AMRL-TR-67-140
VOL. I

# THE MAINTENANCE TASK SIMULATOR (MTS-2): A DEVICE FOR ELECTRONIC MAINTENANCE RESEARCH

## VOLUME I: APPLICATION AND OPERATION

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FOREWORD


This study was initiated by the Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, Aerospace Medical Division, Wright-Patterson Air Force Base, Ohio. It represents a portion of the exploratory development program conducted under Project 1710, "Human Factors in the Design of Training Systems," Task 171004, "Techniques for Training, Aiding, and Evaluating the Performance of Technical Tasks." Dr. Gordon A. Eckstrand was project scientist. This research was begun in April 1966 and was completed in April 1967.

This report covers part of the research conducted under Contract AF 33(615)-3966 by Applied Science Associates, Inc. Dr. John D. Folley, Jr. was principal investigator. Mr. John P. Foley, Jr. of the Technical Training Branch, Behavioral Sciences Laboratory, monitored the contract.

This technical report has been reviewed and is approved.


WALTER F. GRETHER, PhD
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## ABSTRACT

The MTS-2 was developed in response to a demand for a realistically complex, relatively low cost, reliable, substrate on which the tasks associated with electronic maintenance could be performed.  It provides the capability for collection of performance data on such tasks as front panel check-out, between and within stage troubleshooting, alignment, and remove-replace operations, with a minimum of interference with task performance.  A time based record of control manipulations, component exchanges, and test point tests is automatically printed.  In addition, the device provides a measure of capability for varying such equipment characteristics as front panel layout, type of controls and displays, type of internal circuitry, data flow configuration, etc.  Physically, the MTS-2 is composed of six relay racks which contain or support 96 solid-state circuit modules of 20 types, 85 controls and displays of 15 types, and all response sensing and recording equipment.

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# SECTION I

## INTRODUCTION

The maintenance task simulator-2 (MTS-2) was developed in response to a need for an equipment simulator to be used in the study of electronics maintenance tasks. Although paper and pencil tasks can simulate parts of actual maintenance tasks, particularly the cognitive parts, they probably eliminate many important contextual factors and certainly eliminate the perceptual-motor factors that bear on performance. On the other hand, many problems are associated with the use of live electronic equipment as a substrate on which the maintenance tasks of checking, aligning, trouble-shooting, and repairing are to be performed for study. Operational equipment designed to perform such functions as weapons control, computation, etc. when set up in the laboratory in order to achieve the controls necessary for research brings with it high initial cost as well as high maintenance cost. Such complex equipment tends to fail frequently, disrupting experimental control. And if the equipment is to be modified so as to permit reduced interference with task performance as a result of data collection activities, additional cost and failure likelihood is incurred. Finally, it is virtually impossible to adjust such equipment to the needs of the particular experimental study. Thus, either a new piece of equipment must be selected for each new study, or as is often the case, studies must be selected to be compatible with available equipment.

The MTS-2, an extensively modified and expanded version of the MTS-1 simulator described in AMRL-TR-64-99 dated October 1964, provides a realistically complex, relatively low cost, reliable substrate on which the tasks associated with electronic maintenance can be performed. It can be used to collect performance data with a minimum of interference and it provides a measure of capability for variation of equipment characteristics. The term "equipment characteristics" is used here to refer to those factors in maintenance tasks which are primarily a result of the particular equipment on which the tasks are performed and which are known (or suspected) to be potent in determining the quality (speed and accuracy, for the most part) of task performance. Examples of such characteristics are: data flow, tolerance requirements, number and arrangement of front panel controls, and availability of test points and of monitor outputs.

The MTS-2 is composed of six relay racks which contain or support all associated equipment. Three racks support a front panel on which a variety of controls and displays can be mounted in virtually any configuration (Figure 1). One rack contains only power supplies and equipment necessary for response sensing and recording (Figure 2). Two racks support a total of 96 modules containing solid state circuitry of 20 types (Figure 3). The modules are provided with screwdriver-adjustable controls and toggle switches, and each has two test jacks which serve as input and output check points (Figure 4). A patch panel permits interconnection of the circuit modules and control and display module (Figure 5) in a wide variety of ways.

When a front panel control is touched or released, when a test probe is inserted into one of the module test jacks, or when a module is removed or inserted in the system, a time based record is automatically printed on a paper tape (Figure 6).

The MTS-2 can be divided into two more or less separate functional entities: the equipment simulator, composed of the modules, front panel controls and displays and their interconnections; and the response sensing and recording equipment composed of a digital clock, a printer and associated control circuitry.

Figure 7 is a diagram of the relations among major MTS functional units.

On the diagram a signal beginning at point A on patchboard (all signals used in the MTS-2 are generated in modules) is patched to patchboard III which is internally connected to a module chassis. The signal at A then serves as an input to circuit module 1, the output of which is also internally connected to patchboard III. The output of module 1 is then patched to the input of module 2 on patchboard III and thence through module 2 and module 3 to patchboard II; then on to the control on the front panel; back to patchboard II; from patchboard II to patchboard I; and thence to display 1. Although displays can be connected directly to each other or to controls, circuit modules cannot be connected to each other directly; they must be connected through the patchboards.

Response recording is accomplished as follows: when a control is touched, that information is sent to the front panel sensing circuits which sense which control was touched and send the control name to the printer. At the same time the sense circuits also send a read command to the digital voltmeter (DVM) and an "action" to the printer. The DVM reads the input voltage from the control which has been touched and sends this "setting" information to the printer along with a print command. When the printer receives the print command, it prints the setting, the name, the action (control touch) and whatever time is currently on the clock. Since the clock runs continually except during a print cycle, the time since the beginning of the sequence or since the last element in the sequence can easily be identified.

If, instead of a control manipulation, the action is removal of a module, this information, along with the module name, is sent to the circuit module sense circuits. The action (module removal) is identified and this information sent to the printer, along with the module name. At the same time, the sense circuits send a read command to the DVM which in turn sends a print command to the printer which prints the name of the module, the action performed, and again, the time.
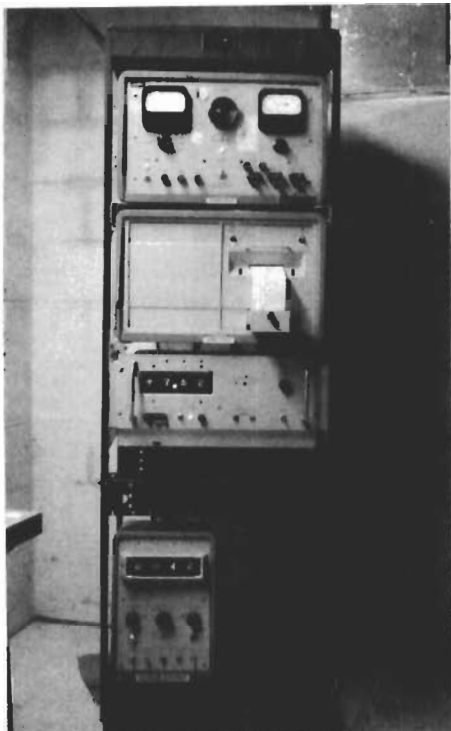
2

Figure 1. The MTS-2 front panel

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Figure 2. Power supplies and recording equipment.
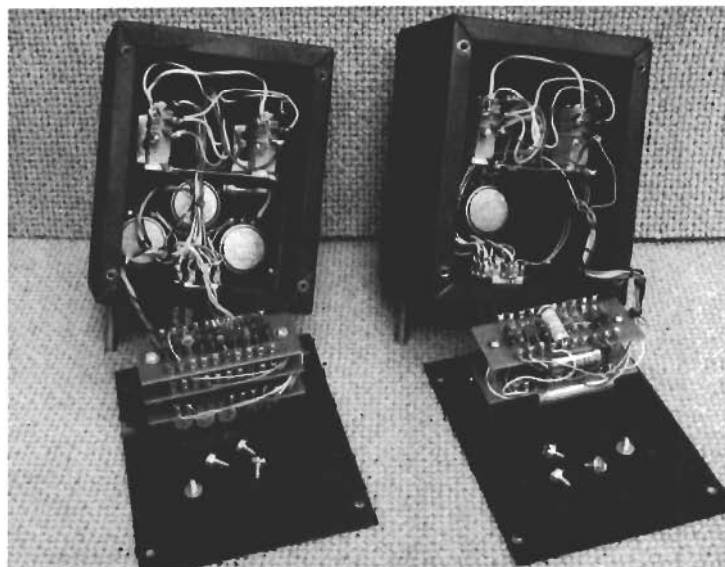


