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Application of Adaptive Decision Aiding Systems to Computer-Assisted Instruction: Adaptive Computerized Training System (ACTS).

by

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This report describes the Adaptive Computerized Training System (ACTS) which combines the techniques of circuit simulation, artificial intelligence, decision modeling, and adaptive computer-assisted instruction to provide training in decision making. The ACTS incorporates an adaptive computer program which learns a student's value structure and uses this structure to train the student in practical decision making.

This report describes the development and operation of the ACTS as it is

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20. applied to training electronics troubleshooting. Experimental evaluations have demonstrated that the adaptive decision model accurately models a student's performance, and that adaptively-selected instructions and decision feedback can improve troubleshooting performance.

FOREWORD

The Educational Concepts and Evaluation Work Unit Area of the Army Research Institute for the Behavioral and Social Sciences (ARI) performs research and development in areas of educational technology with applicability to military training. Of special interest is research in the area of computer-based training systems. Development and implementation of such systems is seen as a solution to such current Army problems as a shortage of qualified instructor personnel, a student population of widely varying abilities, and increased training costs. Computer-based training systems also provide the potential to increase training effectiveness and efficiency by increasing the extent to which the training process can be made to adapt to the characteristics and performance of the individual student.

This Technical Report describes the third phase of a research effort to develop a technique for individualizing training through the use of "artificial intelligence" techniques. In order to accomplish this research, ARI's resources were augmented by contract with Perceptronics, Inc., an organization selected as having unique capabilities for research and development in this area.

The entire research work unit area is responsive to the requirements of RDT&E Project 2Q762717A764, "Educational and Training Technology," the 1976 ARI Work Program, and to special requirements of the Product Manager, Computerized Training Systems.

Joseph Zeidner
Acting Technical Director

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APPLICATION OF ADAPTIVE DECISION AIDING SYSTEMS TO COMPUTER-ASSISTED INSTRUCTION: ADAPTIVE COMPUTERIZED TRAINING SYSTEM (ACTS)

BRIEF

Requirement:

To continue the development and evaluation of a computer-based system which uses adaptive techniques to train electronic troubleshooting procedures. During the training process, the student troubleshoots a simulated electronic circuit by making test measurements and replacing the malfunctioning part. The key component of the system is an adaptive program, based on an Expected Utility (EU) decision model, which "learns" the student's utilities for troubleshooting decisions. These utilities can then be compared with those of an expert, and instructional feedback can be provided to reduce the discrepancies between the two sets of utilities. Specific objectives were: (a) to develop a control program which permits the instructor/experimenter to select system parameters and instructional options easily; (b) to document the ACTS software; (c) to install the ACTS software at ARI; (d) to select and analyze a military circuit for use on the ACTS; and (e) to conduct a further evaluation of the training effectiveness of instructional feedback and decision aiding.

Procedure:

An instructor/experimenter control program was developed and incorporated as part of the ACTS. Software documentation was also developed. The key portion of the documentation was the User's Manual, which describes the operation of the ACTS from the viewpoint of both the experimenter/instructor and the student. A military electronic circuit was selected with the cooperation of personnel from the U.S. Army Signal School. An experimental study evaluated the effectiveness of decision aiding (providing the student with the expert's three best choices before the student is required to select an action) and feedback (showing the student the action that the expert would have taken after he has selected an action).

Findings:

The instructor/experimenter control program and other software are documented in a separate report (Kuppin, 1976). Forty-three options are available, which permit changing such things as the parameters of the learning algorithms, the sequence in which problems are presented, and the information about student performance which is recorded. The A9000 Power Supply for the R/T 524 VRC Receiver-Transmitter was the military circuit selected for installation on the ACTS. An analysis of the circuit was performed, which provides the information necessary for installation. While the results of the study of the effectiveness of decision aiding and feedback are limited by the small number of students used, they do suggest that both types of assistance can improve later troubleshooting performance.

Utilization of Findings:

These findings provide sufficient evidence to justify continued development and evaluation of the system. The goal of this process is the cost and training effectiveness evaluation of a prototype version within an ongoing course of instruction at an Army school. These findings will be used by ARI, the U.S. Army Training and Doctrine Command Training Support Center, and the U.S. Army Signal School to determine resource requirements for the evaluation and possible future implementation.

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APPLICATION OF ADAPTIVE DECISION AIDING SYSTEMS TO COMPUTER-ASSISTED INSTRUCTION: ADAPTIVE COMPUTERIZED TRAINING SYSTEM (ACTS)

1. SUMMARY

This report describes the third year's effort in the development of the Adaptive Computerized Training System (ACTS). The ACTS is a computer-based instruction system that employs principles of artificial intelligence and decision theory in adaptive decision training. Training focuses on the cognitive skills of judgmental decision making. The ACTS simulates a realistic decision task and allows a student to interact freely with the task to learn the elements of successful decision making. Part of the ACTS program functions as an "expert" instructor who serves as both a source of help to the student and as a standard against which the student is evaluated.

The ACTS incorporates an adaptive computer program which learns the student's diagnostic and decision value structure, compares this structure to that of an expert, and provides instructional feedback to eliminate discrepancies. An Expected Utility (EU) model of decision making is the basis of the student and instructor models which, in conjunction with the decision task simulator, form the core of the CDT system. The student model is dynamically adjusted using a trainable network technique of pattern classification. Heuristic algorithms generate the training instructions. The instructor model also generates suggested actions in response to student requests for assistance.

The present training system focuses on electronic troubleshooting. The student's task is to troubleshoot a complex circuit by making various test measurements, replacing the malfunctioning part, and making final verification measurements. The model of the student evaluates the student's selection of measurements and replacement of circuit modules. Troubleshooting provides an excellent application for the ACTS methodology because it is heavily dependent on judgment and probabilistic inference. In addition, troubleshooting is of great practical importance in numerous Army systems, and it lends itself to economical implementation for training purposes.

Work to date has produced an operational system which demonstrates the feasibility of applying artificial intelligence techniques to computer-assisted instruction in a minicomputer-based training system. Experimental evaluations of the ACTS have demonstrated that the adaptive decision model accurately learns the utilities of an expert technician and that students can effectively use the simulated troubleshooting task.

Additionally, instructions based on the utilities can further improve the decision performance of students; however, feedback of optimum choices immediately following the student's choice also seems necessary.

1.1 Accomplishments

The focus of the current year's development activities was: (1) to produce, test and document a software routine which permits an experimenter to exercise effective control of the ACTS variables; and (2) to prepare, test, and deliver the ACTS for operation on the interactive color graphics computer system at ARI. Research efforts centered on analysis of a new electronics course in preparation for incorporating additional lessons in the ACTS. In addition, further experimental evaluation of the ACTS training capabilities was conducted by examining the decision feedback functions.

1.2 System Development

The first two years of the program produced a system which includes: (1) the simulation of the electronic circuit; (2) decision models of the student and an instructor; (3) adaptive algorithms for real-time updating of decision model parameters; (4) instructional logic which adaptively selects instructions based on student performance; and (5) a performance assessment routine. Additional activities optimized the operation of the adaptive computer algorithms and the student-computer interactions.

The major focus of the current year's work was development of the experimenter control program and delivery of the ACTS to ARI for operation on the interactive color graphics system. The experimenter control program allows the experimenter to operate the ACTS by typing a few commands to initiate a student session, change system parameters, save records of student training sequences, or terminate student sessions. Student interactions with the ACTS were modified for the program installed on the interactive color graphics system. The revised interaction takes advantage of the color graphics display and utilizes the trackball controller which eliminates any requirement for typing skills. Operation of ACTS is thoroughly described in the ACTS User's Manual (Kuppin, 1976).

The primary evaluation of the current year focused on analyzing an additional electronic circuit for future incorporation as an ACTS lesson. A power supply circuit of the RT-524/VRC receiver-transmitter was selected for analysis. This circuit is currently used during electronics training at the U.S. Army Signal School and provides a representative sample of lessons currently in use. Analysis of this circuit identified the troubleshooting activities performed by a student technician. The analysis also provided a preliminary design for the circuit diagram and for the student-computer interactions to be incorporated in the ACTS.

An experimental evaluation was also conducted to examine the decision training provided by ACTS decision aiding and feedback. This study suggests that feedback of optimum choices can promote cost-effective decision making early in training.

2. THE ADAPTIVE COMPUTERIZED TRAINING SYSTEM (ACTS)

2.1 ACTS Objectives

The ACTS has been developed as an application of basic artificial intelligence techniques to training. The objectives of the development program have been three-fold:

(1) To produce a computer-based instruction system, using artificial intelligence and simulation techniques, to provide individualized training which is responsive to changing student knowledge and skills.

(2) To demonstrate and evaluate the suitability of using artificial intelligence techniques in a training system that is implemented in a minicomputer with limited available memory, and

(3) To develop a system for training decision-making skills.

These objectives have been met in the development of the ACTS, which combines the techniques of circuit simulation, artificial intelligence, and decision modeling to provide decision training for electronic troubleshooting. The ACTS is a computer program that models or simulates the four functional units of training: (1) the task being trained, (2) the student, (3) an instructor, and (4) the instructions. The organization of these four units in the ACTS are illustrated in Figure 2-1.

2.2 Task Simulator

The student's decision task involves troubleshooting an electronic device. In the ACTS, this troubleshooting task centers on a model of an electronic circuit in which faults can be simulated. The circuit currently being used is a modular version of the Heathkit IP-28 regulated power supply.[1] The simulated circuit has 10 functional modules which can be replaced and 29 measurements which can be used to isolate faults. The behavior of the power supply is simulated by the computer program, using a table-driven simulation of the fault systems. The program simulates the results of checking symptoms, taking measurements, and replacing modules.

Training in the present system occurs with certain restrictions on the extent of circuit simulation. The student interacts with a terminal display of the simulated circuit, thus he cannot make such troubleshooting observations as smelling faulty capacitors, looking for burned resistors, or touching overheated semiconductors. In addition, the measurement results are presented in a semi-interpreted form (high, normal, low),

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[1]Commercial designations are used only for precision of description. Their use does not constitute endorsement by the Department of the Army or the Army Research Institute.

