# Models 172A, 173A <br> Instruction Manual 

Contains Operating and Servicing Information for the Models 172A, 173A Digital Multimeter


INSTRUCTION MANUAL
Digital Multimeter
Models 172A, 173A

INSTRUCTION MANUAL<br>Digital Multimeter<br>MODELS 172A/173A

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ILLUSTRATIONS


1-1. INTRODUCTION. The Models 172A and 173A Digital Multimeters are wide-range, generalpurpose measuring instruments, capable of measuring ac/dc voltage, ac/dc current and resistance. (See Table 1-1 for Specifications, Page 1-2).

1-2. FEATURES.
a. Automatic Ranging and Polarity.
b. Manual Range Selection and Range Hold.
c. HI and LO Ohms Capability.
d. Line Operation.
e. Optional Battery Operation, Model 1728.
f. Floating Capability to $\pm 1400 \mathrm{~V}$ peak.
g. Optional Isolated Digital Interface, Model 1722/1723.

1-3. WARRANTY INFORMATION. The warranty is stated on the inside front cover of the manual. If there is a need for service, contact your keithley representative or authorized repair facility as given in our catalog.

1-4. CHANGE NOTICE. Improvements or changes to the instrument not incorporated into the manual will be explained on a change notice sheet attached to the inside back cover of the manual.

1-5. OPTIONAL MODEL 1728 RECHARGEABLE BATTERY PACK. The Model 1728 is an accessory battery pack which enables either line or battery operation. The Model 1728 has builtin recharging circuitry. The Model 1728 is field-installed on the Model 172A/173A chasis.

1-6. OPTIONAL MODEL 1722 DIGITAL INTERFACE. The Model 1722 is a field-installable digital output option. It provides isolated open-collector BCD outputs and control lines.

1-7. OPTIONAL MODEL 1723 IEEE STANDARD 488 BUS INTERFACE. The Model 1723 is a fieldinstallable digital interface option that provides logic and control functions necessary to make the Model 172A or 173A bus compatible in accordance with the IEEE Standard 4881975. Refer to the Instruction Manual for Model 1723 for operation and service instructions for this option.

IMPORTANT
The $₫$ symbol can be found in various places in this Instruction Manual. Carefully read the associated CAUTION statements with regard to proper use and handling of the instrument. Damage to the instrument may occur if these precautions are ignored.
The
symbol can be found in various places in this Instruction Manual. This symbol indicates those areas on the instrument which are potential shock hazards. Carefully read the associated WARNING statements with regard to proper use and handling of the instrument. Serious personal injury may result if these precautions are ignored.

SPECIFICATIONS

| As an Auto/ | Aanging | ter |  |  | TEMPERATUAE |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| RANGE | Maximum READING | ACCURACY $[ \pm$ ( $\%$ of rdg + dtgita) ) <br> $\left(24 \mathrm{~h}, 25^{\circ} \pm 1^{\circ} \mathrm{C}\right)\left(6\right.$ monthis, $\left.20^{\circ}-30^{\circ} \mathrm{C}\right)\left(1\right.$ yeer, $\left.20^{\circ}-30^{\circ} \mathrm{C}\right)$ |  |  | $\begin{aligned} & \left(0^{\circ}-200^{\circ} \mathrm{C} \text { and } 30^{\circ}+53^{\circ} \mathrm{C}\right) \\ & \pm(\% \text { of rog }+ \text { digit }))^{\circ} \mathrm{C} \end{aligned}$ | $\begin{gathered} \text { INPUT } \\ \text { RESISTANCE } \end{gathered}$ | max. ALIOW. ABLE INPUT |
| 300 mv | 299.99 | $0.000 \%+1 d$ | 0.013\% + 50 | 0.015\% + 1d | $0.0010 \%+0.10$ | >1000Mด | 1200 V peak* |
| 3 V | 2.9990 | $0.006 \%+10$ | 0.013\% + 10 | 0.015\% + 10 | 0.0010\% + 0.10 | $>1000 \mathrm{mh}$ | 12000 peax. |
| 30 V | 29.929 | 0.009\% + 10 | 0.013\% + 10 | 0.015\% + 1d | 0.0015\% + 0.10 | OMA | 12000 peek |
| 300 V | 299.98 | 0.009\% + 10 | 0.013\% + 10 | 0.015\% + 1d | 0.0015\% + 0.10 | TOME | 1200V peak |
| 1200 V | 1200.0 | 0.009\% + 1d | 0.013\% + 10 | 0.015\% + 10 | 0.0035\% - 0.1d | 100m | 1200v peak |