Figure 3. Module Cabinets

Figure 4. (upper and middle) MTS-2 circuit modules;
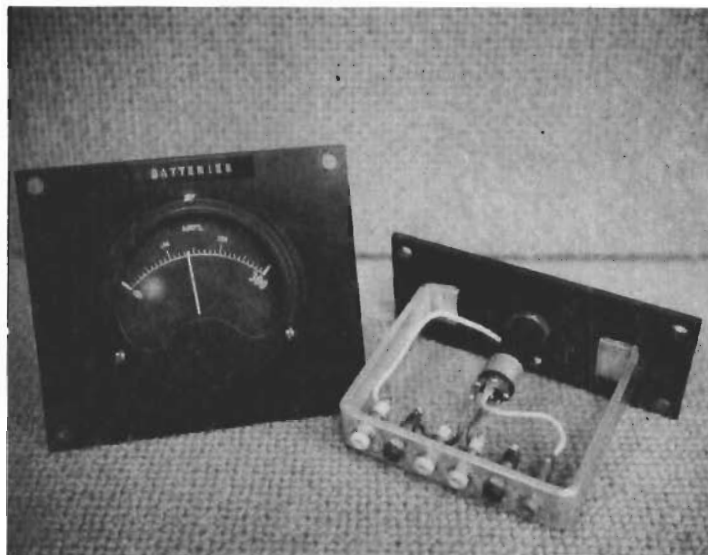(lower) example circuit boards.

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Figure 5. Front Panel Modules
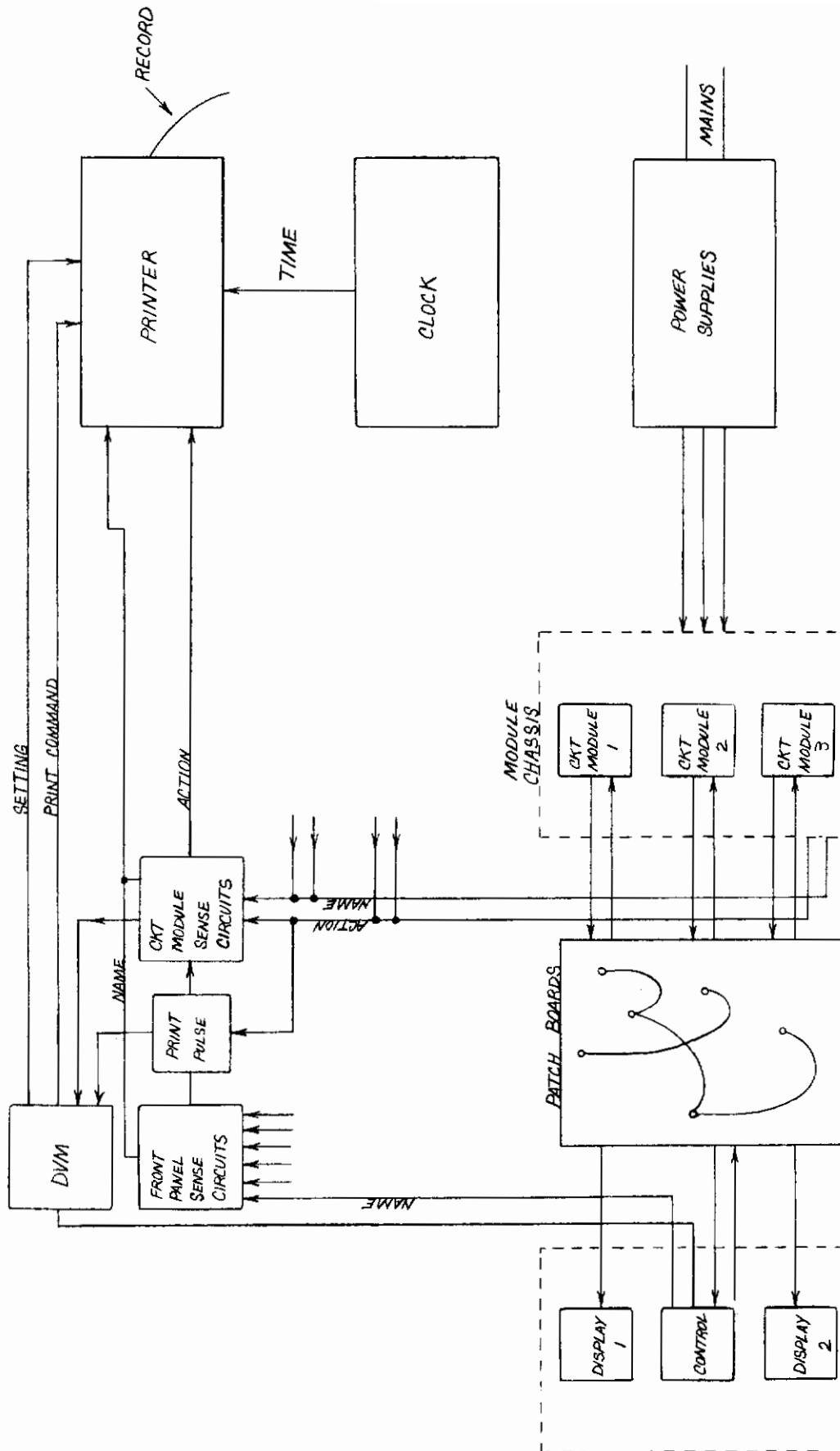


Figure 6. Performance Record Tape

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Figure 7. MTS-2 Functional Block Diagram

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SECTION II

APPLICATIONS AND OPERATION

The activities required in building a system into the MTS-2 are as follows:

1. System design. (selection of controls, displays, accessory units and circuit modules to be used, and design of interconnections)
2. Installation of the selected elements in the MTS-2.
3. Patching together the system elements.
4. Testing and adjustment.
5. Recording normal readings and system state.
6. Connecting response sensing and recording.

## System Design

The character of the equipment system built into the MTS-2 will necessarily reflect, both, the purposes for which the system is to be used, and the constraints imposed by the simulator's size and the number and character of the controls, displays, and circuit modules currently available.

The number and variety of system elements presently available for the MTS-2 makes it virtually impossible to describe all the ways the elements can be interconnected. The system designer is assumed to have sufficient technical knowledge to decide through reference to schematics of system elements which elements can be connected to each other and how it is appropriate to connect them. However, during design and construction of the elements and during generation of the first systems using them, many items of information were recorded which can be employed in designing new systems. Working within the constraints of the system designer's particular goals, the outcome will be a result largely of the designer's ingenuity; but familiarity with the materials which describe the system elements (and the application notes which deal with problems of interconnection) will be of value.

## Controls and Displays

| Item | Number Available |
| --- | --- |
| Voltmeter, sensitivity dependent on shunt | 3 |
| Light, 24v | 10 |
| Potentiometer, 10k ohm | 9 |
| Micropot, 5k ohm | 2 |
| Circuit Breaker | 3 |
| Circuit Breaker (Instrumented Dummy) | 5 |

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## Controls and Displays (cont'd)

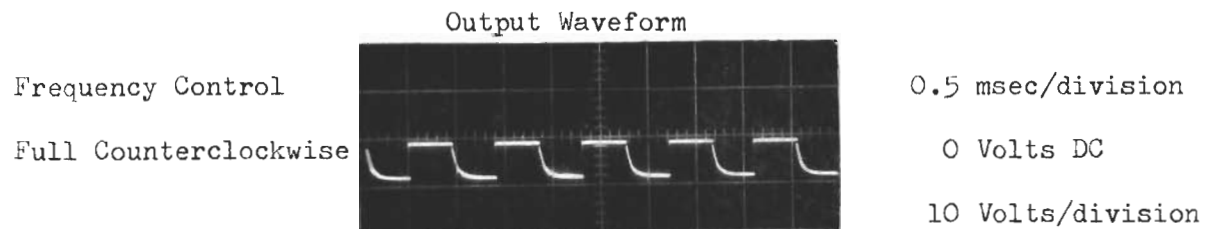| Item | Number Available |
|---|---|
| Toggle Switch, SPDT | 16 |
| Multiple Contact Rotary Switch, 3-13 contacts | 9 |
| Toggle Switch (Momentary) DPDT | 4 |
| Rotary Switch (Center-off Momentary), DPDT | 2 |
| Counter, 6 Digit | 2 |
| Push Button Switch, SPST | 5 |
| Push Button Switch (Lighted), DPST | 3 |
| Oscilloscope Dumont, 304AR | 2 |
| Total controls and displays | 75 |

Schematics will be found in volume II (see reference section).