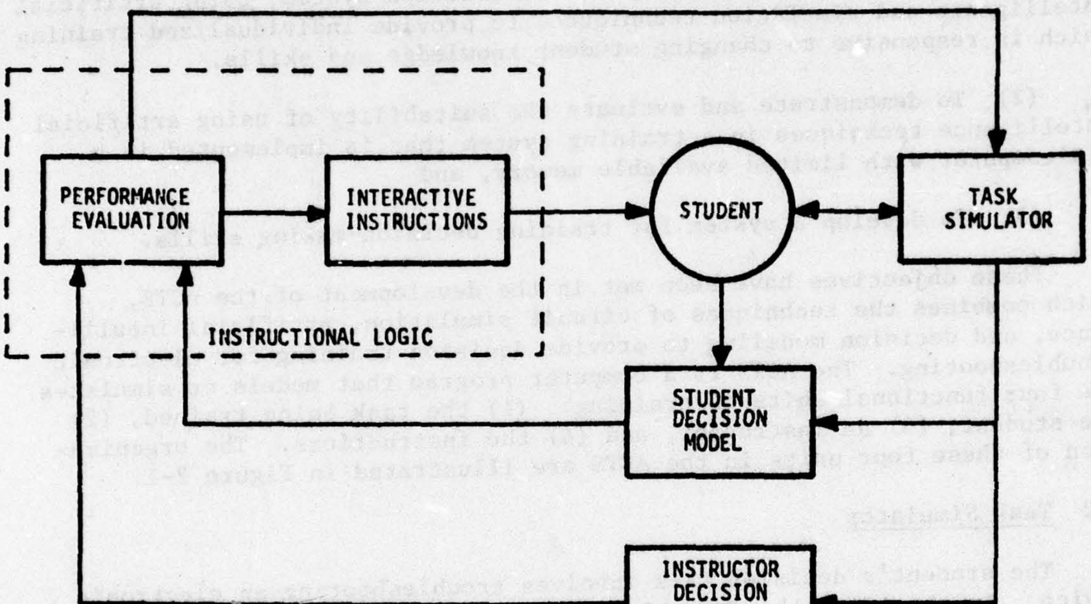

FIGURE 2-1. ACTS FUNCTIONAL ORGANIZATION

rather than as absolute readings (3.6 volts, 1.25 mA) so that the student need not refer to a table of normal circuit levels. These simplifications do not affect the inherent judgmental nature of the troubleshooting task.

The circuit simulation was designed to meet several objectives. In addition to providing an environment for observing troubleshooting behavior, the simulator gives the results of the student's choice of alternatives by displaying the measurement results. Finally, the circuit model is designed to simulate the essential characteristics of decision making under uncertainty. Thus, the outcomes of the measurements are probabilistic, reflecting the uncertain fault locations.

2.3 Student Decision Model

The student model is the first of two decision models in the ACTS which are used to mathematically model the decision behavior of the trainee and his instructor. A mathematical model provides a method of describing or defining the student's behavior. The ACTS then uses the model to infer the current state of the student's knowledge.

The decision model not only describes the initial state of the student's knowledge but it also tracks changes in the student's performance, adapting the model parameters to describe the student's improvements and his errors. From this model of the student's behavior, the ACTS gives instructions to improve the student's decision making.

An expected utility (EU) decision model is used to represent the student. The EU model is both a descriptive and normative model of decision making which assumes that a "rational" decision maker selects the alternative with the greatest expected utility. According to the model, decision making is a product of two factors: (1) the probability that a particular outcome will occur if the alternative is chosen, and (2) the utility of obtaining the outcome of that chosen alternative. The expected utility for each possible alternative is:

$$EU_j = \sum_i P_{ij} U_{ij}$$

where P_{ij} = probability that the ith outcome will occur if the jth alternative is chosen

U_{ij} = relative utility of the ith outcome of the jth alternative.

Given the available alternatives, outcome probabilities and utilities, the optimum choice is determined according to the maximum EU principle by calculating the expected utility for each possible alternative and then selecting that alternative with the greatest EU.

The ACTS uses the EU model not only as the description of the student's decision making but also as the basis for estimating changes in his knowledge as inferred from his decision behavior. A technique of artificial intelligence, known as a learning network approach to pattern classification, is used to estimate the student's utilities in the EU model. The utility estimator observes the student's choices among the possible decision alternatives, viewing his decision making as a process of classifying patterns of event probabilities. The utility estimator then attempts to classify the event probability patterns by means of an expected utility discriminant function. These classifications are compared with the student's choices and an adaptive error-correction training algorithm is used to adjust pattern weights, which correspond to utilities, whenever the classifications are incorrect. This utility estimator operates in real time while the student is performing the troubleshooting operations; thus, the EU model continuously tracks the student's decision performance as it changes during the course of training.

2.4 Instructor Decision Model

The second decision model in the ACTS is an EU model of an expert decision maker's performance. This model is used as a standard to which the utilities of the student model are compared, and as a source of help in directing the student's activities and suggesting good alternatives. The instructor model has the same mathematical form as the student model, except that the utilities remain constant throughout training. The utilities of this model are adaptively estimated prior to the training session by "tracking" an experienced technician as he locates simulated faults.

The instructor model includes an algorithm for calculating the conditional probabilities of action outcomes. Conditional probabilities are of the form:

> The probability of obtaining a particular measurement outcome, given the previous measurement history.

These conditional probabilities are aggregated by the ACTS algorithm from the prior probabilities which have the form:

> The probability of a particular measurement outcome, given a specific fault.

The prior probabilities are obtained from an expert technician during the development of the task fault model. The conditional probabilities are not only used by the instructor model, they are also displayed to the student during ACTS troubleshooting problems. Thus, the student learns to consider a decision in terms of probabilistic outcomes.

2.5 Instructional Logic

The fourth major functional unit of the ACTS computer program is the instructional logic which selects the instructions and aiding for the student. The instructional logic compares the utilities of the student decision model with those of the instructor model to select instructions designed to reduce discrepancies between the two sets of utilities.

The instructional logic is in the form of Boolean expressions that state the conditions under which a specific instruction is to be given. For example, when the student's utility for the normal outcome of measurement 19 is less than his utility for measurements 2, 3, or 4; an instruction would be given. Such an instruction would describe the usage of measurement 19 in troubleshooting the circuit, highlight its cost relative to other measurements, and describe the probability states under which it whould be used. The instruction might state:

> "Measurement 19 serves well to isolate the operation of the transformer and reference DC source. Since this measurement is relatively inexpensive, use it even when the probability of the normal outcome is low."

It is assumed that the student knows electronic theory and basic troubleshooting procedures. Thus, instructions are not focused on the type of measurements to make or the functions of specific components or subcircuits. Rather, the ACTS instruction is directed toward training an inexperienced technician to evaluate the usefulness of the alternative measurements he can make and to select those alternatives that are most effective, given their relative costs.

In addition to the instructions that are displayed on the basis of the student's decision performance, the ACTS also includes instructions that the student can select. These instructions are given whenever the student requests "HELP." The HELP instructions use the expert decision model to suggest which measurement to make. In addition, the HELP routine gives a list of the circuit modules that could possibly be faulty, given the measurement results already obtained.

2.6 Student's View of ACTS

From the student's viewpoint, the ACTS is a series of circuit troubleshooting problems that are presented on a computer terminal. The student's computer terminal consists of a color video display and a trackball control. On the display is shown a schematic diagram of an electronic circuit, plus printed messages indicating possible actions and giving information. The student uses the trackball to move a cursor around the display face, selecting displayed data. No keyboard is required, thus eliminating any need for typing skill.

Each troubleshooting problem consists of a single circuit fault which the student must locate and replace. The student can select a number of activities to isolate the fault in the displayed power supply circuit. Among these activities, the student can choose to take a voltage or current measurement, replace any circuit module, declare the circuit to be "OK," or he can request "HELP." Following a student's command to perform these activities, the ACTS program displays the results of the simulated activity and then indicates the next allowable activities.

Interspersed among the fault problems, the ACTS presents the instructions which describe recommended circuit measurements and the conditions during which they should be chosen. After the instructions have been displayed the fault problems are resumed. However, the student can request to see the instructions at any time by selecting the appropriate point on the display screen. A complete description of the "student" mode of operation is provided by Kuppin (1976).

2.7 Instructor's View of ACTS

During training sessions, the ACTS operates automatically with no intervention required by an instructor. However, a number of options are available. Thus, the instructor performs a number of activities while in control of the ACTS. In the "control" mode the instructor can start or terminate a student session, change the options for the student session, save the current state of the system, run the "simulated student," or terminate ACTS.

The instructor (experimenter) may operate the ACTS from a teletype, CRT, or a video display terminal with a graphics display and keyboard. The instructor controls the ACTS by typing the name of the option to be executed and then responding with the information requested by the option. The options allow the instructor to: (1) change a parameter of the model, such as the training constant, or allow or disallow some student action, such as allowing "NONE"; (2) save or print model or student actions; or (3) start or terminate a student session or the ACTS program. A complete description of the "control" mode of operation is given in Kuppin (1976).

3. ELECTRONIC CIRCUIT SIMULATOR

The present ACTS decision task involves troubleshooting an electronic power supply. The task is based on a block diagram of the power supply circuit. The behavior of the power supply is simulated by the computer program. This program includes a fault model of the power supply which provides the simulated symptoms of faulty circuit behavior. The task simulator generates circuit faults and simulates the results of checking symptoms, taking measurements, and replacing modules. Measurement results are simulated by looking them up in a table of measurement results for each fault and measurement.

3.1 ACTS Circuit Model

The student's task is to decide which measurements to make and which modules to replace in troubleshooting an electronic circuit. The ACTS program simulates the circuit, including inserted faults, measurement results that vary according to the faults, and replaced modules that correct the circuit faults. The simulated circuit is derived from the Heathkit Model IP-28 regulated DC power supply with current limiting and voltage regulation features. The unit is designed to provide from 1 to 30 volts DC with a current limiting range from 10 milliamps to 1 amp. The IP-28 includes front-panel control of two voltage ranges and two current-limiting ranges with continuous potentiometer controls within the ranges. A meter also displays either current or voltage output and front-panel switches are provided for ON/OFF control of the AC input and the DC output.

For the purposes of the simulated decision task, the Heathkit power supply has been divided into functional modules. The circuit diagram of the IP-28 power supply, with the modular divisions, is shown in Figure 3-1. The circuit diagram displayed on the student's terminal includes the modules, the module interconnections, and the allowed measurements, as shown in Figure 3-2. However, the individual components within the modules are not displayed. Thus, the displayed circuit diagram emphasizes the restriction that entire functional blocks, rather than individual components, are to be tested and replaced.

3.2 Power Supply Modules

Each module in the power supply performs a specific function in the operation of the supply. These functions are described in the following paragraphs.

B: DC Power Source. This module is a combination of rectifier and filter that changes the output of the transformer from alternating current (AC) to a relatively steady direct current (DC).

