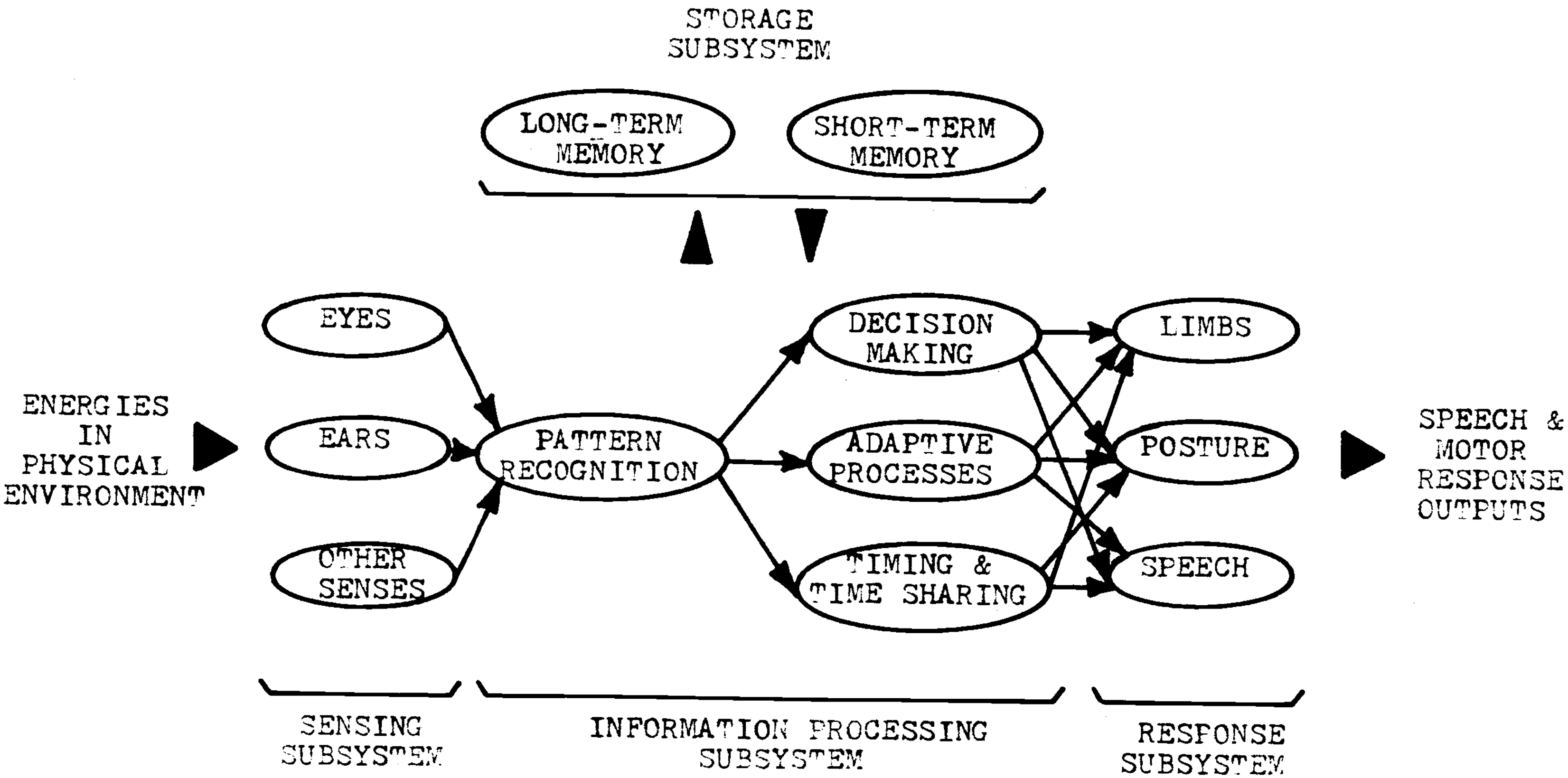


FIGURE 2-2 THE HUMAN INFORMATION PROCESSING SYSTEM (after Welford, 1960)

provides long-term and short-term storage of encoded information. The response subsystem transduces information into such actions as postural adjustments of the body and limbs, search and scan movements of the eyes, and production of speech. Within the budgetary limitations of the simulator design project, two areas of primary interest will be emphasized in this study; the sensing subsystem and the response subsystem interface of the human processing system. Both functions are present in the simulation of a closed-loop electromechanical servosystem where the human operator functions as an error-nulling agent in a tracking task (Figure 2-3). A tracking operation is defined as follows:

1. A paced (i.e., time function) externally programmed input or command signal defines a motor response for the operator, which he performs by manipulating a control mechanism.

2. The control mechanism generates an output signal.

3. The input signal minus the output signal is the tracking error quantity and the operator's requirement is to null this error. The mode of presenting the error to the operator depends upon the particular configuration of the tracking task but, whatever the mode, the fundamental requirement of the error nulling always prevails. The measure of operator proficiency ordinarily is some function of the time-based error quantity.

The primary target for the design of a tracking simulator will center on visual displays. Auditory tracking tasks have been devised. Auditory tracking operations are limited however to very few specialized operations and stimulus presentation is limited to audio transducers within the audible spectrum only. In the area of visual tracking tasks, the simplest and best known

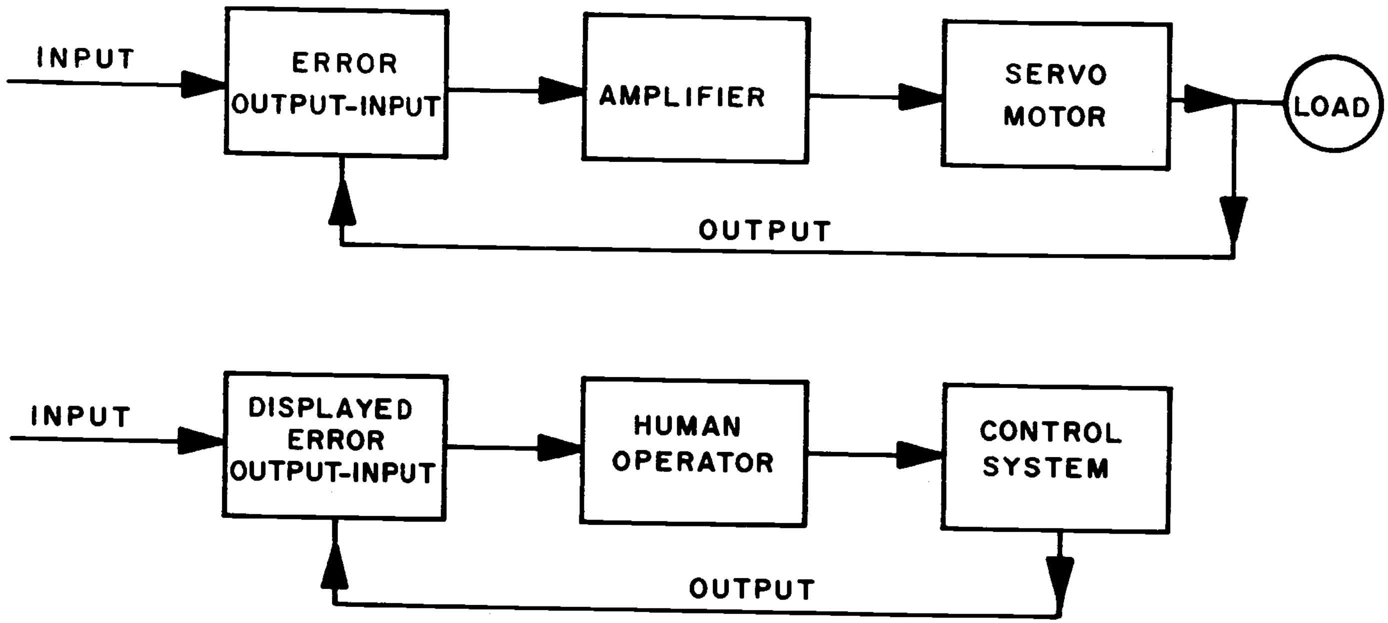


FIGURE 2-3 CONTROL LOOP DIAGRAM

method is the Rotary Pursuit Test employing a repetitive input signal. In this design exercise however, a more elaborate system will be developed which allows for controlled manipulation of such variables as the function for the input signal, scale factors and characteristics of the control mechanism. In addition, studies will take place in a controlled, and variable environment taking into account temperature, humidity, illumination of the environment, luminance of the displays, sound level and display-control orientation with respect to the operator or subject. A basic assumption in this study is that a tracking task is not merely classified in the category "motor skills," it is of utmost importance to control all variables and provide a means of recording them. No attempt can be made within the scope of this study to control the variables, or measure them, in the area of individual differences, including perceptual and motivational states as influential determiners of motor behavior. The controllable independent variables influencing tracking behavior will be divided into two categories: task variables and procedural variables. The task variables are machine-centered, the physical values of the tracking device, and include such factors as the nature of the input signal, configuration of the display, design of the control system, mathematical transformations relating to control displacement and changes in the output signal, etc. Procedural variables are man-centered. They are the manipulable nontask quantities such as instructions, number of practice trials, length of the practice trial and time between trials.

Additionally, the indicants displayed to the operator will be implicitly assumed as simple elements, such as needles or dials, pointers, dots on CRT's etc. Special problems that arise when the display is perceptually complex and requires the interpretation of forms, shapes, colors, etc. will not be considered.

# CHAPTER III

# THE HUMAN IN MANUAL CONTROL SYSTEMS[2/]

## One Dimensional Tracking Task

The one dimensional tracking task will be described by, but not limited to, the following conditions:

1. An input signal, generated by an external source defines an index of performance and the operator actuates a control system to maintain alignment of the output signal of this control system with the input signal. Any difference between these two signals is the error and the operator responds to null this error. Tracking tasks are divided into two basic gropus, depending on how the error is presented to the operator.

   (a) Pursuit Tracking. The operator is presented with two separate visual signals, one actuated by the input signal and one controlled by the output signal of the manual control system. The two signals are presented directly to the operator, and he responds

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2/ "The substance of this chapter, exclusive of references to the simulator system described in Chapters IV through VII is contained in Kidd and Van Cott (1972), Frost (1972), and Adams (1971). In Chapter III these sources are quoted almost verbatim (hopefully not unjustly), for clarity sake and ease of presentation without benefit of quotation marks or literature citation."

to null the error difference between them. (b) Compensatory Tracking. Here, only the error itself is presented to the operator, the input signal minus the output signal. Similar to pursuit tracking, the operator has to null this displayed error. The basic difference is thus, that with compensatory tracking the operator never observes the uncontaminated variations of the input or output signals, only the difference between them.

2. Regardless of operator actions, the input signal is time-based and totally independent of his response. This is called a paced task. The self-paced task where the stimulus changes as a function of operator controlled output is not included in the design.

3. Limitations of the control system limits the degree of control by the operator to certain transitional courses. The operator cannot transfer the control from a given position to any other position without moving through defined intervening states of the control system. In a one-dimensional visual tracking task using a pivoted or joy-stick control lever with hypothetical control positions A, B, C, and D assume the control at position B, at time t. The operator now has a three choice decision for moving the control at time t+1, each with a probability of being correct: he can repeat the response of time t and leave the control at position B, or he can move to either

position A or C. At the two extreme limiting positions of the control, only two choices are involved: leave the control in position, or move it to the position adjoining the limiting one. By this definition, any tasks where the operator has free transitional access to all of the control system states is prohibited from being a tracking task.

4. Transitional constraints on the input signal are the same as those on the control system. The input signal, in changing from time t to t+1, must change according to constraints defined by the control system. By imposing the same constraints on the input signal and the control system, the tracking task presented is given a degree of feasibility for the human operator or subject in laboratory simulation. The simulator should not allow the subject to gain perfect or near perfect performance. Permissible transitional states for the hypothetical four-state tracking task discussed are shown in Table 3-1.

The example is general and does not specify the characteristics of the input signal or control system, other than indicating transitional restraints for both. The input states and responses to them can be discrete or continuous, and the input can have any degree of regularity from nearly random to completely repetitive. True randomness is denied by the conditional restraints as shown

| | A | B | C | D |
|---|---|---|---|---|
| A | yes | yes | no | no |
| B | yes | yes | yes | no |
| C | no | yes | yes | yes |
| D | no | no | yes | yes |

"yes" indicates permissible transition
"no" signifies denial of transition

TABLE 3-1 TRANSITIONAL STATES IN TRACKING

in Table 3-1. Advantages of discrete inputs are that their duration can be controlled, making the number of events per unit of time an important dimension for investigation and data interpretation. This time variable has been termed the "speed of pacing factor" and is analogous to the number of cycles per second when a continuous input is used.

One useful measure expressing the statistical coherency of a discrete input signal and the duration of its events is the informational measure of bits per unit of time. The rate of change, as well as higher derivatives, can be a variable for discrete input events but no attempt will be made to provide a means to explore these more complex dimensions in this design. Included however, will be control of all other dimensions in one-dimensional visual tracking, as well as the issues surrounding them. Rather than the servotheory approach which has been the frame of reference of most investigators to date, an attempt will be made to provide a means to demonstrate that tracking behavior involves a linked chain of overt and internal stimuli and responses and is much more complex than implied by the prominent error nulling characteristics of the servoanalogy. While the servoanalogy is sufficiently adequate for its schematic purposes, behavioral phenomena cannot be viewed so simply. There are three major areas to be identified: the observing response which orients receptors to sense stimulus events on the display, the prediction responses where the operator learns to anticipate future characteristics of the input signal, and the hypothesis that measured motor response, even in continuous tracking, is intermittent and not smooth graded movements as they might appear to a casual observer.

Pursuit Tracking

The sensing of the displayed indicants driven by the input and output signals, as well as the error between them, is by the observing response. Each of these three stimuli play an important role in pursuit tracking and their moment-to-moment state is sampled as the observing response orients the receptors to them. The input indicant is the desired state; the error difference between the input and output signal represents how well the desired state is achieved; and the output indicant gives knowledge of results on how specific motor movements are represented on the display (Figure 3-1). Some investigation has taken place of the general role of observing response but within the context of tracking it is considered as having two functions: head and/or eye movements to direct the visual receptors to spatially separate stimuli, and the discrimination of stimulus change. The head and/or eye movements can be considered overt aspects of the observing response and potentially measurable. The discrimination function of the observing response however, is an inferred phenomena, with its locus unspecified. Experience has indicated that besides the necessity for an observing response, it is in itself an important function. Adams, using the rotary pursuit test, found that operations of repeatedly activating the visual observing response independently of the arm-hand goal response, and which presumably served to fatigue the observing response, resulted in a goal response decrement and permitted the inference that the performance level of the goal response is partly determined by the strength of the intervening observing response. Studies have shown that pursuit tracking performance deteriorated when the two pointers on the display were increased in spatial separation. The display must be large enough to accommodate the maximum range of the input signal without making the scale so small that it compromises system resolution.

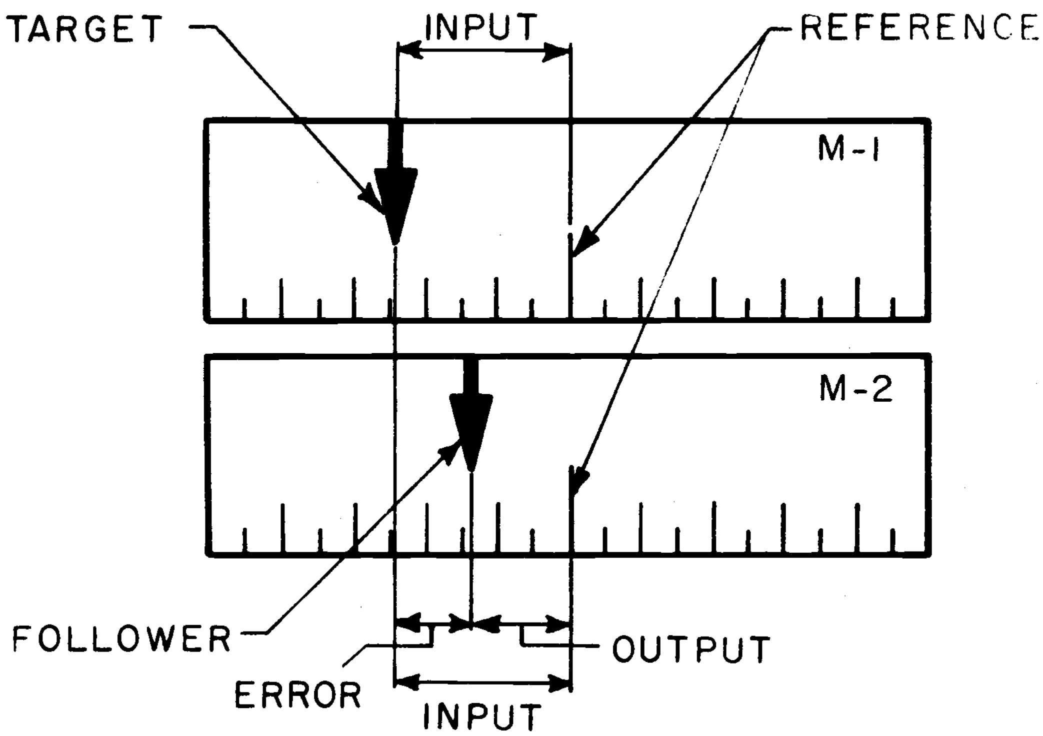


FIGURE 3-1 PURSUIT TRACKING DISPLAY

Predicting Regularities in the Input Signal

The input signal in pursuit tracking actuates an indicant which is directly observed by the operator or subject. To the extent that the operator can predict the regularities inherent in this input signal he will be able to anticipate the correct response movement and initiate at a time to minimize error. In the absence of a predictive capability the operator must wait for the change in the output signal to actually occur on the display, with the result that his response will generate tracking error as a function of a delay of at least one reaction time interval. The type of input in the design is of a pseudo-random cyclic character, therefore, while no advance information is intentionally given, the operator will nevertheless be able to predict the course of future signals on the basis of his past experience. An evaluation was made of practice and two levels of input complexity, a simple harmonic motion and a complex harmonic or cyclic course. Taking an anticipation of change in the input signal as a response of duration less than expected reaction time of about 200 mSec., it was found that the subjects were predicting the simple harmonic course both early and late in practice. Although overall tracking error decreased with practice on the complex input course, there was no evidence for improvement in anticipation and the conclusion was drawn that the improvement was largely attributable to increased manual dexterity.

This also investigated the smoothness of tracking, defined by the number of unnecessary discrete changes of speed that were made. The fewer the number of such changes, the better the performance. With the simple harmonic course, it was found that smoothness of response increased with practice, but no such changes were found for the complex input. This measure of smoothness was viewed as an additional index of anticipation because, when the operator was not anticipating, he would show a greater number of corrective movements.

## Types of Input Functions

Input functions in the typical manual control system may be either periodic or non-periodic, and they may be either continuous or transient (Figure 3-2). This classification of inputs is somewhat arbitrary since periodic transients can be approximted to any desired degree by properly weighted sums of harmonically related sinusoids. Harmonically related frequencies are those related by integer multiples.

Frequencies of 120 Hz and 180 Hz are second and third harmonics of 60 Hz. Conversely, the sum of four or more non-harmonically related sinusoids appears to be quite random to the operator in a tracking system, and a stationary random process can be considered a segment of a periodic signal of infinite period (Figure 3-3). Within the classification of periodic inputs are not only simple sine waves but also sums of harmonically related sine waves since these repeat once for each cycle of the fundamental frequency. Sums of non-harmonically related sine waves are not included since, although they are periodic, their period is much longer than that of the lowest frequency. Actually, their period is equal to the period of a wave whose frequency is the largest common denominator of the frequencies included. Square waves, triangular waves, sawtooth waves and recurrent impulses are also classed as periodic inputs, although with the exception of square waves, they are not normally used in tracking simulations. The design will not accomodate

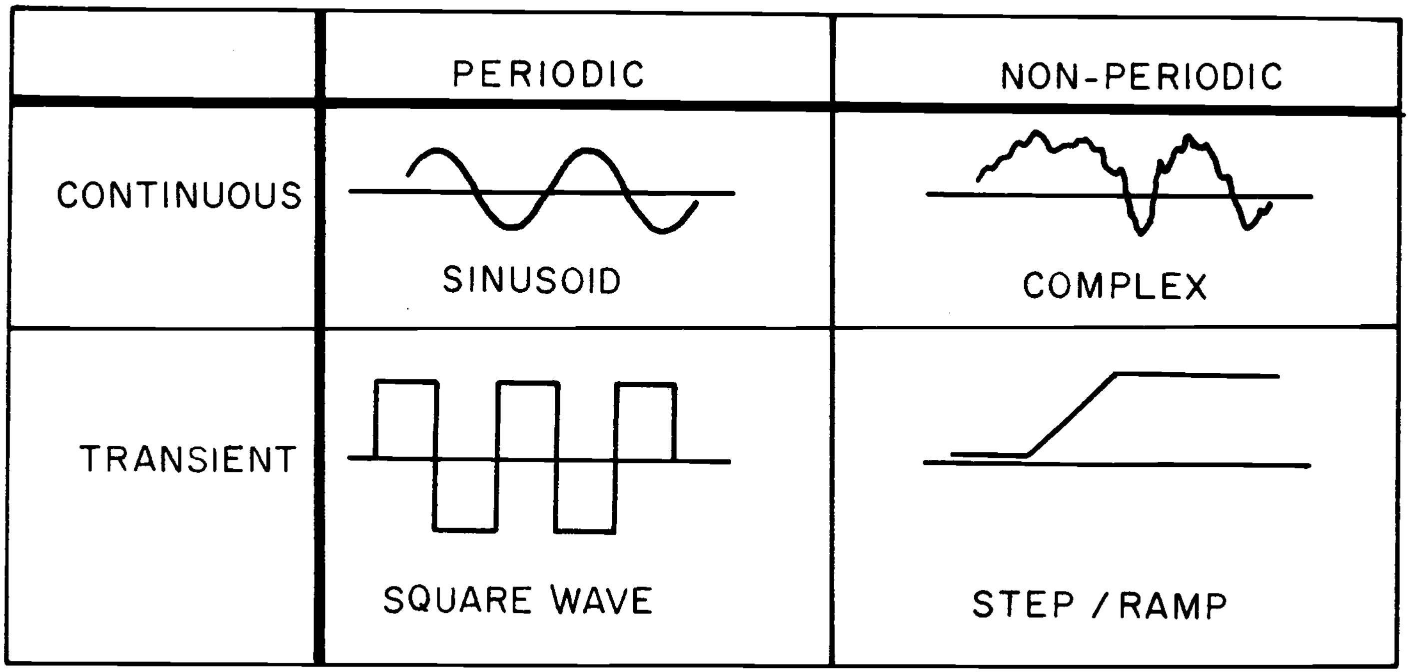


FIGURE 3-2 TYPICAL INPUT FUNCTION

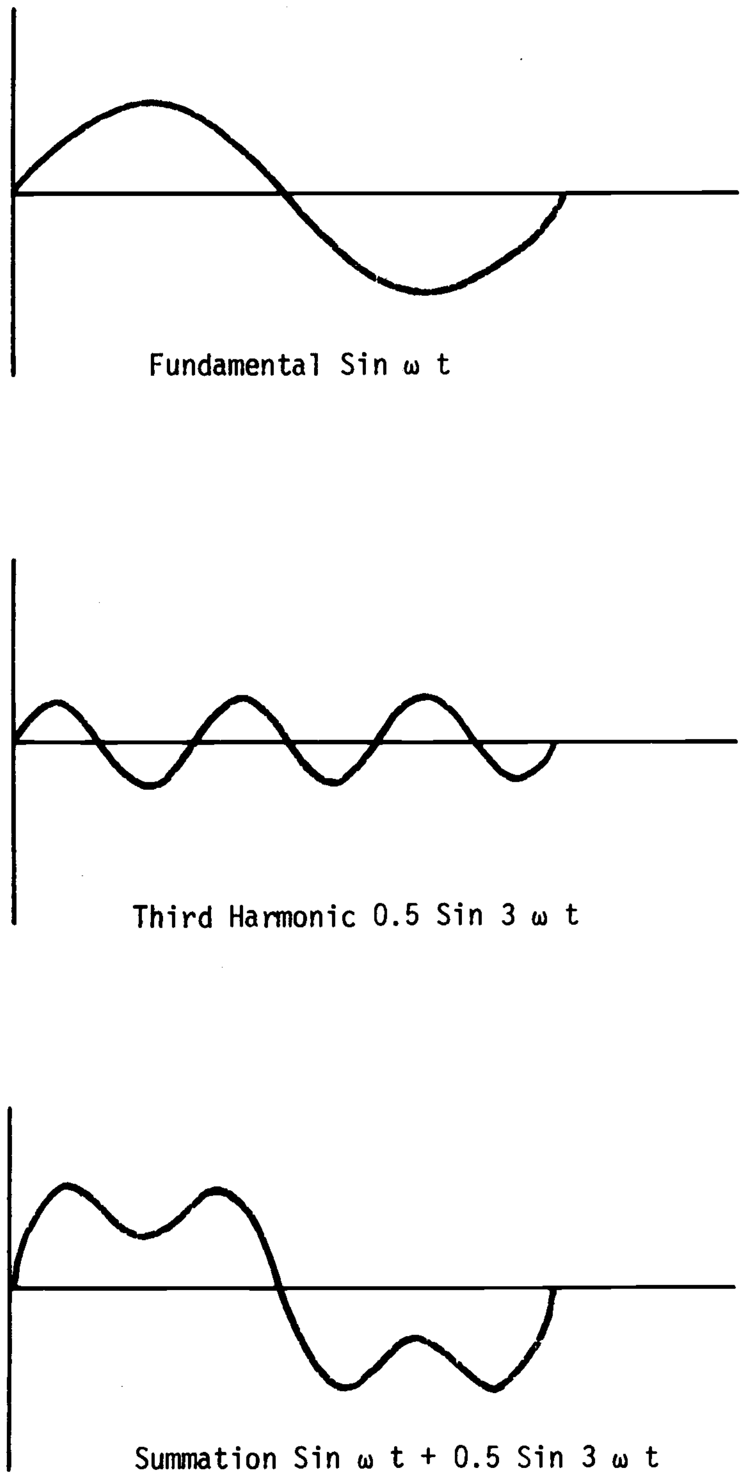


FIGURE 3-3 SUMMATION OF SINE WAVES

those input functions. In general, an experienced operator will recognize simple periodicity or cyclic nature or the input function and adapt his behavior to make use of this additional information. The fact that operators do recognize periodicity in input functions and modify their behavior accordingly creates a problem for the investigator of tracking behavior. The input function therefore, can be periodic only to the extent that variations to the cyclic nature are obscured for other than the long term operator (Figure 3-4). Specifically, it is impossible to use simple periodic inputs (e.g., sine waves) to determine how an operator will track in an operational situation where the input is in fact random. Results of these studies must be considered with extreme caution since they are generally overly optimistic of the operator's ability to track random inputs. Studies of tracking behavior with very simple inputs are useful in evaluation studies of the human sensory system and eye movement studies.