NOTE: rdg means reading.
*Overioad on manual range not to exceed 600 volts continuous or 1200 V tor 3 seconds.
NORMAL MODE REJECTION RATIO: Greater than $80 \mathrm{~d} 日$ over 1 digit at 50 and
CONMON MODE REJECTION RATIO \{1kO unbalance\}: Greater than 120dB at dc and 50 Hz to 10 kHz .
ON RANGE RESPONSE TIME: Less than 0.8 second to within $0.1 \%$ of tinal reading.
As an Auto/Manual Ranging AC Voltmeter

Accuracy ( $0.3 \%$ to 100\% of Range: 1 Year, $20^{\circ}-30^{\circ} \mathrm{C}$ )

| RANGE | MAXIMUM AEADING | ( 50 Hz to 201 dHz ) | 20 Hz to 50 Hz (kMz to 100 kHz ) |
| :---: | :---: | :---: | :---: |
| 300 mV | 299.99 | $0.20 \%+6 d^{* \cdots}$ | 1.0\% + 20d |
| 3 V | 2.9999 | 0.20\% + 60 d | 1.0\% + 20d |
| 30 V | 29.999 | 0.20\% + 6d | 1.0\% + 20d |
| 300 V | 299.99 | 0.20\% + 6d | 1.0\% + 20d |
| 1000 V | 1000.0 | 0.25\% + 60 | 1.0\% + 200** |

Average responding calibrated in rms of a sine wave.


- $50 \mathrm{~Hz}=10 \mathrm{kHz}$
$\because 20 \mathrm{~Hz}-50 \mathrm{~Hz} \& 10 \mathrm{kHz}-20 \mathrm{kHz}$
*"With input shorted. display reads approxamataly 0.2 mV .
MAXINUM ALLOWABLE INPUT: 1000 V rms sine or de. $2 \times 10 \mathrm{~V} 0 \mathrm{~Hz}$.
ON RANGE RESPONSE TIME: Less than 1.3 second to within $0.05 \%$ of finad reading.
COMMON MODE REJECTION RATIO ( $1 \mathrm{k} \Omega$ Unbwance. Lo diven): Greater than 100 dB at de and 50 to 60 Hz . decreasing to 70 dB at 10 kHz . INPUT IMPEDANCE: 2 megonms shunted by less than 50 prcofarads.

As an Auto/Manual Ranging Ohmmeter

| RANGE | maximanm READING | ACCURACY ( 1 year, $20^{\circ} \cdot 30^{\circ} \mathrm{C}$ ) <br> $\pm$ ( $\%$ of rodg + algits) <br> H1 - mode - LO |  | maximum voltage ACROSS UNKNOWN ON RANGE* <br> HI - mode - LO |  | allowable 4-TERMINAL LEAD gESISTANCE | TEMPERATURE COEFFICIENT |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 300 ด | 299.99 | - | 0.035\% +10 | - | 03 V | $10 n$ | - - | 00034*0 19 |
| 3k $\Omega$ | 2.9999 | 0.035\% + 10 | 0.035\% + 10 | 3 V | 03 V | $100 n$ | $000034+010$ | 00034 +0 19 |
| 30 k ת | 29.999 | 0.035\% + 1d | 0.035\% + 10 | $3 V$ | 0.3 V | 1000 | 0.003w $+0.1 d$ | 0003\% + 0.18 |
| $300 \mathrm{k} \Omega$ | 299.90 | 0.035\% + 1d | 0.045\% + 10 | 3 V | 0.3 V | 1008 | 0.0034 - 0.16 | 2004*4+0 010 |
| 3M0 | 2.9999 | 0.05\% + 10 | 0.15\% + 1d | 3 V | 0.3 V | 1000 | 0.004\% - 0 1d | 002\% + 010 |
| 30 MR | 29.999 | 0.18\% + 18 | $0.8 \%+1 d$ | 3 V | 0.3 V | 1000 | $0.02 *+0.10$ | 0154-010 |
| $300 \mathrm{M} \Omega$ | 299.90 | 1.5\% + 10 | - | 3 V | - | 1000 | 0.15 t-0.0 |  |