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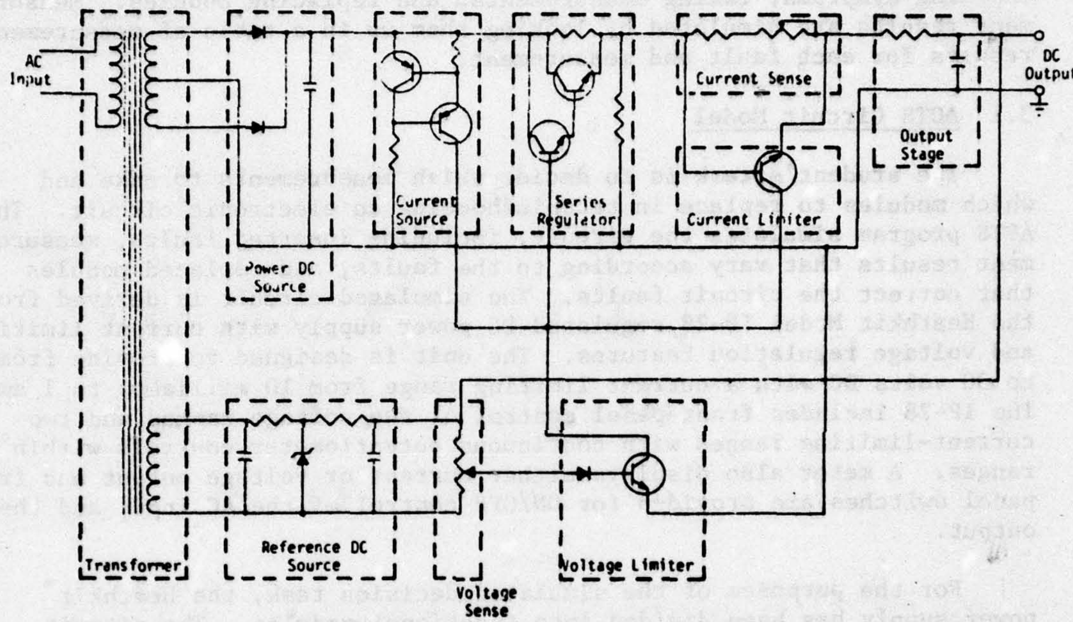

FIGURE 3-1. IP-28 POWER SUPPLY CIRCUIT DIAGRAM

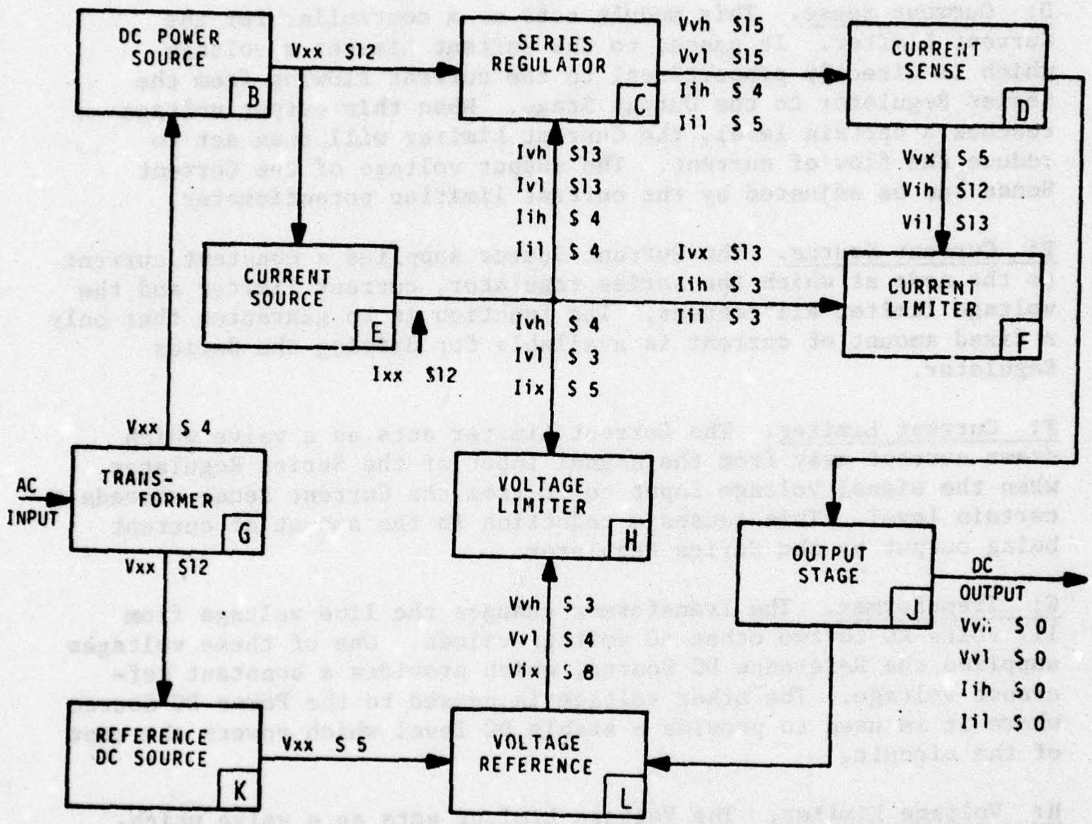

FIGURE 3-2. ACTS SIMPLIFIED POWER SUPPLY CIRCUIT DIAGRAM

C: Series Regulator. This module is placed in series with the output load to regulate the flow of current to the load. The Series Regulator consists of a Darlington pair of transistors which are controlled by the Current Limiter or Voltage Limiter which act to maintain a constant current input to the Series Regulator from the Current Source.

D: Current Sense. This module acts as a controller for the Current Limiter. It passes to the Current Limiter a voltage which is directly proportional to the current flowing from the Series Regulator to the Output Stage. When this output voltage reaches a certain level, the Current Limiter will then act to reduce the flow of current. The output voltage of the Current Sense can be adjusted by the current limiting potentiometer.

E: Current Source. The Current Source supplies a constant current to the node at which the series regulator, current limiter and the voltage limiter all connect. Its function is to guarantee that only a fixed amount of current is available for driving the Series Regulator.

F: Current Limiter. The Current Limiter acts as a valve which draws current away from the signal input of the Series Regulator when the signal voltage input to it from the Current Sense exceeds a certain level. This causes a reduction in the amount of current being output by the Series Regulator.

G: Transformer. The Transformer changes the line voltage from 117 volts AC to two other AC voltage values. One of these voltages supplies the Reference DC Source, which provides a constant reference voltage. The other voltage is passed to the Power DC Source where it is used to provide a stable DC level which powers the rest of the circuit.

H: Voltage Limiter. The Voltage Limiter acts as a valve which draws current away from the signal input of the Series Regulator according to the size of the signal voltage output to it from the Voltage Reference module. The more current drawn away by the Voltage Limiter, the less there is available for the Series Regulator, thus causing it to reduce the amount of current sent to the Output Stage and thus the output voltage. Similarly, by drawing away less current from the Series Regulator, the Voltage Limiter can cause an increase in the output voltage.

J: Output Stage. This module is an output filter which acts to stabilize the current and voltage feedback loops, thus providing a more constant DC output.

K. Reference DC Source. This module rectifies and filters the output of the transformer. In addition, the zener diode maintains a constant output voltage, thus providing a constant, extremely clean reference voltage to the Voltage Reference potentiometer.

L. Voltage Reference. This module is a potentiometer which is used to select a desired reference voltage from the Reference DC Source. The Voltage Limiter uses this reference voltage as a comparison standard for the actual output voltage.

These modules function together to form the regulated DC power supply. This power supply includes both a current feedback loop and a voltage feedback loop. The current feedback, including the Current Sense, Current Limiter, and Series Regulator modules, functions to maintain a constant current at the output stage. The voltage feedback loop maintains a constant output voltage. The voltage feedback includes the Voltage Reference, Voltage Limiter, and Series Regulator modules. The Reference DC Source also influences the voltage feedback since it supplies the reference voltage to the Voltage Reference module.

3.3 Circuit Measurements

A student performs the troubleshooting task by taking measurements at various points throughout the power supply circuit, inferring a fault location from the results of the measurements, and replacing the suspected bad module. Basically, there are two types of measurements that the student can make with the simulated power supply--voltage measurements and current measurements. In the case of voltage measurements, it is assumed that no load is applied to the output of the power supply and that the voltage is measured between various pairs of points in the circuit. For example, measurement 2 is a voltage measurement between the two output lines from the Transformer secondary winding to the Reference DC Source. In the case of current measurements, it is assumed that a load, such as a large power resistor, is applied to the output of the power supply and that current is measured at selected locations in the circuit. For example, measurement 4 is a current measurement of the output of the Current Source.

Recall that the actual Heathkit IP-28 power supply has front panel controls for adjusting voltage and current regulation. Each includes a two-position range switch plus a continuous potentiometer control within the range. Thus the voltage regulation is adjustable within the range 1-10 volts and 1-30 volts. Similarly, the current regulation is adjustable within the ranges .001 to .1 amp and .001 to 1.0 amp. To simulate these adjustments, the ACTS provides several measurements at the same point with changed circuit controls. For example, a voltage measurement can be made with the voltage controls set to the minimum value, 1 volt, or to the maximum value, 30 volts. These two conditions are labeled Voltage Low and Voltage High states, respectively. In a similar manner, current measurements can be made with the current controls set for a Current High or Current Low state. In some instances, the state of the voltage or current controls does not matter when the measurement is taken. In these cases, only one voltage or current measurement is provided at that measurement point. For some measurement conditions, a current measurement or a voltage measurement may be the only meaningful measurement. However, in these conditions, it is still desirable to know the measurement results for both voltage and current states. Thus a current measurement can be made in the Voltage High state (i.e., with no output load and with the voltage regulation controls set to 30 volts).

The possible measurements are shown on the circuit display in mnemonic form, adjacent to the measurement location. The mnemonic indicates the type of measurement--voltage (V) or current (I), and the state of the circuit--voltage high (vh), etc. As shown previously in Figure 3-2, the cost of making a measurement is displayed adjacent to the measurement mnemonic. Table 3-1 illustrates the meanings of all possible measurement mnemonics. For reference, each measurement is given a unique letter or number, shown in Figure 3-2.

The measurements taken at the output of the power supply are distinguished from all other measurements and called symptom checks since they can be made on the actual IP-28 power supply without removing the chassis cover. These symptoms are labelled with letters (p, g, r, and s) in Figure 3-3.