Results from those studies determine limits of resolution to be designed into the simulator, size of the display as well as maximum angular velocity of the input target should not conflict with the limitations of the human sensory system such that the tracking task is totally non-feasible. Existence of said limitations is obvious from the eye movement detector recordings (Figure 3-5), as obtained by Heyning. General conclusion of those studies indicate that the gain of the visual closed-loop system is about 0.8, for the sinusoidal input the gain being defined as the ratio

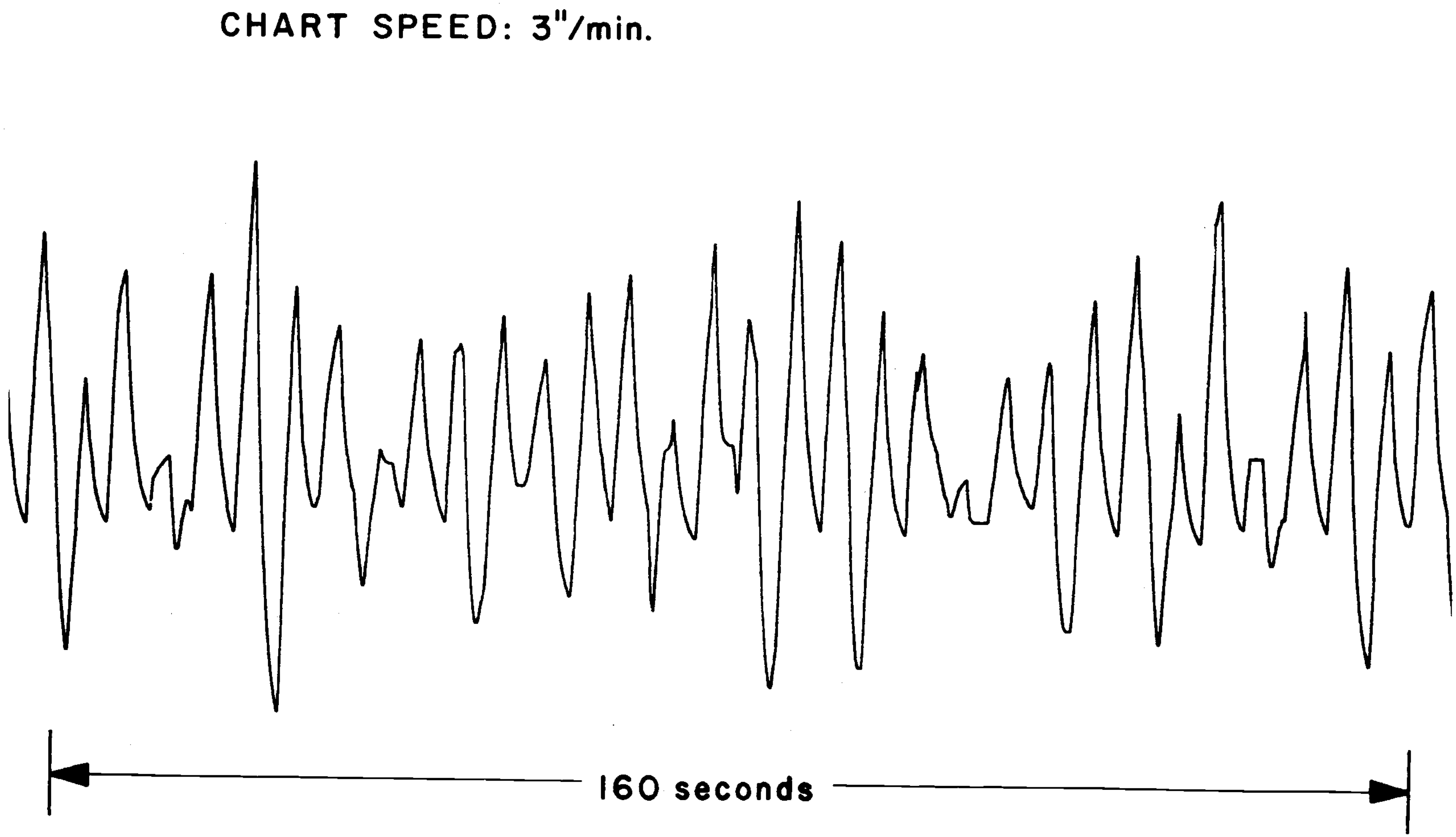


FIGURE 3-4 SIMULATOR INPUT SIGNAL

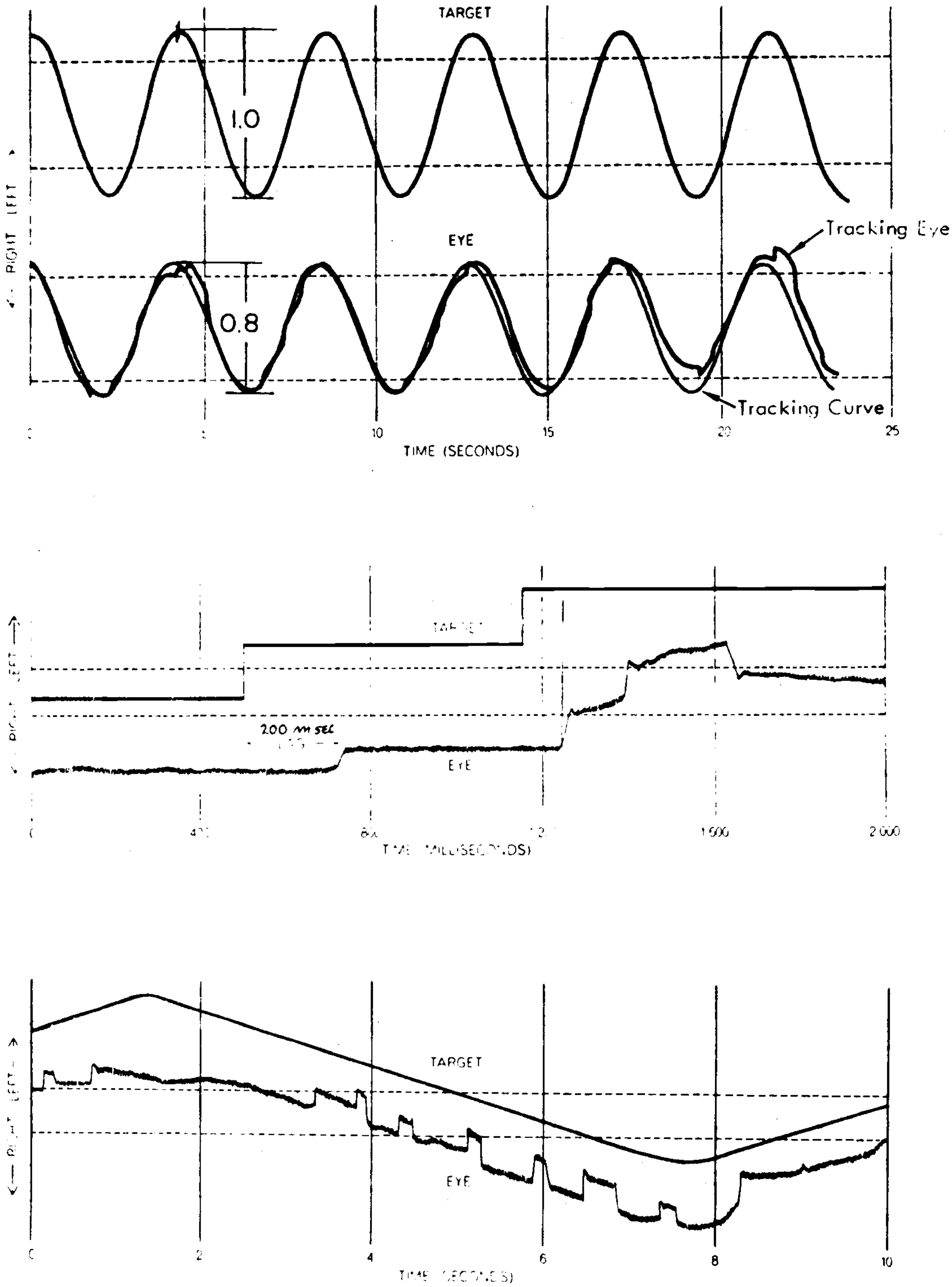


FIGURE 3-5 EYE MOVEMENT DETECTOR READINGS

of output signal amplitude over input signal amplitude. The corresponding phase lag of the system is about five degrees or 6 mSec, while the sinusoidal frequency is about 0.25 Hz. The eye seems to act as a low-pass filter with a cutoff frequency at about three cycles per second (Figure 3-6).

Compensatory Tracking

Capabilities and limitations of the human operator discussed under pursuit tracking apply also to the area of compensatory tracking. The basic difference exists in the manner in which the data is organized and presented on the display (Figure 3-7). The presentation of only the error quantity in compensatory tracking generally means that performance will be poorer for two reasons. The system operator is unable to see the actual input signal meaning that he is handicapped in the acquisition of prediction responses, especially where input signals of a periodic or cyclic nature are presented. Additionally, the operator cannot see the output signal directly, so he is handicapped in receiving knowledge of results. In addition to influencing the acquisition of simple visual-motor learning where prediction behavior is absent, this factor also influences the acquisition of prediction responses because the operator cannot unequivocally verify the results of any particular prediction response. Previous investigation has shown that prediction behavior does occur with practice in compensatory tracking but that prediction is impressively superior in pursuit tracking.

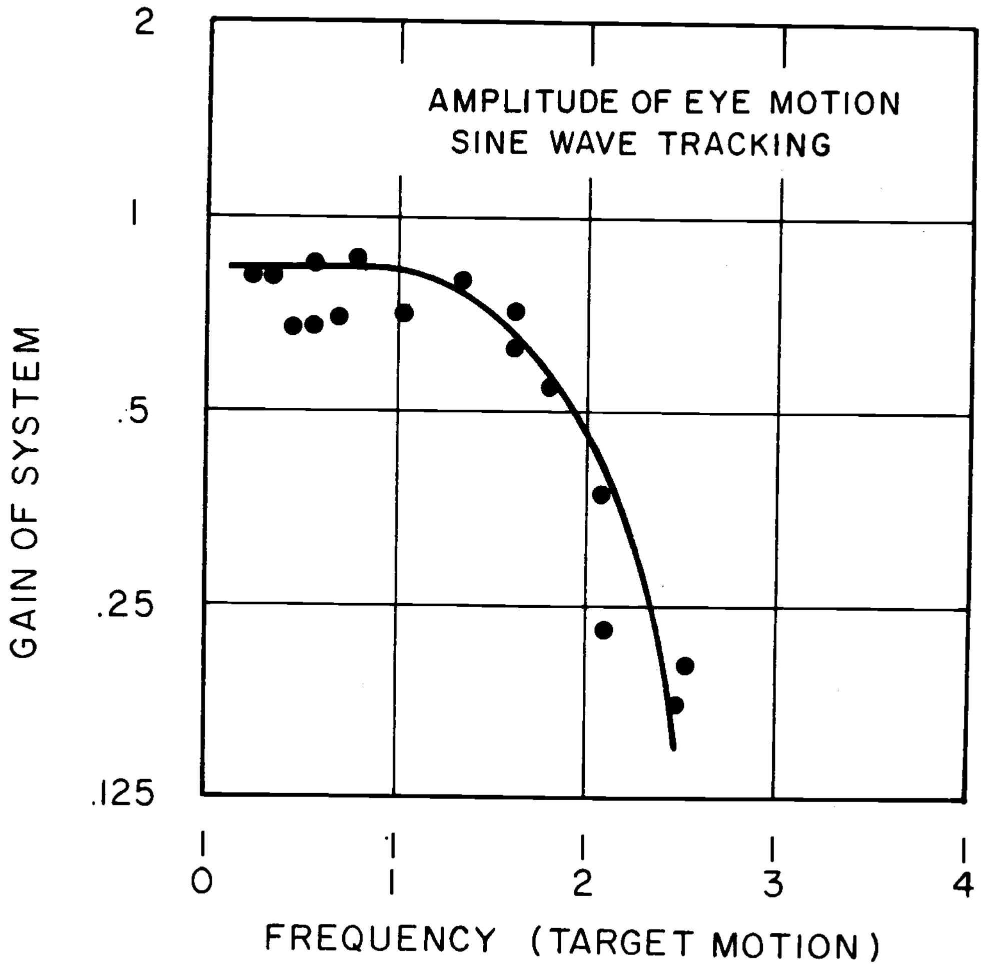


FIGURE 3-6 CUT-OFF FREQUENCY OF THE EYE

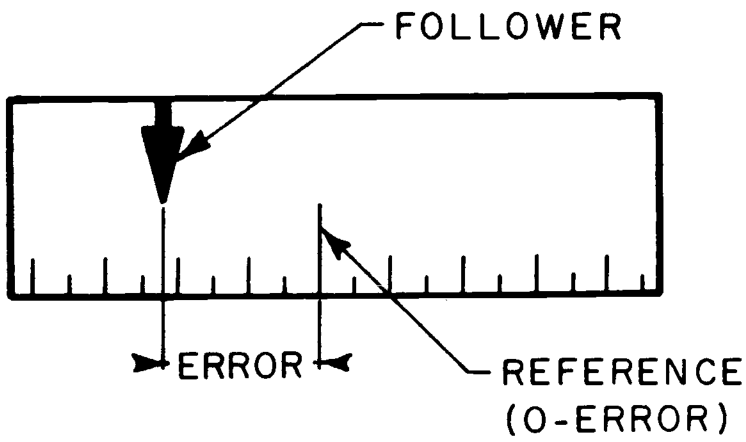


FIGURE 3-7 COMPENSATORY TRACKING DISPLAY

Total absence of a direct presentation of the output signal does not mean that knowledge of results is completely absent. There is evidence from several studies that when the input signal of a continuous tracking task is a low frequency input, the subject receives fairly adequate knowledge of results, probably because the motor movements produce output frequencies which are higher than the input frequency changes. This information is obtained from the slightly better performance that was found in this study for compensatory over pursuit tracking when the input was a low frequency signal. At higher frequencies, they found that pursuit tracking maintained its well-known advantage over compensatory tracking. It should be noted however, that these investigators did not take the limits of resolution of the human visual system as found by Heyning into account. One marked advantage of a compensatory display is that the display scale factor can be chosen to magnify the system error without regard to the total range of the input.

# CHAPTER IV

# CRITERIA OF USEFUL CONTROL SYSTEMS[3/]

## Types of Controls

Controls are essentially transducers to convert the operator's output -- force and/or displacement -- into useful machine inputs. The design and selection of specific controls for the simulator are discussed in Chapter 5.

The output of a control may be a physical movement of some other part of the system such as a hydraulic valve or steering system deflection, or it may be an electrical signal into a servo amplifier which controls some other part of the system. The nature of this output is specified by the requirements of the system "down-stream" of the control. Considering the type of output as a given or fixed requirement, of main interest then is input to the control and input-output relationships. When designing or selecting a transducer for use as an element in a system, it is useful to know what must be converted into what. When dealing with man, this information is not readily available since man's output may be a pure force into an isometric (stiff-stick) control, a pure displacement into an

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3/ "The substance of this chapter, exclusive of references to the simulator system described in Chapters IV through VII is contained in Kidd and Van Cott (1972) and Frost (1972). In Chapter IV these sources are quoted verbatim (hopefully not unjustly), for clarity sake and ease of presentation without benefit of quotation marks or literature citation."

isotonic (unrestrained) control, or some combination of force and position output into a loaded moving control. When designing or selecting a control, it is useful to consider the output per unit force and the output per unit displacement as independent design variables. For a simple spring loaded control stick, these variables are related by the spring constant (Figure 4-1). The point x on the plane represents a given spring loaded control stick. An applied force results in a given displacement and a corresponding output. The slope of the line passing through the origin and point x is the spring constant. If the gain of the system downstream of the stick is changed, the point x moves along the line. If the gain is held constant and the spring is changed, the slope of the line is changed and point x moves either vertically or laterally depending on whether the stick output is sensed by a position or force sensor. From this, it can be seen that the isometric and isotonic controls are simply limiting cases of spring restrained controls. The isometric stick has an infinite spring constant while the isotonic stick has a zero spring constant. Although the design will only incorporate isotonic or pseudo-isotonic controls, the next section will contain information on isometric as well as isotonic controls as limiting cases of the general control design problem. Spring loaded controls and controls having appreciable mass and damping are not included. Information on all controls is available in Tables 4-1 and 4-2.

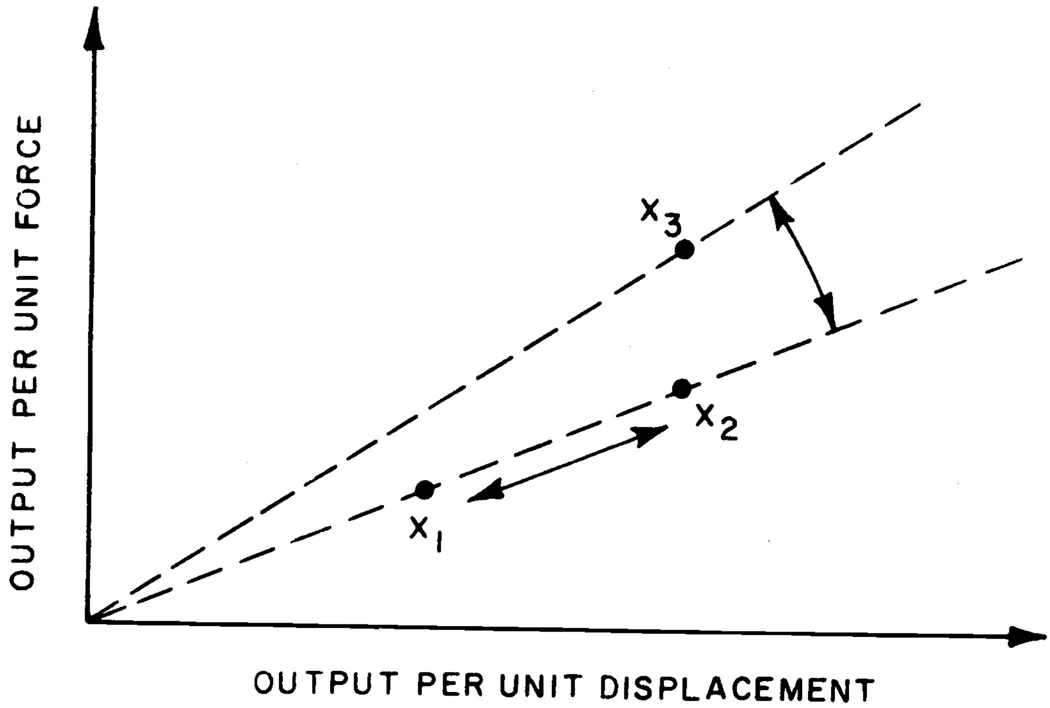



FIGURE 4-1 SPRING LOADED CONTROL

| Characteristic | knob | thumb wheel | hand wheel | crank | pedal | lever |
|---|---|---|---|---|---|---|
| large forces can be developed | no | no | yes | yes | yes | yes |
| time required to set | ----- | ----- | ----- | ----- | ----- | ----- |
| recommended number of control positions | ----- | ----- | ----- | ----- | ----- | ----- |
| space requirements | small | small | large | medium | large | medium |
| likelihood of accidental activation | low | high | high | medium | medium | high |
| desirable limits to control movements | un-limited | 180° | $\pm$60° | un-limited | small | $\pm$45° |
| effectiveness of coding | good | poor | fair | fair | poor | good |
| effectiveness of visually identifying control position | fair | poor | poor | poor | poor | fair |
| effectiveness of identifying control position by feel | poor | poor | fair | poor | poor | poor |
| effectiveness of operating control in an array | poor | good | poor | poor | poor | good |
| effectiveness as part of a good combined control | good | good | good | poor | poor | good |

TABLE 4-1 COMPARISON OF CHARACTERISTICS OF CONTROLS FOR CONTINUOUS ADJUSTMENT

| Characteristic | rotary switch | thumb wheel | push button (hand) | push button (foot) | toggle switch |
|---|---|---|---|---|---|
| large forces can be developed | ----- | ----- | ----- | ----- | ----- |
| time required to set | medium | ----- | very quick | quick | very quick |
| recommended number of control | 3-24 | 3-24 | 2 | 2 | 2-3 |
| space requirements | medium | small | small | large | small |
| likelihood of accidental activation | low | low | medium | high | medium |
| desirable limits to control movement | 270° | ----- | 1/8-1½" | ½-4" | 120° |
| effectiveness of coding | good | poor | fair | poor | fair |
| effectiveness of visually identifying control position | fair | good | poor | poor | fair |
| effectiveness of identifying control position by feel | fair | poor | fair | poor | good |
| effectiveness of operating the control in an array | poor | good | good | poor | good |
| effectiveness as part of a combined control | fair | fair | good | poor | good |

Adapted from AFSCM 80-3

TABLE 4-2 COMPARISON OF CHARACTERISTICS OF CONTROLS FOR DISCRETE ADJUSTMENTS

## Isometric (Force) Controls

The isometric or "stiff-stick" controller is essentially a force transducer. The output of an isometric control is generally an electrical signal to a servo amplifier in the controlled system. Its advantages and disadvantages derive from the fact that no appreciable motion is involved. The advantages of an isometric control are the following:

1. Single-axis tracking, particularly high-frequency inputs, is better with isometric controls than with isotonic controls. This may involve as much as a 50% reduction in error with rate controls.
2. No space is required for control movement.
3. Output returns to zero when control force is removed.
4. There is less problem of inadvertent input under vibration and G loading if good forearm support is provided.

The principal disadvantages of isometric controls are:

1. Deadzone must be introduced in multi-axis tracking to prevent inadvertent cross-coupling between axis.
2. Continuous force application is required to maintain non-zero output with position control systems or when tracking very low-frequency input signals. This in turn may lead to fatigue during prolonged operation.

## Isotonic (Position) Controls

A true isotonic control is only an engineering abstraction since any real control has some mass and some friction. Proper design can reduce the resulting inertial and frictional forces to negligible values, but some force must still be developed in the controlling muscle groups to overcome the effective mass and spring of the controlling limb. For this reason, there is always some lag associated with operation of position controls. This lag is in addition to any reaction time delay that also exists. The advantages of isotonic control are:

1. No force is required for constant output.
2. Visual feedback of control position is available.

Disadvantages of isotonic control are:

1. They are more subject to inadvertent inputs from operator and environment than isometric controls.
2. They do not return to a zero-off position when released.
3. They do not provide clearly defined zero output information.
4. Tracking error is generally higher, especially with high-frequency inputs.

## Loading Moving Controls (Real Controls)

Most practical controls lie somewhere between the two extremes described. There are three types of linear forces which act on moving controls:

1. Elastic (spring) forces proportional only to the displacement of the control.
2. Viscous friction (damping) forces proportional only to the velocity of the control.
3. Inertial forces proportional only to the acceleration of the control.

In addition to these linear forces, certain non-linear forces act on the moving control:

1. Friction forces, which are of constant magnitude and oppose the direction of motion.
2. Stiction forces, which account for the difference between starting (breakaway) friction and sliding friction.
3. Preload forces, which are of constant magnitude and always in a direction to center the control.
4. Other non-linearities such as backlash and non-linear gearing.

It is shown previously (Figure 4-1) that the simple spring-loaded control lies on a plane defined by its output per unit force and its output per unit displacement. Numerous studies have been conducted by a number of investigators to define the optimum gain or optimum control-display ratio for different types of systems. Most of these studies are not generalizable only beyond the context in which they were conducted. Some of the useful conclusions that could be deducted are the studies by Gibbs (1962) and by North and Lomnicki (1961). Gibbs showed that for a variety of controlling limbs, the optimum sensitivity of a very lightly spring-loaded (pseudo-iostonic) control is a constant when measured in terms of angular movement of the controlling joint. That is, if the stick output is expressed by volts per radian of thumb, wrist, or elbow movement, the same control sensitivity is optimum for all three joints. North and Lomnicki defined the optimum control-display ratio for an isotonic controller in a rate-control tracking task and in the same task with an isometric controller. Noting that any spring-loaded controller lies on a plane defined by the iosmetric and isotonic axes, he suggested that the locus of optimum gains for any spring-loaded control lies along an ellipse in the plane and is anchored by the optimum sensitivities of the isometric and isotonic cases. Unfortunately, no validation study of this theory seems to be available. The general consensus is that optimum gain or control-display ratio is more important than optimum spring constant.

Further considering the possibility of force feedback through the control to the operator and through the environment such as operator or control orientation, acceleration, sound, light and temperature, it becomes obvious that the subject area controlled element dynamics is beyond the scope of this study. In selecting the controls for the simulator it is important to note the following general observations from previous research:

1. Man operates more as a position output device than as a force output device.
2. An isometric stick is superior to an isotonic control when the control system has oscillatory position control dynamics, but --
3. The differences become smaller with increasing natural frequency and with increasing damping of the control system.

Control Loop Modifications; Gain Adjustment

Gain adjustment is one of the easiest ways to achieve system stability. Most control systems are stable if the gain is sufficiently low, although they may not track very well. Conversely, most systems can be driven to instability if the gain is sufficiently high. Conditionally stable systems, which are stable for only a narrow range of gain adjustments, will not be considered. In a manual control system, the loop gain is equal to the product of the display, operator, controller and controlled element gains. Changes in any of these has similar effects. It has been established that the human adjusts his gain over a wide range (100:1) to compensate for non-optimum system gain. This compensation by the operator requires additional effort on his part and results in degraded opinion ratings of the system, fatigue and poorer system performance. Thus, even though the operator can adjust the loop gain, it is desirable to adjust the gain in other parts of the system so that the operator functions at or near the optimum level for a specific task. Display gain is limited on its upper limit by the necessity to keep the displayed quantity on the display device without saturation. It is bounded on its lower limit by the necessity for the operator to see the smallest significant error. Control gain is limited on its upper limit by the inability of the operator to make very precise changes in force or position. It is bounded on its lower limit by the maximum displacement or maximum force the operator can achieve. The control must have sufficient power or "authority" to respond to the extreme expected command within the system criterion time. Care must be taken to insure that the gain is high enough to prevent limiting due to the controller hitting its stops and/or rate limiting downstream of the operator in the control loop, rendering the prescribed task impossible.

Feed-Forward Compensation; Aiding

Aiding is one form of forward loop compensation. Aiding has come to be used to refer to any form of forward loop compensation. A rate control system to which a position feed-forward has been added is referred to as an aided system. The objective of aiding, or forward loop compensation, is to modify the closed-loop behavior of the system. The proper aiding ratios to achieve the desired man-machine system response can be determined analytically using standard control system design techniques in conjunction with the describing function model of the operator.

## Unburdening

The term "unburdening," in the control system sense, refers to raising the order of the system. The idea is to remove the "burden" of performing as an integrator to meet the requirements of system performance. The term unburdening has also been used in reference to changes in the control system which remove the requirement for the operator to act as a differentiator. While this does reduce the operator's task load, or burden, it is perhaps more properly referred to as aiding if it is done by adding feedforward loops. If feedback loops are closed around various portions of the loop, it is generally referred to simply as stability augmentation.

## Quickening

In some systems it is not possible, for physical or financial reasons, to modify the hardware portion of the system. In such systems it may be possible to compensate the system by modifying the signal fed back to the operator's display. This is known as "quickening" the operators display and will be included in the simulator design. Quickening is usually applied to higher order slow-responding systems in the form of derivative signals summed with the system output signal back to the display. Quickening can be a useful technique when it is necessary for an operator to stabilize an unstable or marginally stable system. It can result in poor response to time-varying command signals unless the command signal is passed through an "anti-bias" network to make the system respond as it would without any quickening. Additional information on gain, aiding, unburdening and quickening in system block diagrams and tabular format is available in Appendix E.

# CHAPTER V

# THE TRACKING SIMULATOR AS A SYSTEM

## Meeting The Basic Requirements

The previous chapters have barely scratched the surface of the sensing and response subsystem analysis in man-machine dynamics. The areas discussed however, provide a background against which many features of the tracking simulator system can be evaluated. The basic assumption in the design was that if any variable elements were introduced in the simulator design, then a means of evaluating the effects of human performance in the simulator must also be provided. The circuits provided in the simulator are discussed in detail in appendix B. Their function and interface is shown in Figure 5-1, for pursuit tracking and Figure 5-2, for compensatory tracking. System component photographs are displayed in Figures 5-10 and 5-11.

## Set-up For Pursuit Tracking

The machine interface for pursuit tracking is set up for an input signal of a cyclic, pseudo-random nature (Figure 3-4) with an average frequency of 0.2 Hz, providing a DC voltage ranging from 0.4 volts to 5.5 volts to function as an input signal for a display (Figure 5-3). A control is available to vary the amplitude of this input signal (Figure 5-4), without affecting

| | |
|---|---|
| RVG | Random Voltage Generator |
| RVS | Reference Voltage Source |
| SC | Subject Control Element |
| ED-a&b | Error Detectors (Upper & Lower Limit) |
| M-1&2 | Displays |
| SR | Sample Timer |
| RSR | Random Sample Timer |
| EDT | Experiment Duration Timer |
| DCT | Digital Cumulative Timer |
| DEC | Digital Event Counter |
| SG | Shock Generator |
| SCC | Subject Control Console |

Circuit description see appendix B

TABLE 5-1 CODING OF CIRCUIT BLOCK DIAGRAM TRACKING CONTROL UNIT

the nature of its behavior, i.e. frequency, mean, variance, etc. This feature provides a means of evaluating system gain without altering the gain of the operator control interface. The input is fed to an edgewise meter having a scale width of 3.5 inches from zero to full scale. The indicator travel from the input signal corresponds to 3.24 inches, and maximum angular velocity of the input target $\omega$ = 0.32 radians/second. This established a design criteria for the subject control, which must be able to