## Circuit Modules

Below each brief description which follows, typical waveforms illustrative of circuit function are shown where appropriate. At the left of each output waveform the positions of module front panel controls associated with the illustrated waveform are indicated. At the right of each waveform, the 0-volt DC reference level is indicated, usually in the center of the vertical scale along with horizontal (upper) and vertical (lower) scale factors. The large squares are the division referred to by the scale factors. Thus, there are four vertical and ten horizontal divisions on the graticule. All measurements are made with a 10X attenuator probe.

Free Running, Variable Frequency Multivibrator - Module #100.
This circuit employs two transistors and two diodes, plus an emitter follower output stage to generate a symmetrical square wave. The output is variable in frequency from 800 to 1000 cycles per second by means of a control on the module front panel. It can be turned on and off by a toggle switch on the module front panel, or it can be controlled externally by applying negative 18 volts DC at the module's input. Three of these modules are available. The multivibrator output waveform is shown below:

Output Waveform



Frequency Control                                    0.5 msec/division

Full Counterclockwise                                0 Volts DC

                                                     10 Volts/division

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Bi-stable Multivibrator - Module #200. This multivibrator employs three transistors and three diodes plus an emitter follower output stage and produces a level change of 0.3 of 1 volt in response to a negative shift of 2 or more volts at its input. The rate of change at the output is one change of state per each input shift. Thus, if the input shifts occur at a coherent frequency, the output will appear as a square wave as seen in the input and output waveforms shown below. Four of these modules are available.

Input Waveform
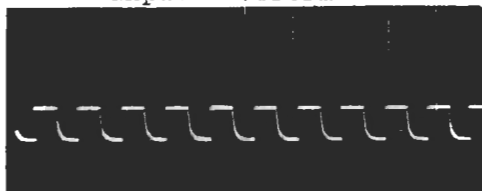


1 msec/division

0 Volts DC

10 Volts/division

Output Waveform

Reset - Down



1 msec/division

0 Volts DC

10 Volts/division

Variable Frequency and Variable Amplitude Sinusodial Oscillator - Module #300. The circuit in this module employs three transistors and a dual emitter follower output to provide a sine wave variable in frequency from 10 to 13 kilocycles per second by means of a front panel control. In addition, the output amplitude may be varied by means of a front panel control from 0 to approximately 6 volts peak-to-peak. The oscillator may be turned on and off either by means of external input or by a switch on the module front panel. Two of these modules are available. The output waveform is shown below:

Output Waveform

Frequency Extreme
Full Counterclockwise

AMP Extreme -
Full Clockwise



0.1 msec/division

0 Volts DC

5 Volts/division
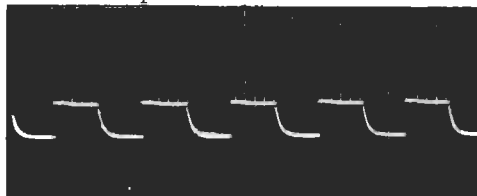
Triggered Mono-stable Multivibrator - Module #400. This multivibrator employs two transistors and four diodes, plus an emitter follower output stage, and generates a negative-going square wave, variable in width from 0.1 to 0.4 milliseconds. The input requirement is a negative 3-volt front. An output waveform with a typical input is shown below:
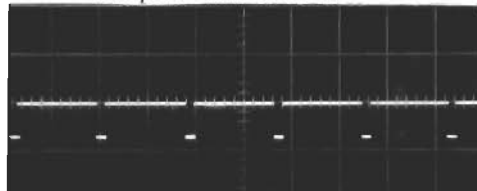
Input Waveform

.05 msec/division

0 Volts DC

10 Volts/division
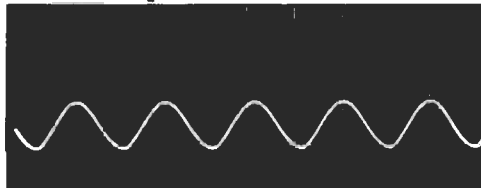
Output Waveform

Width-- Full
Clockwise

0.5 msec/division

0 Volts DC

10 Volts/division

Variable Threshold Schmidt Trigger - Module #500. This circuit employs two transistors plus an emitter follower output stage. It provides a constant output level for any input which exceeds a threshold. The threshold can be varied by means of a front panel control from minus 10 to plus 6.5 volts. A different output level is maintained for any input which fails to exceed the threshold level. Thus, for any input which varies above and below the selected threshold the output of the Schmidt Trigger will be a square wave of a width equal to the time between threshold passages. Four of these modules are available. Typical waveforms are shown below:

Input Waveform

50 usec/division

0 Volts DC

10 Volts/division

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Output Waveform

Trigger - Full
Counterclockwise

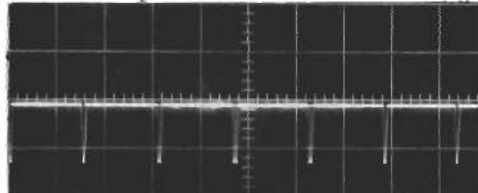50 usec/division

0 Volts DC

10 Volts/division

Variable Frequency and Amplitude Trigger Generator - Module #600.
This circuit employs a unijunction transistor and an emitter follower
stage and provides a negative-going 0.1 millisecond, 5-volt trigger
variable in frequency from 500 to 1500 cycles per second. Trigger amplitude
is variable by means of a front panel control between 0 and 5 volts, and
the circuit may be turned on or off either by means of external input or
by a front panel switch. Two of these modules are available. Typical
waveforms are shown below:

Output Waveform

AMP - Full Clockwise

0.2 msec/division

Frequency - Full
Clockwise

0 Volts DC

5 Volts/division

Electronic Switch - Module #700. This circuit employs a silicon-
controlled rectifier, one diode and one transistor to switch-on negative
18 volts at its output in response to a negative 2-volt level change in
its input. It may be reset to the off position by a toggle switch on
its front panel, providing that the input level is at that time more
positive than negative 2 volts. Five of these modules are available.

Variable Frequency Sawtooth Generator - Module #800. This circuit
employs a unijunction transistor and an emitter follower output stage
and provides a sawtooth voltage, variable in frequency from 625 to 2000
cycles per second by means of a module front panel control. It may be
turned on and off by external input or by a front panel switch. Two of
these modules are available. A typical output waveform is shown below:

Output Waveform

Frequency - Extreme
Counterclockwise
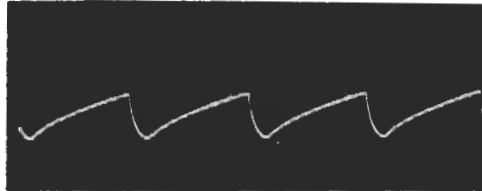
0.2 msec/division

0 Volts DC

10 Volts/division

RC Integrator - Module #900.  This circuit employs a single transistor
to produce at its output a waveform which represents the integral of
a waveform applied at its input.  Both the amount of integration of
the input waveform and the reference level of the output signal are
variable by controls on the module front panel.  Three of these
modules are available.  Typical waveforms are shown below:

Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Intg. - Full clockwise

Zero level - Full
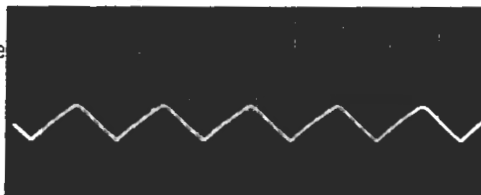Counterclockwise

0.5 msec/division

0 Volts DC

2 Volts/division

Output Waveform

Intg. - Full clockwise

Zero level - Midrange

0.5 msec/division

0 Volts DC

1 Volt/division

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RC Differentiator - Module #1000.  This circuit employs two transistors to produce a waveform which represents a derivative of the input waveform.  Both the degree of differentiation and the level of the output waveform are adjustable by front panel controls.  Seven of these modules are available.  Typical waveforms are shown below:
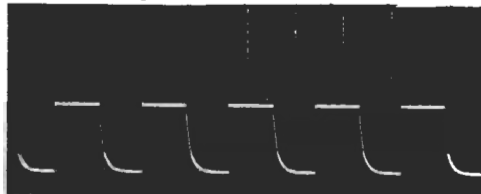
Input Waveform



0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Diff. - Full Counter-Clockwise

Level - Full Counter-Clockwise



0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Diff. - Full Clockwise

Level - Full Clockwise
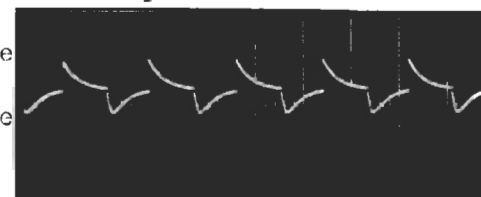


0.5 msec/division

0 Volts DC

5 Volts/division

Variable Gain Non-Inverting Amplifier - Module #1100.  This module contains a three-transistor amplifier having a maximum overall gain of 10 and a maximum swing of approximately five volts; gain is variable from zero by means of a front panel control.  Nine of these modules are available.  Typical waveforms are shown below:

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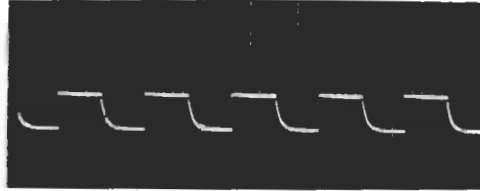
Input Waveform

0.5 msec/division

0 Volts DC

10 Volts/division

Output Waveform

Gain - Midrange

Bal. - Midrange

0.5 msec/division

0 Volts DC

10 Volts/division

Positive And Gate - Module #1200. This circuit employs five tran-
sistors and three diodes, plus an emitter follower output stage. It
produces an output level of negative 6 volts, only if both of its
inputs exceed negative 6 volts. Five of these modules are available.
Typical waveforms are shown below:
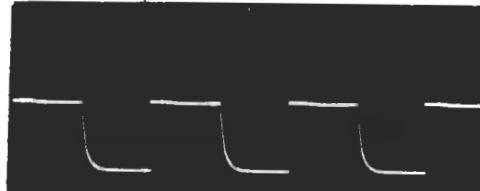
Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Auxiliary
Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform



0.5 msec/division

0 Volts DC

5 Volts/division

Adder - Module #1300.  This circuit employs one transistor to produce an output which represents the algebraic sum of two inputs. The gain of both input circuits is individually controllable by means of controls on the front panel.  Six of these modules are available. Typical waveforms are shown below:

Input Waveform



0.5 msec/division

0 Volts DC

5 Volts/division

Auxiliary
Input Waveform



0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Gain I - Full Clockwise

Gain II - Full Clockwise



0.5 msec/division

0 Volts DC

5 Volts/division

Negative Clipper - Module #1400. This circuit employs a Zener diode and one transistor to produce an output exactly representing its input, except that the portion of the input signal which falls below the set clip level is absent. The clip level is adjustable from 0 to minus 5 volts by means of a front panel control. Seven of these modules are available. Typical waveforms are shown below:
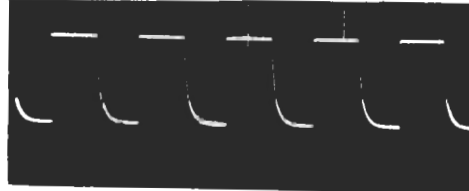
Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division
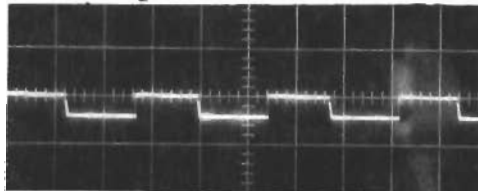
Output Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Positive Clipper - Module #1500. The positive clipper is identical to the negative clipper, except that the positive portion of the input waveform is clipped. Seven of these modules are available. Typical waveforms are shown below:

Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

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Output Waveform

Clip. Level - Full
Clockwise

0.5 msec/division

0 Volts DC

5 Volts/division

Attenuator - Module #1600. The attenuator employs one transistor
and associated circuitry to attenuate the amplitude of incoming signals.
Both the amount of attenuation, which varies between no attenuation and
complete attenuation (zero out), and the reference level of the output
signal are variable by means of module front panel controls. Nine of
these modules are available. Typical waveforms are shown below:
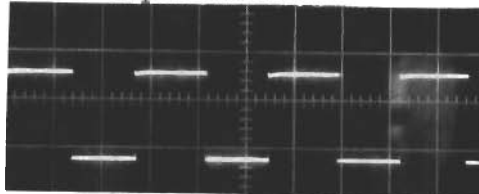
Input Waveform

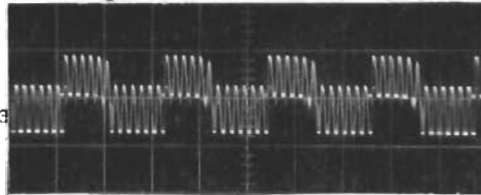0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

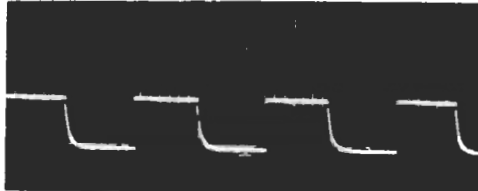Attn. - Midrange

Level - Full Clockwise
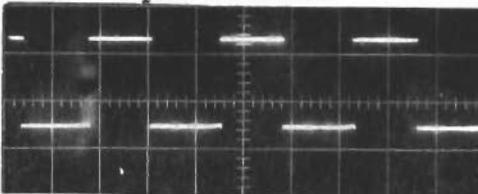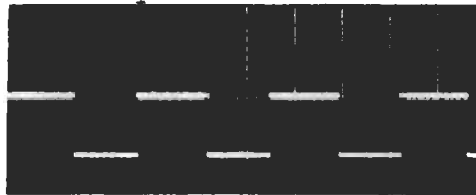
0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Attn. - Midrange

Level - Full Counter-
Clockwise

0.5 msec/division

0 Volts DC

5 Volts/division

<u>Variable Gain Inverting Amplifier with External Feedback - Module #1700.</u>
This amplifier employs four transistors to achieve an open loop gain of 70.
With a feedback resistance of approximately 2000 ohms, the gain, however,
is reduced to 2.5.  Front panel adjustments are gain, balance, and bias.
Nine of these modules are available.  Typical waveforms are shown below.

Input Waveform



0.5 msec/division

0 Volts DC

1 Volts/division

Auxiliary
Input Waveform
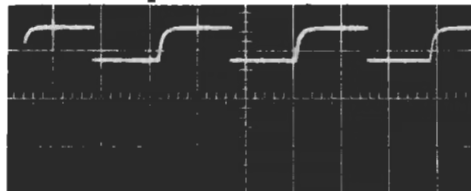


0.5 msec/division

0 Volts DC

1 Volt/division

Output Waveform

Gain - Max. Clockwise

Bias - Counterclockwise

Bal. - Minimum Distortion



0.5 msec/division

0 Volts DC

5 Volts/division

<u>Negative And Gate - Module #1800.</u>  This circuit employs four
transistors and three diodes, plus an emitter follower output stage.
It produces an output level of negative 6 volts, only if both inputs
are 0 Volts DC.  Three of these modules are available.  Typical waveforms
are shown below:

19
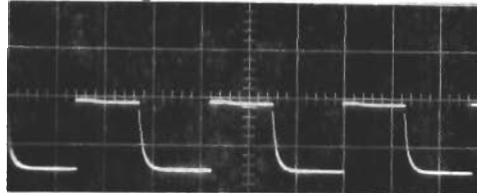
Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Auxiliary
Input Waveform
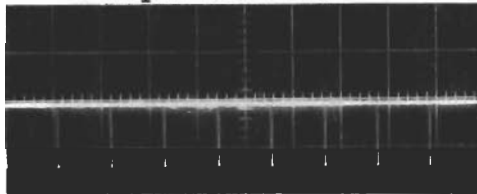
0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Signal Gate - Module #1900.  This circuit employs two transistors and permits one signal to be used to turn another on and off.  The gate threshold level is adjustable by front panel control.  Five of these modules are available.  Typical waveforms are shown below:

Input Waveform

0.5 msec/division

0 Volts DC

5 Volts/division

Auxiliary
Input Waveform
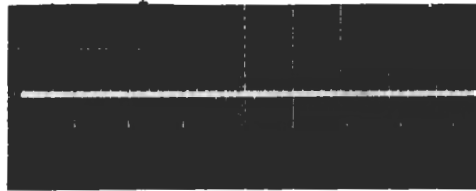


0.5 msec/division

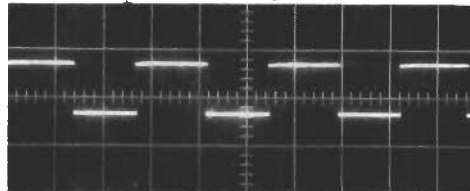0 Volts DC

1 Volt/division

Output Waveform

OFF level - Full
Clockwise
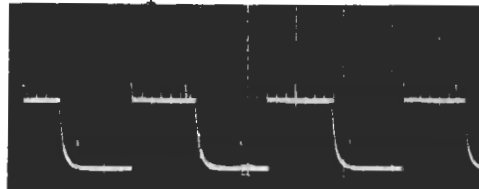


0.5 msec/division

0 Volts DC

5 Volts/division

Level Shifter - Module #2000.  This circuit employing one transistor permits the reference level of an input signal to be varied between plus and minus 17 volts DC without change in waveshape or amplitude.  Seven of these modules are available.  Typical waveforms are shown below:

Input Waveform



0.5 msec/division

0 Volts DC
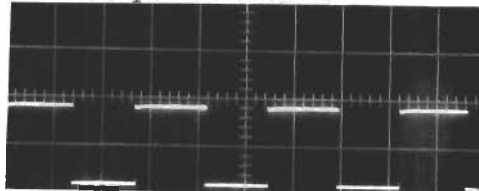
5 Volts/division

Ouput Waveform

Level - Midrange



0.5 msec/division

0 Volts DC

5 Volts/division

Output Waveform

Level - Full Counter-
Clockwise
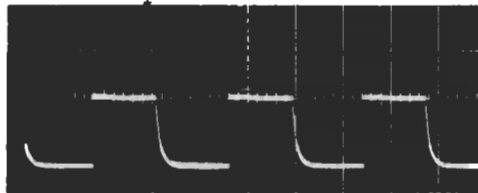


0.5 msec/division

0 Volts DC

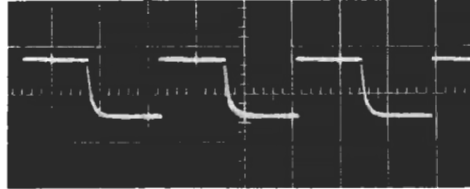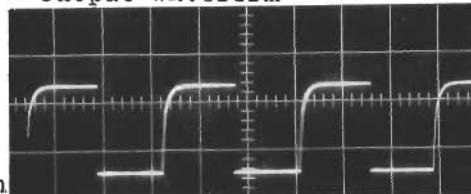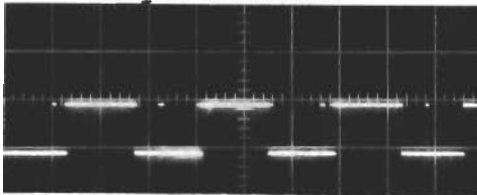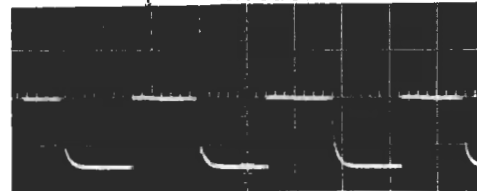5 Volts/division

Lamp and Relay Drive - Module #2100. This circuit employs a negative 2-volt input to control the application of a load on the auxiliary power supply module #2000. The lamp and relay driver schematic contains a block diagram demonstrating the manner in which modules are connected to effect the control. Seven of these modules are available.

Full Wave Bridge Rectifier and Regulator - Module #2200. This module employs 4 diodes in bridge configuration, a series regular transistor and Zener diode to provide -24.5 volts at up to 1 amp with a maximum of 0.5 volt peak to peak ripple. It is used in the system as an auxiliary power supply to operate lamps and relays. Two of these modules are available.

Blank - Module #2300. Modules of this type are identical to all other modules, except that they contain no circuitry between input and output. They may be used as dummies to fill unused module locations in the system, but their intended function is to serve as a receptacle for circuitry which might later be necessary but unavailable. Nine of these modules are available.

Accessory Units

In addition to the controls and displays and circuit modules, three accessory units are available to operate circuit modules or front panel elements: (1) a time delay variable from zero to 5 minutes, (2) a bistable switch, and (3) an electrically reversible motor driven pot with adjustable speed. These accessory units are permanently mounted inside cabinet 3 (Figure 9) and have no external test points. Figure 8 shows one of the ways these units can be connected.

Referring to Figure 8, momentary depression of the "Standby Switch" brings the bistable switch from neutral to a "zero" condition which lights the standby light and causes the time delay unit to begin delay. At the end of delay, the time delay monitor line comes up, lighting the ready light and enabling both the "radiate" switch and the tuning motor. When the radiate switch is depressed momentarily, the bistable switch unit switches to a "one" condition, disabling the tuning motor, re-setting the time delay and turning on the "radiate" light. The line to the radiate light can be used to drive other devices such as relays or lamps. Figure 8 shows the accessory modules in place in cabinet 3.
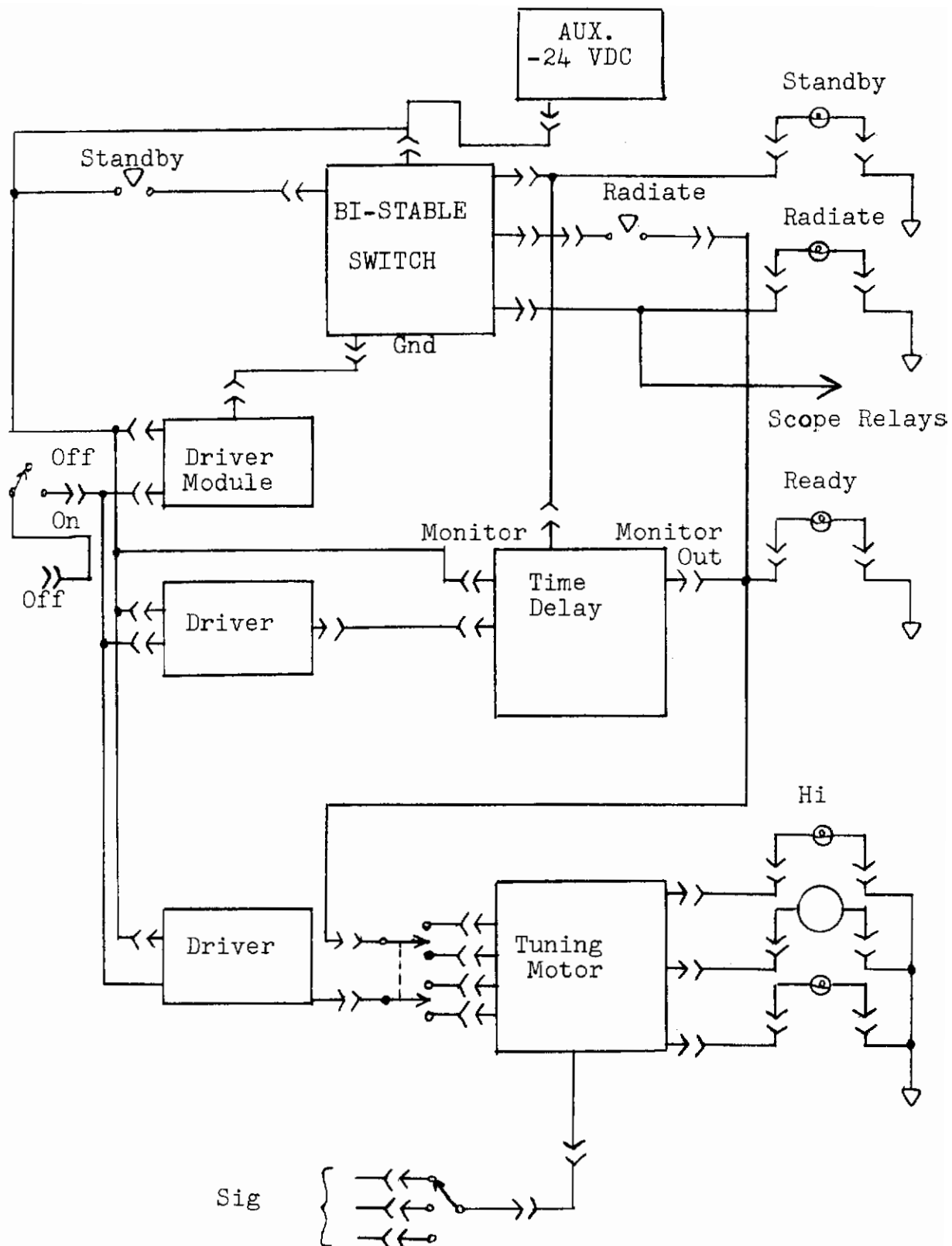
**Figure 8. Accesory Circuit Interconnection**