When a measurement is made, one of several results or outputs can occur. As described in Kuppin (1976), the measurement output mnemonic is displayed on the screen after the measurement has been taken. The possible outputs are also displayed to the student during his considerations of the output probabilities. In this latter case, the output probability bar graphs are identified by letter mnemonics. The measurement outcome mnemonics and letter mnemonics are shown in Table 3-2. All measurements can have a normal outcome. In addition to this normal outcome, several non-normal outcomes are possible for each measurement. The outcomes are shown in interpreted form rather than a specific number (such as 0.026 amp or 6.1 volt). The interpreted outcomes are defined as follows:

A. NORMAL (N): The measurement result (outcome) is within the normal range for the measurement point.

B. VARIES (V): This outcome is incorrect but does not take any specified value. Thus, it can be too high, too low, etc. but the specific value is immaterial.

C. ZERO (Z): This means that the measurement result has a value of zero or essentially zero.

TABLE 3-1. TYPES OF MEASUREMENTS

Mnemonic	Meaning
Vxx	Voltage measurement (circuit state is irrelevant)
Vvh	Voltage measurement in the voltage high state
Vvl	Voltage measurement in the voltage low state
Vvx	Voltage measurement in any voltage state
Vih	Voltage measurement in the current high state
Vil	Voltage measurement in the current low state
Vix	Voltage measurement in any current state
Ixx	Current measurement (circuit state is irrelevant)
Ivh	Current measurement in the voltage high state
Ivl	Current measurement in the voltage low state
Ivx	Current measurement in any voltage state
Iih	Current measurement in the current high state
Iil	Current measurement in the current low state
Iix	Current measurement in any current state

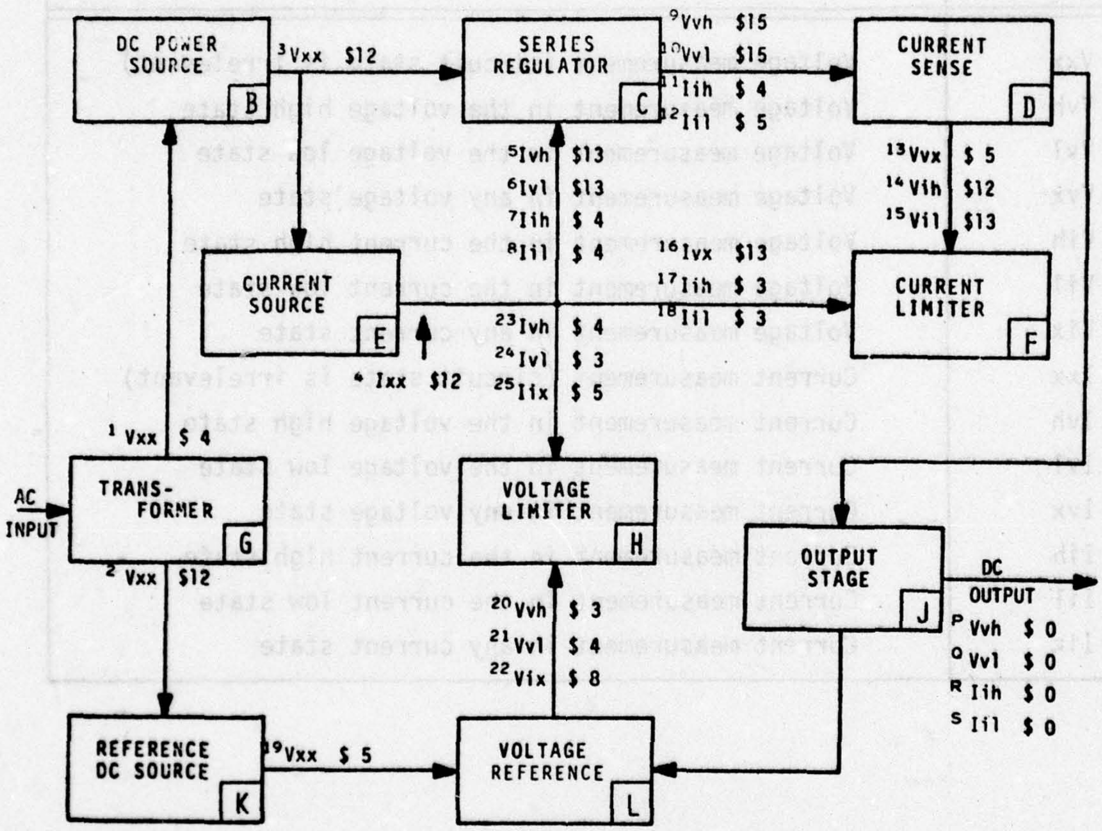

FIGURE 3-3. ACTS POWER SUPPLY CIRCUIT DIAGRAM WITH MEASUREMENT NUMBERS

TABLE 3-2. MEASUREMENT OUTCOME MNEMONICS

Letter Mnemonic	Mnemonic	Meaning
N	NOR	Normal
V	VAR	Varying
Z	ZER	Zero
X	VLO	Very Low
L	LOW	Low
H	HI	High
F	FLT	Floating

D. VERY LOW (X): The measurement outcome is much lower (more negative) than normal but measurably greater than zero.

E. LOW (L): The outcome is less than the normal outcome but greater than zero.

F. HIGH (H): The outcome is greater than the normal range.

G. FLOATING (F): This outcome for a voltage measurement means that the measurement is made with some reference other than the chassis ground, usually indicating that a component (such as a transistor junction) is open.

Table 3-3 lists each measurement with its mnemonic, measurement type, location, circuit state, possible non-normal outputs and default cost. As described in Section 1.5 of the ACTS User's Guide, the End-of-Problem report includes the utilities for the outcomes of all measurements. The first outcome of each measurement is the NORMAL outcome. Each subsequent outcome corresponds to the non-normal outcomes listed for each measurement in Table 3-3.

For example, Figure 3-4 shows that the utilities for the outcomes for measurement 24 are NORMAL = 90, VARIES = 93 and ZERO = 95.

3.4 Circuit Faults

A number of faults can be inserted into the circuit as the basis for troubleshooting problems. These faults involve malfunctioning components such as a shorted or leaky capacitor, a shorted or open transistor, or a resistor of improper resistance. The possible faults are restricted to those involving a single module and they are further restricted to a single fault for each problem. Thus, a fault is not the result of a more fundamental circuit malfunction.

The faults are described in Table 3-4 with a brief description of the effect of the fault. The faults are associated with specific circuit modules, as shown in Table 3-4. The order of fault presentation can be generated randomly by the ACTS or the instructor can specify the fault to be presented with each successive problem. The ACTS includes a default sequence of 30 problems.

Associated with each fault is a specific pattern of measurement outcomes. The student makes selected measurements to discover a subset of the pattern of outcomes, inferring the faulted module from this subset. The measurement outcomes for all faults are shown in Table 3-5.

TABLE 3-3. AVAILABLE MEASUREMENTS

No.	Mnemonic	Location & Measurement Type	Circuit State	Default Cost	Possible Non-Normal Outputs
P	Vvh	Output Voltage	Voltage-High	0	Z X L
Q	Vvl	Output Voltage	Voltage-Low	0	Z L H
R	Iih	Output Current	Current-High	0	Z L
S	Iil	Output Current	Current-Low	0	L H
1	Vxx	Transformer - Power Secondary Output Voltage	Any	4	L F
2	Vxx	Transformer - Reference Secondary Output Voltage	Any	12	L F
3	Vxx	DC Power Source Output Voltage	Any	12	L F
4	Ixx	Current Source Output Current	Any	12	V Z
5	Ivh	Series Regulator Base Input Current	Voltage-High	13	V Z
6	Ivl	Series Regulator Base Input Current	Voltage-Low	13	V Z
7	Iih	Series Regulator Base Input Current	Current-High	4	V Z
8	Iil	Series Regulator Base Input Current	Current-Low	4	V Z
9	Vvh	Series Regulator Output Voltage	Voltage-High	15	V F
10	Vvl	Series Regulator Output Voltage	Voltage-Low	15	V F
11	Iih	Series Regulator Output Current	Current-High	4	V Z
12	Iil	Series Regulator Output Current	Current-Low	5	V Z
13	Vvx	Current Sense Output Voltage	Voltage-Any	5	V F
14	Vih	Current Sense Output Voltage	Current-High	12	V Z
15	Vil	Current Sense Output Voltage	Current-Low	13	V Z
16	Ivx	Current Limiter Input Current	Voltage-Any	13	V
17	Iih	Current Limiter Input Current	Current-High	3	V Z
18	Iil	Current Limiter Input Current	Current-Low	3	V Z
19	Vxx	Reference DC Source Output Voltage	Any	5	V Z
20	Vvh	Voltage Reference Output Voltage	Voltage-High	3	V F
21	Vvl	Voltage Reference Output Voltage	Voltage-Low	4	V Z
22	Vix	Voltage Reference Output Voltage	Current-Any	8	F
23	Ivh	Voltage Limiter Input Current	Voltage-High	4	V Z
24	Ivl	Voltage Limiter Input Current	Voltage-Low	3	V Z
25	Iix	Voltage Limiter Input Current	Current-Any	5	V

--ACT SYSTEM--   STUDENT: MICKEY MOUSE   12 DEC 76   15:30   PAGE 1

SUMMARY FOR PROBLEM 1

PROBLEM NUMBER:	1	TIME USED:	2:17
REAL FAULT:	7	PROBLEM COST:	$ 59
BAD MODULE:	B	TOTAL COST:	$ 59

TIMES "NONE" USED:	1	COMPETENCE:	91
TIMES "HELP" USED:	2	CONSISTENCY:	91
TIMES "IR" USED:	0	ALPHA:	95
TIMES "OK" DECLARED:	1	ALPHA OF	
INSTS PRESENTED:	0	CONSIDERATIONS:	15

MODULES REPLACED:	1	DECISIONS MADE:	3
MEASUREMENTS TAKEN:	2	ADJUSTMENTS MADE:	1
SYMPTOMS TAKEN:	0		

STUDENT UTILITY VALUES

MEAS/ SYMP	1ST OUTCOME	2ND OUTCOME	3RD OUTCOME	4TH OUTCOME	# OF ADJS	TIMES CNSRD	TIMES TAKEN	AVG DEV
P	100	100	100	100	0	0	0	0
Q	100	100	100	100	0	0	0	0
R	100	100	100		0	0	0	0
S	100	100	100		0	0	0	0
1	100	100	100		0	0	0	0
2	100	100	100		0	0	0	0
3	100	100	100		0	1	0	0
4	100	100	100		0	0	0	0
5	100	100	100		0	1	0	0
6	100	100	100		0	0	0	0
7	100	100	100		0	0	0	0
8	100	100	100		0	0	0	0
9	100	100	100		0	0	0	0
10	100	100	100		0	0	0	0
11	100	100	100		0	0	0	0
12	100	100	100		0	1	1	0
13	100	100	100		0	0	0	0
14	100	100	100		0	0	0	0
15	100	100	100		0	0	0	0
16	100	100			0	0	0	0
17	100	100	100		0	0	0	0
18	100	100	100		0	0	0	0
19	100	100	100		0	1	0	0
20	100	100	100		0	0	0	0
21	100	100	100		0	1	0	0
22	100	100			0	0	0	0
23	105	103	106		1	1	1	5
24	90	93	95		0	1	0	7
25	100	100			0	1	0	0