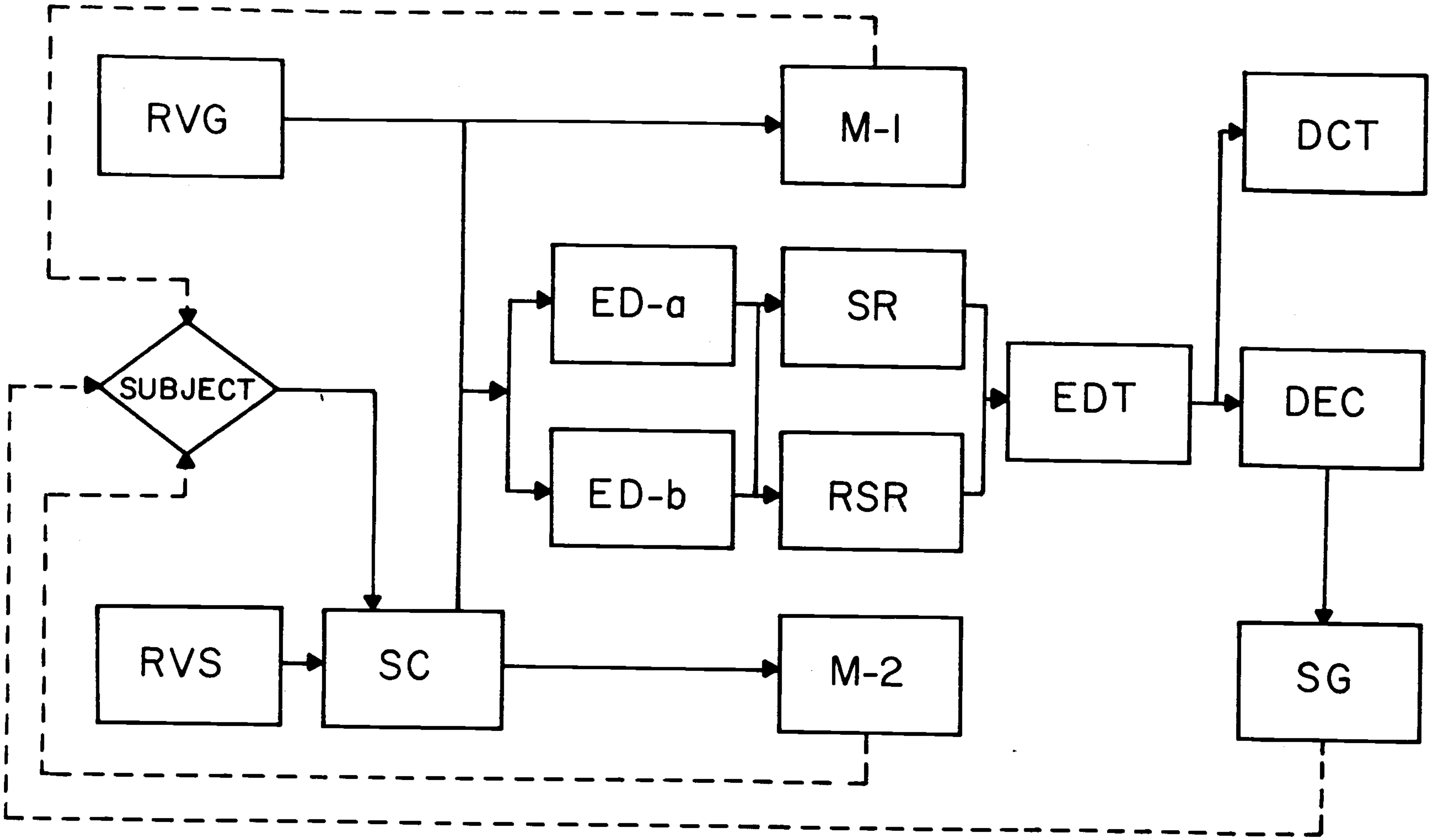



FIGURE 5-1 PURSUIT TRACKING MACHINE INTERFACE

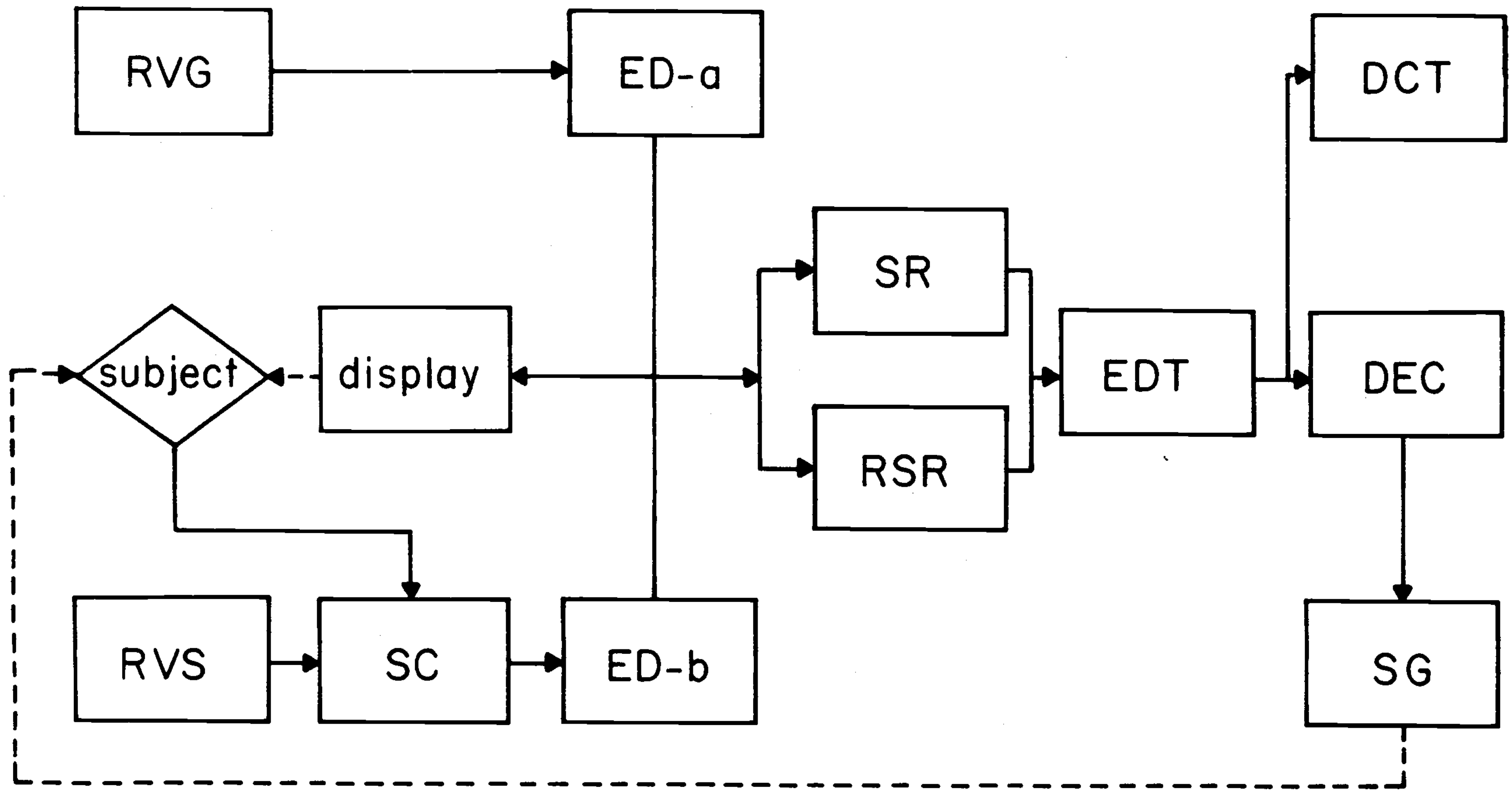
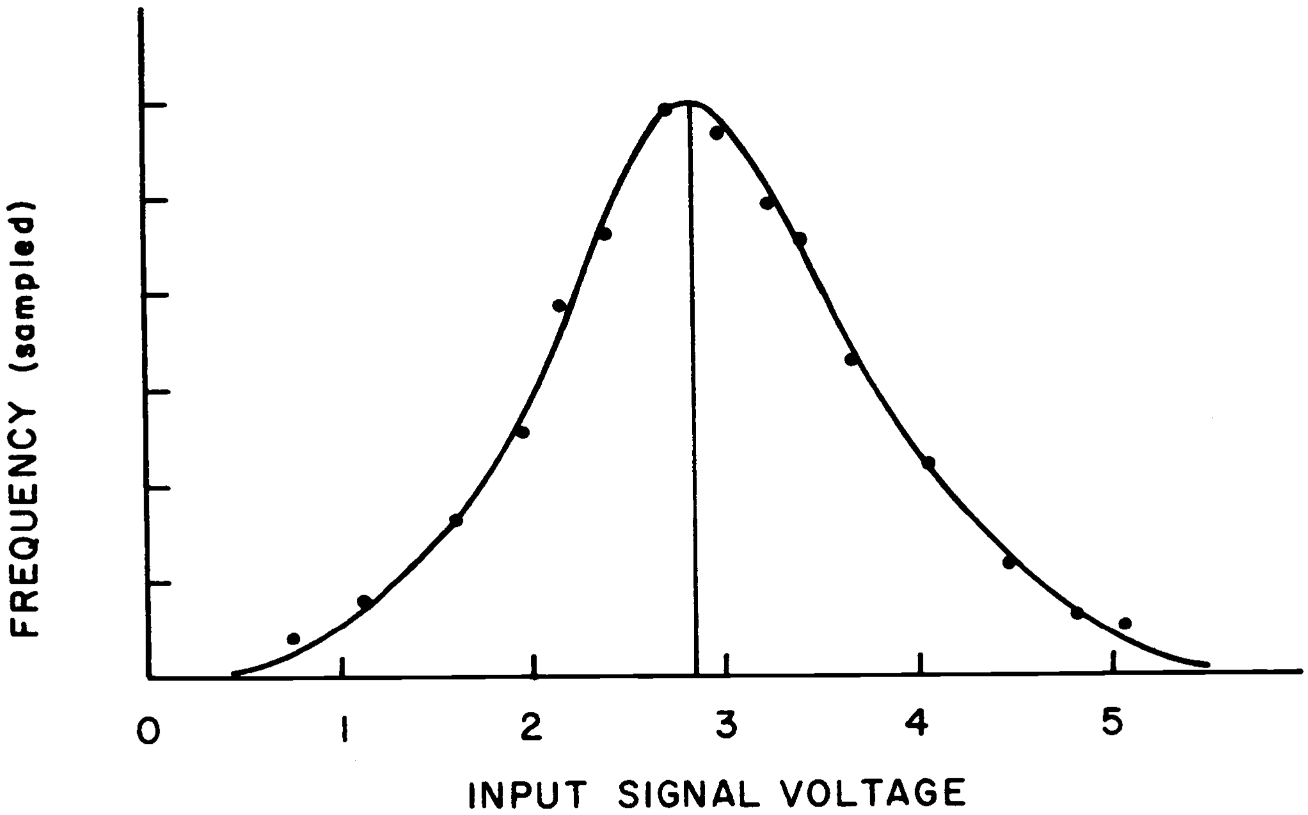


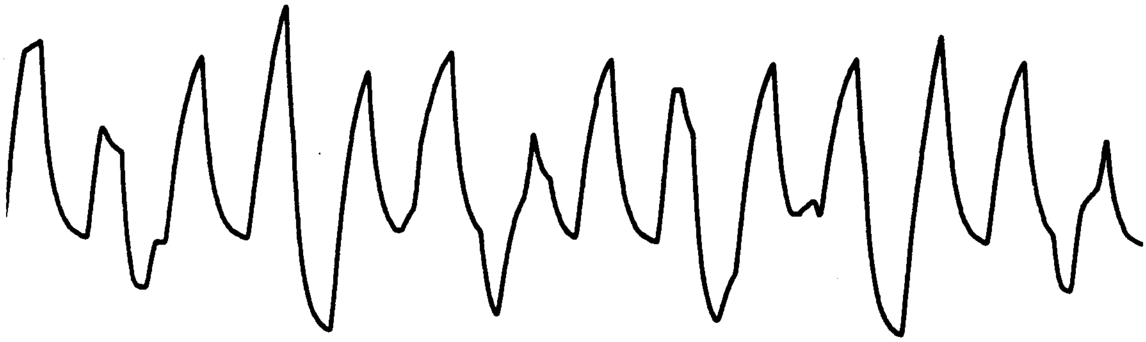

FIGURE 5-2 COMPENSATORY TRACKING MACHINE INTERFACE




INPUT VOLTAGE FROM RVG SCALED FROM RECORDER CHART OF TYPICAL 300 SECOND RUN.

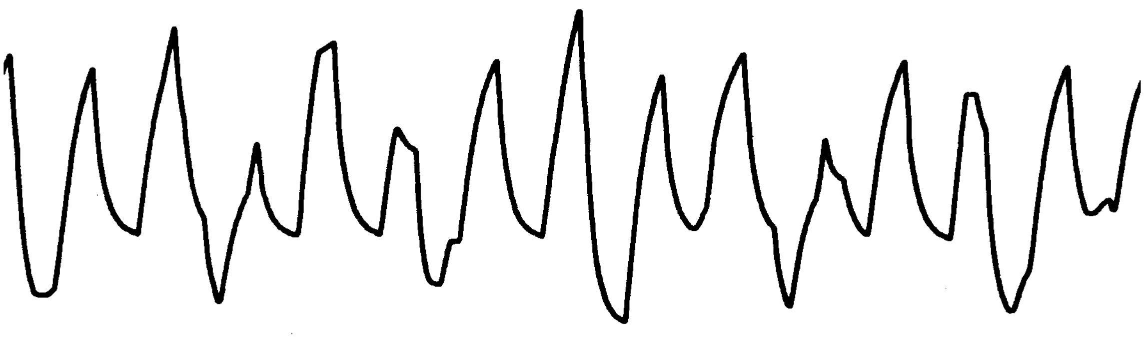
MEAN: 2.88

FIGURE 5-3 DISTRIBUTION OF INPUT SIGNAL



DRIFT RATE 1

DRIFT RATE 3



DRIFT RATE 2

FIGURE 5-4 DRIFT RATE CONTROLLED OUTPUT

allow at least equal adjustment speed per unit time to give the task a degree of feasibility. The subject control circuitry provided allows adjustment of speed in the tracking mode of 0.75 radians/-second and two-delayed settings of 0.62 and 0.50 radians/second. The system will accept external input signals of any nature desired, sinusoidal, square wave, triangular or random within the limits as described in appendix B. Differences in the output signal and input signal are measured and several settings are provided for machine evaluation of this differential. Accuracy of this evaluation is virtually constant over the entire range of the input signal (Figure B-4), and error detection limits are available for 5, 10 and 15% of full display deflection (zero to full scale) of the input signal, corresponding to a voltage differential of input signal and operator generated tracking signal of 10, 20 and 30%. The relationship of operator control movement versus tracking signal display (Figure 5-5) movement can be varied by utilizing different types of potentiometric controls in the subject control unit. The subject controls substations 1, 2, 3, 4 and 5 give a logarithmic relationship, changeover potentiometric elements are available for substations 1, 2 and 3. These elements give a linear relationship over the full operational range within 5% accuracy (Table 5-2). Operator performance data are collected in three modes. A sampling system is available for spot-checking tracking performance at 20, 30 or 60 times per minute or at random intervals (Figure B-6). A timing facility is available for obtaining

| DIVISION ON EDGEWISE METER DISPLAY | ROTARY CONTROL ROTATION DEGREES* | JOY STICK MOVEMENT DEGREES* |
|---|---|---|
| 20 | 13 | 9 |
| 30 | 14 | 10 |
| 40 | 15 | 11 |
| 50 | 16 | 12 |
| 60 | 17 | 14 |
| 70 | 18 | 16 |
| 80 | 20 | 18 |
| 90 | 22 | 20 |
| 100 | 24 | 22 |
| 110 | 26 | 24 |
| 120 | 29 | 26 |
| 130 | 32 | 28 |
| 140 | 37 | 30 |
| 150 | 43 | 34 |
| 160 | 50 | 40 |
| 170 | 60 | 50 |
| 180 | 75 | 67 |

*Operational display range 20 - 180

TABLE 5-2 OPERATOR CONTROL CHARACTERISTICS

actual duration of either on or off-target time as a function of overall experiment duration, accurate to ± 1/60 second. This timing facility has a BCD output to drive a digital printer for automatic collection of data (Figure D-3). In addition to this

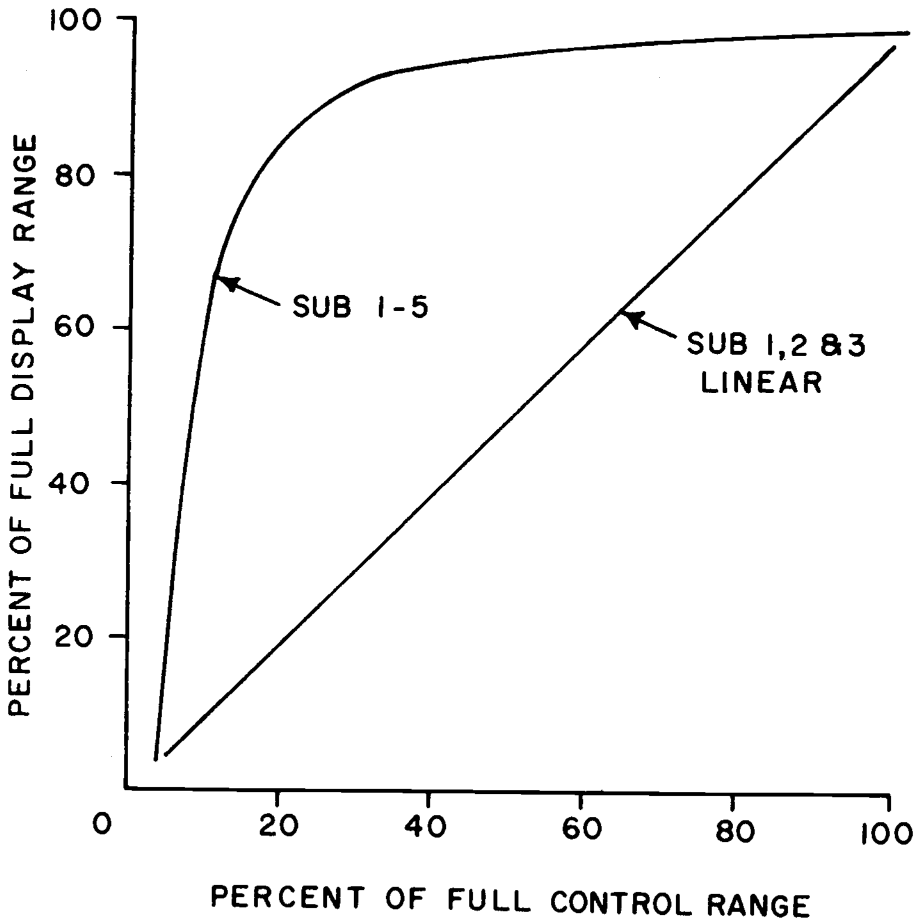



FIGURE 5-5 TYPICAL CONTROL CHARACTERISTICS

form of data collection, a facility is available to record the magnitude of the error in pursuit tracking on a servo chart recorder. These recordings (Figure 5-6) can be used for scaling overshoot and recovery facotrs to evaluate subject performance, and for graphic comparison of all available tracking modes, display configurations and control systems. Suggested data recording forms are shown in Appendix F, Figures F-1 and F-2.

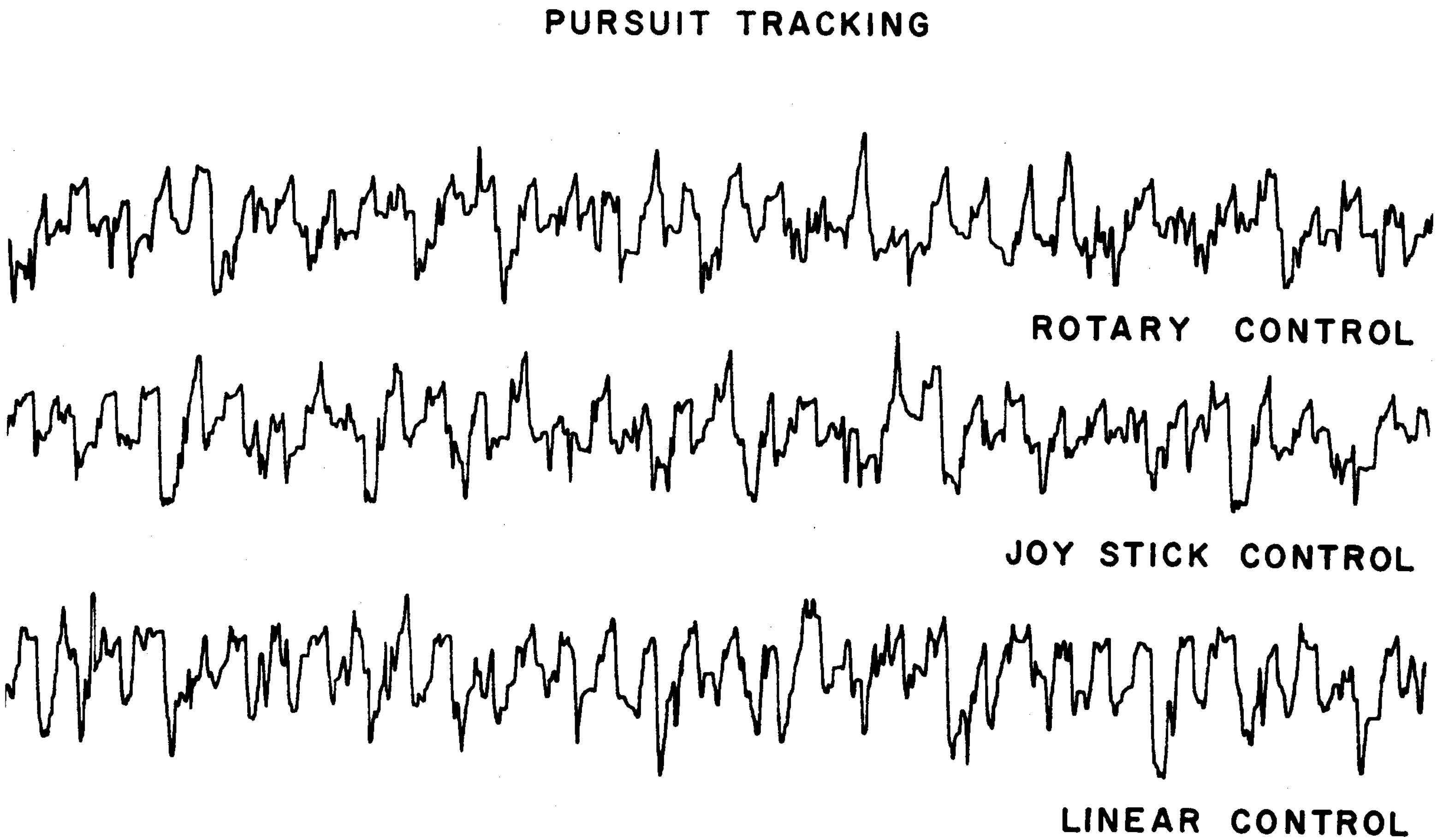



FIGURE 5-6 PURSUIT TRACKING PERFORMANCE TRACES

Set-up for Compensatory Tracking

The machine functions for compensatory tracking are similar to those in pursuit tracking. With internally provided interface changes the overall system operating mode (Figure 5-2) allows evaluation of operator performance under error display conditions only with all the flexibility of pursuit tracking. Fixed interval, random and continuous timing, drift rate control, tracking delay control and machine error evaluation control considerations apply to this mode also. A main data collection difference is that the display is in operation, the deviation from a baseline, representing 0-error on the chart recorder, also provides a hard copy for operator performance evaluation (Figure 5-7). Through combination of the various modes of operation, choice of stimulus display and subject control element, the choice of experiments is very large indeed. Creation of a data file from these experiments makes valid and valuable studies of all aspects of pursuit and compensatory tracking a challenging undertaking. To the already large number of test configurations available can be added variable environmental conditions and expansion to multi dimensional tracking as described in Chapter 6.

Tracking and the Environment

This section will briefly look at the importance of the effects of environmental factors on the human operator. Performance

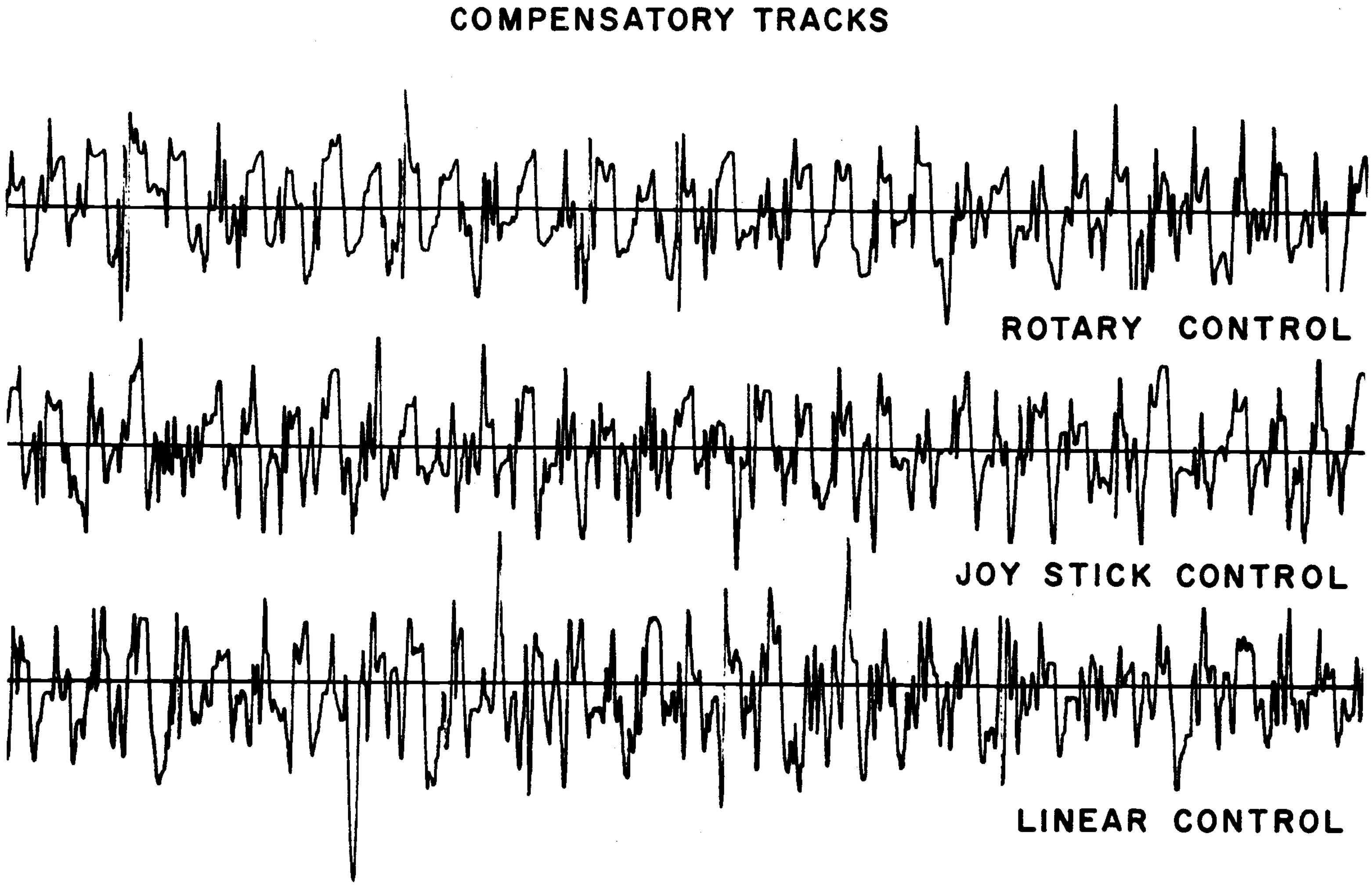



FIGURE 5-7 ACTUAL COMPENSATORY TRACKING DISPLAY

limitations are imposed by ambient conditions in the environment on virtually any task. Some of these variables are body-, workstation-, display- and control vibration or movement, noise levels and spectral composition of noise, temperature, illumination and/or luminance of workstation, display or control. All these factors have been subject to intensive studies. A number of others, e.g. acceleration forces, weightlessness, intermittent photic and acoustical stimulation, radiation and anoxia are highly specialized cases that also have received a great deal of attention. Experiment procedures and results of the last group are usually of a classified nature and difficult to obtain for further evaluation.

In many studies performed in all these areas, the psychological research has been, often of necessity, poorly controlled, unsystematic and idiosyncratic, and, dependent variables of major interest have been physiological or introspective rather than behavioral (in the sense of performance functions). The most important consequences of whole body vibration, for example, are nausea and even tissue damage. It is logical that such traumatic effects as these should receive priority as research topics over mere performance functions in tracking or whatever task. Similarly, human comfort is as important a consideration of an overall system as is measured human proficiency. In fact, severe discomfort would seem almost certain to produce performance degeneration in the long run, even if the two measures are uncorrelated in short term laboratory investigations. Work in the area of environmental control has usually been prompted by a particular design problem. The U.S. space program for instance, provided a major impetus for studying visual, intellectual, and particularly psychomotor performance under unorthodox "G" conditions, ranging from crushing G-forces to 0-G. Development of jet aircraft has been the occasion for intensified research on a variety of noise effects. Operations in arctic and tropical climates has demanded that more be learned about temperature effects and so on. Some of the environmental conditions mentioned are either very costly or simply impossible to reproduce with any degree of fidelity in a laboratory simulator. For the purpose of evaluating tracking performance, it is important however, to provide a workstation in which some of the basic conditions, i.e. temperature, noise level and illumination can be controlled for the purpose of making valid comparative experiment data analysis over time.

Controlled Environment Chamber

An environmentally controlled chamber has been provided as part of the system (Figure 5-8), in order to control or to vary the three basic conditions mentioned. Control of the environmental conditions are:

1. Temperature (Figure A-1), controlled by the air conditioning system of the building in which the chamber is located. Separately controllable over the 55 - 80°F control range, within 1.5°F, plus or minus.

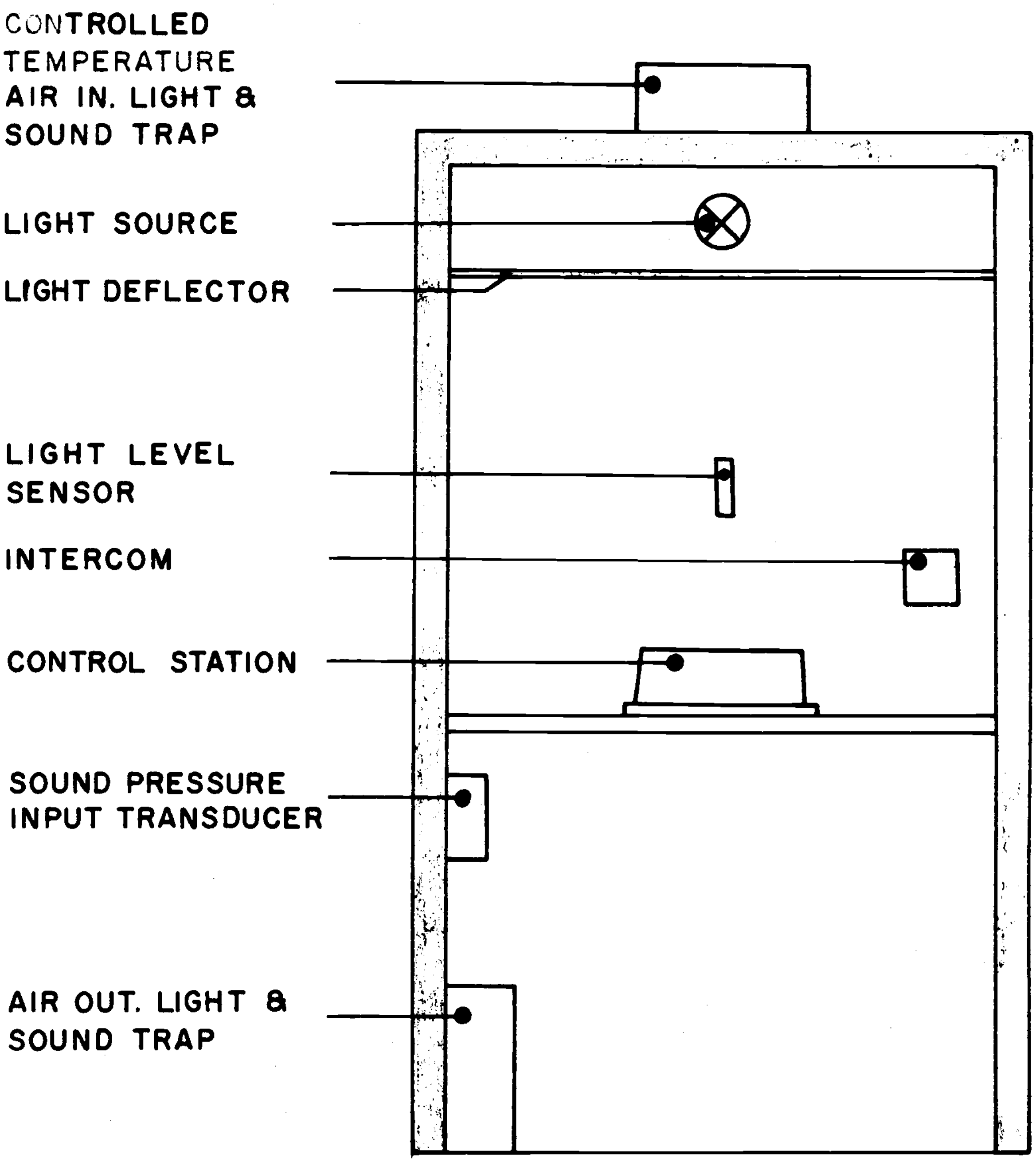



FIGURE 5-8 ENVIRONMENTALLY CONTROLLED CHAMBER

2. Light (Figure A-1), direct or reflective light. Level variable from 0 to 100 Ft-c. Chamber is finished in diffused white with a reflectance of 85 (when new).
3. Sound (Figure A-1), average chamber sound level 48 dB (air conditioner noise). Provision to add pure tones between 20 and 20,000 Hz. to sound pressure levels of 100 to 120 dB, depending on frequency.

Complete data on the system are available in Appendix A. Utilization of these functions depends on the research objectives. The prime purpose is to set temperature, light and sound pressure at fixed levels. In addition, well controlled and recorded variation of any of the variables will allow evaluation of the effects of such a change on a specific tracking task. The objective here could be to determine which human states, activities or functions are most critical to preserve in field situations, i.e., vigilance, visual performance, perceptual motor skills, and what are the ranges of environmental conditions that characterize a field situation, what are the ranges of acceptable performance, and finally, does performance on the critical activities over the significant range of conditions fall within the tolerable limits. Or, alternatively, is it possible to drive performance out of these limits experimentally? Whichever way it is phrased, the question focuses on decrement, in relevant activities, and in significant amounts, all as a comparative study with the simulation (task, display and control) system selected. There is a possibility that ambient environmental conditions might sometimes serve to enhance performance, or that interactive effects might be important: e.g., several "tolerable" conditions may summate to produce an intolerable one, or one may partially offset another.

| |
|---|
| Input signal; random or sine wave |
| Input signal display on chart recorder or meters |
| Three input signal drift controls |
| Five operator tracking controls |
| Three tracking tolerances |
| Four performance sampling modes |
| Two real time performance measurements |
| Work station temperature control |
| Work station sound pressure control |
| Work station illumination control |
| Four electric shock stimuli |
| Galvanic skin response measurement |

TABLE 5-3 SUMMATION OF POSSIBLE EXPERIMENT VARIABLES IN PURSUIT AND COMPENSATORY TRACKING

Finally, it can be said that trivial effects -- whether good or bad -- can contribute to the understanding of human performance even if they are of no consequence for the issue under investigation. While altogether providing a flexible system of environment control for the operator, no evaluation of individual differences is possible, this introduces an uncontrolled variable, giving more momentum to the thought that those that can be, should be strictly, accurately controlled.