ON RANGE RESPONSE TIME: Hi ohms below 1OMS: less than 0.9 second to within $0.01 \%$ of finat reading. 10M to t00M $\Omega$ and Lo ohms tess than 2.2 seconds to within $0.01 \%$ of final reading.

## CONFIGURATION: 4-terminal or 2-terminal, switch selected.

- Maximum open-circult voltage. 5 volts

MAXIMUM ALLOWABLE INPUT: 360 V peak, 250 V rms or dc.
As an Auto/Manual Ranging AC and DC Ammeter
(Modet 172A only)

| GANEE | maximum READING | DC ACCURACY (1 year, $20^{\circ}-30^{\circ} \mathrm{C}$ ) <br> $\pm$ ( K of $\mathrm{rdg}+\mathrm{dight}$ ) | $\begin{gathered} \text { AC ACCUAACY } \\ \left(\begin{array}{c} \text { Yoer, } 20^{\circ}-30^{\circ} C \end{array}\right. \\ 50 H 2-5 \mathrm{kHz} \\ \pm(\% \text { of rdg }+8 \mathrm{tightaf}) \end{gathered}$ | $\begin{aligned} & \text { INPUT } \\ & \text { RESIS- } \\ & \text { TANCCE } \end{aligned}$ | Fuse PROTEC. TION |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $300 \mathrm{MA}$ | $\begin{aligned} & 299.99 \\ & 20000 \end{aligned}$ | $\begin{aligned} & 0.25 \%+2 d \\ & 0.25 \%+2 d \end{aligned}$ | $0.5 \%+18 d$ $0.5 \%+18 d$ | $1.3 \Omega$ | $2 \mathrm{~A} .250 \mathrm{~V}$ |

"Self-heating effects of currents greater than 1 ampere can double \% of reading accuracy.

TEMPEAATURE COEFFICIENT $\left(0^{\circ}-20^{\circ} \mathrm{C}\right.$ and $\left.30^{\circ}-55^{\circ} \mathrm{C}\right)$ :
.DC: $\pm$ ( $0.005 \%$ of reading +0.2 digits $/^{\circ} \mathrm{C}$.
(Model 173A only)
$\mathrm{AC}: \pm(0.03 \%$ of reading +1 digit $) /{ }^{\circ} \mathrm{C}$.

| RAMGE | MAXIMUNA READING | DC ACCURACY <br> ( 1 yamr, $20^{\circ}-30^{\circ} \mathrm{C}$ ) <br> $\pm$ ( $\%$ of rdg + digits) | AC ACCURACY <br> (1 yoer. $20^{\circ}-30^{\circ} \mathrm{C}$ ) 50Mz-3 HMz <br> $\pm$ ( $\%$ of mose + digtta) | $\begin{aligned} & \text { INPUT } \\ & \text { PESIB } \\ & \text { TANCCE } \end{aligned}$ | $\begin{aligned} & \text { FUSE } \\ & \text { PGOTEC- } \\ & \text { TION } \end{aligned}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| 300 HA | 299.99 | 0.1\% + 20 | 0.3\% + 18d | 10n | 3A, 250 V |
| 3 mA | 2.9899 | 0.1\% + 20 | 0.3\% + 18d | 100 ก | 34. 250 V |
| 30 mA | 29.999 | $0.1 \%+2 \mathrm{~d}$ | 0.3\% + 18d | 10 h | 3A. 250 V |
| 300 mA | 299.98 | 0.1\% + 2d | 0.3\% + 18d | : 3 ก | 3A. 250 V |
| $3 \mathrm{~A}^{\text {. }}$ | 2.9999 | 0.1\% + 26 | 0.3\% + 18d | 040 | 3A. 250 V |

ON RANGE RESPONSE TIME:
DC: tess than 0.8 second to within $0.01 \%$ of final reading.
AC: less than 1.3 second to within $0.05 \%$ of final eeading.