MODULE UTILITY VALUES

B	C	D	E	F	G	H	J	K	L
100	100	100	100	100	100	100	100	100	100

FIGURE 3-4. EXAMPLE OF A PROBLEM SUMMARY REPORT PRINTOUT

TABLE 3-4. CIRCUIT FAULTS

FAULT NO.	FAULTED MODULE	FAULT	EFFECT
0	None	No Fault	Normal Outcomes
1	G. Transformer	Break in Primary	No Output at Main or Reference Secondary
2		Short in Secondary	Reduced Output at Main and Reference Secondary
3		Break/Short in Main Secondary	Reduced Output at Main Secondary
4		Short in Reference Secondary	Reduced Output at Reference Secondary
5		Break in Reference Secondary	No Output at Reference Secondary
6	B. DC Power Source	Capacitor Short	No Source Output
7		Open Diode or Leaky Capacitor	Reduced Source Output
8	E. Current Source	Open Collector	No Output Current
9		Base-Collector Short	Excess Output Current
10		Base-Collector-Emitter Short	No Current
11		Bad Value, Bias Resistor	Reduced Output Current
12	C. Series Regulator	Base-Collector-Emitter Open	No Output
13		Low Beta Value	Low Output Current
14		Base-Collector-Emitter Short	Excess Output Current
15	D. Current Sense	Open Series Resistor	No Output Current
16		Potentiometer Short	Reduced Control Voltage
17		Improper Resistor/Potentiometer Value	Reduced Current in Current High State
18	F. Current Limiter	Transistor Short	Excess Control Current
19		Transistor Open	Reduced Control Current
20	K. Reference DC Source	Bad Value, Match Resistor	Low Reference Voltage
21		Zener or Capacitor Short	No Reference Voltage
22	L. Voltage Reference	Open Potentiometer Wiper	No Current to Voltage Limiter
23		Short Potentiometer Wiper	Excess Current to Voltage Limiter
24	H. Voltage Limiter	Transistor Short	Excess Control Current
25		Transistor Open	Reduced Control Current
26	J. Output Stage	Open Resistor or Capacitor Short	No Output Current
27		Leaky Capacitor	Reduced Output Current

TABLE 3-5. MEASUREMENT OUTCOMES ASSOCIATED WITH CIRCUIT FAULTS

MODULES	FAULTS	P	Q	R	S	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
NORMAL	0																													
G. TRANSFORMER	1	L	H	L	H	F	F	F	Z	Z	Z	Z	Z	F	F	Z	Z		Z	Z		Z	Z	Z	F	Z	F	Z	Z	
	2	X				L	L	L	V	V		V		V		V			Z			Z		V				Z		
	3	X				L	L	L		V				V											V			Z		
	4	X					L			V				V										V				V		
	5	Z					F			V				V										Z				V		
B. DC POWER SOURCE	6	L	H	L	H			F	Z	Z	Z	Z	Z	F	F	Z	Z		Z	Z		Z	Z		V	V		Z	Z	
	7			Z				L								V			V			Z								
E. CURRENT SOURCE	8	Z			H				Z	Z	Z	Z	Z	F	F	Z	Z		Z	Z		Z	Z		V	V		Z	Z	
	9		Z		L				V		V		V		V		V			V		V	V			V		V	V	
	10		Z		L				V	V	V	V	V	V	V	V	V		V	V		V	V		V	V		V	V	
	11			Z					V			V				V			V			Z						V	V	
C. SERIES REGULATOR	12	L	H	L	H					V	V	V	V	F	F	Z	Z		Z	Z		Z	Z		V	V			Z	
	13			Z								V	V	V	V	V	V		V	V		V	V					V	Z	
	14		Z		L					V	V	V	V	V	V	V	V		V	V		V	V		V	V		V	V	
D. CURRENT SENSE	15	Z	Z	L	H					V	V	V	V	V	V	V	V	V	Z	Z		Z	Z		V	V		V	V	
	16				L							V	V			V	V		V	V		V	V							
	17			Z								V				V			V			V								
F. CURRENT LIMITER	18				L							V	V			V	V		V	V		Z	Z							
	19	X	Z	L	H					V	V	V	V	V	V	V	V		Z	Z	V	V	V		V	V		V	V	V
K. REFERENCE DC SOURCE	20	X								V				V										V	V			V		
	21	Z								V				V										Z	V		F	V		
L. VOLTAGE REFERENCE	22		Z							V	V			V	V										F	F	F	V	V	V
	23		Z								V				V											V	F		Z	
H. VOLTAGE LIMITER	24		Z							V	V			V	V										V	V		Z	Z	
	25	L	H	L	H					Z		Z	Z	F	F	Z	Z		Z	Z		Z	Z		V	V		V	V	V
J. OUTPUT STAGE	26	L	H	L	H					V	V	V	V	V	V	V	V		V	V		Z	Z		V	V		Z	Z	
	27	X								V	V	V	V	V	V	V			V		V	Z			V			V	V	

MEASUREMENTS

Blank spaces are normal outcomes

4. EVALUATION OF AIDING AND FEEDBACK FOR INSTRUCTION

4.1 Overview

Previous evaluations of the ACTS (May, Crooks, & Freedy, 1976) have examined the performance of the adaptive decision model, the characteristics of student interactions with the decision task, and the training effects of an initial set of instructions. These studies demonstrated that the adaptive decision model tracks the performance of consistent decision makers and accurately ranks an expert's preferences for circuit measurements. Additionally, students demonstrate improved decision making performance after extended practice with the ACTS. The evaluation of the initial set of instructions suggested that instructions stating the conditions for selecting specific decision alternatives must be accompanied by explicit reinforcement and immediate knowledge of results to be effective.

An additional study was conducted during the current year to explore further the training potential of the ACTS. Training in the ACTS is provided through practice with the circuit simulation model and by the adaptive instructions selected on the basis of student decision model parameters. The adaptive instructions are described in Section 2.5 of this report. The ACTS also includes training capabilities in the form of aiding, in addition to the adaptive instructions. This aiding is given whenever the student requests the "HELP" option. The "HELP" option uses information available in the decision model of the expert to (1) suggest the next best decision alternative, and (2) list the remaining possible faulted circuit modules. An experimental study was conducted to evaluate the potential training effectiveness of aiding and feedback based on a modified version of the "HELP" option.

The interaction sequence of the ACTS was modified to allow presentation of the expert model's set of the three best decision alternatives. The student was then able to use these suggested best alternatives to help select his choice. This aiding is similar to that provided by the HELP option. However, for experimental purposes, the aiding was automatically presented rather than being presented on request. This study of aiding considered not only the performance impact of giving suggested best alternatives but also the impact of immediate feedback regarding the adequacy of decision choices. Immediately following the student's selection of an alternative, the expert model's best alternative was displayed. This feedback provided an immediate comparison by which the student could evaluate his own choice.

4.2 Experimental Design and Procedures

During the normal sequence of interactions with the ACTS, the "HELP" routine is optionally available to the student. If the student chooses HELP the computer program tells the student which symptom, measurement, or module that the expert model would choose, (1) from among the alternatives that the student is considering, or (2) from the entire list of possible alternatives. Additionally, the HELP program lists all remaining modules that could still be malfunctioning, given the measurement results that have been obtained and the modules that have been replaced to that point.

This study was designed to evaluate the training effectiveness of providing suggested decision alternatives. The study was also intended to examine a particular form of immediate feedback, in which the student is told what alternative an expert would have chosen. Three experimental conditions were included in the experimental design. In the first condition (A: Alternative Selection and Decision Feedback) the student did not list the alternatives that he wished to consider. Rather, the computer automatically provided a list of the three best alternatives. The student then selected from among these pre-selected alternatives. Immediately following the student's choice, the computer indicated which choice the expert model made. The second condition (B: Decision Feedback) included only the display of the expert decision model's choice immediately following the student's choice. The student was required to provide his own list of three alternatives from which to choose. The third condition (C: No Feedback) provided neither a list of alternatives from which to choose nor an indication of the expert model's choice.

The available information in each condition is illustrated in Table 4-1. As shown, condition A included both aiding and feedback during the same sessions, whereas condition B included only feedback, and condition C included neither form of information.

TABLE 4-1. EXPERIMENTAL CONDITIONS

CONDITION	EXPERT ALTERNATIVES GIVEN	EXPERT CHOICE GIVEN
A	Yes	Yes
B	No	Yes
C	No	No

As in the earlier studies of the ACTS, students were given training during several sessions over successive days. The students were first given an introductory session of five practice problems, during which Condition C was in effect. The students were then assigned to one of the three groups shown in Table 4-2. Group 1 students had an initial test session with both forms of instructional assistance; (1) aiding in the form of preselected alternatives and (2) feedback of the expert's choice. The instructional assistance for Group 1 was reduced to feedback alone in the second test session. Both forms of assistance were withdrawn during the third session. Group 2 students received no aiding from preselected alternatives but did have two sessions with feedback. Group 3

TABLE 4-2. EXPERIMENTAL DESIGN

GROUP	SESSION 1	SESSION 2	SESSION 3
1	A	B	C
2	B	B	C
3	C	C	C

had only practice during all three sessions with no aiding or feedback. This design permitted comparisons among conditions of decreasing amounts of instructional assistance, both across and within students. Comparisons among the three groups, made during the first session, provide an indication of the potential advantage of the instructional assistance; whereas the performance of Group 1 students over the three sessions illustrates the effects of progressively withholding assistance. The performance of Group 2 students demonstrates the effects of giving only feedback initially in training and then phasing out the feedback later. Group 3 was a control group with no aiding or feedback during the three sessions.

Six students were selected to participate in the study. These students were recruited from electronics and engineering classes at local colleges. A short-form electronics test, covering basic knowledge of electronics principles, terminology and circuit operation, was administered and scored to insure selection of students with sufficient background in electronics. Following administration of the electronics test, the participants were randomly assigned to the three experimental groups. Each test session consisted of predetermined sequences of 15 problems, with each participant receiving the same problem sequences. The participants completed each test session in 1-1/2 to 2 hours.