Skin Conductance Measurements

A galvanic skin response monitor is provided as part of the system which can be used for checking operator skin conductance at intervals or continuous. (Appendix D, Figure D-1.) An analog output is available for recording monitor output on a servo chart recorder. The galvanic skin response monitoring electrode is attached to the subjects hand using electrode paste to insure good and steady contact. The idea is that the subject reacts to any element of stress or fatigue induced by either the task he performs by the environmental conditions or, more likely, a combination of both. A typical skin conductance graph for a subject performing the pursuit tracking task is shown in Figure 5-9. Trace A represents the skin conductance variations in micro ohms for a subject who had never taken the experiment prior to this recording. Trace B is the skin conductance variation for a subject familair with the tracking system. The very low skin resistance, or high skin

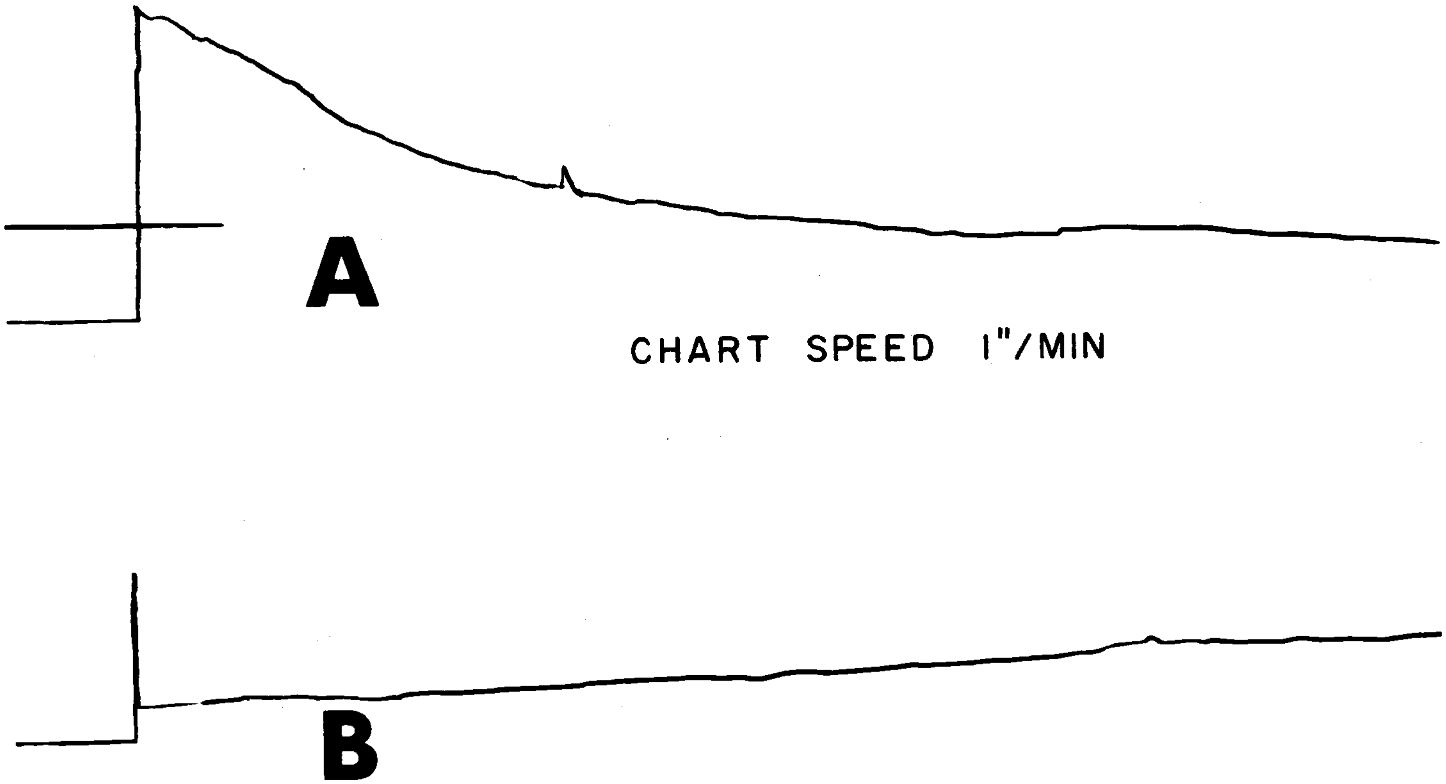
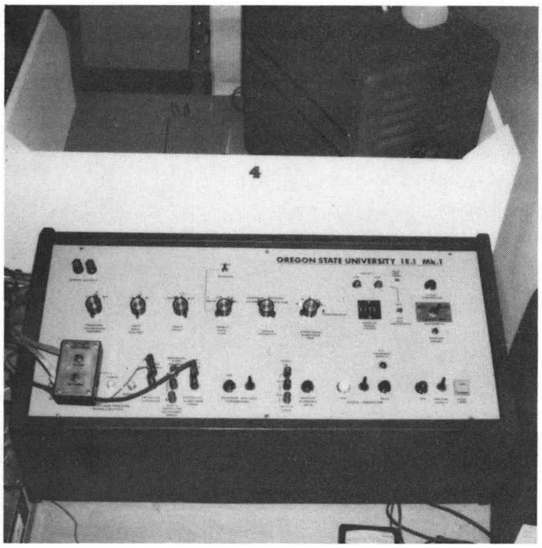
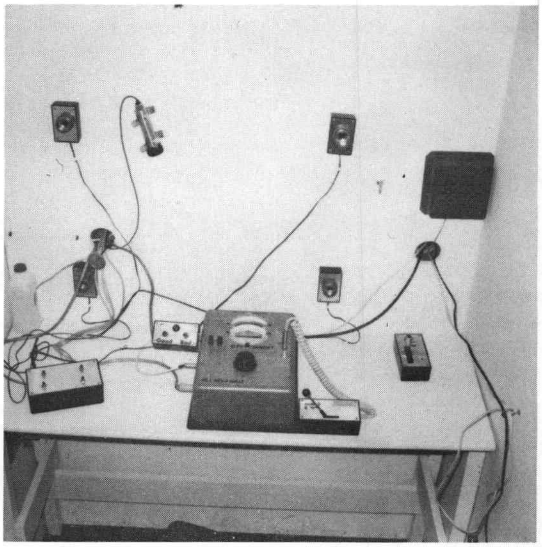



FIGURE 5-9 SKIN CONDUCTANCE TRACES

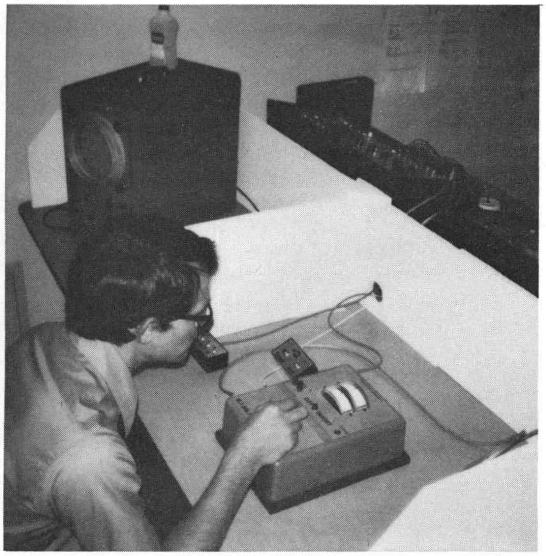
conductance (the reciprocal of resistance( is probably due to anxiety over the unknown features of the task to be performed on the part of A. Trace B shows a fairly linear increase in conductance which relates to the effort required for the tracking task and possibly fatigue. Being in itself a very interesting measure of subject behavior, related to a tracking task, data obtained are valid only for comparative studies with this limited system.



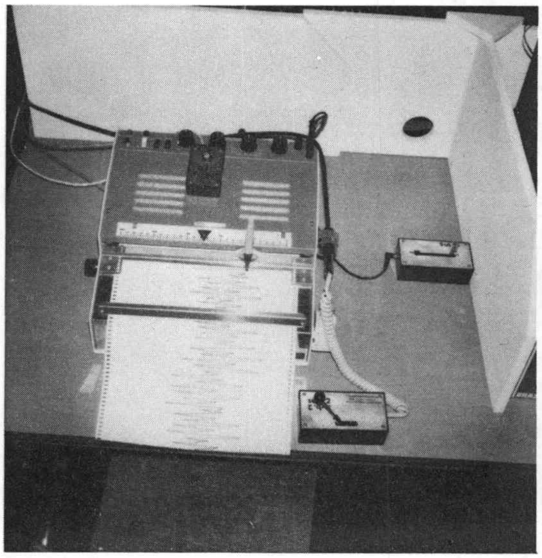

TRACKING CONTROL CENTER



PURSUIT TRACKING SUBJECT CONTROL IN ENVIRONMENTAL CHAMBER

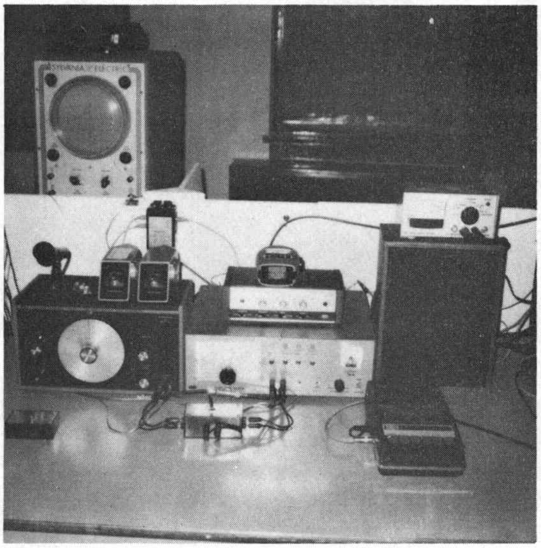


PURSUIT TRACKING CONSOLE

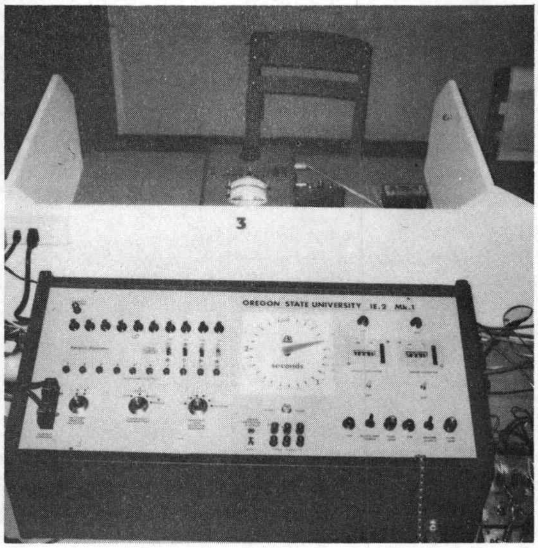


COMPENSATORY TRACKING CONSOLE

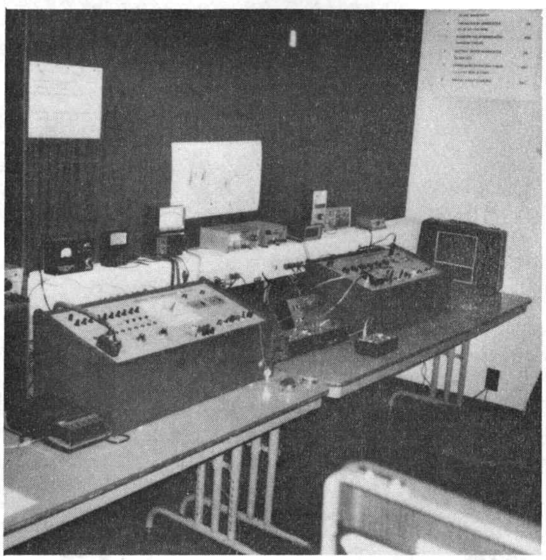
FIGURE 5-10 SYSTEM COMPONENT PHOTOGRAPHS



SOUND GENERATING SYSTEM




RESPONSE-ORIENTATION CONTROL CENTER



OVERVIEW OF CONTROL CONSOLE

FIGURE 5-11 SYSTEM COMPONENT PHOTOGRAPHS

# CHAPTER VI

# MULTI DIMENSIONAL TRACKING

## Two Dimensional Visual Tracking Unit

As a basic difference, the two dimensional tracking task has two stimulus sources requiring operator action. The apparatus described in Appendix C, which is primarily designed for use as a complete system for multi-channel response versus orientation and reaction time measurement experiments, is available as an input signal source for adding a second dimension to the pursuit and compensatory tracking experiments (Figure 6-1, Table 6-1). Specific techniques and methods of analysis of data obtained from the system will not be discussed in this report. The main purpose here is to evaluate tracking performance under multi-task conditions. A two dimensional visual tracking task could consist of two meter display stimulus sources with a left-hand control for response to one and a right hand control for response to the other. In this case both stimuli are visual, the tracking system and an indicator light and response control pushbutton.

The number of indicator lights used, their spatial orientation as well as response pushbutton control orientation can be varied at will to provide any workstation layout required (Figure 6-2, 6-3). An additional measure of performance evaluation

| CODING OF CIRCUIT BLOCK DIAGRAM RESPONSE-ORIENTATION AND REACTION TIME EXPERIMENT CONTROL UNIT | |
|---|---|
| RPG | Random Pattern Generator |
| CT | Central Control Timer |
| PL | Pattern Limiter |
| DCC | Digital Cycle Counter |
| SB | Subject Response Button |
| ED | Error Detector |
| EDT | Experiment Duration Timer |
| DEC | Digital Event Counter |

Circuit description see Appendix C

TABLE 6-1 CODING OF CIRCUIT BLOCK DIAGRAM RESPONSE-ORIENTATION AND REACTION TIME EXPERIMENT CONTROL UNIT

is the brightness of the indicator light, which can be varied in both luminance and color desired. In multi-channel configurations the actual number of stimulus presentation can be controlled from the main control unit (Figure C-6), and operator performance data are collected automatically on this unit on two digital counters. These data provide information on the number of stimuli presented and the number of correct control responses by the subject. The duration of stimulus presentation can be selected by changing cams inside the control unit. Basic duration is set at 180 mSeconds, interval between stimulus presentation is set at intervals which

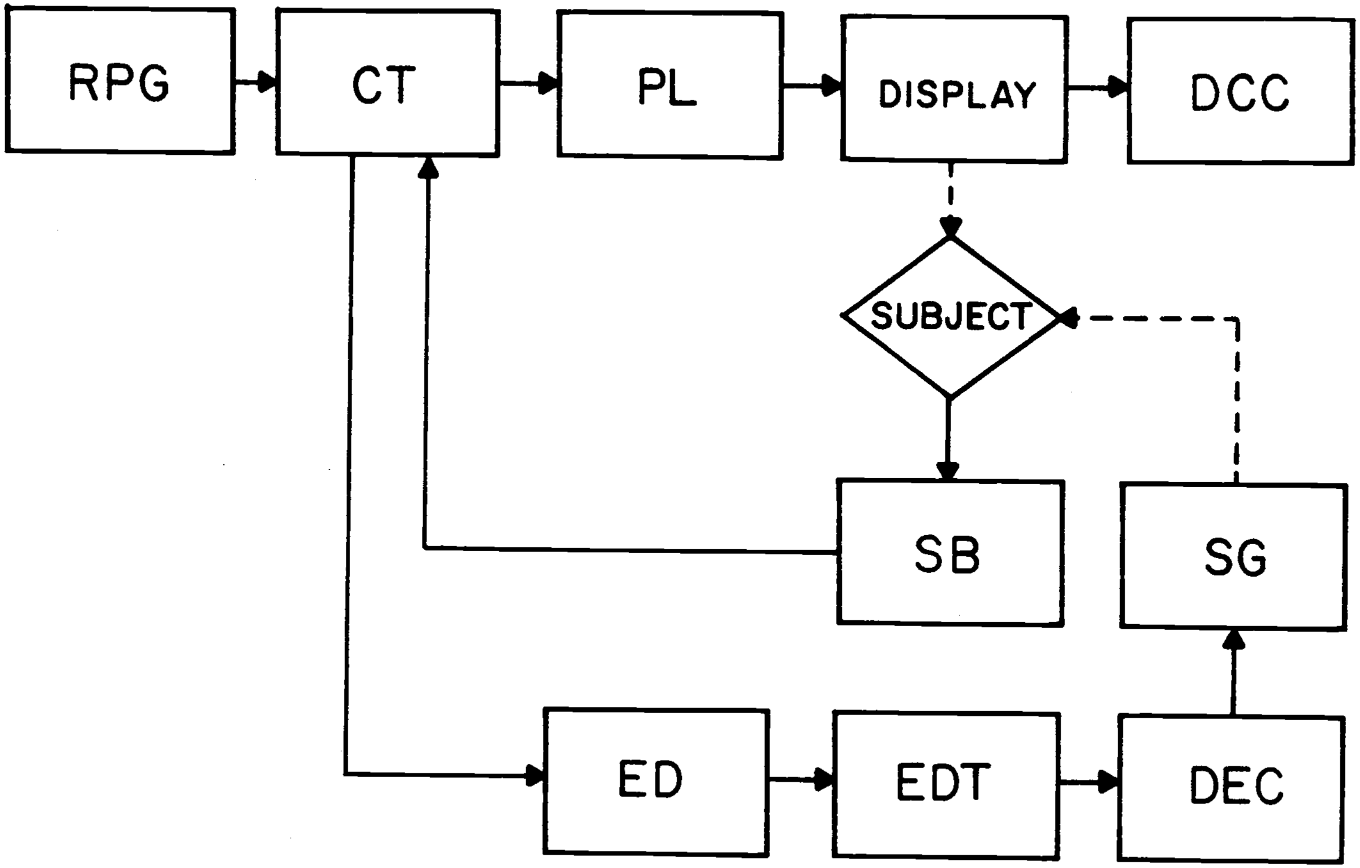
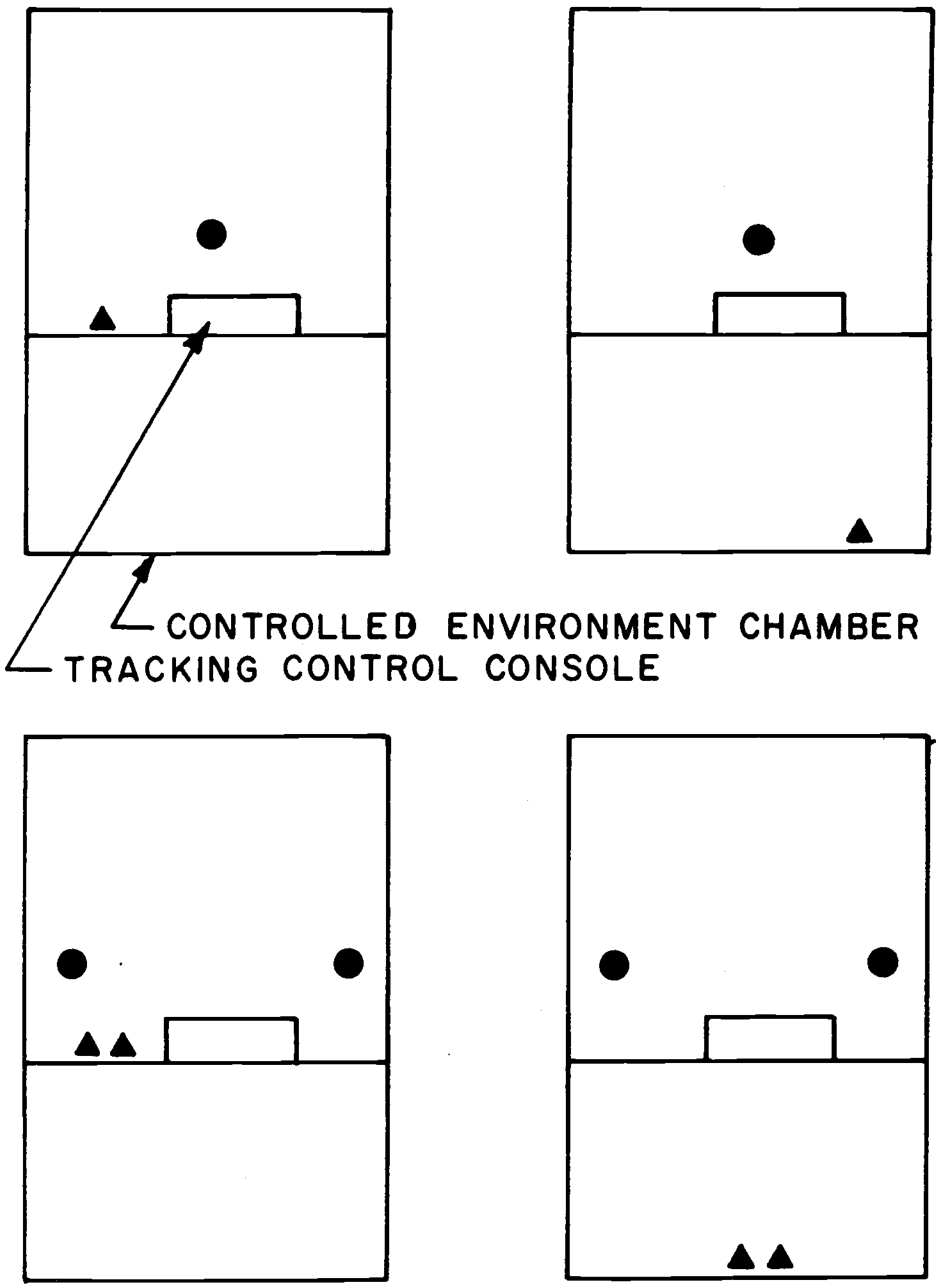



FIGURE 6-1 RESPONSE-ORIENTATION EXPERIMENT MACHINE INTERFACE




● STIMULUS LIGHT

▲ RESPONSE BUTTON

FIGURE 6-2 SUGGESTED MULTI CHANNEL EXPERIMENTS

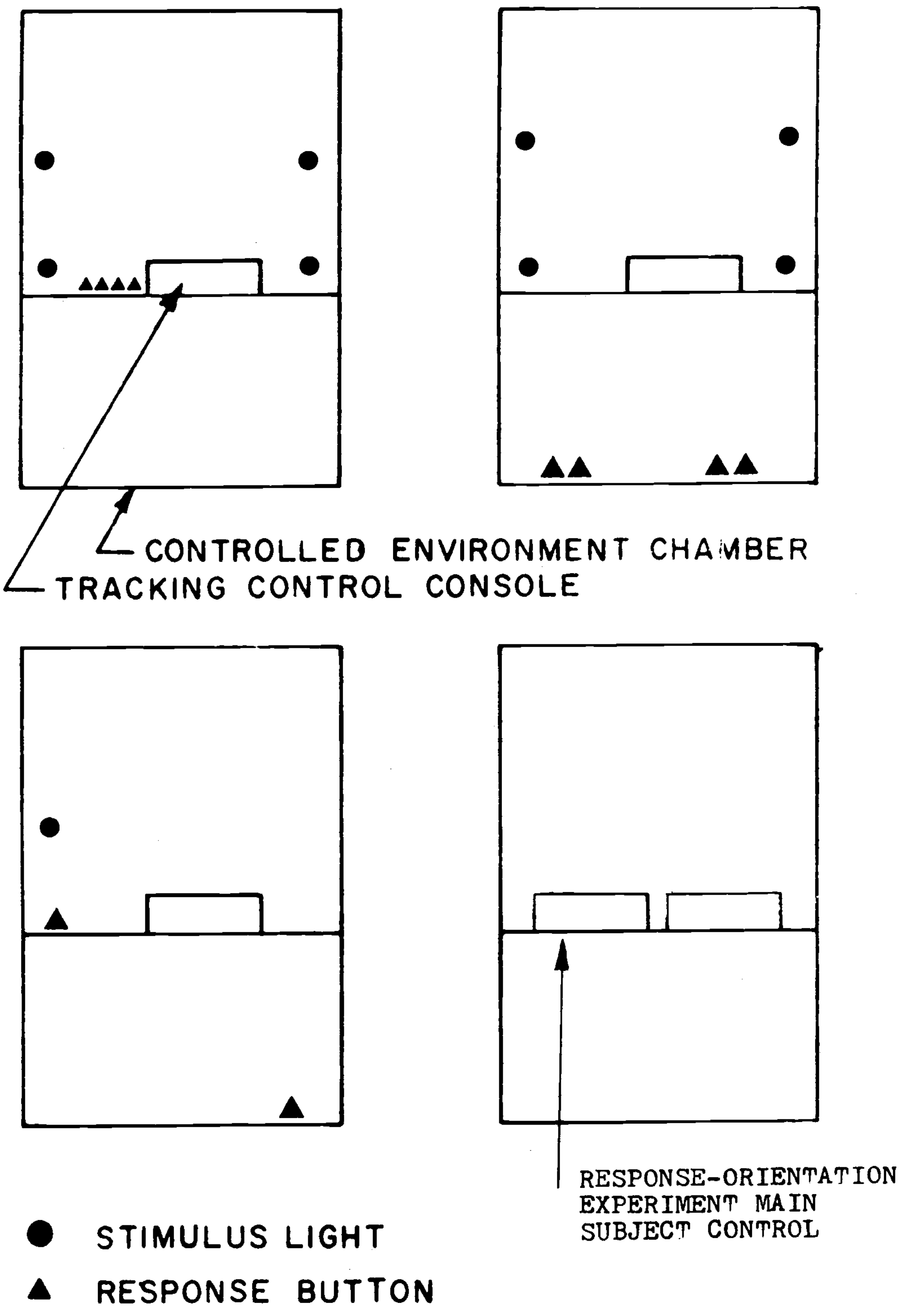



FIGURE 6-3 SUGGESTED MULTI CHANNEL EXPERIMENTS

are multiples of 2.609 seconds, the machine recycling time. Presentation is random otherwise.

Scanning Between Sources

The difference in a two dimensional tracking task is that there is not only the need for scanning within a source, but also the more demanding requirement to scan between sources. This added response requirement is a product of the task variable called load. Load is defined as the number of stimulus sources and has an expected interaction with the rate of events emitted from each source, the latter variable is called speed. Performance deteriorates both with increase in speed and load and response proficiency is a function of the extent to which events in spatially distributed sources overlap in time and command two simultaneous responses, which is the case in the suggested system because the tracking input signal requires continuous operator control updating. The pseudo-random nature of stimulus generation by the response-orientation experiment main control station (Figure 6-4), render the effect of prediction responses insignificant. An implication for prediction responses in two dimensional tracking tasks is that they might reduce the major requirement for visual scanning the stimulus sources and improve tracking performance. Prediction responses in a one dimensional task are known to benefit motor performance. It has been suggested that in a two-dimensional task there is not only prediction within each source, but also prediction

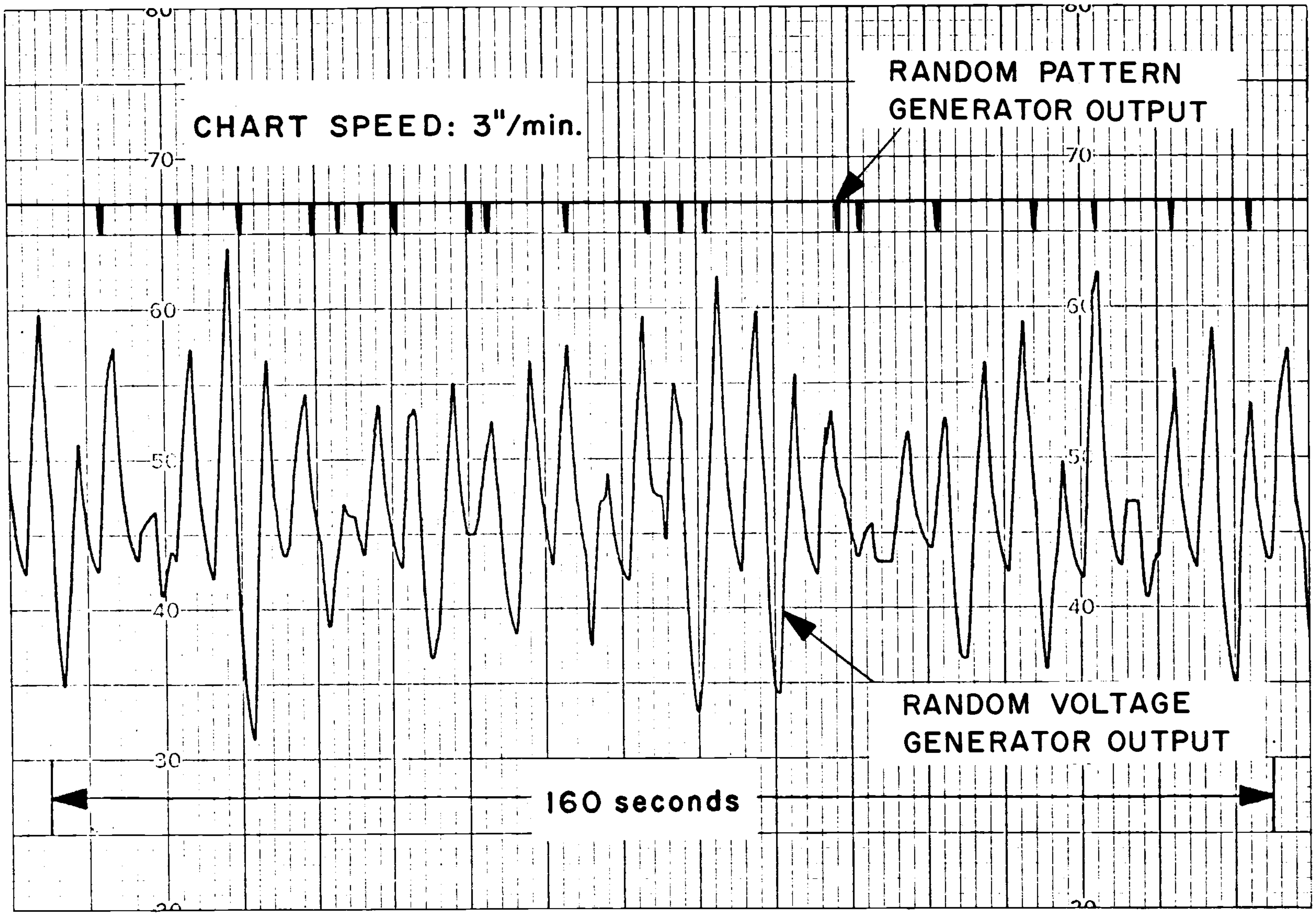



FIGURE 6-4 TWO DIMENSIONAL TRACKING STIMULI

between sources. If the human operator can learn to predict events within a source, it would seem that he might learn of the covariation between the events of the two sources. This theory will hold true when two pulses or step function input sources are scanned; there the operator would have some likelihood of correctly predicting the concurrent event in the other source and consequently, would not need to attend visually to his source as often.