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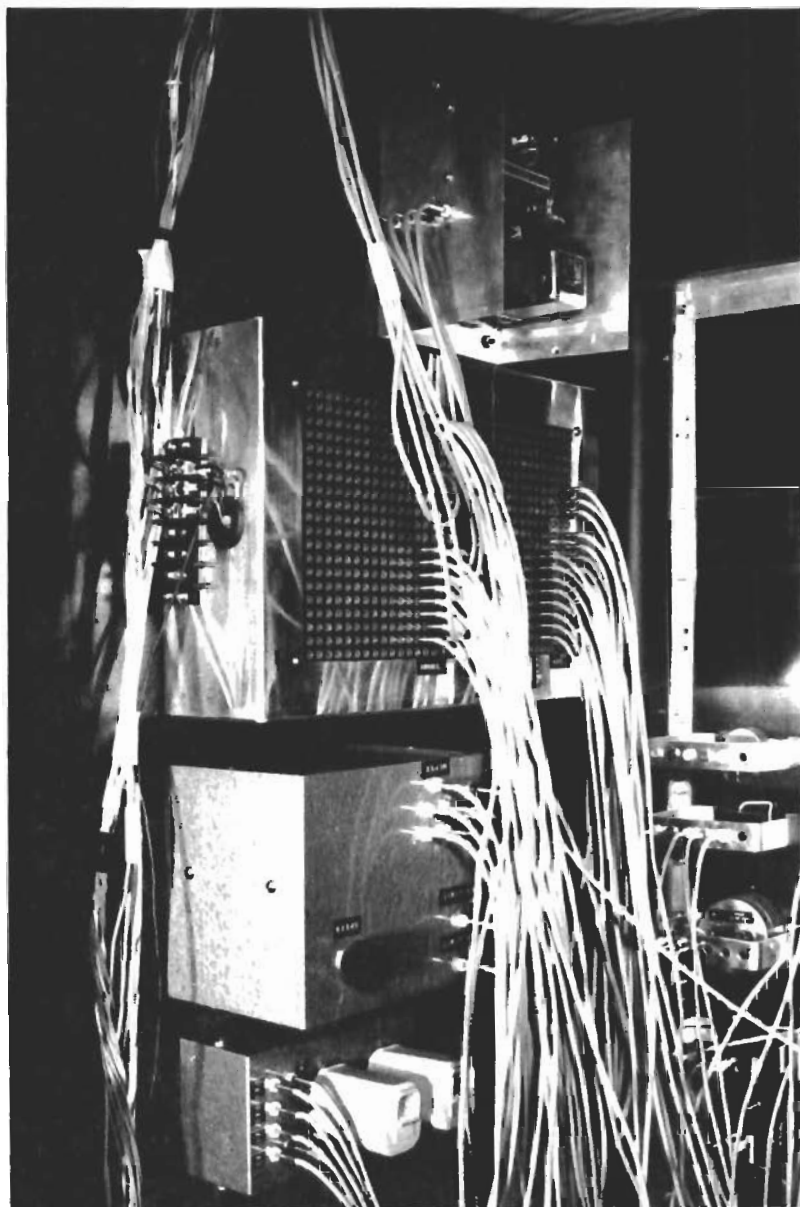
Figure 9. Patch Board and Accessory Circuitry

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# SECTION III

## INTERCONNECTIONS

### Application Notes

The information which follows is in the form of brief notes, each dealing with a particular objective or potential problem in interconnection. Occasional reference to schematics is made in the notes. These schematics will be found in volume II (see reference section). If it is desired to use one or more of the blank modules to produce additional copies of modules already available, construction notes are listed in appendix II of volume II.

1. Any circuit module input (Pin 7) may be connected to negative 18 volts or ground without damaging the module, although some circuits will not work when connected in this manner.

2. Any circuit module output (Pin 8) may be connected to ground without damage to the module.

3. The positive supply should not be connected either to circuit module inputs or outputs.

4. If the negative supply is connected to the output of any circuit module containing an emitter-follower, the emitter-follower transistor will be destroyed.

5. Occasionally distortion is seen in the output of the Schmidt Trigger (Module 500). This is usually corrected by following the Schmidt Trigger with one of the emitter-follower modules such as the adder, attenuator or level shifter.

6. Distortion or saturation of both the inverting and non-inverting amplifier is frequently produced by too large an input voltage. When this distortion cannot be eliminated by an adjustment in gain, bias, or balance controls; it may sometimes be eliminated by following the amplifier with an emitter-follower module. Care should be taken to see that gain of amplifier modules is kept low if they are to be series connected.

7. The level-shifter is generally most useful in shifting waveforms in a positive direction. The adder is generally most useful in shifting waveforms in a negative direction. This is accomplished by inserting -18 volts at the adder auxiliary input. Both of the above modules are useful in preceding negative and positive clippers and in setting an appropriate level for input to amplifiers.

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8. The positive and negative and gate circuit modules are best driven by the monostable multivibrator or the bistable vibrator. This is particularly true if gates are to be cascaded.

9. In addition to its function in changing waveshapes, the integrator module will be found useful as a meter-drive circuit. Depending upon the sensitivity of the meter, it may be necessary, however, to interpose either an amplifier or an attenuator between the integrator and the meter.

10. Variable time delay may be achieved by inverting the output of the monostable multivibrator so that the trailing edge of its waveform may be used to trigger a following circuit. Time delay is then controlled by variation in the width control on the monostable multivibrator module.

11. The inverting amplifier has a strong tendency to oscillate when feedback is too low, and most particularly when input amplitude is too high. This tendency is reduced somewhat if, instead of an attenuator module, a variable resistor is used in the feedback loop.

12. Both the sawtooth generator and the free-running multivibrator may be synchronized by inserting on their auxiliary inputs the amplified output of the trigger generator. Synchronization of these two modules is necessary when it is desired to mix their outputs. Trigger generator frequency should be set slightly higher than the frequency of the sawtooth generator. Both of these adjustments are quite critical but stable once obtained after 15 minutes warmup.

13. Occasionally, the output of the trigger generator will appear at considerably reduced amplitude in the output of other modules to which it is not connected. This can frequently be corrected by changing the location of the trigger generator in the system.

14. The latching switch is used primarily to turn signal generator modules on in response to a MTS front panel control movement. Note carefully on the latching switch schematic that full supply voltage should not be applied to the input of the switch. Note also that the latch must be reset and the input to the latch must be removed in order to turn off the controlled module.

15. The auxiliary power supply module was provided so that lamps and relays associated with the front panel circuitry might be operated at 24 volts DC. This permits the regulated plus and minus 18 volt supplies to operate within a good load safety factor. Lamps and relays may be operated directly from the auxiliary supply or indirectly through the use of a driver module. The method of connection of the driver module is shown on that module's schematic. Note that it can be used only with the auxiliary supply.

16. It will frequently be necessary to change front panel meter shunts to provide the desired meter range.

17. Additional notes on interconnection of scope, accessory units, and other modules are shown on their schematics in volume II (see reference section).

18. Though the attempt was made in design of the system elements to reduce the probable consequences of errors in interconnection, by fusing, series resistors, etc., some care is still required. Before making a contemplated connection, the schematics of both units should be checked to determine what the effect of the connection is likely to be in terms of component and power supply loading.

## Interconnection Diagram

Prior to installation of system elements, an interconnection diagram should be prepared to serve during design as a control document and later as a reference aid in maintenance. A block diagram such as the one shown in Figure 10 is useful. Initially the diagram shows only blocks containing module type numbers and interconnections. As the installation of elements proceeds, locations can be written above the boxes, and control and display names added. Patchboard termination points are added later, along with such other information as may be needed, e.g. critical adjustments, waveshapes, etc.

## Installation of Circuit Modules and Front Panel Elements

Working from the interconnection diagram, the operator should plug in the circuit modules and record their locations. Locations are numbered from 1 to 8 on each module chassis, thus "7-5" would indicate position 5 on module chassis 7. Modules with more than one input or more than one output must be installed on module chassis 9 through 12 in cabinet 5.

The space for front panel control and display modules is laid out in units 2-1/16" high by 4-13/16" wide. On cabinets 1 and 3, the front panel provides 4 columns, each 16 units high. On cabinet 2, the front panel provides, from top to bottom: a blank space of 4 by 4 units for mounting oscilloscopes; 4 columns, 5 units high; and a 4 by 4 blank space for scopes; 4 columns 3 units high. With the exception of the oscilloscope, all control and display modules are either one or two units high and one unit wide. They are attached to the front panel by screws at each corner.