4.3 Results and Discussion

The results of this study indicate that although the groups did not differ in the median number of decisions required to solve the fault problems, those students who received aiding or feedback solved the problems at lower costs than those students who received neither aiding nor feedback. Table 4-3 shows the median number of decisions required

TABLE 4-3. MEDIAN DECISIONS REQUIRED TO SOLVE FAULT PROBLEMS

GROUP	STUDENT	SESSION 1	SESSION 2	SESSION 3
1	1	5	7	6
	2	6	7	4
2	3	5	5	5
	4	6	7	6
3	5	6	8	6
	6	7	7	7

by each student during each test session. Similarly, Table 4-4 shows the median cost expenditures for each student. As illustrated in Figure 4-1, all groups demonstrated improved cost expenditures following practice over the several sessions. Moreover, the groups who received aiding through suggested alternatives and/or feedback of optimum choices demonstrated superior cost performance during the early training.

TABLE 4-4. MEDIAN COST EXPENDITURE ($) TO SOLVE FAULT PROBLEMS

GROUP	STUDENT	SESSION 1	SESSION 2	SESSION 3
1	1	54	66	57
	2	61	67	49
2	3	55	65	61
	4	71	69	63
3	5	89	81	70
	6	72	81	55

The fault problems were the same during the first and third experimental sessions. Thus, performance in these two sessions can be compared directly. However, a different set of faults were presented during the second session. For this latter problem sequence, the students required a median of 6.8 decisions per problem, while the other problem sequence required a median of 5.75 decisions per problem. Thus, the faults used in Session 2 were apparently more difficult. This increased difficulty is reflected in the cost performance during the second session where the expected decrease due to practice did not occur for any of the experimental groups.

Although the small number of students in this study limits the generalizations that can be made, the results of this limited study suggest that a student's decision performance is improved early in training with aiding and feedback. Aiding, through suggestions of good alternatives, apparently promotes improvement in decision choices.

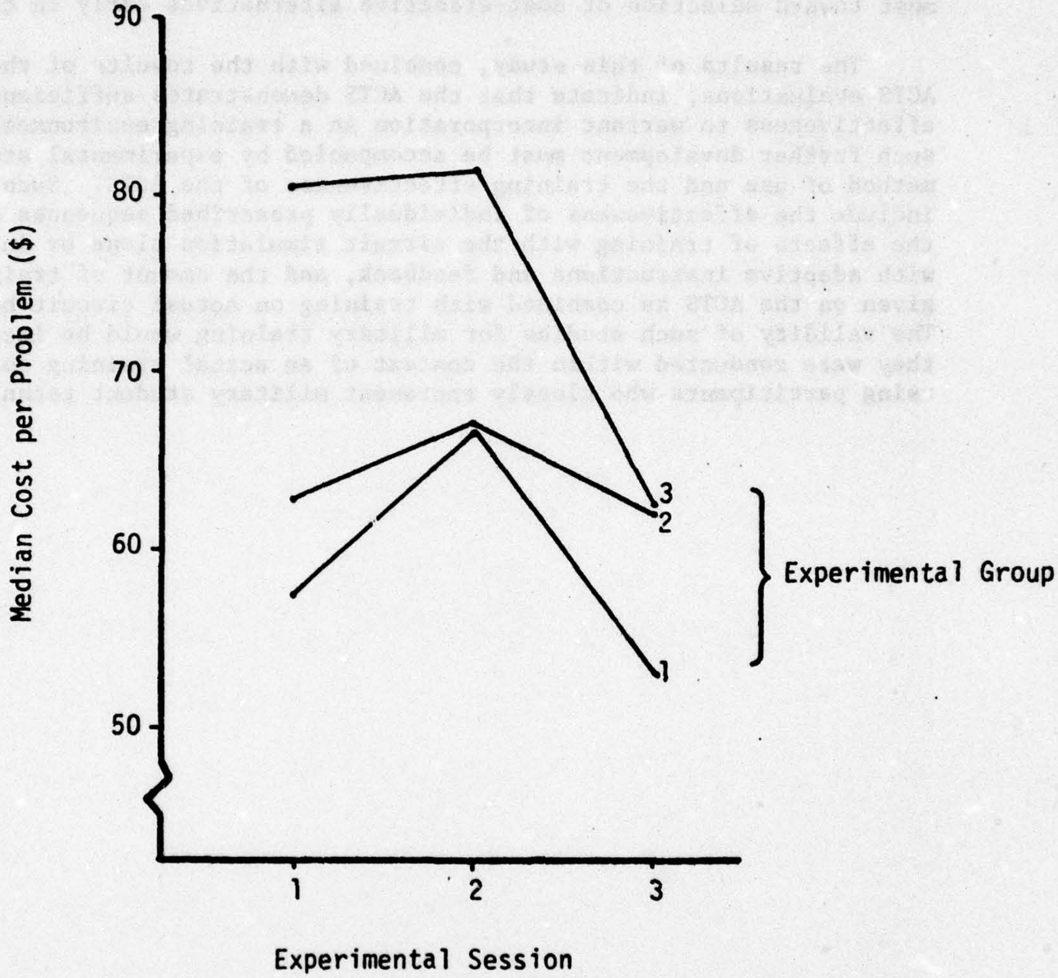

FIGURE 4-1. MEDIAN COST EXPENDITURE TO SOLVE FAULT PROBLEMS

However, feedback describing the appropriate choices evidently contributes most toward selection of cost-effective alternatives early in training.

The results of this study, combined with the results of the earlier ACTS evaluations, indicate that the ACTS demonstrates sufficient training effectiveness to warrant incorporation in a training environment. However, such further development must be accompanied by experimental studies of the method of use and the training effectiveness of the ACTS. Such studies include the effectiveness of individually prescribed sequences of problems, the effects of training with the circuit simulation alone or in combination with adaptive instructions and feedback, and the amount of training time given on the ACTS as combined with training on actual circuit hardware. The validity of such studies for military training would be increased if they were conducted within the context of an actual training course, using participants who closely represent military student technicians.

5. EXTENSION TO NEW LESSON

The prototype ACTS has been developed with a simulation of a Heathkit IP-28 regulated power supply. However, to make the ACTS more directly applicable to military electronics technical training, a subassembly of the RT-524/VRC Radio Receiver-Transmitter has been analyzed for development as lesson material in the ACTS. Selection of the subassembly will permit direct analysis of ACTS training effectiveness in an ongoing Army technical training course.

5.1 Radio Repair Course

As a portion of his technical training, an Army electronics technician participates in a Radio Repair course (31E), taught by the staff of the Communications Equipment Department at the Army Signal School. The technician trainee has previously received instruction in basic electronics training courses and the 15-week 31E course provides training in Direct Support (Third Echelon) and General Support (Fourth Echelon) maintenance of radio equipment.

Training in the radio repair course is based on understanding and using the radio equipment technical manuals and test equipment to perform test-and-repair or replacement maintenance. For each lesson, the trainee is given a Performance Guide that describes the objectives of the lesson, lists the required technical manuals and test equipment, specifies the applicable chapters in the technical manuals, includes a performance quiz, and lists the maintenance tasks to be performed in the electronics training lab.

During the sequence of the 31E course, the trainee learns to perform maintenance on the RT-524/VRC Radio Receiver-Transmitter. This device is a vehicle-mounted FM radio that operates from the 24 volt power of the vehicle. The RT-524/VRC consists of 14 major assemblies such as a Transmitter Speech Amplifier Assembly, a Voltage Regulator Assembly, etc. Among these assemblies is the Power Supply (A9000) which converts the vehicle power to the voltages and frequencies required by transmitter, power amplifier, and cooling blower.

Occurring in the seventh or eighth week of the fifteen-week 31E course, the lesson on the A9000 assembly is the first lesson in fourth echelon (General Support) maintenance procedures. For the RT-524/VRC, fourth echelon maintenance supplements third echelon (Direct Support) troubleshooting procedures by focusing on several specific assemblies that generally do not require higher echelon maintenance. Contrasted with the operational and equipment performance checks performed at a lower echelon (organizational level), third and fourth echelon maintenance is concerned with tracing an equipment fault (1) to a major component (sectionalization), (2) to a defective assembly (localization), and (3) to specific parts within an assembly (isolation); replacing certain parts; and finally aligning or adjusting major assemblies after the equipment has been repaired.

The Performance Guide for the A9000 assembly lesson first instructs the trainee to read the troubleshooting procedures in the technical manual (TM 11-5820-399-35) and to answer questions regarding these procedures. The technical manual describes the procedures for taking voltage and resistance measurements, includes drawings of the circuit boards to illustrate measurement points, and gives the complete circuit diagram of the A9000 assembly. Earlier chapters of the technical manual give a description of the function of the power supply assembly and describe the operation and function of all subcircuits within the assembly. A second technical manual, TM 11-5280-401-12, describes the operation and mechanical configuration of the RT-524/VRC. This manual gives detailed procedures for removing and replacing the assemblies, including the A9000. However, the technical manuals do not provide a table of faults that would be associated with specific symptoms. Rather, the technical manual lists the value of the normal result for each specified measurement and the technician must isolate the faulted components on the basis of abnormal measurements and his knowledge of electronics.

Following the reading of the assigned paragraphs in the technical manuals and completion of the performance quiz, the trainee works with the radio to practice isolating faults. The Performance Guide tells the trainee to have his instructor physically insert faults into the radio and then instructs the trainee to isolate the faults according to the procedures described in the technical manual. The Performance Guide includes the list of possible measurements and the trainee records all measurement results for each practice problem. The trainee keeps the guide as part of the documentation he will use as an electronics technician. Thus, the recorded measurement results can be used later as an abbreviated fault/symptom table.

Within the context of the A9000 lesson, the ACTS could serve as a substitute for, or an addition to, the practice problems with the hardware. A primary purpose of the practice problems is to allow the trainee to investigate the relationships between test measurement results and circuit faults. The ACTS circuit simulation can provide the measurement results in a format similar to that shown on the test instruments. The simulation could also provide the opportunity for many fault problems for a single trainee since the time required for power supply assembly and disassembly is eliminated. Thus, the circuit simulation acts as a direct substitute for hardware-based practice. In addition, the decision models of the ACTS provide the basis for instructions on appropriate choices of suspected faults. Thus, the A9000 power supply circuit has been analyzed for incorporation as a lesson in the ACTS.

5.2 Power Supply Assembly

The A9000 assembly consists of a DC-to-DC converter and a DC-to-AC converter. The purpose of the DC-DC converter is to change the input 25.5 volts to the higher voltages necessary for the transmitter driver and power amplifier assemblies. The DC-AC converter changes the input 25.5 volts DC to 115 volts AC for the operation of the cooling blower motor.