## Motor Interaction

Two dimensional tracking involves two or more component response effector systems, such as both hands or a hand and a foot, and this raises the issue of motor interaction between the two systems. In the initial stages of total response in a multi-dimensional task, it will be typified by a level of uncoordinated activity and error far greater than might be expected from low habit strength in each component response separately. With allowance for ample practice time, these interactions of component responses should show a marked decrease or even drop out completely with each participating component response effector system becoming smoothly proficient. This general problem area is called component response differentiation.

# CHAPTER VII

## CONCLUSIONS AND RECOMMENDATIONS

In the process of designing the various features into the tracking experiment system, it became obvious that the task at hand could be dragged out virtually to infinity. The subject of tracking has been investigated by many independent scientists, both engineers and psychologists, both in the format of original research and applied research. In view of the system requirements, a flexible system is now available, with one major advantage. All functions or variables provided in this system meet all the requirements for a tracking simulator. While suggestions for improvement to the features of the system could be endless, a select few important areas for flexibility expansion are present; this without putting too much of a strain on the resources available.

1. Real time recording equipment. A real time recorder, either digital print readout or as a marker function on a strip chart, would greatly facilitate and expand the possibilities in the area of data acquisition.

   It would provide the experimenter a way of correlating events over the experiment duration. This real time facility should provide a resolution of 1/100 second, rather than the 1/60 second timing now available.

2. Multi-channel recording equipment should be added to the equipment. The presently available Heath EU-20B servo chart recorder is a single channel unit of doubtful stability. A multi-channel recorder would allow recording all events related to the experiment simultaneously and present a perfect source for subject performance evaluation and studying the effects of altered input, output or environmental conditions (Figure 7-1).

3. While the input signal display facilities now available are probably adequate to keep an investigator busy for several years in all experiment nodes, it would be desirable to acquire a DC, dual trace oscilloscope. This would allow presentation of the input signal for both pursuit and compensatory tracking in a fashion which allows direct comparison of the performance data as compared to the present pursuit tracking on the edgewise meters and compensatory tracking on the chart recorder. Possible presentation of input signal and output signal and error signal are shown in Figure 7-2.

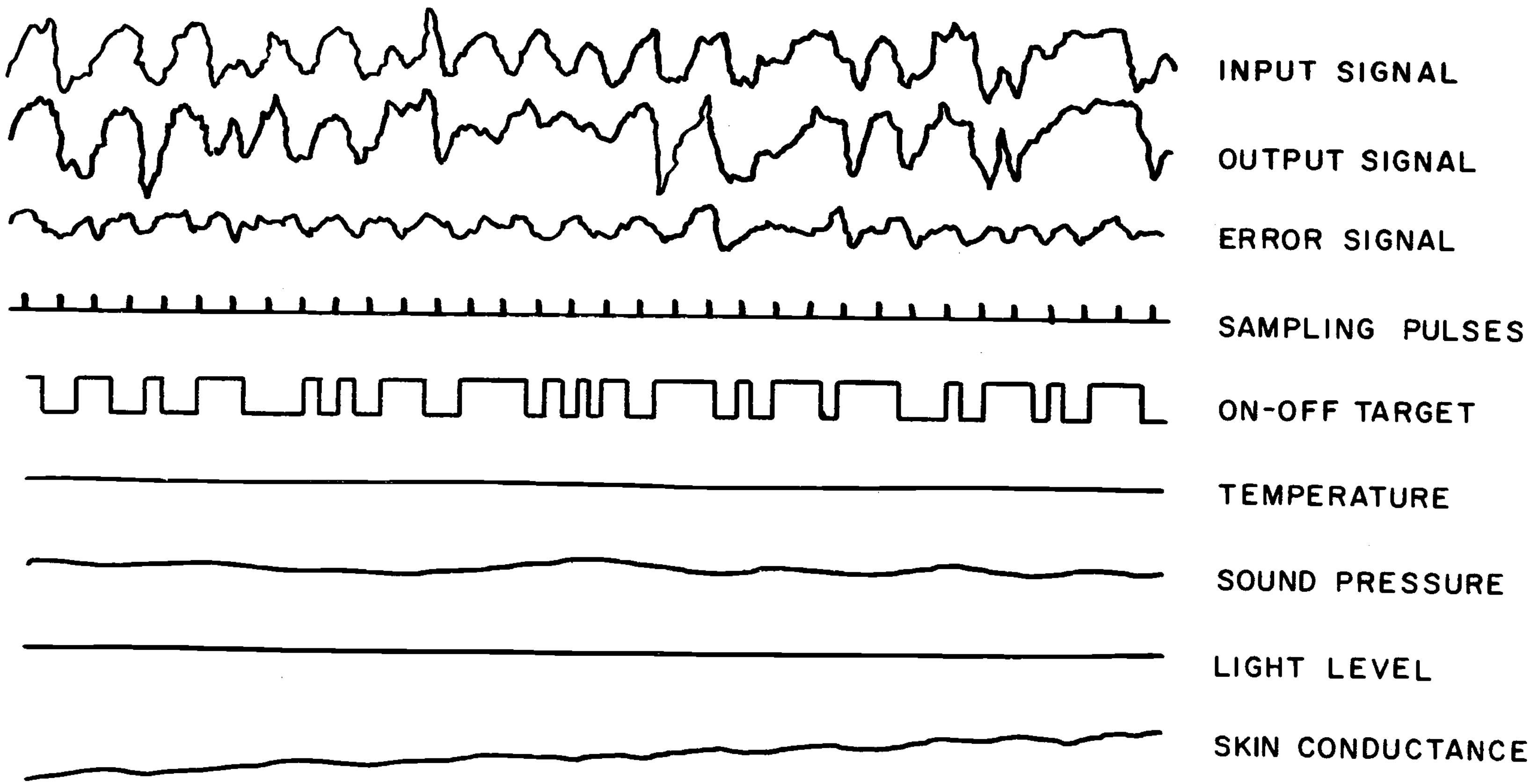



FIGURE 7-1 DESIRABLE DATA COLLECTION FORMAT

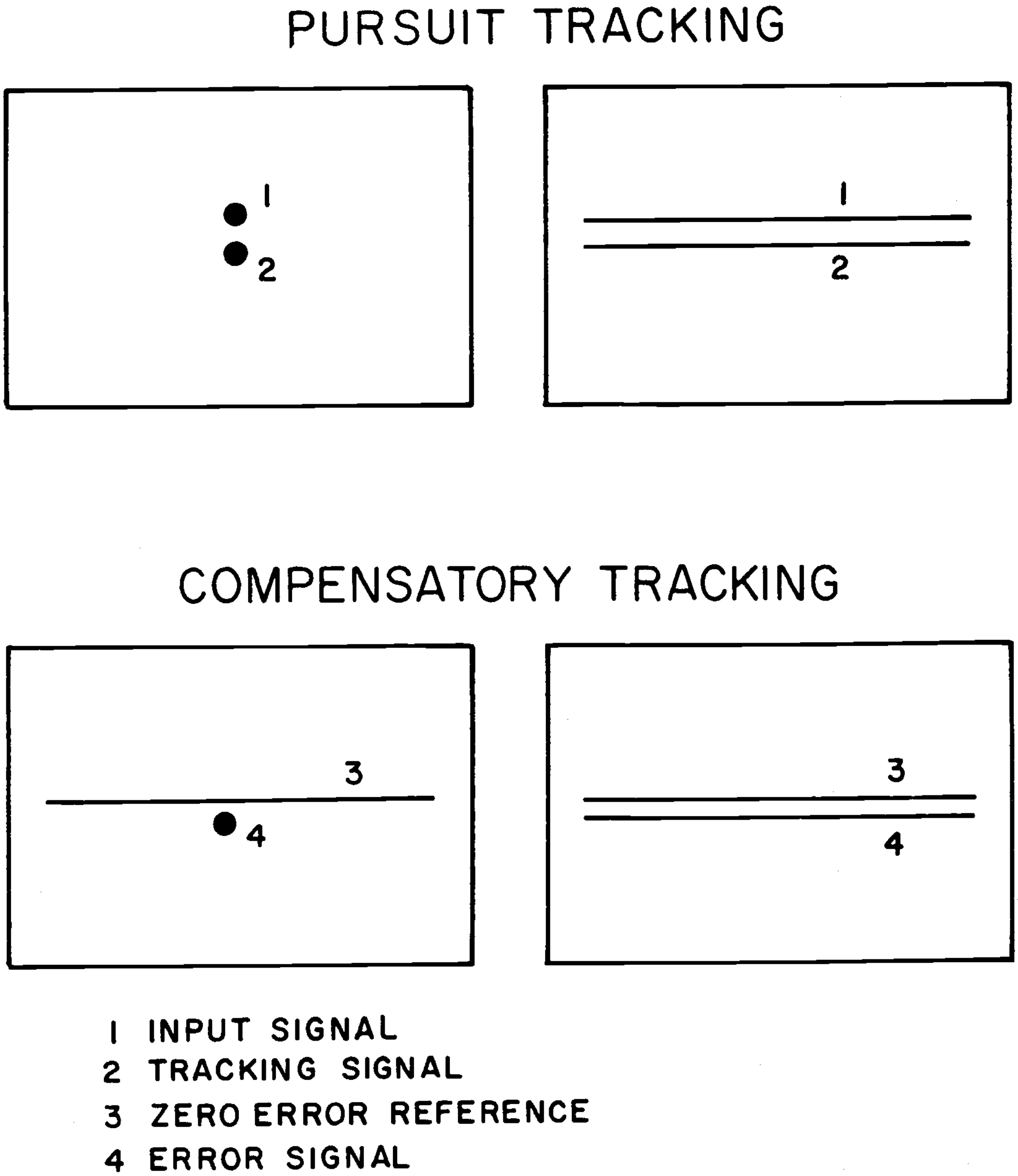



FIGURE 7-2 CRT DISPLAY

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# APPENDICES

# APPENDIX A

# ENVIRONMENTAL CONTROL SYSTEMS

## The Controlled Chamber

The chamber provided for workstation enclosure is constructed of 1/4" panel board on the outside and 1/2" acoustic softboard on the inside. A 2" space between the wall is filled with 2" acoustic fiber blanket. Air intake and exhaust is routed through two baffled enclosures to trap both light and sound. Illumination is provided by a 200 Watt light source, controlled by a Dremel type 6, silicon controlled rectifier voltage control and allows adjustment of the chamber light level from 0 to 100 Ft.-c (Table A-1, A-2).

Actual workstation illumination is indirect. A light level meter is available for measuring chamber light level outside. The sensor for this instrument is mounted in a position such as to indicate reflected light level from the actual operator control station.

The basic sound pressure in the chamber averages 48 dB. This sound originates in the air temperature control system and has its peak 48 dB in the 5000 Hz. region.

The natural resonant frequency of the chamber has been recorded at approximately 275 Hz. with the chamber occupied by an average person in a seated position at the subject control console. Two sound level meters are available for experimentation, with a

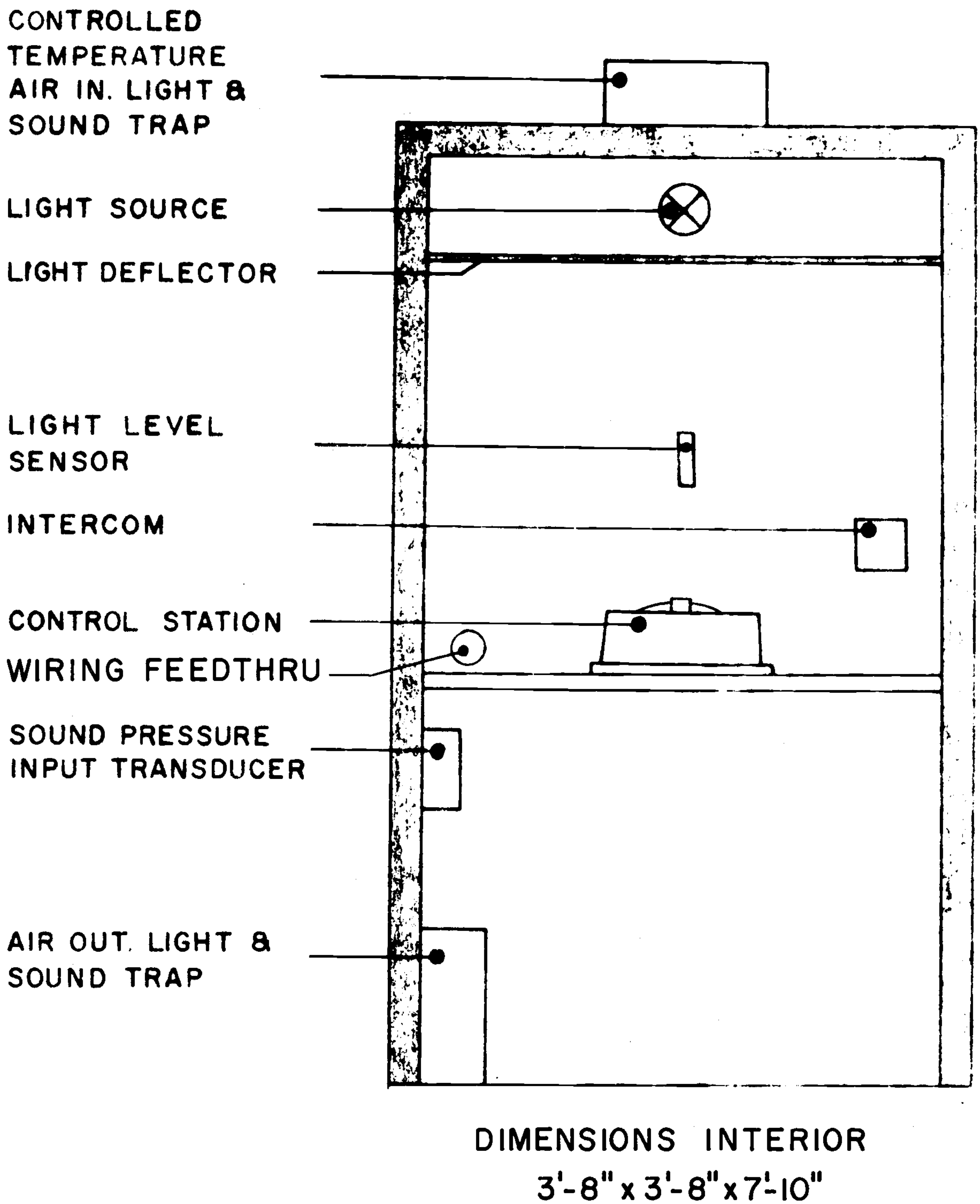



FIGURE A-1 ENVIRONMENTALLY CONTROLLED CHAMBER

GENERAL ILLUMINATION LEVELS

| TYPE OF TASK OR AREA | ILLUMINANCE LEVEL Ft-c |
|---|---|
| Sewing, inspecting dark materials. | 100 |
| Machining, drafting, watch repairing. | 50-100 |
| Reading, general office or laboratory work. | 20-50 |
| Washrooms, waiting rooms, kitchens. | 10-20 |
| Recreational facilities. | 5-10 |
| Restaurants, warehouses. | 2-5 |

TABLE A-1

LEVELS OF LUMINANCE

| DESCRIPTION | LUMINANCE Ft-Lamberts |
|---|---|
| Upper limit of visual tolerance | 50,000 |
| Fresh snow on clear day | 10,000 |
| Average earth on clear day | 1,000 |
| Average earth on cloudy day | 100 |
| White paper in good reading light | 20 |
| White paper 1 Ft. from std. candle | 0.9 |
| Snow in full moon | 0.02 |
| Average earth in full moon | 0.002 |
| Snow in starlight | 0.0002 |
| Grass in starlight | 0.00002 |
| Absolute threshold of vision | 0.0000009 |

TABLE A-2

test range of 60 to 116 dB, accurate to ± 2 dB from 40 - 14,000 Hz. Two settings are provided for ASA Standard -- fast and slow. Basic sound pressure level in the chamber was obtained using a Simpson model no. 885 sound level meter.

## Sound Generating Facility

A facility is available for adding pure tones to the chamber at frequencies of 20 - 20,000 Hz.

Signals from a sinewave generator with a distortion of less than .1% are fed to a 28 Watt RMS modified high fidelity amplifier to provide a flat amplification rate over the useful range, 20 - 16,000 Hz. within 2 dB. An audio transducer is placed in the chamber. This transducer is of the acoustic suspension type (nonvented enclosure) and reproduces within 3 dB from 35 to 16,000 Hz.

A self powered condenser microphone is available for the system for sound adding or sound feedback purposes. The frequency response of this microphone is ±1 dB flat from 30 to 16,000 Hz. Maximum produced sound pressure level in the chamber was 128 dB at 1 kHz (Figure A-2).

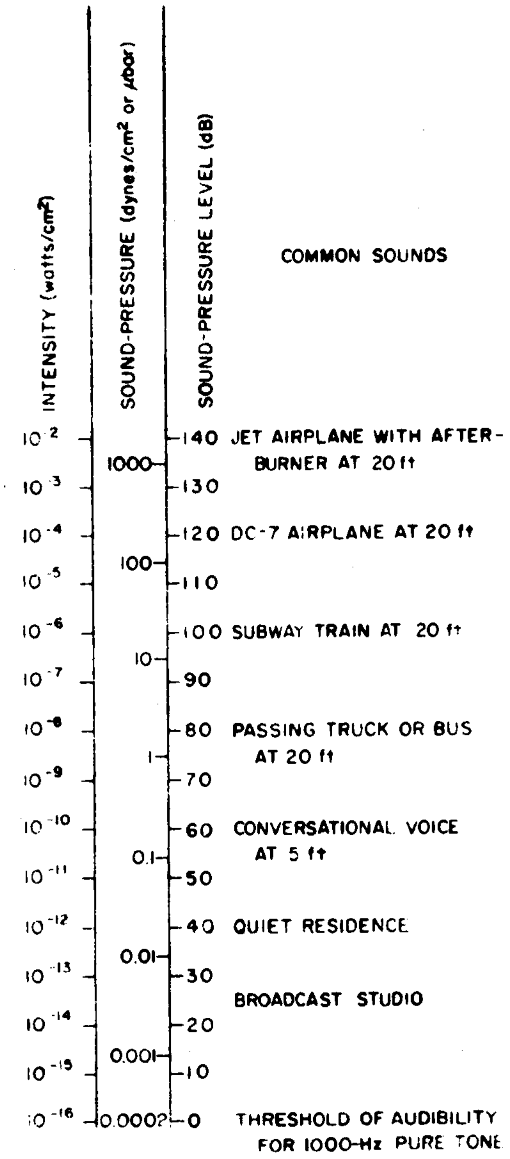



FIGURE A-2 COMMON SOUND LEVELS

# APPENDIX B

## CIRCUIT DESCRIPTION TRACKING EXPERIMENTS CONTROL UNIT

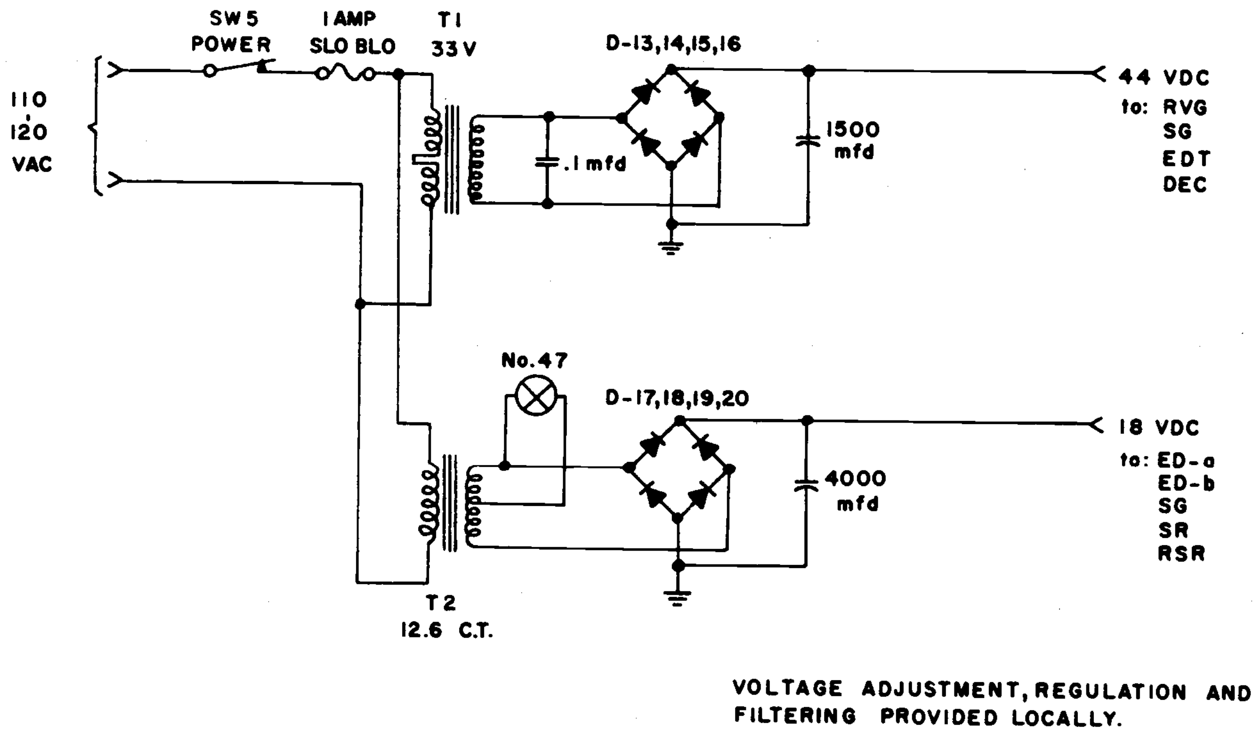
All individual circuits in the control unit are connected to a power supply, providing 44 VDC and 18 VDC, full wave rectified, unregulated but filtered and connected to a common ground (Figure B-1).

Transistors Q1 - Q6 (Figure B-2) form three astable multivibrators running at different rates and with different duty factors. The three outputs are summed through the collector resistors of values 18K, 33K and 8.2K and isolated by D-2, D-3 and D-4. The resultant voltage appears at the common terminal of SW-4 as a random voltage running from 0.6 VDC to 9.8 VDC without load, and a 0.4 VDC to 5.5 VDC when connected to M-1 of the subject control console. The drift rate of this random voltage is damped by capacitance selected by SW-4. 0, 100, 150 or 200 mfd can be connected across the output.

The output voltage typically generated is shown in Figure 6-4 The output of the Random Voltage Generator (RVG) is coupled to the Error Detectors (ED-a and ED-b) (Figure B-3) and to the low limit detector in the Timing Pulse Generator (Figure B-5), providing a base for the generating of random timing pulses in the Random Timing Pulse Generator (RSR).

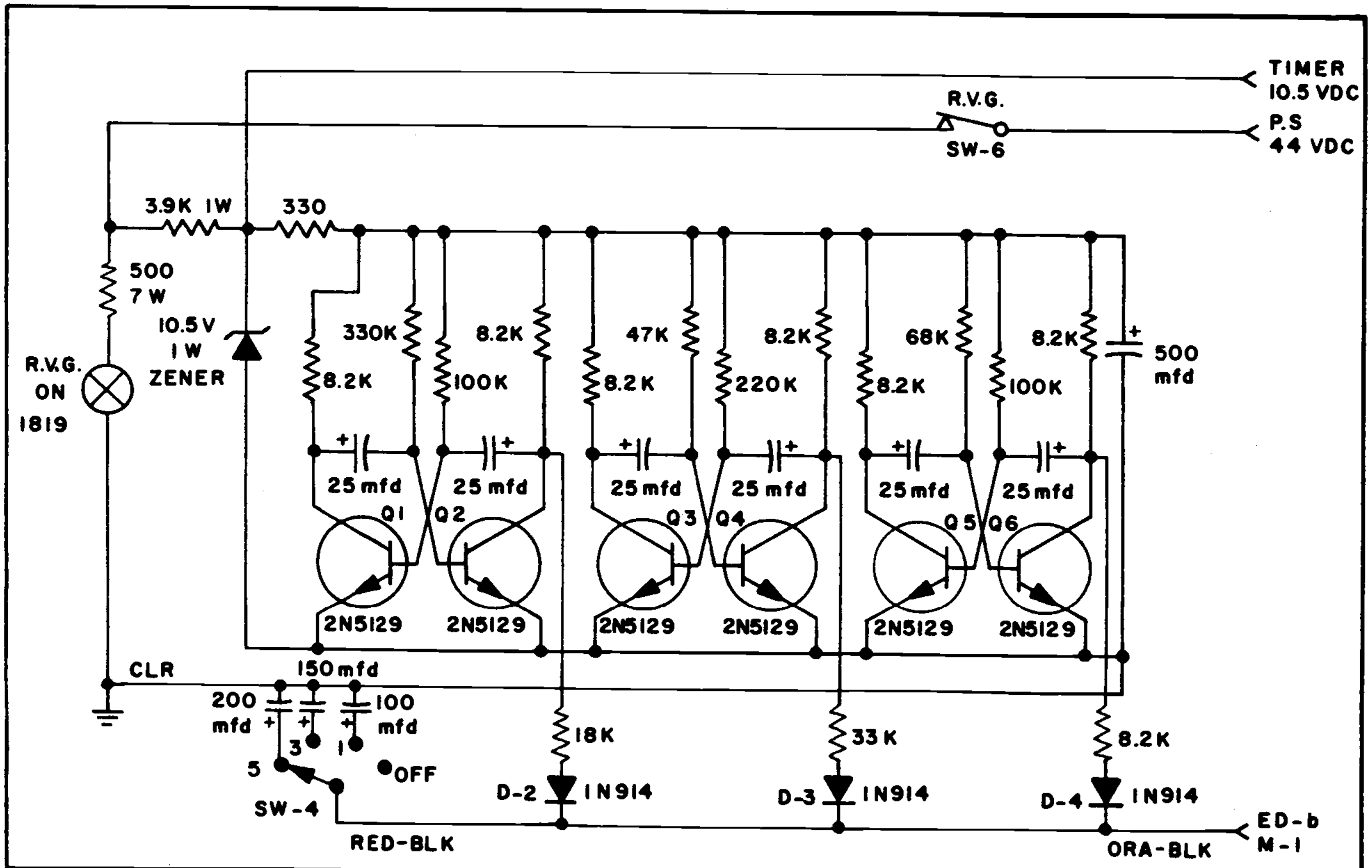
Power supplied to the Random Voltage Generator is 44 VDC, locally regulated at 10.5 VDC by zener diode.

Transistors Q14 - Q16 and Q17 - Q-17 form an upper and lower limit voltage comparator, operating in the 0.6 and 10.0 VDC