After the front panel elements to be used are installed, unused spaces should be filled with blanks. These are available in one or two unit high by one unit wide sizes. Modules are labeled with such legends as are required, using a tape writer. Care should be taken to insure a clean module surface if tape is to adhere. Also, it is well
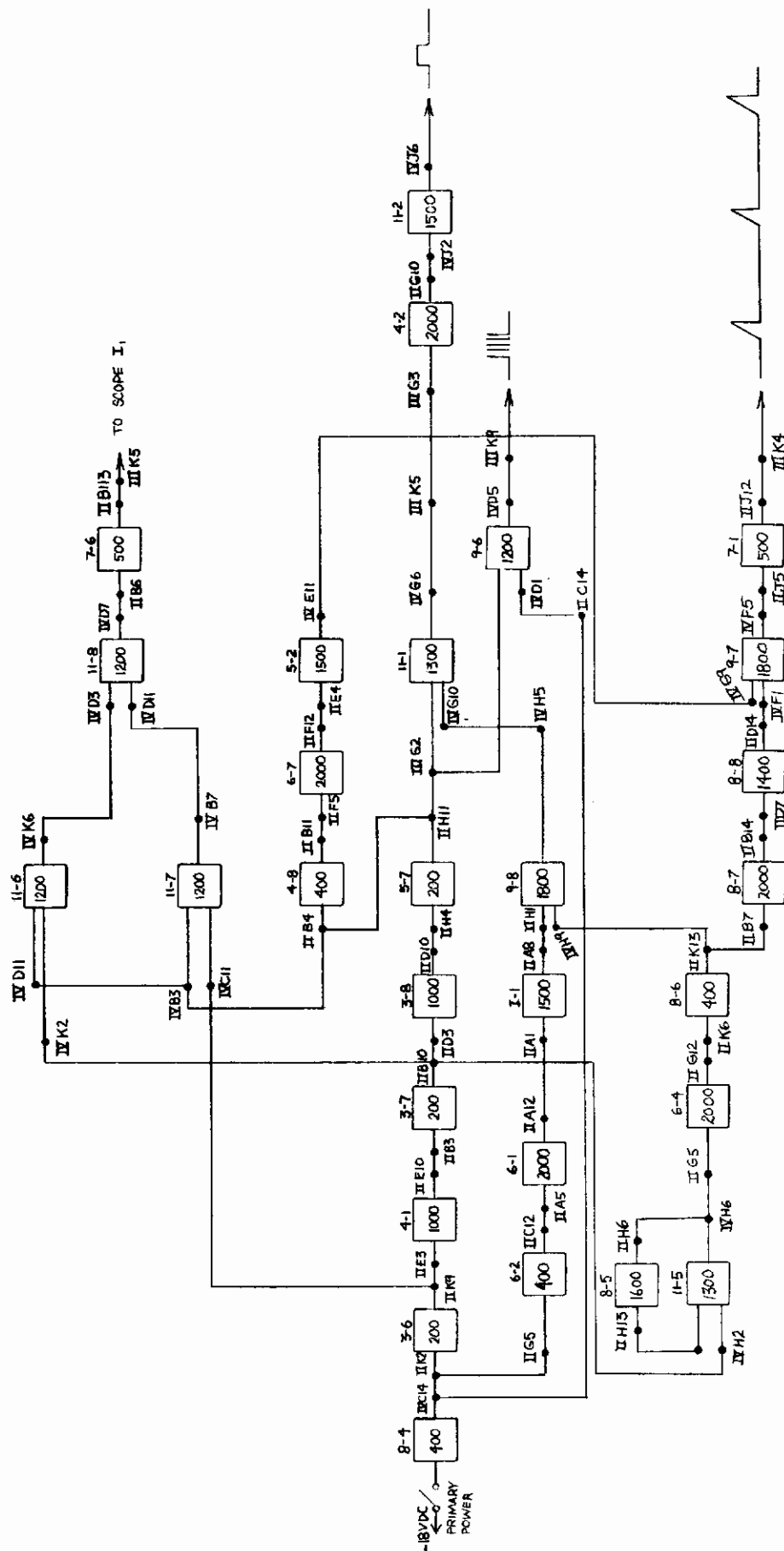
Figure 10.   Example Interconnection Diagram

to avoid pieces of tape less than 1/2 inch in length. A diagram of front panel space will be useful for organizing the installation of the modules and may have some use later in designing check procedures, although ideally, check procedures are designed before installation of front panel elements.

## Patching

Four patchboards on the outside of cabinet 3 provide for interconnection of modules and front panel elements. All circuit module inputs and outputs terminate on patchboards III and IV. Patchboards I and II reflect point for point identical patchboards located inside cabinets 2 and 3. Thus, a connection between a circuit module and a front panel element requires a patch from the element to the patchboard inside its cabinet and a patch from the appropriate patchboard on the outside of cabinet 3 to the appropriate point on patchboard III (or IV, depending on the location of the module). All connections are made with standard 40-inch flexible patch cords with identical pin jacks at each end.

All patchboards are divided into sectors having 4 plugs. Sectors are lettered horizontally and numbered vertically. Patchboards I and II and their internal reflections have A-K by 1-16 sectors. Patchboard III has A-K by 1-14 sectors and patchboard IV has A-K by 1-12 sectors. "I" is omitted from the A-K lettering in every case. IIJ7 then, identifies the sector at J by 7 on patchboard II.

Once system elements have been installed, the patchboard termination of the modules (tabled in appendix I of volume II) should be added to the interconnection diagram (p. 28) to serve as a guide in patching. Control and display modules and accessory units (time delay, etc.) should be patched to the internal patchboards and their terminations recorded. Patch wires should be installed with system power off due to the possibility of dangling wires touching cabinetry which is at ground potential.

## Recording Normal System Conditions

When testing and adjustment of the completely wired system are complete, the lock nuts on the circuit module controls should be tightened and the patchboard wires harnessed. A photographic record should be made of the signal at each test point in the system along with settings of front panel controls or circuit module switches which might affect the signal. The record can be placed on cards and filed by test point numbers. Such a card is shown in Figure 11. The record is necessary for system alignment, particularly after replacement of components in the circuit modules. It is also necessary when modules are replaced with spares, to adjust the controls on the spare to meet output requirements.
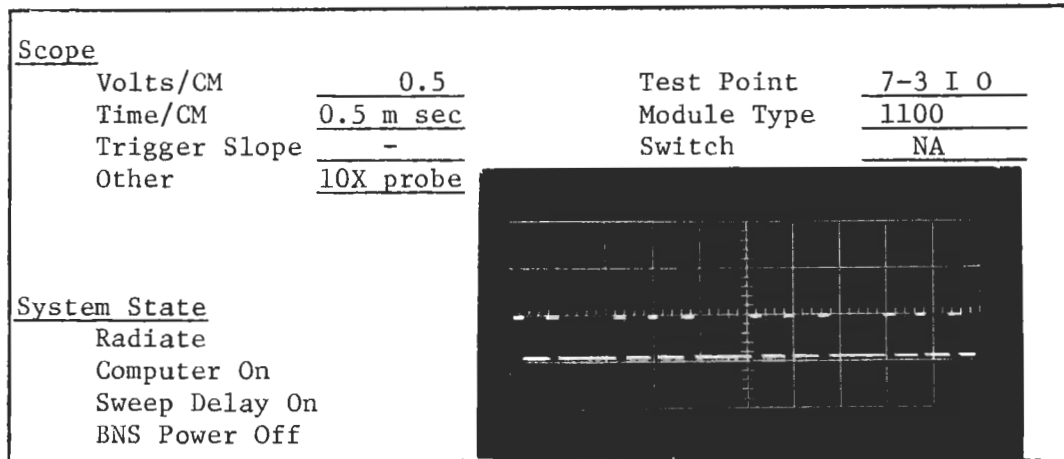
System 3966 Waveshapes



| Scope | | | | |
|---|---|---|---|---|
| Volts/CM | 0.5 | | Test Point | 7-3 I 0 |
| Time/CM | 0.5 m sec | | Module Type | 1100 |
| Trigger Slope | - | | Switch | NA |
| Other | 10X probe | | | |

System State
    Radiate
    Computer On
    Sweep Delay On
    BNS Power Off

Figure 11.    Example System Waveshape
Record Card

## Response Sensing and Recording

Since the sensing of activities performed on the circuit modules
is built in, no further connections are required.  However, to sense
control manipulation, a patch cord must be connected from the white
jack on each control module to a white jack on the sense chassis in its
cabinet.  At this point, a check should be made for continuity between
the control knob and the white jack.  If absent, continuity can be
restored with a conductive point such as is available for printed circuit
repairs, but be sure the knob's set screw is pointed.  If it is also
desired to sense control position, a patch cord must be connected from
the green jack on each control module to the green jack immediately
adjacent to the white jack to which the control is connected on the sense
chassis.  The control names (identification numbers) should then be deter-
mined and recorded by operating each control and examining the printed
tape.  Module location identification numbers are tabled in appendix I
of volume II (see reference section).

Each print of the tape contains 10 digits.  From left to right, the
first four digits represent time in 10th of seconds.  Note that the
counter stops for approximately 0.1 second during each print cycle so
that time obtained from the counter is not "real" time.  But if the
number of prints per real time unit is small, less than 10 prints per
minute on the average, the discrpenacy between real time and counter
time is of no consequence.