As described in the technical manual (TM-11-5820-399-35), and illustrated in Figure 5-1, the DC-to-DC converter consists of a power oscillator which converts the 25 volt DC input to a 2000 Hz AC current, a transformer that converts the input voltage to three output voltages, and three rectifier circuits that convert the AC output from the transformer to +700 volts DC, +275 volts DC, and -14 volts DC. The simplified schematic diatram of the DC-to-AC converter, shown in Figure 5-2, illustrates the power oscillator which converts the input 25 volts DC to 25 volts, 400 Hz AC for input to the transformer. The output 115 volts, 400 Hz is filtered by the output coils and capacitor.

The complete circuit diagram of the power supply is shown in Figure 5-3. This diagram illustrates the physical organization of the assembly, with the power oscillator transistors mounted on the heat exchanger at the rear of the RT-524/VRC case, the test points (TP9001 through TP9007) located on a single circuit board, and the control relays, K9001 and K9002. The control relays operate when the transmit button on the radio microphone is depressed, activating the A9000 power supply. Figure 5-3 also shows the numerical designation of all components and test points. Thus, this diagram is a critical item during a maintenance operation since all test measurements are described in terms of component and test point designations. The technical manual also includes parts location and wiring diagrams to assist in making circuit measurements.

The test measurements that can be made in the A9000 assembly are listed in the technical manual in three lists. The technician is first instructed to make the VOLTAGE measurements listed in Table 5-1 while the power supply is in the receiver-transmitter. If the voltages are abnormal, the technician is then instructed to remove the power supply and then make the RESISTANCE measurements at the J9001 terminal, shown in Table 5-2. He is further instructed to measure the RESISTANCE of the transformer and coil windings listed in Table 5-3. On the basis of these sets of measurements, the technician is expected to identify a faulted component within the A9000 subassemblies, including the test point circuit board, component circuit board, inductor and transformer chassis, and transistor adapter assembly. Further, in fourth echelon maintenance, the technician is authorized to remove and replace any defective transformers, inductors, or relays.

During the practice problems with A9000, the instructor inserts one of several possible fualts in the actual power supply. These faults include defective transformers, coils, and relays as well as open diodes. Table 5-4 gives a brief description of each A9000 fault used in the 31E Radio Repair course. Associated with each fault is a particular pattern of measurement results. The technician would use these results to formulate a hypothesis about the defective component. Analysis of the A900 circuit diagram has provided the measurement outcomes for each fault as shown in Table 5-5.

The measurement results shown in Table 5-5 are interpreted, rather than given as specific values. The actual measurement results would be

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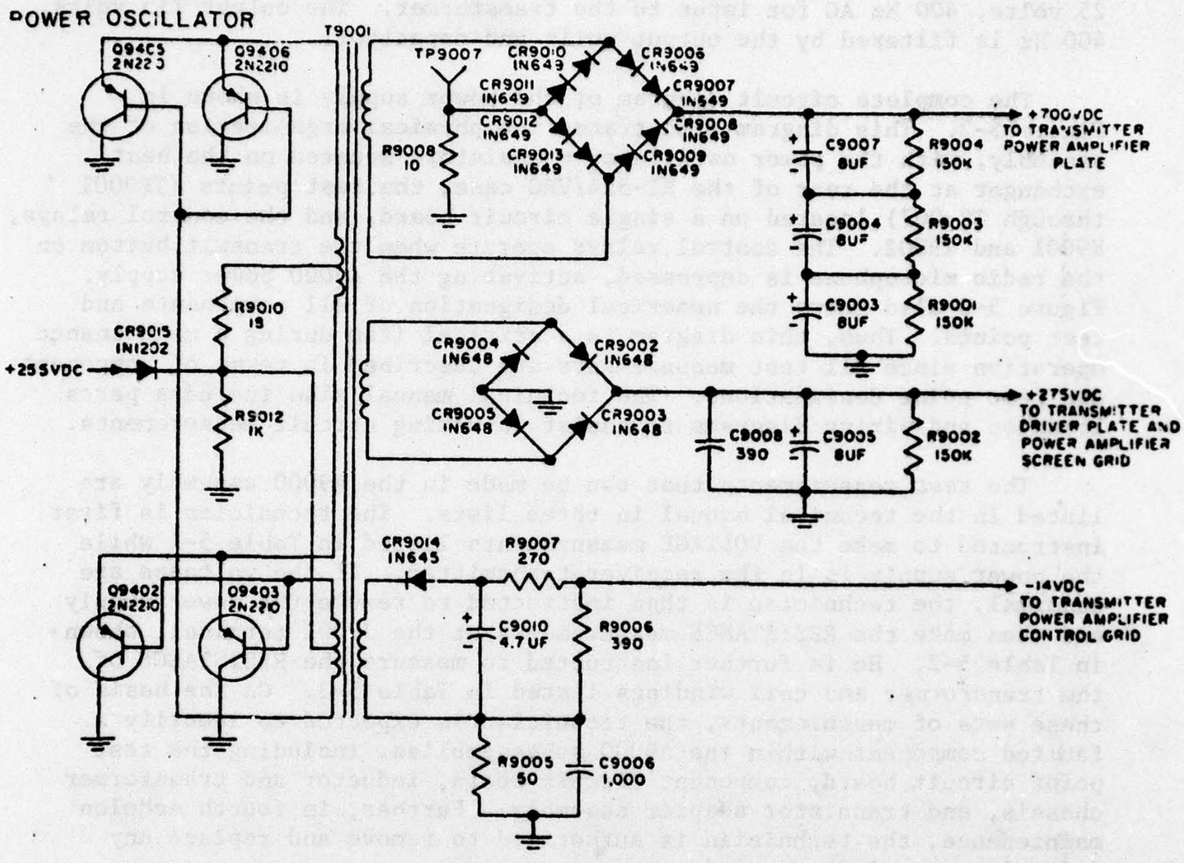

FIGURE 5-1. DC-TO-DC CONVERTER SIMPLIFIED SCHEMATIC DIAGRAM

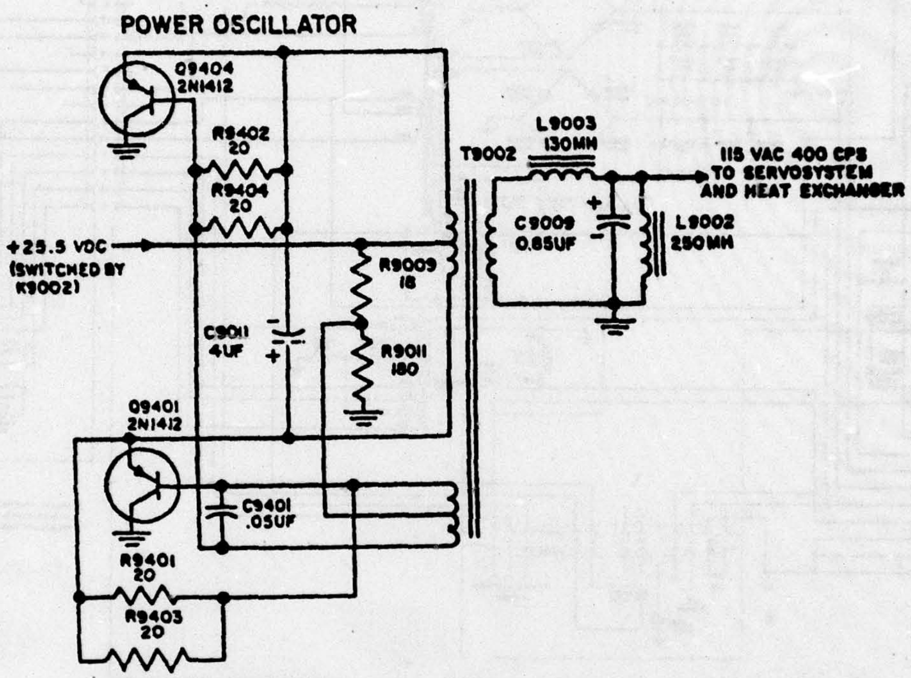

FIGURE 5-2. DC-TO-AC CONVERTER SIMPLIFIED SCHEMATIC DIAGRAM

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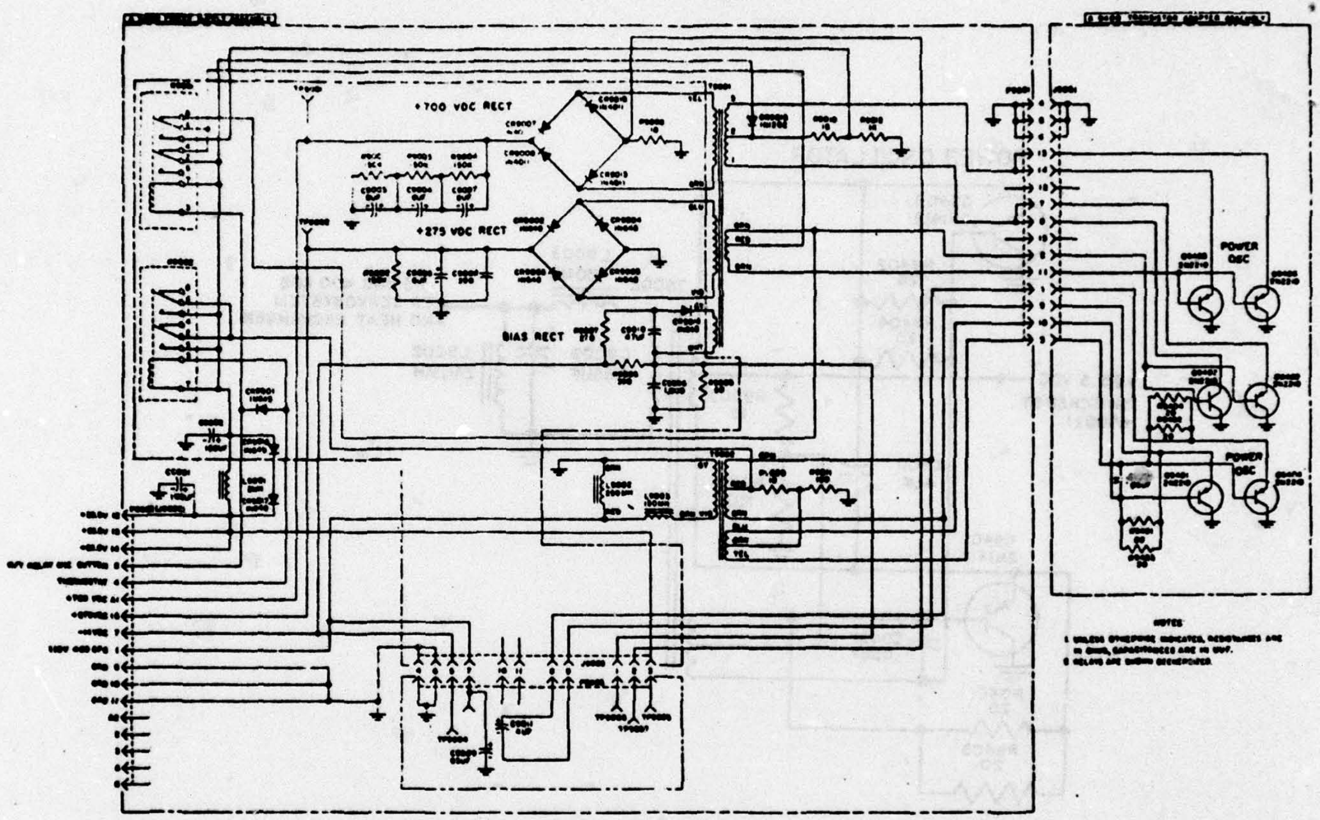