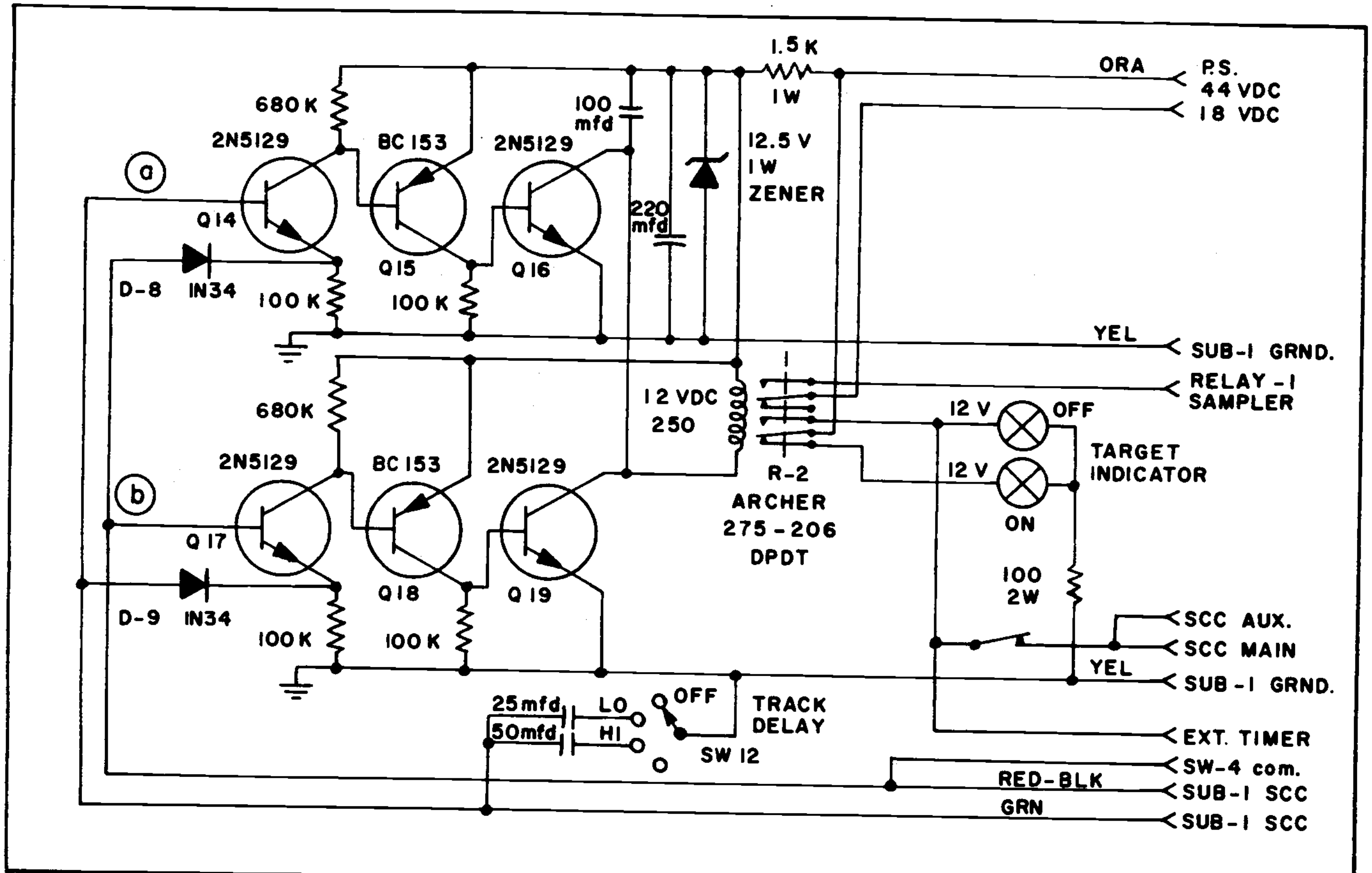

SCHEMATIC DIAGRAM. POWER SUPPLY. IE-1

FIGURE B-1




SCHEMATIC DIAGRAM. RANDOM VOLTAGE GENERATOR. R.V.G. IE-1

FIGURE B-2




SCHEMATIC DIAGRAM. ERROR DETECTOR, ED-a & ED-b. IE-1

FIGURE B-3

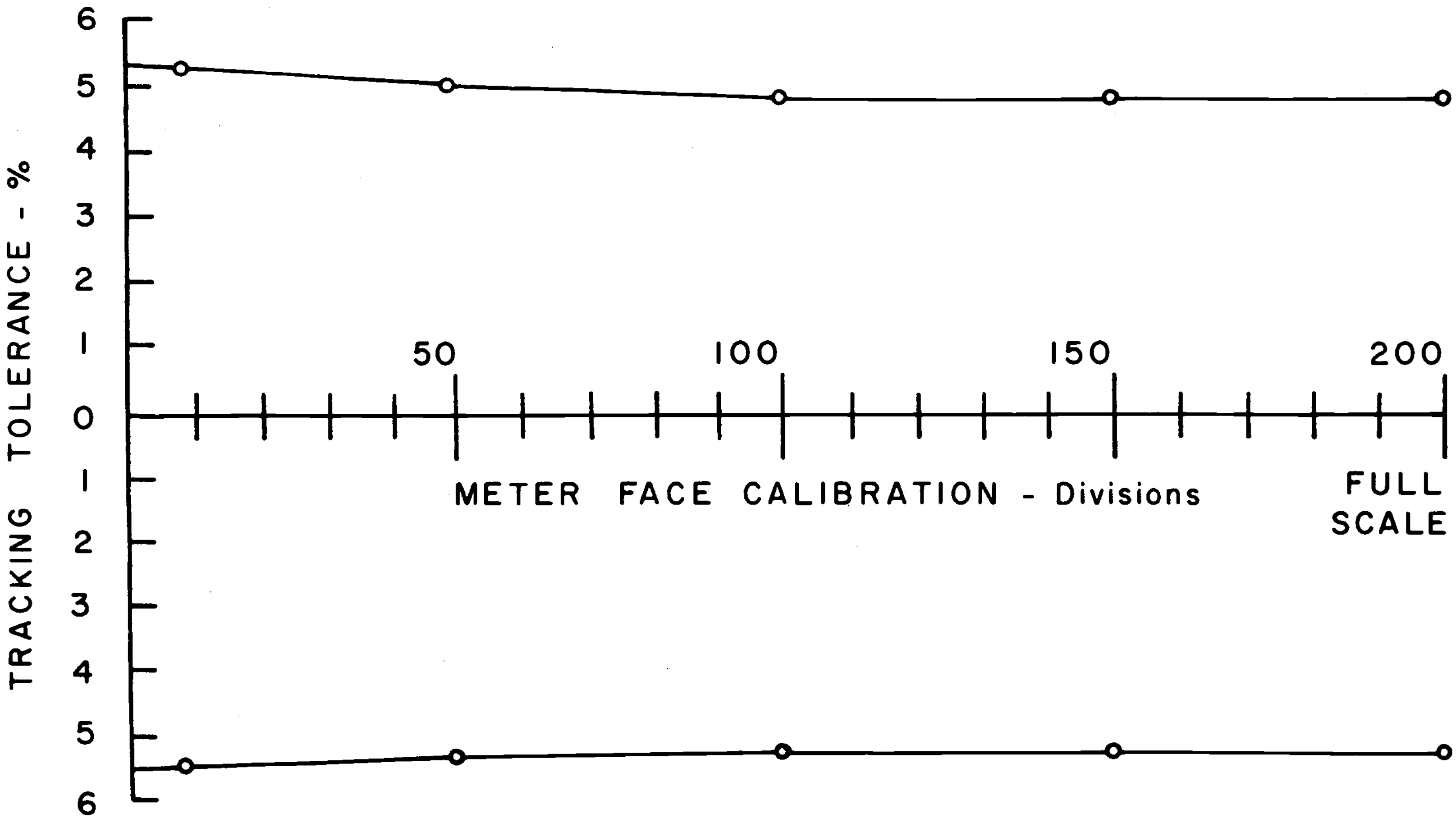
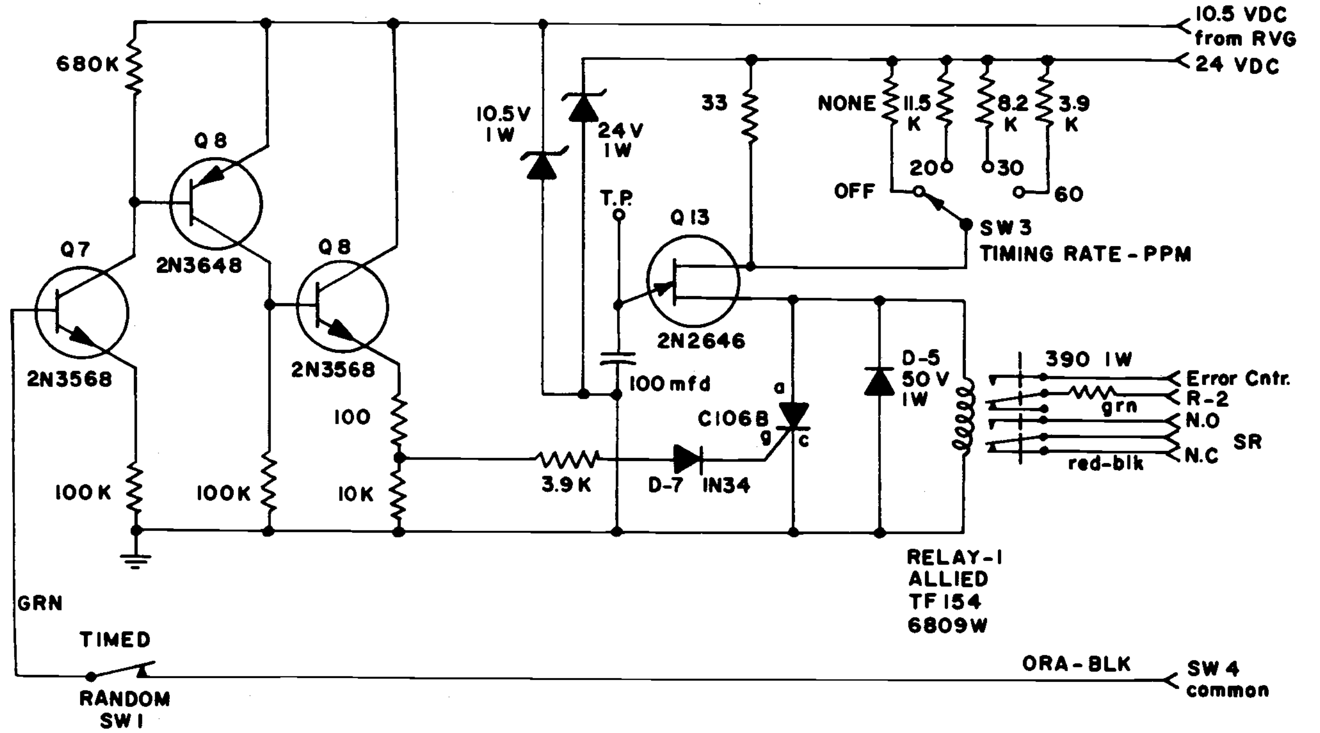



FIGURE B-4 TRACKING TOLERANCE ACCURACY




SCHEMATIC DIAGRAM. TIMING PULSE GENERATOR. S.R. & R.S.R. IE-1

FIGURE B-5

range (Figure B-3). The voltage differential required for switching the output voltage from 0.0 VDC to 12.6 VDC at the collectors of Q16 and Q19 is 25 mV. The voltage differential detection sensitivity is presented as a percentage of full scale meter deflection of M-1 in Figure B-4. These error detectors ED-a and ED-b energize the DPDT relay R-2. Auxiliary inputs to both detectors are provided on the front panel. An off-target auxiliary output is also provided on the front panel for controlling the digital cumulative "off-target" timer.

Power supplied to the error detectors is 44 VDC, locally regulated at 12.5 VDC by zener diode.

An accurate timing pulse, with high thermal stability is provided by Uni-Junction Transistor Q13. The 100 mfd. capacitor in the circuit (Figure B-5) discharges and causes a voltage change at the emitter of the UJT, causing it to conduct and momentarily energize the 8PDT relay R-1. Capacitor discharging time is selected by the setting of SW-3, limiting current flowing from the supply voltage of 24 VDC to the capacitor through selected resistors, providing timed intervals of 1, 2 and 3 seconds, or, as marked on the front panel, 20, 30 and 60 pulses per minute (PPM).

Power supplied this, the Sample Rate (SR) section of the timing pulse generator, is 24 VDC.

The timing facility also generates a pseudo-random timing pulse (RSR) by short circuiting the coil of R-1, for random periods through the Silicon Controlled Rectifier (SCR) Q23.

This SCR is gated by the pulse coincidence detector, formed by Q7 - Q9. Essentially, the voltage generated by the RVG multi-vibrators and the pulses generated by the timing pulse generator (SR) must coincide to result in a timing pulse energizing R-1. The summed total of the RVG must be less than 0.6 VDC while the timing pulse generator must be at peak voltage at the same instant. The pattern of pseudo random pulses (Figure B-6) can be somewhat influenced by different settings of SW-3 and SW-4 in any combination.

Power supplied to the random sample rate (RSR) section of the timing pulse generator is 10.5 VDC, derived from the RVG local regulator.

An auxiliary outlet of the SR and RSR output pulses is provided on the front panel.

An electric shock generator (Figure B-7) is formed around silicon controlled rectifier Q12. 44 VDC is supplied to the circuit primary 4 Ohm winding of transformer T-3, if it were not for the non-conducting SCR which acts as an open switch. As the 220 mfd. capacitor charges, the voltage across the SCR gate network builds up. When this gate receives the required trigger voltage, the SCR fires (conducts) to discharge the 220 mfd. capacitor across the T-3 primary winding. As soon as this discharge occurs, the 220 mfd. has essentially no voltage across it, current through the SCR falls below the holding current level, the SCR is returned to its non-conducting state, and the cycle repeats itself. The triggering rate is determined by the setting of the 20K potentiometer. The

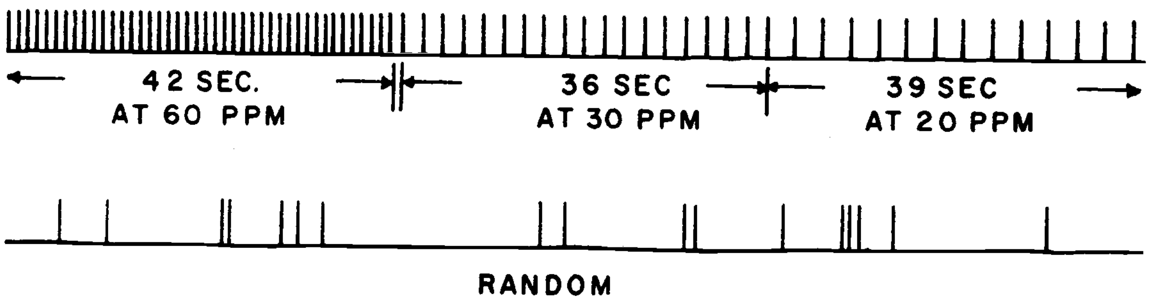



FIGURE B-6 Timing Output

turns ratios of the transformer T-3, are such that several hundreds of volts are generated across the secondary for each primary current pulse. Four different turn ratios can be selected by setting SW-7, delivering shocks of varying intensity labelled as Mild, Normal, Strong and Severe on the front panel. The network of resistors and neon bulbs (NE-51's) is provided to both load and limit the output of the shock generator (SG) and to provide a visual indication of its operation and frequency on the front panel. The shock is transmitted to the output terminals on the front panel only when the normally open pushbutton switch on the front panel is depressed. A special electrode and subject hand strap is provided. The circuit formed by transistors Q10 and Q11

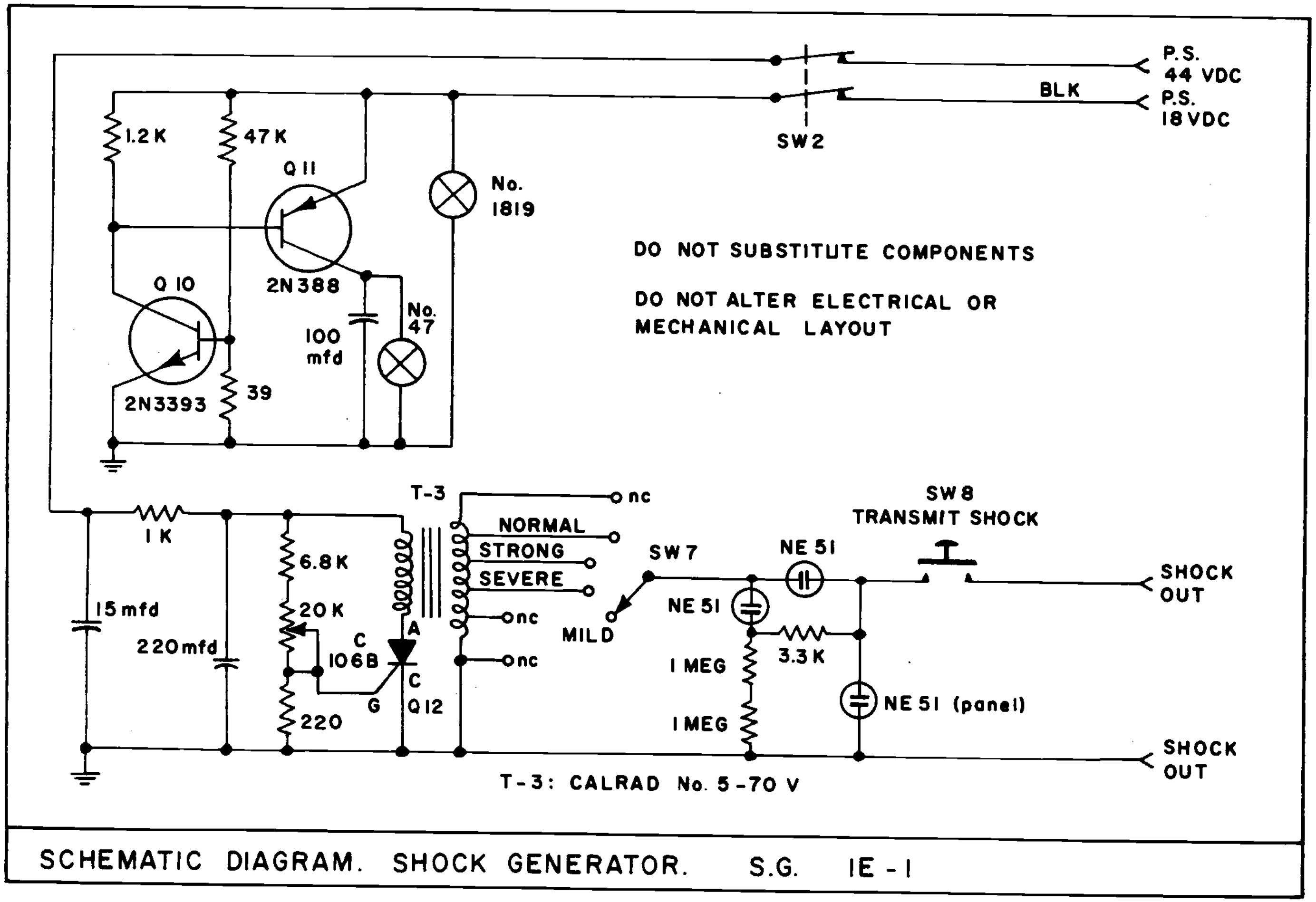

P.S.
44 VDC
BLK
P.S.
18 VDC
SW 2
1.2 K
47 K
Q 11
2N388
No.
1819
Q 10
2N3393
39
100
mfd
No.
47
DO NOT SUBSTITUTE COMPONENTS
DO NOT ALTER ELECTRICAL OR
MECHANICAL LAYOUT
T-3
nc
NORMAL
STRONG
SEVERE
nc
nc
MILD
SW 7
NE 51
NE 51
SW 8
TRANSMIT SHOCK
SHOCK
OUT
1 K
15 mfd
220 mfd
6.8 K
20 K
C
106B
A
C
G
Q12
220
1 MEG
1 MEG
3.3 K
NE 51 (panel)
SHOCK
OUT
T-3: CALRAD No. 5-70 V
SCHEMATIC DIAGRAM. SHOCK GENERATOR. S.G. IE-1

FIGURE B-7

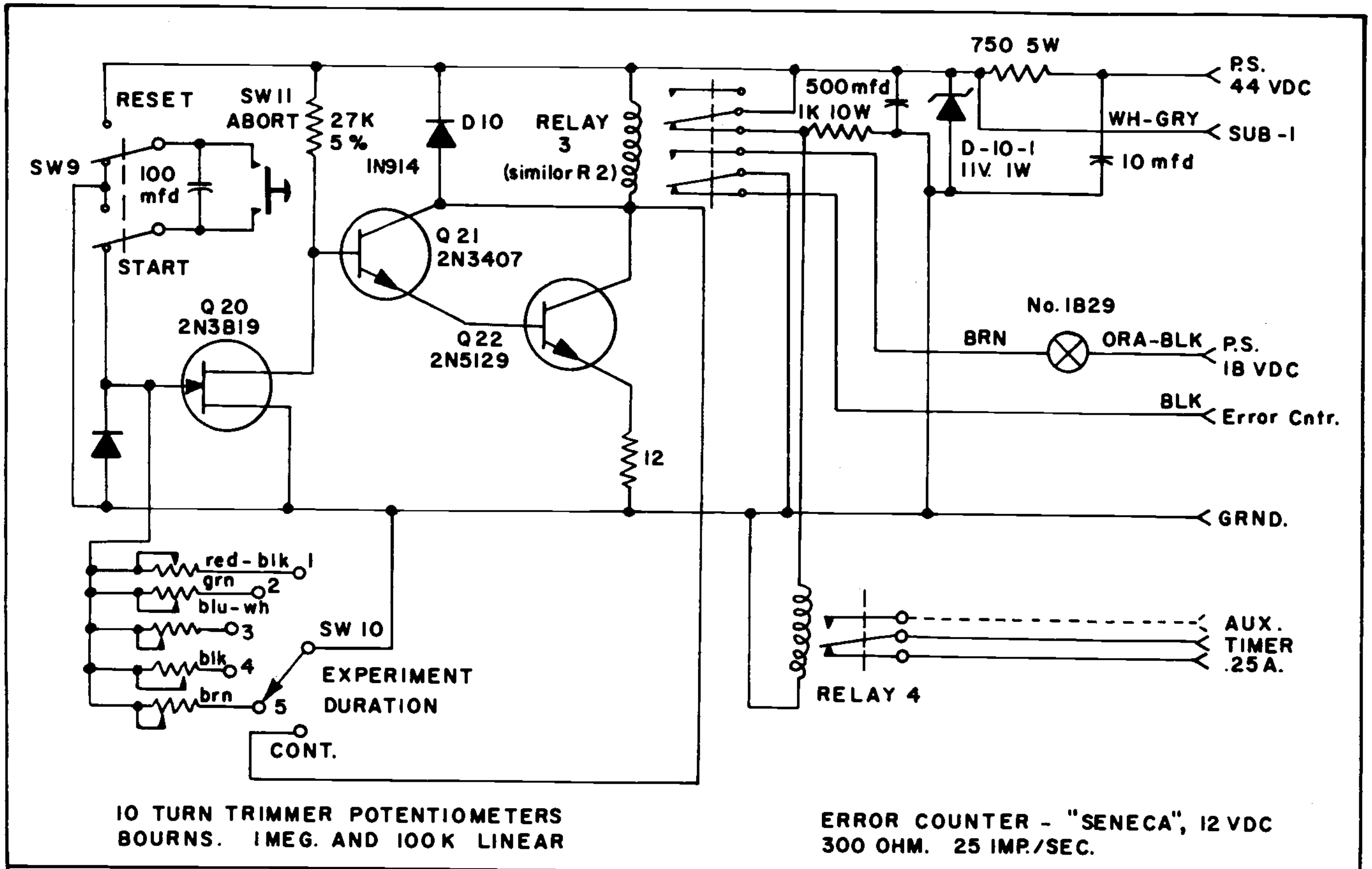
is a free running multi-vibrator serving as a lamp driver. The No. 1819 lamp is mounted on the front panel and provides a clear indication for the operator that the SG is switched on.

Power supplied to the warning lamp driver circuit is 18 VDC directly from the Power Supply through DPST switch SW-2.

Field Effect Transistor (FET) Q20 and trnasistors Q21 and Q22 (Figure B-8) form a timer circuit of high repeatability,accuracy and thermal stability. The 100 mfd. capacitor is charged to 11.0 VDC in the reset position of SW-9. In the start position, the capacitor charge is applied to the very high input impedance of the FET's gate, and allowed to drain to ground through a resistor selected by SW-10. These resistors are 10 turn trimmer potentiometers of values ranging from 100K to 1 Meg. and allow accurate calibration of the timing intervals. Timed periods of 1, 2, 3, 4 and 5 minutes are provided and so labelled on the front panel. In addition, a position for continuous operation is provided. Whenever a positive voltage is present at the gate of FET Q20, relay R3 is energized through Q22. In the continuous cycle mode, the collector of Q22 is connected directly to ground, bypassing the junction of Q22 and energizing R-3. A manual cycle terminating "abort" switch SW-11 is provided on the front panel.

Power supplied to the Experiment Duration Timer is 44 VDC, locally regulated to 11.0 VDC by zener diode.

The control unit is connected to the Subject Control Console, Sub 1, by a 5 conductor cable (Figure B-9). The Subject Control




SCHEMATIC DIAGRAM. EXPERIMENT DURATION TIMER. E.D.T. IE-1

FIGURE B-8

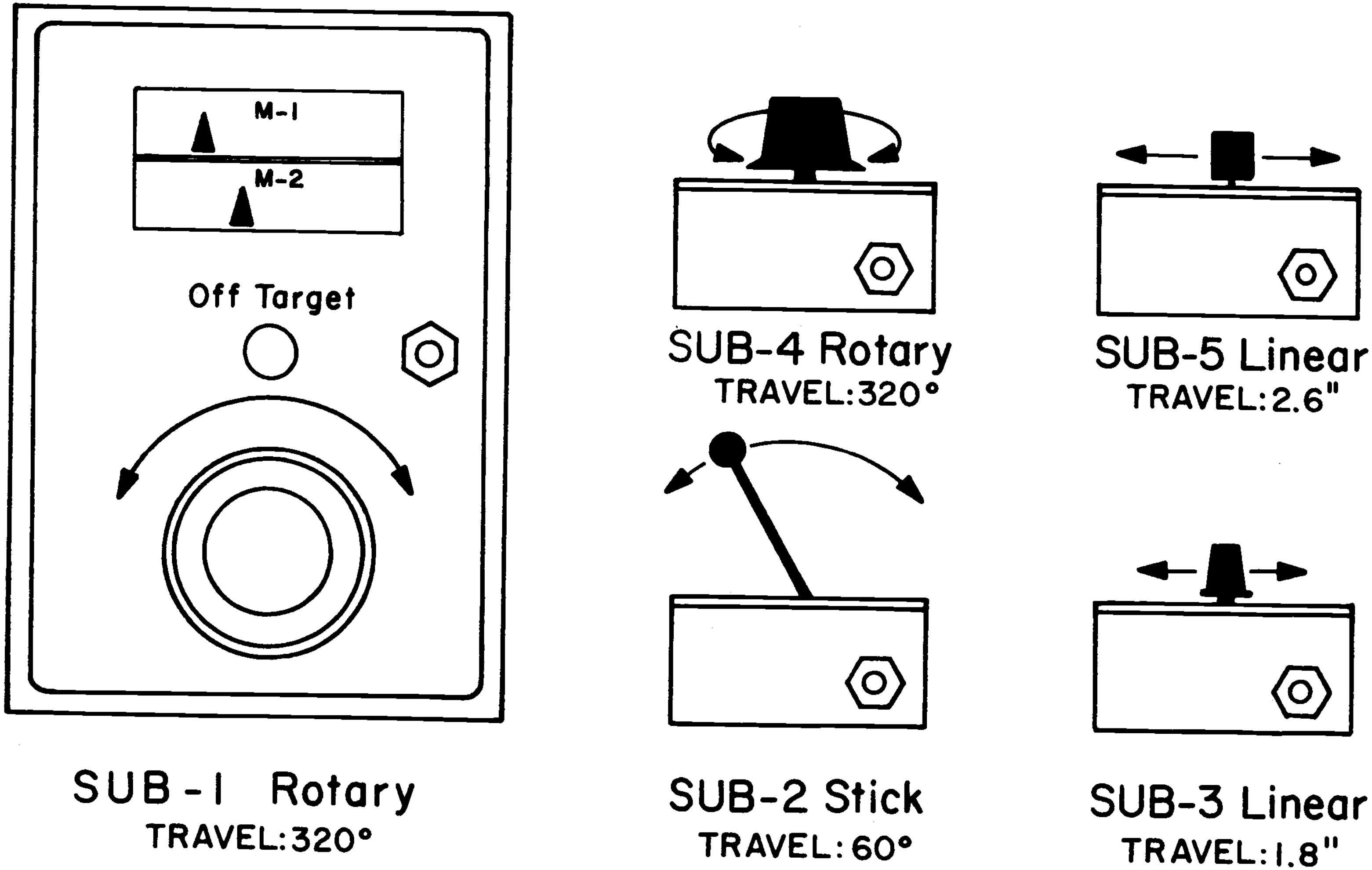



FIGURE B-9 SUBJECT CONTROL CONSOLE LAYOUT

Console Sub-1 (Figure B-10), contains two meters, M-1 and M-2, a rotary subject control, an auxiliary control input jack and an error indicator light. Ten turn trimmer potentiometers are provided for calibration of the meter drive signals, to provide similar meter positions with equal signal levels generated by the RVG and the subject controlled potentiometer.

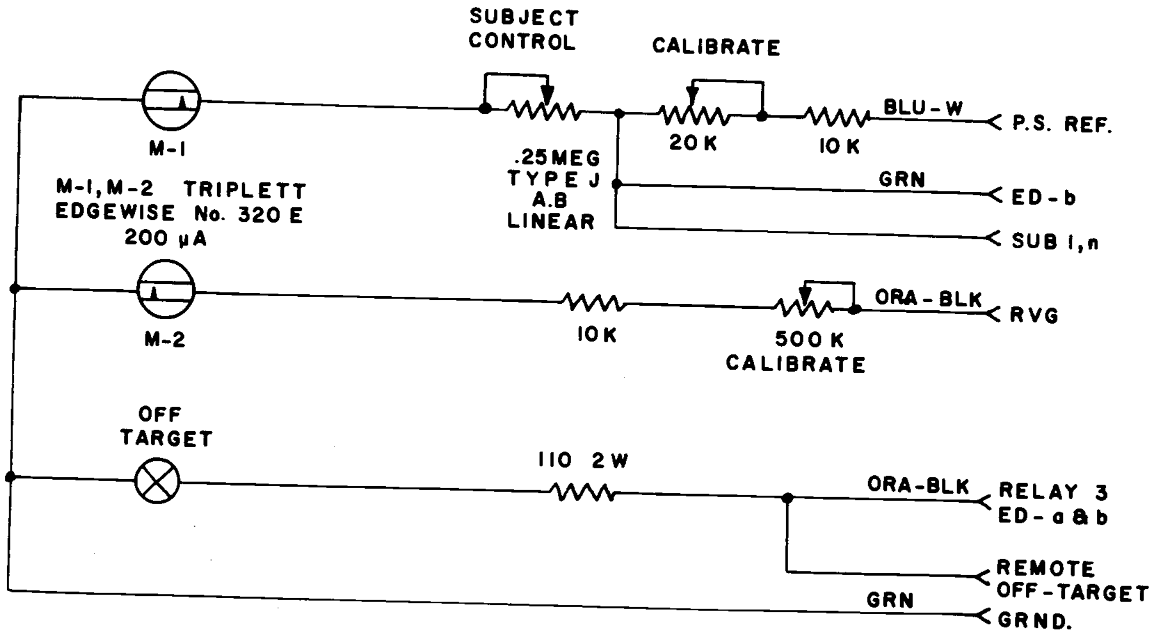
When other means of control are required, any mechanism, providing a resistance ranging from 0 to 100 K, corresponding to 0 or full scale deflection of M-2, can be plugged directly into Sub-1, setting the control on Sub-1 in the extreme CCW position.

SERVO RECORDER ADAPTER FOR COMPENSATORY TRACKING EXPERIMENTS

An adapter is provided to feed the signals of the RVG and the subject control potentiometer to a Heath EU-20B Servo Chart Recorder.

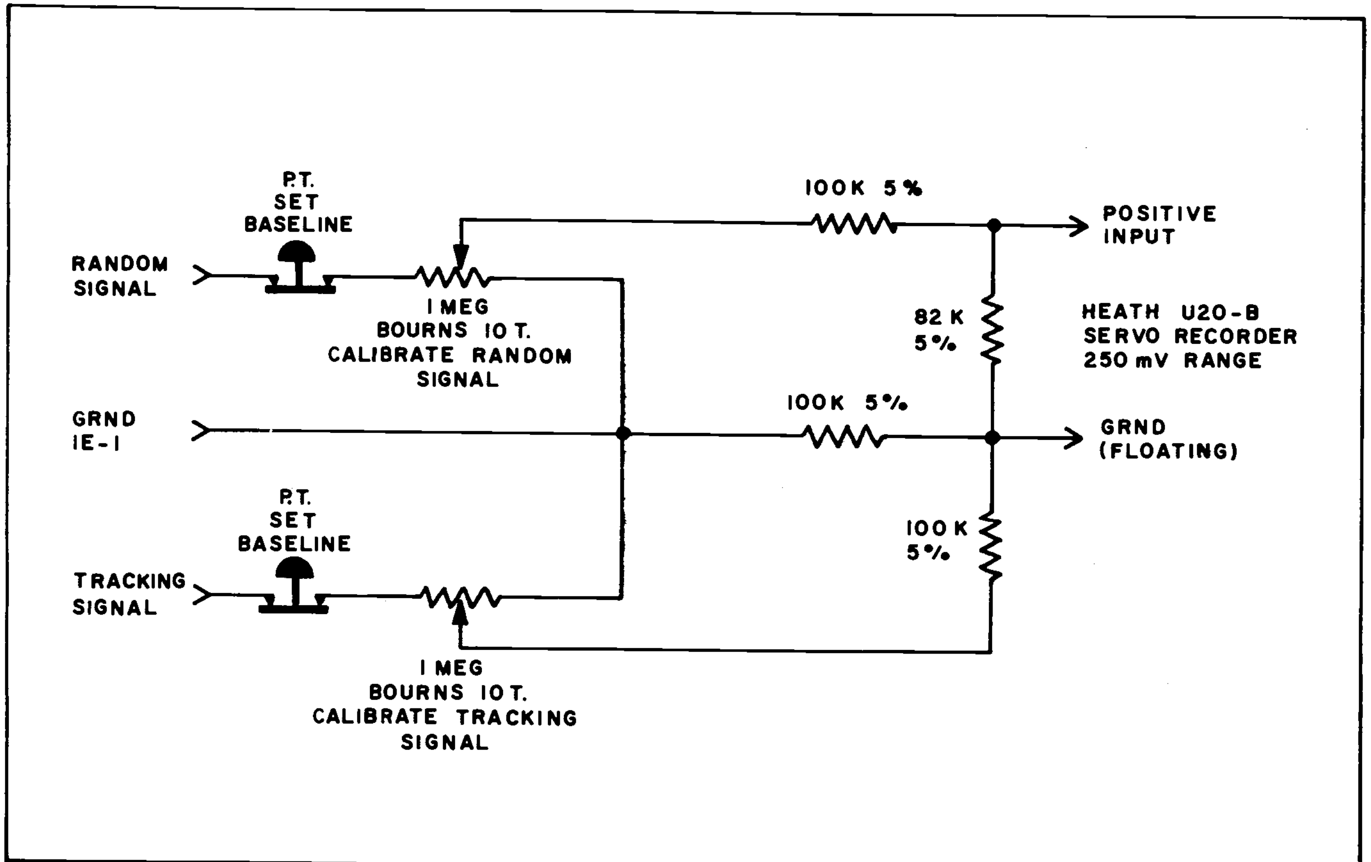
The signals are subtracted from each other delivering a stable DC voltage regardless of meter positions, of 0.0 VDC when random and tracking voltages are equal.