## GENERAL

ZERO STAEILITY: Autozeroed to within accuracy specifications. $0^{\circ} \mathrm{C}-55^{\circ} \mathrm{C}$.
DISPLAY: Five . 43 inch LED digits, appropriate decimal position, function and polarity indication.
CONVERSION PERIOD; 320 milliseconds.
ISOLATION: Input LO to power line ground. greater than 1000 megohms shunted by approximately 300 picotarads. Maximum input between LO and power line ground, 1400 volts peak.
POLARITY: Automatic. minus indicated, plus implied.
FANGING: Automatic or manual. Upranges at 30000 , downranges at 2599.
OVERLOAD INDICATION: Blinks at and above $\pm 1200 \mathrm{~V}$ dc. 1000 V ac. Blanks last four digits above 29999 counts on all other ranges.
SELF TEST: Allows selt-test of functional operation on 30 volt ac and dc ranges, $30 \mathrm{k} \Omega$ ranges and 3 mA ac and dc ranges.
WARMUP: i hour to rated accuracy.
ENYIRONMENTAL L(MITS (without batteries Inslalled):
Operating: $0^{\circ} \mathrm{C}$ to $55^{\circ} \mathrm{C} .0 \%$ to $80 \%$ relative humidity up to $35^{\circ} \mathrm{C}$.
Storere: $\quad-25^{\circ} \mathrm{C}$ to $+65^{\circ} \mathrm{C}$.
POWER: 105 - 125 or 210-250 volts (switch selected), $50 \mathrm{~Hz}-60 \mathrm{~Hz}$ : 20VA. 90 110 volts available. Optional rechargeable battery pack.
CONNECTOAS: Input: Eanana jacks.
DIMENSIONS, WEIGHT: 85 mm high $\times 235 \mathrm{~mm}$ wide $\times 275 \mathrm{~mm}$ deep $(31 / 2 \mathrm{in} . x$ $91 / 4 \mathrm{in}$. $\times 103 / 4 \mathrm{in}$.) Net weight, exclusive of batteries, 2.3 kg ( 5 los .)
Model 172A Autoranging Digital Muitimeler.
Moded 1734 Autoranging Digital Multimeter.
Model 172A/1726 Autoranging Digitial Multimeter with Rechargeable Battery Pack.
Moded 172 A1722 Autormang Dightal Multimeter with Digital Interface.


FIGURE 1-1. Model 173A Front Panel.


FIGURE 1-2. Bottom View Showing Line Cord.


FIGURE 1-3. Tilt Bail Positions.


FIGURE 1-4. Dimensional Data

SECTION 2. INITIAL PREPARATION.

2-1. GENERAL. This section provides information needed for incoming inspection and preparation for use.

2-2. INSPECTION. The Model I72A/I73A was carefully inspected both mechanically and electrically before shipment. Upon receiving the instrument, check for any obvious damages which may have occurred during transit. Report any damages to the shipping agent. To verify the electrical specifications, follow the procedures given in section 6.

2-3. PREPARATION FOR USE. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ is shipped ready-to-use. The instrument can be powered from line voltage or from rechargeable nickel-cadmium batteries (when the optional Model 1728 Rechargeable Battery Pack is installed).
a. Line Power. The Model 172A/173A has an attached three-wire line cord which mates with third-wire grounded receptacles (NEMA 5-15P). The permanently installed line cord is stored by wrapping the cord around the base of the instrument as shown in figure 4.

## CAUTION

1This instrument has an internal line power selector switch that must be set to 234 V position for operation above 125 volts rms, $50-60 \mathrm{~Hz}$.

1. How to set the Internal Line Voltage Switch (S601). The Model 172A/173A has a two position slide switch located on the main circuit board. For operation above 125 volts, the switch setting and fuse must be changed. The top cover must be removed to gain access to the circuit board as described in MAINTENANCE section.

## WARNING

Disconnect the line cord before removing the top cover of the instrument. Line voltage is present at various points on the circuit board and represents a SHOCK HAZARD.