FIGURE 5-3. RT-524/VRC RECEIVER-TRANSMITTER CIRCUIT DIAGRAM

TABLE 5-1. A9000 VOLTAGE MEASUREMENTS

JUNCTION	NORMAL READING
C9001 and L9001 (red)	+ 24.5 V.
L9001 (brn) and C49015	+ 24.5 V.
CR9015 and T9001-2	+ 23.4 V.
R9010 and R9012	+ 22.9 V.
CR9001 and K9002-3	0 V.
CR9001 and K9001-3	0 V.
CR9010 and CR9011	+260 V.
CR9010 and CR9006	+350 V.
CR9006 and CR9007	+400 V.
CR9008 and CR9009	+400 V.
CR9009 and CR9013	+350 V.
CR9013 and CR9012	+260 V.
R9004 and R9003	+470 V.
R9003 and R9001	+240 V.
CR9002 and CR9004	+120 V.
CR9003 and CR9005	+120 V.
R9007 and CR9014	- 24.5 V.
R9009 and T9002	+ 24 V.
R9009 and K9002-2,-6	+ 25.4 V.
TP9001	+700 V.
TP9002	+275 V.
TP9003	115V, 400Hz
TP9004	- 14 V.
TP9005	+ 25.5 V.
TP9006	0 V.
TP9007	variable

TABLE 5-2. A9000 RESISTANCE MEASUREMENTS

Reading	J9001 Terminal	ME-26B/U Test Lead	Meter Scale	Resistance
1	13	Ohms	R x 100	Record[a]
2	14	Ohms	R x 100	Record[a]
3	7	Ohms	R x 100	Record[a]
4	8	Ohms	R x 100	Record[a]
5	13	Common	R x 1	Less than reading No. 1
6	14	Common	R x 1	Less than reading No. 2
7	7	Common	R x 1	Less than reading No. 3
8	8	Common	R x 1	Less than reading No. 4
9	11	Ohms	R x 1	Record[a]
10	2	Ohms	R x 1	Record[a]
11	1	Ohms	R x 1	Record[a]
12	9	Ohms	R x 1	Record[a]
13	11	Common	R x 100	Greater than reading No. 9
14	2	Common	R x 100	Greater than reading No. 10
15	1	Common	R x 100	Greater than reading No. 11
16	9	Common	R x 100	Greater than reading No. 12

[a] *Greater than 0, but less than infinity.*

TABLE 5-3. A9000 TRANSFORMER AND COIL RESISTANCE MEASUREMENTS

TRANSFORMER	LEADS	NORMAL READINGS
T9001	1 to 3	0.03 ohms
	orange to red	0.24 ohms
	brown to red	0.24 ohms
	gray to white	0.77 ohms
	blue to violet	7.75 ohms
	yellow to green	4.6 ohms
T9002	brown to orange	0.55 ohms
	violet to gray	7.0 ohms
	yellow to blue	12.0 ohms
L9003	red to brown	0.06 ohms
L9002	red to brown	9.0 ohms

TABLE 5-4. A9000 POWER SUPPLY AVAILABLE FAULTS

FAULT	DESCRIPTION
1	L9001 Open
2	T9001 Open Primary
3	T9001 Open 275 V Secondary
4	T9001 Open 700 V Secondary
5	T9002 Open Primary
6	K9001 Open Coil
7	K9002 Open Coil
8	CR9002 Open
9	CR9006 Open
10	CR9015 Open

TABLE 5-5. MEASUREMENT OUTCOMES ASSOCIATED WITH A9000 POWER SUPPLY FAULTS

	JUNCTIONS	NORMAL READING	FAULTS 1	2	3	4	5	6	7	8	9	10
	<u>VOLTAGE MEASUREMENTS</u>											
1	C9001 and L9001 (red)	+24.5 V.	0									
2	L9001 (brn) and CR9015	+24.5 V.	0									
3	CR9015 and T9001-2	+23.4 V.	0									L
4	R9010 and R9012	+22.9 V.		L				L				L
5	CR9001 and K9002-3	0 V.										
6	CR9001 and K9001-3	0 V.	0									
7	CR9010 and CR9011	+260 V.	0	0		0		L				L
8	CR9010 and CR9006	+350 V.	0	0		0		L				L
9	CR9006 and CR9007	+400 V.	0	0		0		L			L	L
10	CR9008 and CR9009	+400 V.	0	0		0		L				L
11	CR9009 and CR9013	+350 V.	0	0		0		L				L
12	CR9013 and CR9012	+260 V.	0	0		0		L				L
13	R9004 and R9003	+470 V.	0	0		0		L			L	L
14	R9003 and R9001	+240 V.	0	0		0		L			L	L
15	CR9002 and CR9004	+120 V.	0	0	0			L		H		L
16	CR9003 and CR9005	+120 V.	0	0	0			L		H		L
17	R9007 and CR9014	-24.5 V.	0	0				H				H
18	R9009 and T9002	+24 V.	0						0			
19	R9009 and K9002-2,-6	+25.4 V.	0						0			
20	TP9001	+700 V.	0	0		0		L			L	L
21	TP9002	+275 V.	0	0	0			L		L		L
22	TP9003	115V 400Hz	0				0		0			
23	TP9004	-14 V.		0				H				L
24	TP9005	+25.5 V.	0	0				L				
25	TP9006	0 V.										
26	TP9007	varies	0	L				L				L
	<u>RESISTANCE MEASUREMENTS</u>											
27	T9001 1 to 3	0.03 ohms		H								
28	T9001 orange to red	0.24 ohms										
29	T9001 brown to red	0.24 ohms										
30	T9001 gray to white	0.77 ohms										
31	T9001 blue to violet	7.75 ohms			H							
32	T9001 yellow to green	4.6 ohms				H						
33	T9002 brown to orange	0.55 ohms					H					
34	T9002 violet to gray	7.0 ohms										
35	T9002 yellow to blue	12.0 ohms										
36	L9003 red to brown	0.06 ohms										
37	L9002 red to brown	9.0 ohms										

Blank spaces are normal outcomes.

shown on the multimeter as specific voltages or resistance. All normal values can be expected to vary ± 10% of the nominal value (+0 to -20% for the transformer and coil resistances), thus the interpreted values are considered to exceed that normal range. Additionally, a "LOW" result is meant to include "0" and a "HIGH" result can include infinity, as in an open resistor. The resistance measurements of Table 5-2 are not included in Table 5-5 since no faults are inserted in the Transistor Adapter Assembly.

5.3 Planned Incorporation in ACTS

Simulation of the A9000 power supply in the ACTS is a straightforward procedure since the circuit simulation model is primarily a table of measurement results associated with possible faults. The circuit test measurements have been previously identified in the maintenance technical manual as the voltage and resistance measurements available to the technician. The present set of faults appears to be limited to those which can be readily induced or inserted in the hardware. Thus, it would seem desirable to increase the number of possible faults to include all component failures which would actually occur in field maintenance. Such additional faults might include transistor failures in the power oscillator circuits, and capacitor or resister failures in the rectifier/filter circuits.

Since it is desirable to have a high degree of correspondence between the simulated task and actual maintenance activities, a displayed circuit diagram is included in the ACTS simulation. The circuit diagram provides an interactive method of allowing the student to make circuit measurements. However, the full A9000 circuit diagram contains more detail than can be conveniently displayed. Therefore, a hierarchical display presentation is planned.

As illustrated in Figure 5-3, the complete A9000 diagram has been subdivided (by broken lines, ——— — — ———) to emphasize the physical location of components. Such a subdivision of the displayed circuit can be used to avoid an overly cluttered display. Thus, the trainee will view only a portion of the power supply circuit diagram at any one time. To view some other portion of the circuit, the trainee would actively request that portion of the circuit diagram. This hierarchical division of the circuit diagram will correspond to the separate sub-assemblies of the A9000 power supply. Thus, the trainee will move from one subcircuit diagram to another in a similar manner as moving from a circuit board to a transformer/inductor assembly. All circuit measurements physically located on the hardware subassemblies will be associated with the corresponding subcircuit diagrams.

The trainee will move a cursor around the display to indicate his desired measurement locations. However, measurement locations will not be displayed as unique points. Thus, the trainee must identify the measurement locations on the displayed diagram in a manner similar to locating measurement points on the actual hardware subassemblies.

Measurement results will be displayed as specific values, requiring the trainee to interpret the outcomes to determine whether they occur within the normal range. The fault model of the A9000 uses a table of specific measurement outcomes with the values being either low, normal, or high relative to the normal outcome. However, the specific displayed outcome will be generated by adding to the table-stored value an additional random value within the expected range of the outcome. This procedure will produce sets of randomly varying measurement outcomes that correspond to the measurement results obtained from actual hardware.

Given this circuit simulation, the ACTS provides the capability for circuit troubleshooting problems that can be used as an alternative to fault-isolation problems with actual hardware. The simulation does not require the time-consuming but fault-unrelated tasks of assembling and disassembling the receiver-transmitter. Thus, the simulated circuit has the advantage of encouraging faster problem solution, providing each trainee the opportunity for a large number of possible faults.

The ACTS includes not only the circuit simulation and fault model but also the decision models of the student and an expert technician. In the case of the Heathkit power supply simulation, the decision model focused on the technician's evaluation of the usefulness of measurement outcomes. For the A9000 power supply, the technician's decision sequence includes not only choosing measurements but also selecting appropriate test instrument adjustments, determining the symptoms indicating a fault, and identifying the most probable fault. These portions of the decision task will be analyzed to develop a decision model that focuses on those dimensions of the decision that are considered to be critical in effective maintenance.

6. REFERENCES

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