Any deviation will cause movement of the recorder pen of a logarithmic nature, 1" at 250 mV and 5" pen travel at 5.5 VDC which corresponds to maximum meter deflection. In this mode the recorder ground is floating with respect to the Tracking Experiments Control Unit as wess as the recorder chassis ground. Adapter signal levels are adjustable by means of two 10 turn 1 Meg. trimmer potentiometers (Figure B-11). Two normally closed pushbutton




SCHEMATIC DIAGRAM. SUBJECT CONTROL CONSOLE. IE-1 Sub-1

FIGURE B-10




SCHEMATIC DIAGRAM: DIFFERENTIAL SIGNAL FOR COMPENSATORY TRACKING DISPLAY. IE-I

FIGURE B-11

switches are provided on the adapter panel, allowing interruption of either input signal to facilitate the recorder baseline adjustment procedures.

# APPENDIX C

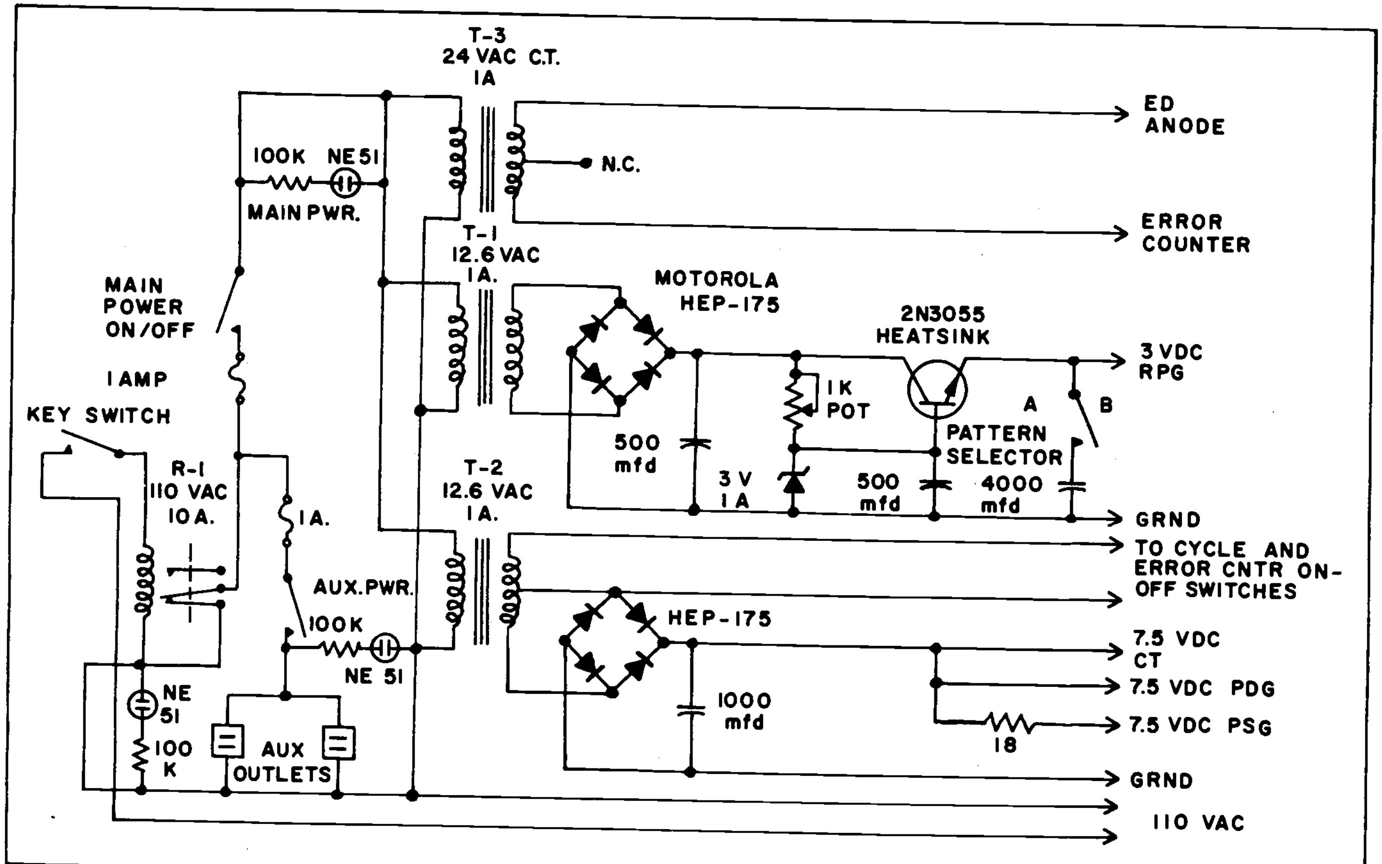
## CIRCUITS DESCRIPTION SPEED VERSUS ACCURACY EXPERIMENTS CONTROL UNIT

All individual circuits are connected to a power supply providing the required voltages. A 24 VAC, 1 Amp, output is provided for the electromechanical cycle and error counters in the control unit.

Regulated 3 VDC at 1 Amp. and full wave rectified 7.5 VDC, non-regulated but filtered are connected to a common ground.

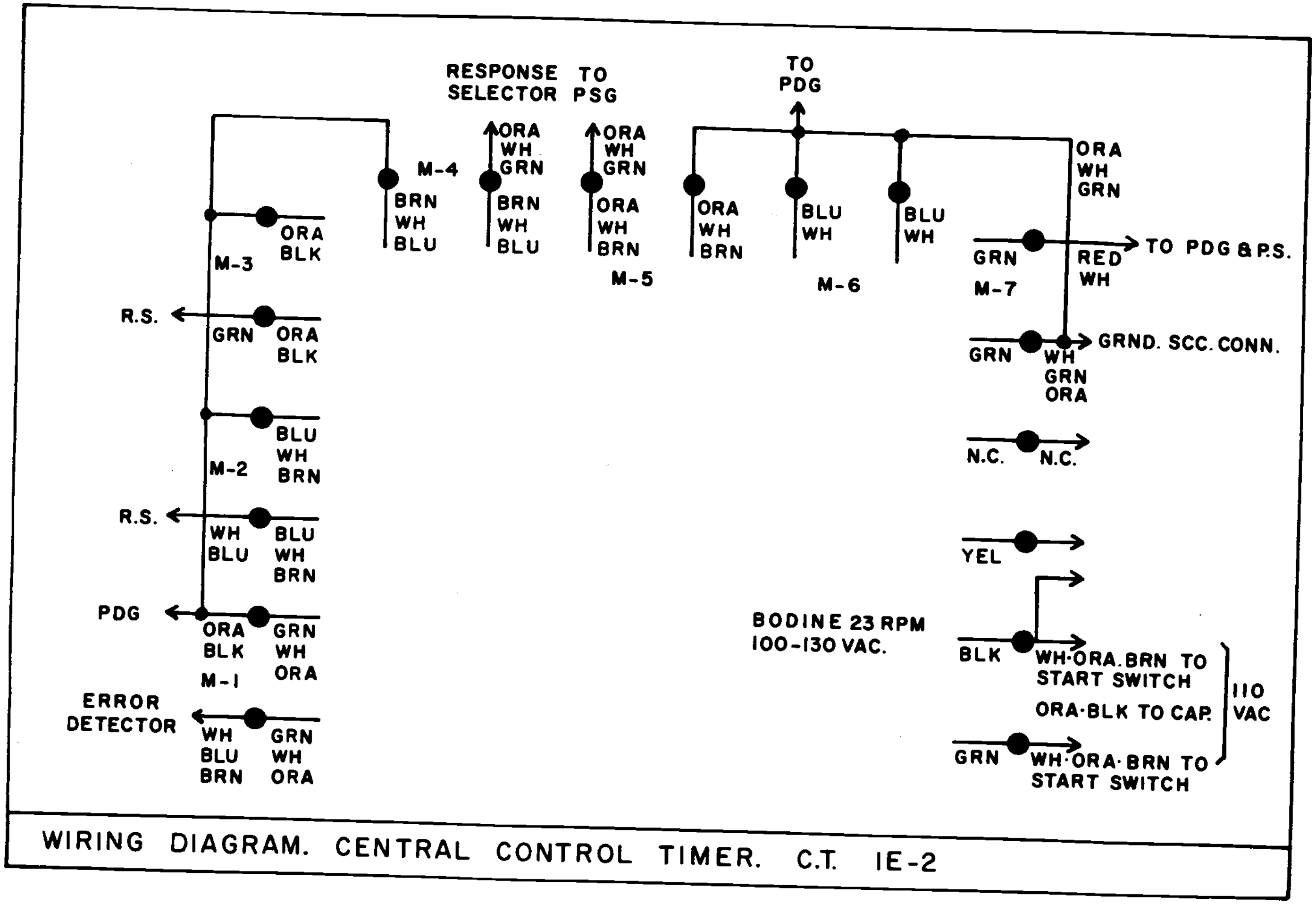
The circuits in this unit are connected to the power sources through the Central Control Timer (CT) (Figure C-2), providing only pulses to the circuits in a fixed sequence and of fixed duration (Figure C-3).

The timer consists of a Bodine Synchronous gear reduction motor, switching a set of 7 micro switches via a Teflon programmed cam. One of those output pulses is provided solely for driving an electro-mechanical cycle counter which can be switched on and off from the front panel. One complete cycle is fixed at 2.609 seconds. A dial, calibrated in tenths of seconds is provided on the front panel, one revolution corresponding to one complete cycle. Main AC power to the control unit is switched via a key operated master switch, in addition to a secondary switch on the front panel. This circuit is fused at 1 Amp. A second power switch on the front panel controls two auxiliary 110 VAC outlets on the rear of the unit. This circuit is also fused at 1 Amp. and controlled by the key operated master switch.




SCHEMATIC DIAGRAM. POWER SUPPLY GROUP. IE-2

FIGURE C-1




WIRING DIAGRAM. CENTRAL CONTROL TIMER. C.T. IE-2

FIGURE C-2

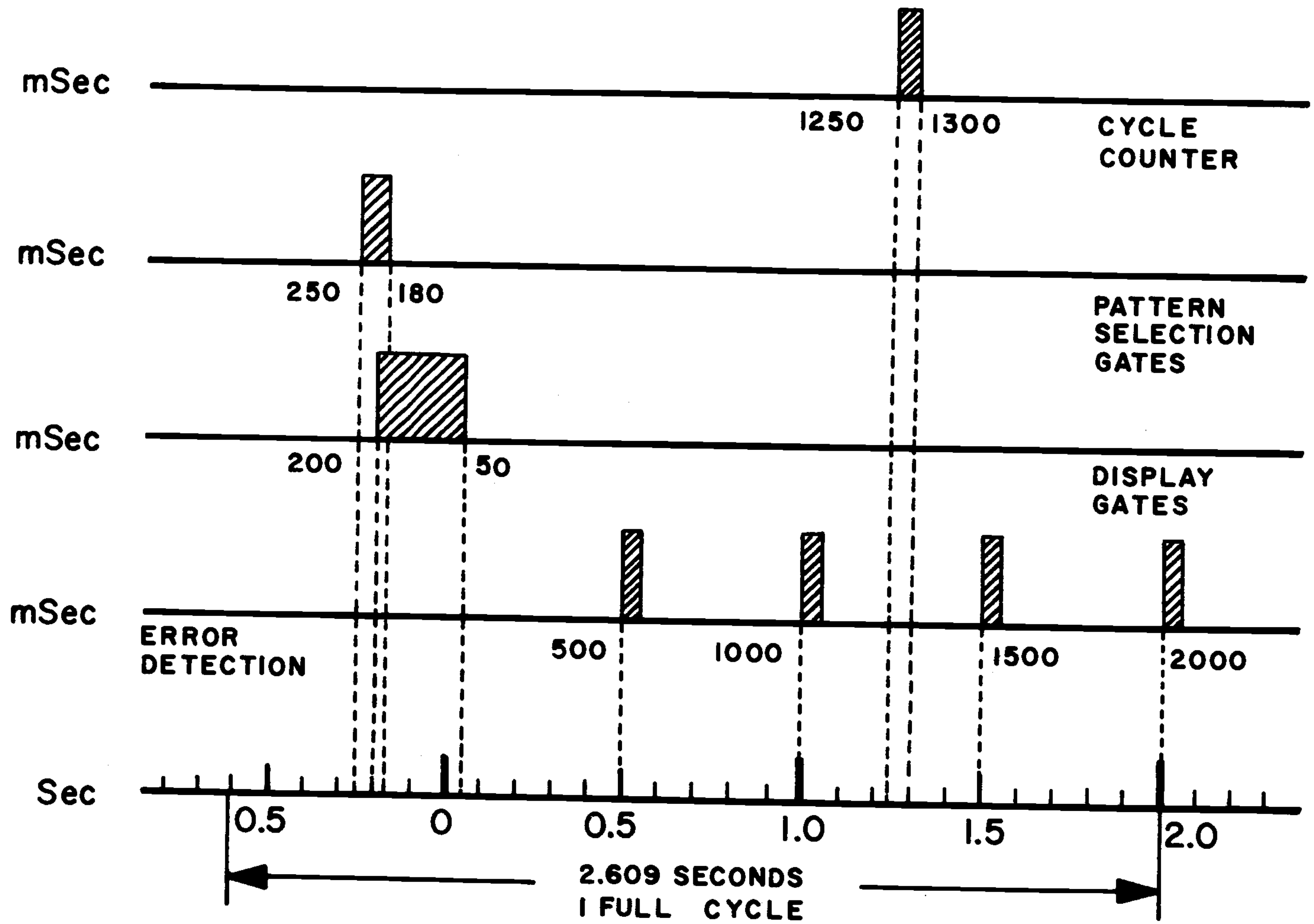
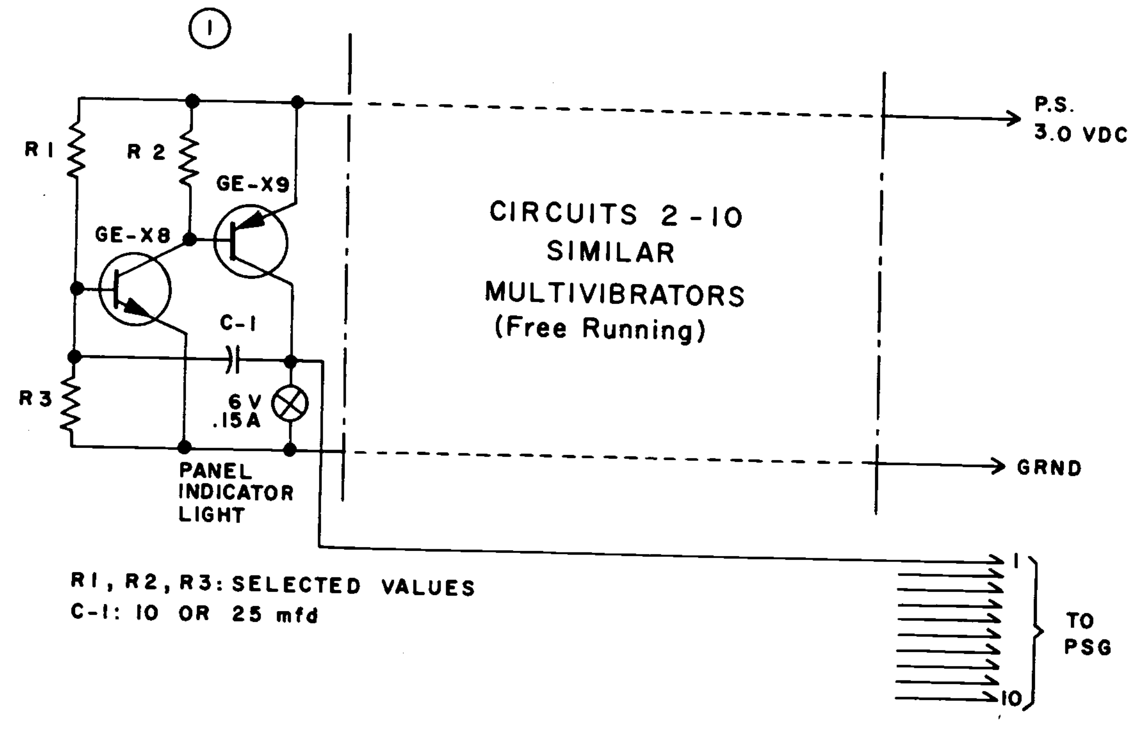



FIGURE C-3 TIMING SEQUENCE AND DURATIONS

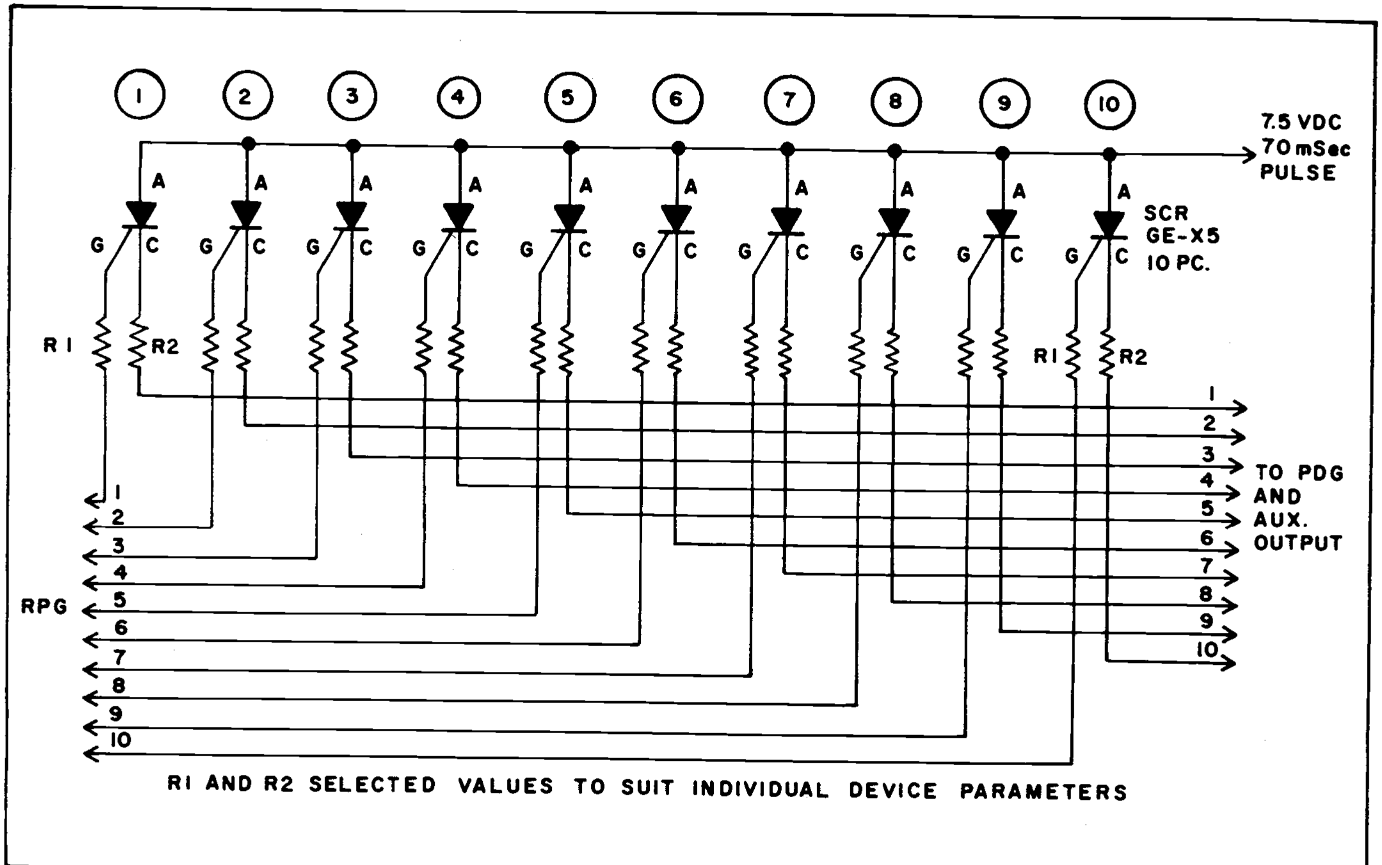
The Random Pattern Generator (RPG) (Figure C-4) is the heart of this control unit. It consists of ten similar free running multi-vibrators, running at different duty cycles and rates, made up around the GE-X8 and GE-X9 NPN-PNP transistor pair. Depending on the number of multi-vibrators in the conducting or "on" position, the supply voltage will vary up to 20%, or, from 2.6 VDC to 3.0 VDC. A 4000 mfd. capacitor can be connected across the power supply with the Pattern Selector Switch (Figure C-1), lowering the power supply impedance and increasing both the duty cycle and rate of the multi-vibrators. Power variations will range from 2.7 VDC to 3.0 VDC. An indication of the operation of the RPG is provided on the front panel by a 10 lamp array (Figure C-4).

The pulses generated by the RPG are applied to a series of 10 SCR's, serving as Pattern Selector Gates (PSG) (Figure C-5). These SCR's themselves receive an anode pulse of 7.5 VDC and 70 mSec. duration from the Central Control Timer each cycle. Those SCR's that are during the application of this 70 mSec. pulse in a conducting state because of a coinciding voltage of 1.5 VDC or higher from the RPG, will transmit the 7.5 VDC to their cathodes. The Pattern Selector Gates have no SCR gate biasing netowrk, resulting in random switching to a conducting state due to a conducting state due to transients, junction saturation and rate-effect adding to the randomness of the PSG output pulse pattern being generated. Auxiliary outputs are provided on the front




SCHEMATIC DIAGRAM. RANDOM PATTERN GENERATOR. RPG. IE-2

FIGURE C-4



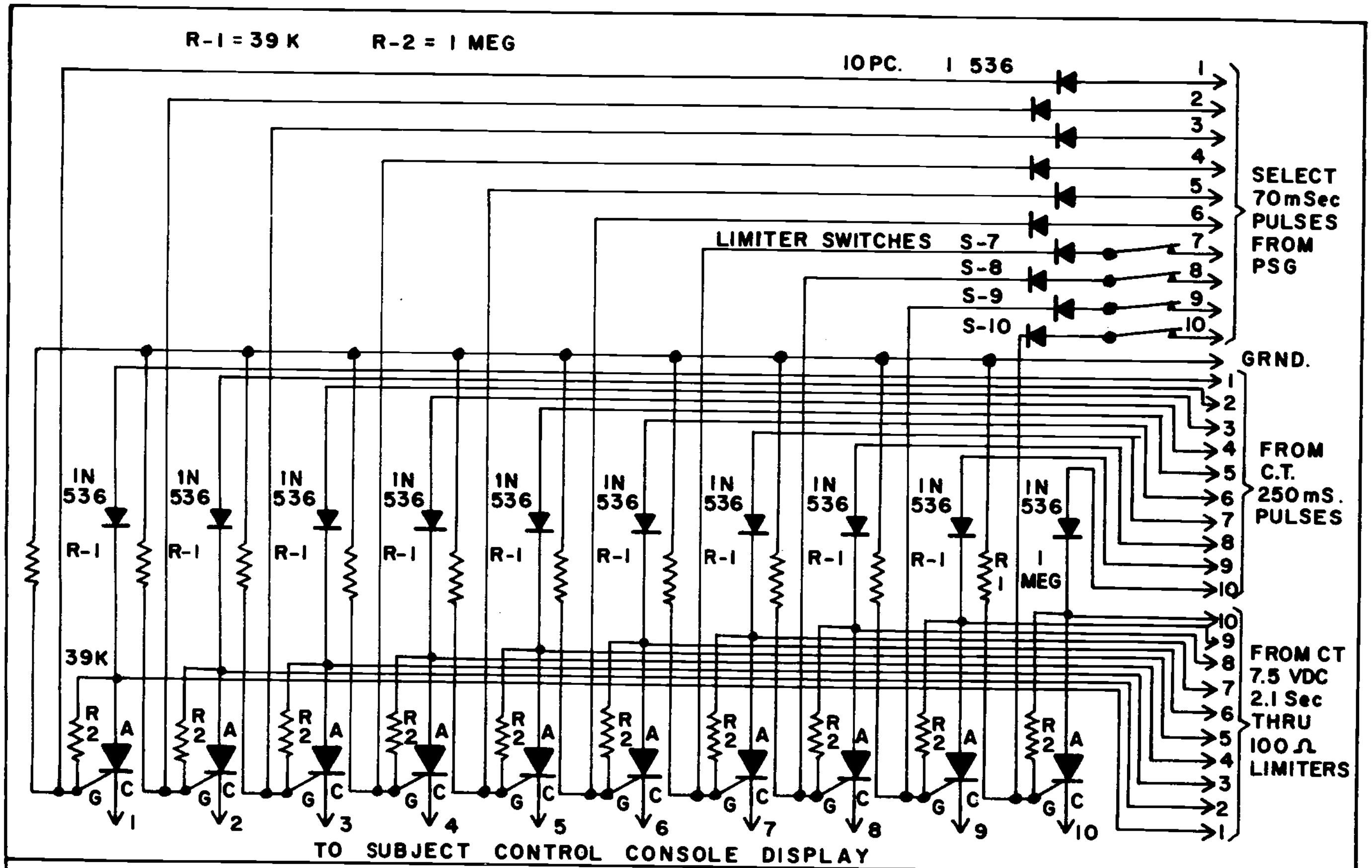

SCHEMATIC DIAGRAM. PATTERN SELECTOR GATES. PSG. IE-2

FIGURE C-5

panel. The DC voltage appearing at the cathodes of the PSG's is applied, through inter-channel isolating diodes to the Pattern Display Gates (PDG) (Figure C-6).

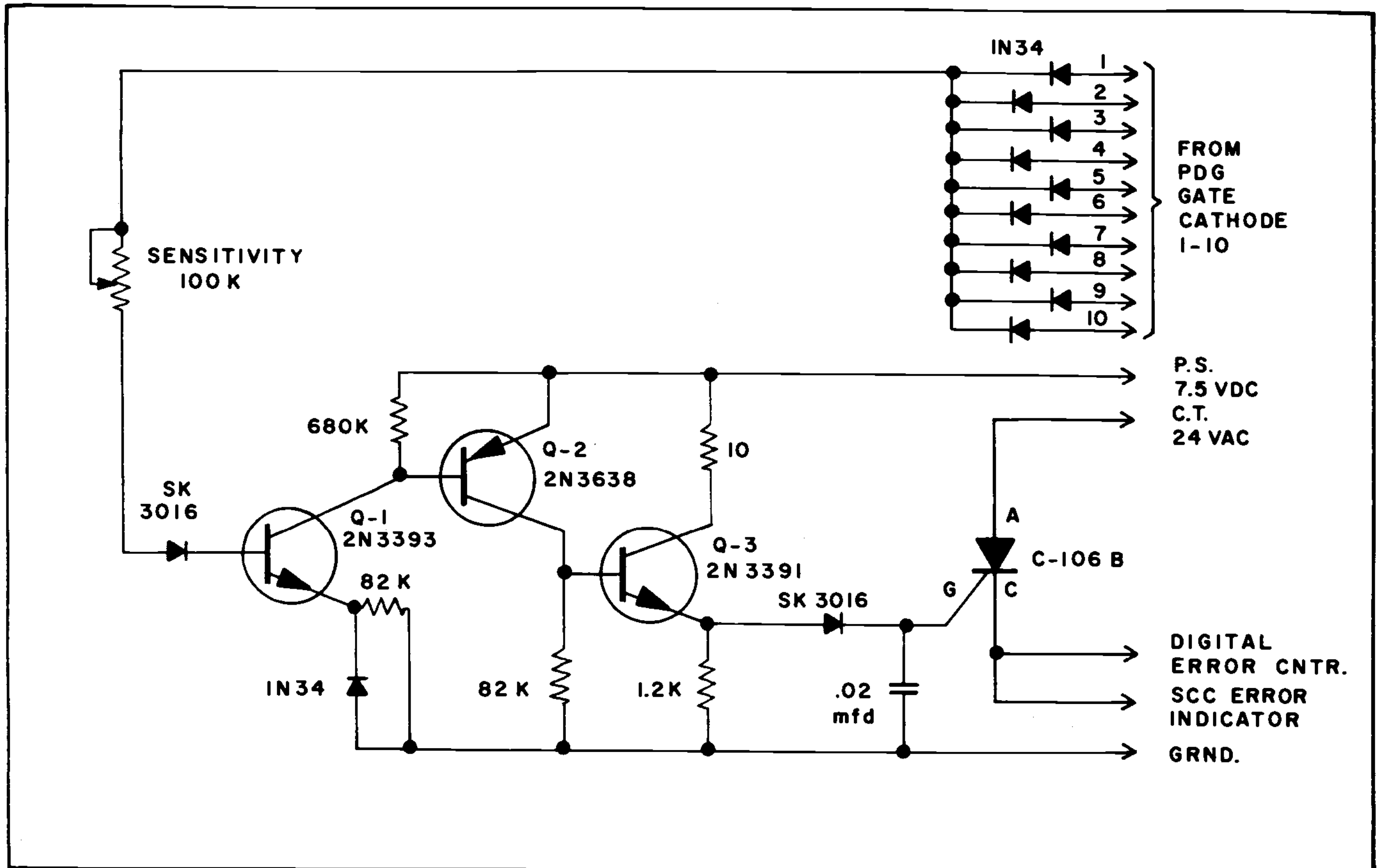
Panel switches allow selection of pulse passage to gates one through five, six through ten, one through ten and individual limiting of gates seven, eight, nine or ten.