The digit in the 5th column on the tape (shown as a blank column
in Figure 6) tells what action was performed on the MTS.  A "-" indi-
cates a front panel control touch or release; a "0", an input check
on a module; a "1", an output check on a module; a "2", removal of
a module; and a "3", installation of a module.  The digits in columns
6, 7, and 8 are the DVM reading.  The decimal in the DVM reading point

is not shown and is usually of no interest, since once an experiment begins its location need never be changed. The digits in the last two columns are the code name of the control module or circuit module on which the recorded action was performed. Thus, there may be a control and a circuit module with the same identification number. They are easily discriminated, however, by use of the information in column 5.

## MTS-2 Operation

During use, the MTS-2 is monitored from the master control panel. Fusing indicators for the major units are found on this panel as well as go-no go lights to assure that all power supplies and recording apparatus are turned on. The interlock lamp on the panel lights whenever a module is removed from the system and stays on as long as a module is out. If for any reason (except power supply failure) a print should fail to occur at the appropriate time, a bell behind the master control panel rings. The panel also has a main power switch which will remove all power from the MTS-2 in case of fire or other disaster.

1. <u>Normal Turn On Procedure</u> (all switches on master control panel)

Verify recording apparatus and power supply normal control positions, then:

|     |              |               |
| --- | ------------ | ------------- |
| 1.  | Main power   | "on"          |
| 2.  | Filaments    | "on"          |
| 3.  | Printer      | "on"          |
| 4.  | DVM          | "on"          |
| 5.  | Counter      | "on"          |
| 6.  | QB-1         | "on"          |
| 7.  | QB-2         | "on"          |
| 8.  | PS-C         |               |
|     | after 30 sec.| "on"          |
| 9.  | HV           | "on"          |
| 10. | Print        | "on"          |

2. <u>Recording Apparatus and Power Supply Normal Control Positions</u> (all controls on respective units)

### Counter

1. Power, "on"
2. Manual Gate, "count"
3. Gate Selector, "manual"
4. Input Sensitivity Control, Mid-position

### Digital Voltmeter

1. Power, "on"

2. Sampling Control, "ext" (switch at extreme clockwise
   limit of rotation)
3. Range Switch, "hold" (Range set at + . . . by
   alternately operating Range Switch to Step position
   then releasing it until proper range is set.)

Printer

1. Power, "on"
2. Spacing Control, "2"
3. Record Switch, "on"

Filament Transformer - Power, "on"

Low Voltage Power Supply QB-1 - Power, "on"

Low Voltage Power Supply QB-2 - Power, "on"

High Voltage Power Supply

1. AC power, "on"
2. HV, "on"


The component and voltage checks below should be performed at the end
of each 100 hours of operation to verify proper functioning. Recording
channels should be checked at the same time by exercising each one at
least once. This can usually be combined with verification of system
waveshapes and levels which should also be done at 100 hour intervals.
One who is experienced in so doing can perform this complete system check
in 1 to 2 hours.


3. Component Check

To Check Counter:

1. Set controls to normal settings - indicators should
   show counting 1 count/0.1 sec.
2. Depress Record Switch on printer - Gate lamp should
   blink off, then on as printer prints.
3. Depress Count Switch - count stops. Press reset button -
   indicators reset to 0000.
4. Rotate Display time Control fully CCW. Set Gate Selector
   Switch to 0 sec. Input Sensitivity Control to Check
   position (Switch at CCW Extreme) - Counter should
   read 60.
5. Reset Controls to normal positions.

To Check Digital Voltmeter:

1. Set controls to normal positions.

2. Set Range Switch to Auto Set Sampling Control out of EXT, but fully CW. Depress Calibrate Button. Meter should read +7.43V + 0.05V.
3. Reset controls to normal positions.

To Check Printer

1. Set controls to normal positions.
2. Depress Record Switch completely - printer should print rapidly.
3. Reset controls to normal positions.

4. <u>Voltage Check</u> (all voltages measured at respective supplies)

| | |
|---|---|
| Thyratron B+ | 150 VDC + 5V |
| Thyratron Bias | -10 VDC + 2V |
| QB-1 Supply | 18 VDC + 0.5V |
| QB-2 Supply | -18 VDC + .5V |
| Gate Supply | +5.75 VDC + 0.5V |
| Latch Supply | -6 VDC + 1V |

SECTION IV

CONCLUSIONS

## MTS-2 Maintenance Tasks

Perhaps the most important function of the MTS-2 in its capacity as a research tool is that of providing a substrate on which maintenance tasks can be performed. It will be worthwhile as a final note to discuss briefly the ability of the device to provide simulation in the case of each of the maintenance tasks listed below.

Equipment Checkout Procedures - This task is generally performed following or in combination with a turn-on procedure. Its usual objective is to verify correct overall unit functioning. Equipment checkout procedures are characterized by rather numerous simple steps, although some procedures occasionally involve rather complex operations. In the maintenance context, equipment checkout procedures are generally performed in order to collect information which will lead to the diagnosis of a suspected or reported malfunction. The MTS-2 provides the capability for development of procedures of virtually unlimited length using a wide variety of controls and displays, and control-display relationships.

Adjusting and Aligning - These activities generally occur as part of, or subsequent to, an equipment checkout procedure. They involve the sequential or simultaneous adjustment of one or more controls to bring a system output within specified tolerances. Adjusting and aligning tasks are characterized by psychomotor coordination involving the simultaneous observation of a display and manipulation of a control. Like equipment checkout procedures, adjustment and alignment procedures are typically fixed in length, sequence and composition and controlled by a performance aid. The majority of MTS-2 modules exhibit from one to three operational controls on their front panel. This, together with the possibilities for module interconnection at the patch boards and front panel, provides extremely broad capability for adjustment and alignment procedure simulation.

Between-stage Fault Isolation - It is convenient to distinguish between the activities of troubleshooting between-stages and troubleshooting within stages because in the typical situations many differences exist in the behaviors required of the technician. Further, between-stage troubleshooting usually precedes within-stage troubleshooting. It deals with relatively large groups of components which can frequently be separated from each other by switches, connectors, or easily replaced assemblies or sub-assemblies. Test points are often available on the front panel or, at least, without a large amount of equipment disassembly.

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The 96 plug-in modules of the MTS-2 with their wide capability for inter-connection also provide capability for realistic task simulation in this area.

   Within-stage Fault Isolation - Within-stage troubleshooting is characterized by rather small groups of piece parts usually of the permanently installed (soldered in) type. Components, and, hence, signals are more richly interdependent compared with those at the between-stage level. Thus, it is considerably more difficult in the former case to make unequivocal statements concerning sequence and dependency of electronic function. The circuitry within the MTS-2 modules is actual circuitry. It is, therefore, questionable whether the word "Simulation" is appropriate to describe the device's capability in this area.

   Use of Common Test Equipment - This activity is associated with the information gathering part of the tasks of both between and within stage troubleshooting. Test equipment such as the oscilloscopes, volt-ohmmeters, signal generators, and transistor checkers have been used commonly in the studies of maintenance behavior on the MTS-2 done to date.

   Component Replacement - The word "Component" is used broadly to refer to replaceable elements at all levels, from the solder-in resistor, capacitor, etc., to large groups of pieces--assemblies, sub-assemblies, major units, etc. The activities associated with this task are highly dependent on the packaging of the equipment on which the task is being performed. The range of activities associated with component replacement in the MTS-2 includes soldering transistors, resistors, capacitors, etc. to terminals, installing point to point wiring, assembly and disassembly of small components using a screwdriver, wrench, pliers and other common hand tools, cleanup of terminals, and installation and removal of plug-in components.


## Applications to Date

   In addition to the pilot studies performed using the MTS-2 during its development (Reference 2) three studies have been performed and recorded (References 3, 4 and 5) and another is in publication. To date, studies have involved performance of all of the maintenance activities described above with the exception of alignment procedures. Their study in the future is anticipated.

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13. ABSTRACT

The MTS-2 was developed in response to a demand for a realistically complex, relatively low cost, reliable, substrate on which the tasks associated with electronic maintenance could be performed. It provides the capability for collection of performance data on such tasks as front panel check-out, between and within stage trouble-shooting, alignment, and remove-replace operations, with a minimum of interference with task performance. A time based record of control manipulations, component exchanges, and test point tests is automatically printed. In additiona, the device provides a measure of capability for varying such equipment characteristics as front panel layout, type of controls and displays, type of internal circuitry, data flow configuration, etc. Physically, the MTS-2 is composed of six relay racks which contain or support 96 solid-state circuit modules of 20 types, 85 controls and displays of 15 types, and all response sensing and recording equipment.

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| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Job performance aids research device | | | | | | |
| Training research device | | | | | | |
| Electronic tasks simulation device | | | | | | |
| Electronics training device | | | | | | |
| Task Analysis device | | | | | | |
| Electronic equipment simulation | | | | | | |
| Simulators | | | | | | |