The anodes of the PDG SCR's receive a 250 mSec. 7.5 VDC pulse from the Central Control Timer. This pulse is applied 20 mSec. prior to cut-off of the 70 mSec. PSG pulse. Those gates that receive a gate voltage from the PSG will conduct for 250 mSec. and the cathode voltage is fed to a series of ten pattern display lamps on the Subject Control Console (SCC) (Figure C-9), resulting in a random "on" pattern (Table C-1). 20 mSec. prior to cut-off, the 7.5 VDC supplied to the anodes for 250 mSec., is supplied for the remainder of the cycle via a series of 100 Ohm resistors, providing adequate holding current across the PDG SCR's, without resulting in a visible glow of the pattern display lamps. This holding current is sampled by the Error Detector (ED) (Figure C-7) at a selectable time interval of 0.5, 1.0, 1.5 or 2.0 seconds following display cut-off. If a voltage is detected, an error will be recorded on the electro-mechanical counter on the front panel. This counter can be switched on or off. The normally closed push-button micro switches on the SCC will momentarily remove the holding current, returning the corresponding SCR to a non-conducting state. In addition, an error indicator is




SCHEMATIC DIAGRAM: PATTERN DISPLAY GATES. PDG. IE-2

FIGURE C-6




SCHEMATIC DIAGRAM. ERROR DETECTOR. E.D. IE-2

FIGURE C-7

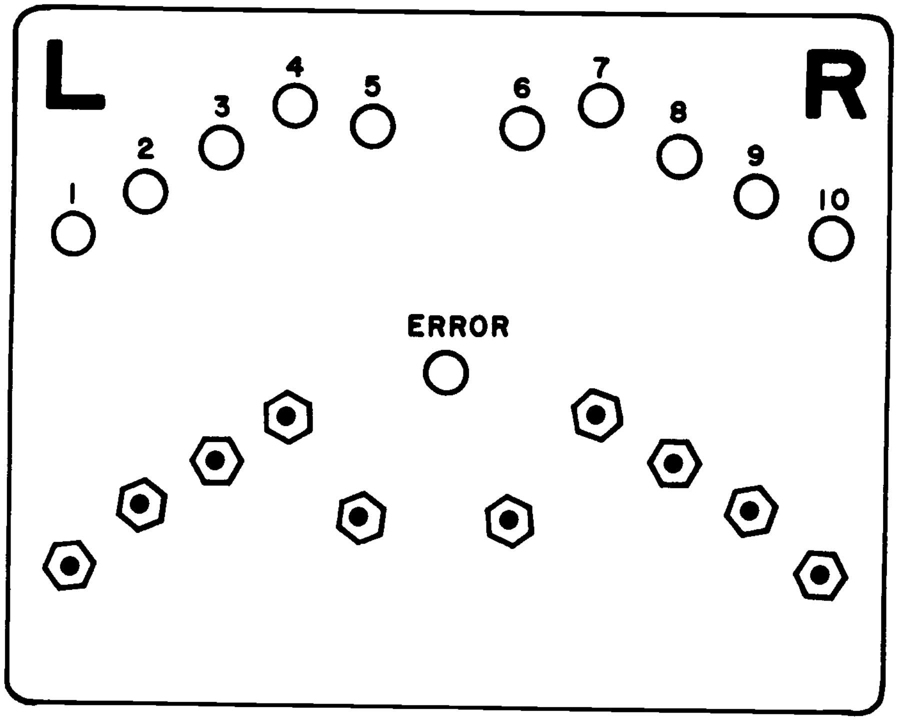
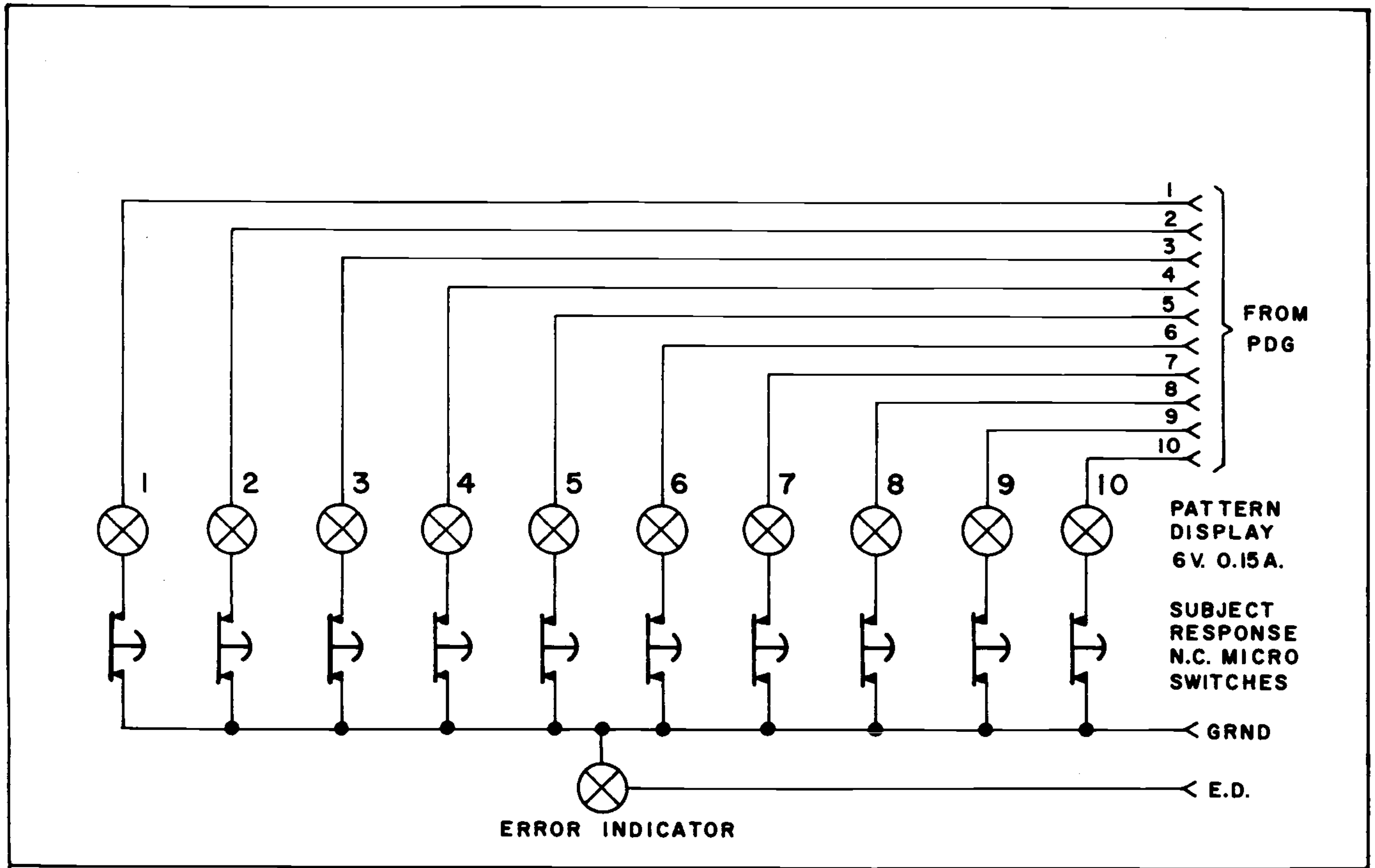



FIGURE C-8 SUBJECT CONTROL CONSOLE LAYOUT

provided on the SCC. The driving pulse for this indicator is obtained from the Error Detector SCR cathode. The PDG's are biased to eliminate erratic undesirable firing of the SCR's in the PDG, resulting in a channel requiring subject action without providing a display or giving a display of less than 250 mSec. duration. Prior to the start of each new cycle, all voltages are removed, resetting all gates (SCR's) to their non-conducting states.




WIRING DIAGRAM. SUBJECT CONTROL CONSOLE. SCC. IE-2

FIGURE C-9

| CYCLE NO. | CHANNEL | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 4 | ● | | ● | | | ● | ● | | | |
| 2 | 1 | | | | | | | | ● | | |
| 3 | 3 | | | | ● | ● | | ● | | | |
| 4 | 5 | | | ● | ● | | | ● | ● | ● | |
| 5 | 3 | | ● | | ● | | | | | | ● |
| 6 | 0 | | | | | | | | | | |
| 7 | 3 | | | | ● | ● | | | | | ● |
| 8 | 5 | | | | ● | ● | ● | | | ● | ● |
| 9 | 5 | ● | ● | ● | | | ● | | ● | | |
| 10 | 1 | | | | | | ● | | | | |
| 11 | 4 | | | | ● | ● | | | | ● | ● |
| 12 | 5 | ● | ● | ● | | ● | | | ● | | |
| 13 | 5 | ● | ● | ● | | ● | | ● | | | |
| 14 | 6 | | | | | ● | ● | ● | ● | ● | ● |
| 15 | 3 | | | | ● | | | ● | ● | | |
| 16 | 3 | ● | | ● | | | | ● | | | |
| 17 | 5 | | | ● | ● | | | ● | ● | ● | |
| 18 | 3 | ● | | ● | | | ● | | | | |
| 19 | 3 | | ● | | | | | ● | ● | | |
| 20 | 4 | | | ● | ● | | | | ● | | ● |
| 21 | 3 | | | ● | ● | | | ● | | | |
| 22 | 5 | ● | | | ● | ● | | | ● | | ● |
| 23 | 4 | ● | ● | | | ● | ● | | | | |
| 24 | 2 | | | ● | ● | | | | | | |
| 25 | 3 | ● | ● | | | | | | | ● | |

DATA OBTAINED FROM RUSTRAK MODEL 392-16 RECORDER CHART

TABLE C-1 TYPICAL PSG OUTPUT

# APPENDIX D

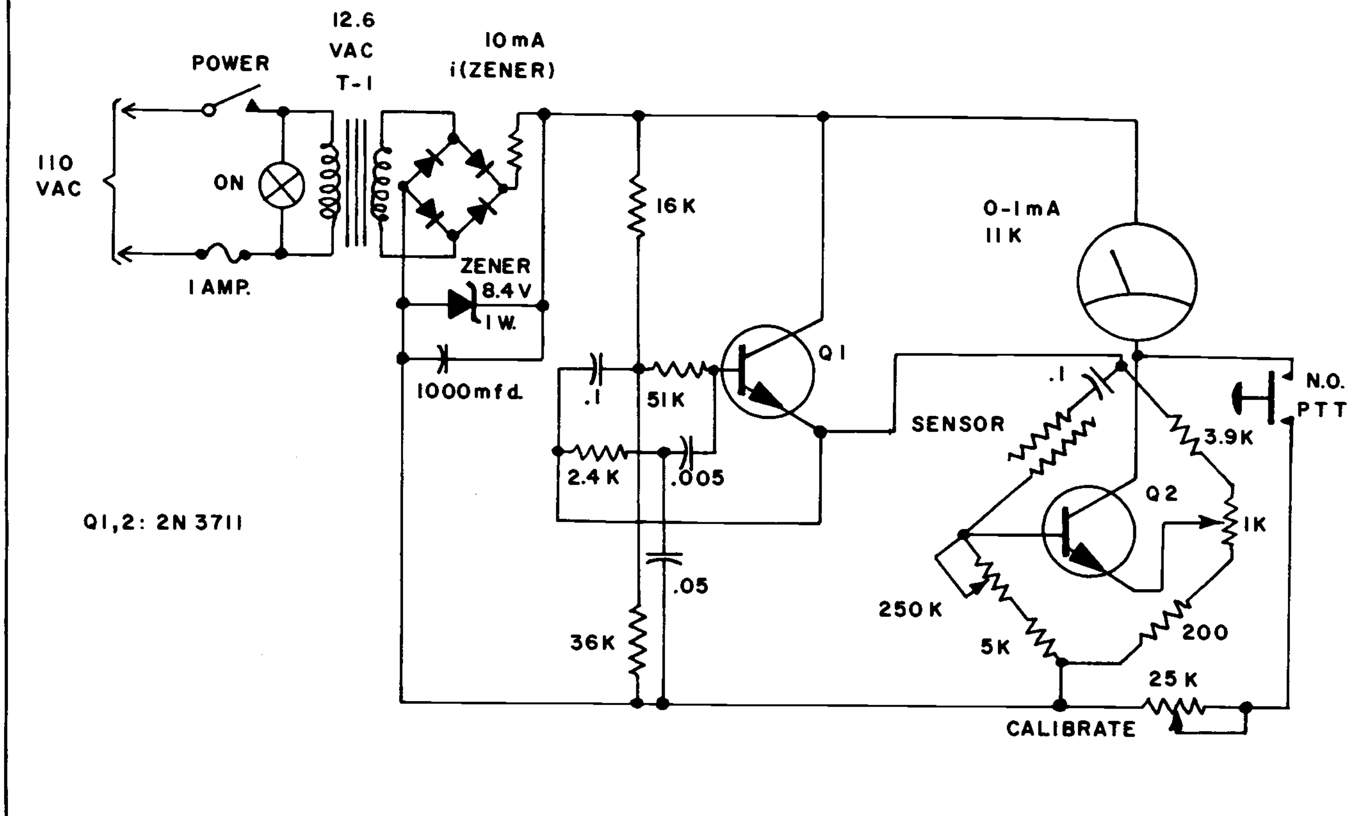
## MAJOR SUB-SYSTEMS

### 1. GALVANIC SKIN RESPONSE MONITOR

Transistor Q-1 and the RC network associated form a twin - T oscillator configuration. With the values shown (Figure D-1), the operating frequency is fixed at 400 Hz. The emitter of Q-1 provides the AC signal to the bridge. Power is supplied to the meter during the positive half cycles. The two potentiometers shown are used to adjust the upper and lower limit on the meter scale. The 1K potentiometer is mounted on the front panel of the unit, and, in full CW position provides a full scale meter reading when the resistance across the subject sensor equals 25K. This potentiometer can be used as an attennuator. The meter readings provide a measure of relative skin conductivity, interpretation of the readings obtained will provide a reliable comparative indication of skin conductivity fluctuations.

The 25K potentiometer is calibrated to provide a full scale meter reading when SW-2 is depressed for calibration and circuit check purposes.

Power is supplied to the unit from a 12.6 VAC secondary output transformer, full wave rectified and regulated at 8.4 VDC by zener diode. 1000 mfd. filtering is provided. Sensor voltage and current are extremely low, with maximum values of .5 VDC at .2 mA.




SCHEMATIC DIAGRAM. GALVANIC SKIN RESPONSE MONITOR

FIGURE D-1

## 2. VOLTAGE SUPPLY AND TIMING FUNCTION UNITS

This unit (Figure D-2) provides a wide range of AC and DC voltages to drive the control relays for multiple experiment duration timers, the Digital Cumulative Error Timer, Subject Performance Indicator and Audio Response Unit in multi channel experimentation. The time base for the Timing Function section is supplied by the external EDT output on IE-1 and can be used to provide two N.O. - N.C. contact sets and six N.O. contact sets.

Maximum current rating for these functions is 0.5 A. at 40 VDC, but can be increased to 1.0 A. at 40 VDC with proper external contact acring suppression.

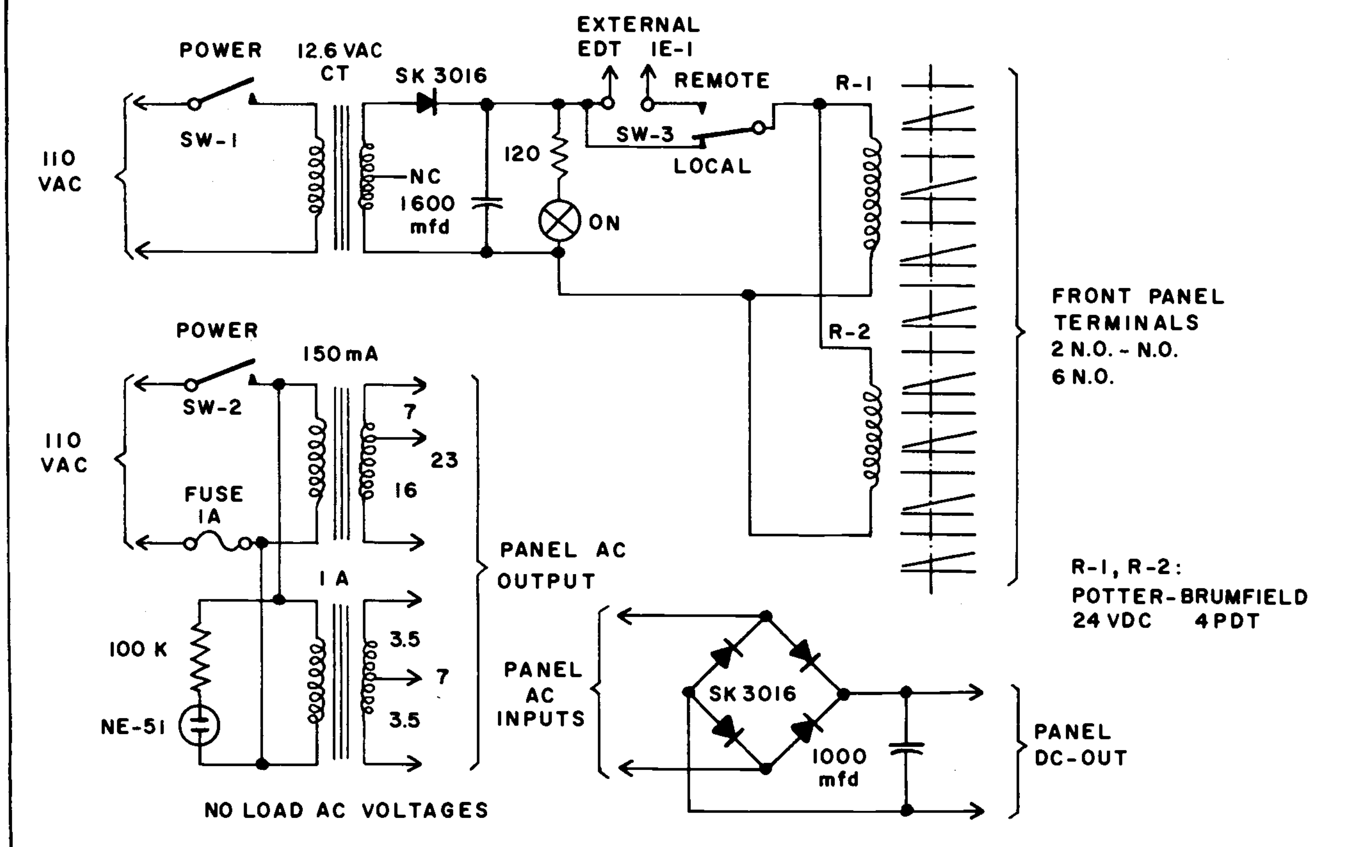
The unit can also be controlled by the Sample Timer (SR), and Random Sample Timer (RSR) auxiliary output terminals on the front panel of IE-1, or by any of the timer outputs on IE-2 with proper voltage isolation on the latter.

The power supply section ratings labelled on the front panel can be doubled for intermittent operation.

The supply output can be shorted, providing high current output pulses. Maximum pulse duration "on" is 100 mSec. "off" is 1.0 Sec.

## 3. DIGITAL CUMULATIVE PERFORMANCE TIMER

A facility is provided for measuring to within 1/60 second, the actual time the operator is on or off targer, as determined by the tracking tolerance setting of 5, 10 or 15% set on the main




SCHEMATIC DIAGRAM. POWER SUPPLY AND TIMING FUNCTION UNIT

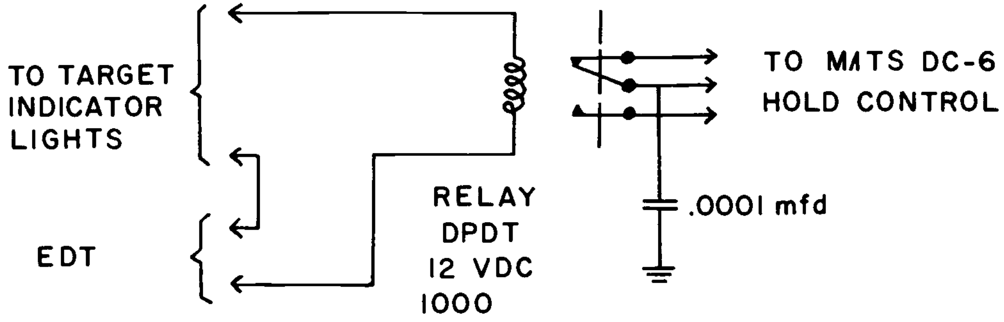
FIGURE D-2

control panel. The timer switching signal is obtained from the voltage at the target indicator lights (Figure B-3) and drives a relay which switches an MITS digital clock unit with BCD output. The driving signal is fed through the Timing Function Unit front terminal relay contacts to provide cumulative timing only when the main control unit Experiment Duration Timer (EDT), (Figure B-8), is in the on position.

The BCD output signal will drive a digital printing unit to obtain a hardcopy of both cumulative time or time intervals between periods on or off target, depending on what voltage is sampled from the indicator lights.

For the 1/60 second timing function, the MITS model DC-6 clock unit is modified to operate in the fast set mode, with continuous hold. The latter is interrupted by the control relay, which is mounted in the main control unit. The capacitor across the relay contact is provided for transient suppression which would cause erratic clock operation. Interface wiring between the main control unit, timing function unit and clock is coaxial cable, the hold control input impedance is in the order of 5 Meg. Substituting longer cables than those provided will result in erratic clock operation.

The clock unit can be switched to normal 24 hour operation with one second resolution for other timing functions. Remote control is also possible in this mode.




SCHEMATIC DIAGRAM. DIGITAL TIMER CONTROL

FIGURE D-3

## 4. ADDITIONAL SYSTEM COMPONENTS

The following is a list of equipment available interface with the main simulator system:

1. MITS DC-6 Digital Clock - Timer with BCD output.
2. B.K. Precision Frequency Generator. 3Hz - 1.2 MHz. Sine and Square Wave. Switch Selectable Attennuation in 2 dB steps from 0 - 54 db.
3. Allied Model T-18 Volt-Ohm Meter.
4. Allied Low Distortion Audio Frequency Amplifier. Output 15 Watt rms.
5. Realistic Audio Transducer. 10 inch, Acoustic Suspension. Response 35 - 16,000 Hz and ± 3 dB.
6. Sony Rm-3, Self Powered Condenser Microphone. Response: Flat 30 - 16,000 Hz. and ±2 dB. 20 - 17,000 Hz.
7. Headphones; Realistic Model Ap-S-2. Response: 80 - 12,000 Hz ± 3 dB.
8. Sound Level Meter. Realistic. Response 40 - 14,000 Hz ± 3 dB. ASA Standard Response Curve.
9. Simpson Model 885 Sound Level Meter. Range 40 - 140 dB. A, B and C Response Curves.
10. Allied Model 1020-W DC Regulated Power Supply. 0 - 30 VDC at 1 Amp.
11. Heath EU-20B Servo Chart Recorder. Full Range Adjustable Chart Speed. Sensitivity 50 mv

into 8 Meg.

12. Dremel Model 6, Silicon Controlled Rectifier AC Voltage Controller. 110 VAC. 6 Amp.

# APPENDIX E

# CONTROL SYSTEM ANALYSIS

The following is provided as an aid in understanding the concepts discussed in Chapter 4, and contains tables and block diagrams from several investigators, although adapted to utilize common symbolism. The format used is compatible for direct comparison with the simulator system data as presented in Chapter 6.

## UNCOMPENSATED SYSTEM

The system consists of a gain, $a_1$, and three integrators. The machine transfer function is given by output/$\delta = a_1/s^3$. Assuming that the man and the display act as a simple gain K, the error-to-input transfer function is output/$\varepsilon$ = $Ka_1/s^3$, which is an unstable system (Figure E-1).

## AIDED SYSTEM

By adding feed-forward loops around the integrators, the machine transfer function becomes:

$$\frac{\text{output}}{\delta} = \frac{a_4s^3+a_3s^2+a_2s+a_1}{s^3}$$

and the error-to-output transfer function becomes:

$$\frac{\text{output}}{\varepsilon} = K\,\frac{a_4s^3+a_3s^2+a_2s+a_1}{s^3}$$

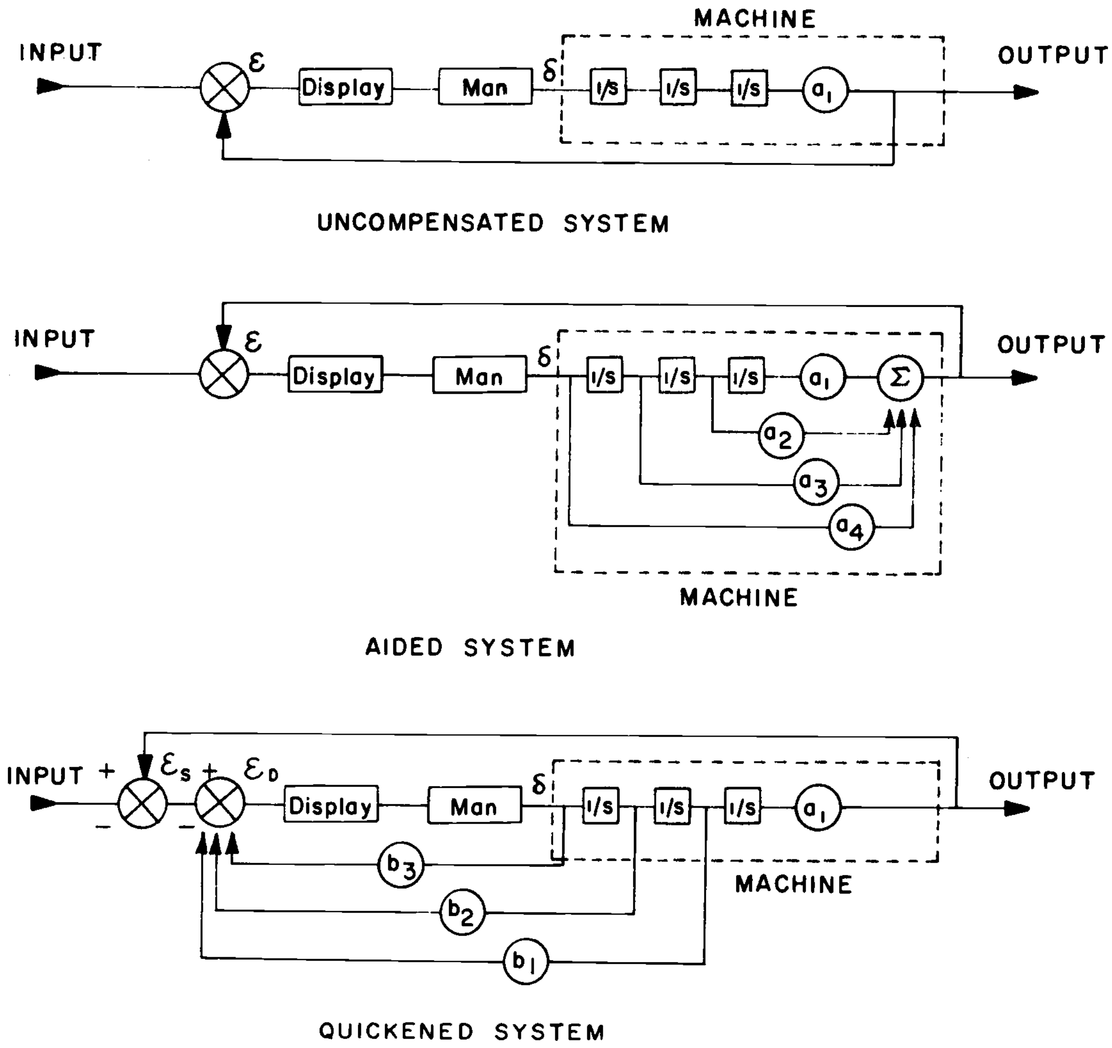



FIGURE E-1 UMCOMPENSATED, AIDED AND QUICKENED SYSTEM

The output for a given display error signal is thus modified with an aided system. The closed loop system transfer function is:

$$\frac{\text{output}}{\text{input}} = \frac{a_1+a_2s+a_3s^2+a_4s^3}{a_1+a_2s+a_3s^2+\frac{Ka_4+1}{K}s^3}$$

which is a stable system if appropriate constants are chosen (Figure ).

QUICKENED SYSTEM

In the quickened system the machine transfer function is the same as for the unquickened system, output/$\delta$ = $a_1/s^3$. Again, assuming that man and the display act as a simple amplifier of gain K, the display to output transfer function is unchanged output/$\delta$ = $Ka_1/s^3$. The error signal however, displayed to the man $\epsilon_D$) is not equal to the actual system error ($\epsilon_S$). In most practical situations, the operator needs both $\epsilon_D$ for control and $\epsilon_S$ for guidance.

The system transfer function is:

$$\frac{\text{output}}{\text{input}} = \frac{a_1}{\frac{(1+Kb_3)}{K}s^3+b_2s^2+b_1s+a_1}$$

The system is stable if the values of the coefficients are properly chosen.

HUMAN ENGINEERING EXPERIMENT STANDARD DATA COLLECTION SHEET 1.

**EXPERIMENT SETTINGS**

IE-1

Pursuit rotary
Pursuit joy-stick
Pursuit linear
Comp. rotary
Comp. joy-stick
Comp. linear
Scope rotary
Scope joy-stick
Scope linear
Project rotary
Project joy-stick
Project linear

Tolerance 5 / 10 / 15

Drift rate 1 / 3 / 5

Delay off / 1 / 2

Sample random / 20 / 30 / 60

Shock none / normal / mild / strong / severe

Shock code A / B / C / D

SCC on / off

Chart Speed:
...............

IE-2

Pattern A
Pattern B

Channel full / I / R / 6 / 7 / 8 / 9
Selected:
6-7-8-9-10

Response 0.5 / 1.0 / 1.5 / 2.0 / 2.5

SCC on / off

Shock code A / B / C / D

**ENVIRONMENTAL**

Noise level: Start / End
remarks:

Illumination: Start / End
remarks:

Temperature: Start / End
remarks:

Humidity:

Barom. Pressure:

Procedure Code:

General Remarks:

Test supervised by: Date: Time:

**IMPORTANT: ATTACH ALL RELATED DATA AND PROCEDURES**

Equipment malfunctions:

FIGURE F-1 DATA RECORDING FORM

HUMAN ENGINEERING EXPERIMENT STANDARD DATA COLLECTION SHEET 2.

TO BE COMPLETED BY SUBJECT: (Voluntary)

Sex: M F
Age group: 15-20 20-25 25-30 over 30
Single: Married: Divorced:
How many years have you had a drivers license:
0 1 2 3 4 5 over 5
Typing speed: slow medium expert
Do you actively engage in sports:
no sometimes regularly often
Do you play a musical instrument, if so, which:
Do you drink alcoholic beverages:
Beer or wine: no moderate frequent
Beer, wine and/or liquor: no moderate frequent
How many cigarettes do you smoke daily:
none 5 10 15 20 over 20
How is your eyesight:
Corrective lenses?:
Ungrad: Grad: Other:
Major:
GPA: left handed - Right handed
How is your hearing: normal below normal left-right-both

I have taken this experiment .... times before.

How do you feel at this moment: sick
bad
tired
comfortable
good
excellent

I do - do not object to the use of mild electric shock as part of the experiment.

EXPERIMENT DATA:

| Galvanometer reading Start | end | Duration or cycles | Error count | Target time off | on | Error/min or Error/cycle |
|---|---|---|---|---|---|---|
| | | | | | | |
| Totals: | | | | | | |

Total average error/min.:
error/cycle.:
on-off target ratio.:
off target/duration.:

Hardcopy number:

FIGURE F-2 DATA RECORDING FORM

# APPENDIX G

## ADDITIONAL READINGS

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