## NOTE

Optional line voltage range is available when wiring modifications are made to transformer T601 as shown on schematic 29145E.

TABLE 2-1.
Summary of Standard and Optional Line Voltages.

| Standard | Optiznal |
| :---: | :---: |
| 105 to 125 V rms | $90-105 \mathrm{~V}$ rms - Transformer wiring |
| 210 to 250 V rms |  |


flgure 2-1. Rear Panel Showing Current Fuse.
2. Line Fuse Requirement. The Model 172A/173A uses a single line fuse to protect the line-operated power supply. The fuse is a 3 AB or 3 AG , slow-blow type. Replace with $1 / 4$ ampere for 117 volts operation or $1 / 8$ ampere for 234 volts.

## IMPORTANT

Replace fuse with correct rating, otherwise, damage to the instrument could result.
3. How to Replace the Line Fuse. The fuse is installed on the main circuit board as shown in Figure 6-2 (Page 6-14). The top cover must be removed to gain access to the circuit board as described in Section 6 . Use Keithley FU-17 (1/4A) for 117 V ; $\mathrm{FU}-20(1 / 8 \mathrm{~A})$ for 234 V .

## WARNING

Disconnect the line cord before removing the top cover of the instrument. Line voltage is present at various points on the circuit board and represent a sHOCK hazard.

## CAUTION

1The fuse installed on the rear panel of the Model 172A/i73A is used only for current range protection. This fuse is not a line voltage protection fuse.
b. Battery Power. To operate the Model 172A/173A from batteries, the Model 1723 Rechargeable Battery Pack must be installed. The Model 1728 can be either field or factory-installed (at the time the Model 172A/173A is purchased).

## note

The Model 1728 Rechargeable Battery Pack can be installed by the user within the Model 172A/173A at any time. However, if the Model 1722 Digital Output is already installed, the Model 1728 cannot be used simultaneously.

1. How to Install the Model 1728 Rechargeable Battery Pack. The batteries furnisnea with the Model 1728 are already installed in the battery pack. The battery pack includes 7 rechargeable "C" cells (1.2V, 2 AMP Hr) and two 19.2 volt packs (sixteen 1.2 V cells per pack). See figure 2-3.
a) Check the fuses on the Battery Pack. Three fuses are used. All are 1 ampere, $3 A B$ or 3 AG , Siomio types, Keithley Part Ho. FU-10.
b) Check for proper installation of batteries in the Battery Pack. If replacement battery cells are to be installed, be certain to observe the proper polarity of the individual cells as shown in Figure 2-3.
c) To install the Battery Pack, turn the instrument over so that the bottom cover faces up. Loosen four slotted screws on the bottom cover. The screws are captive, that is they cannot be removed completely. Turn over the instrument with the top cover facing up, taking care to hold the top and bottom covers together. Carefully, remove the top cover to gain access to the printed circuit board. There is a connection between the top cover and the main circuit board which must be temporaril removed in order to free the top cover. Check to see that the four insulating spacers are in position on the circuit board as shown in Figure 2-3. Plug the two 5 -wire connectors ( $\mathbf{J 4 0 1}$, J402) into the mating receptacles ( P 401 , 3402 ) taking care to orient the connectors as shown. Place the Model 1728 in position on the spacers with the pack oriented as shown in Figure 2-3. Replace the connector from the top cover to the circuit board. Replace the top cover. Turn over tine instrument with the bottom cover facing up and tighten down the four slotted-head screws.


FIGURE 2-2. Model 1728 Rechargeable Battery Pack.

## WARNING

Disconnect the line cord on the instrument before the Battery Pack is installed. Line voltage is present at various places on the circuit board and is a SHOCK HAZARD.


FIGURE 2-3. Installation of Battery Pack.

TABLE 2-2.
Summary of Batteries Used in the Model 1728


CAUTION

1
The Model 1728 is shipped from the factory in an uncharged condition. Therefore, the pack should be installed in the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ and charged prior to use.
2. How to Check Batteries.
a) The Model 172A/173A has a built-in LO BAT indicator to permit easy determination of battery condition. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ also has an indivicuai test point on the bottom panel usually needed only for troubleshooting purposes (See figure 1-2).
b) The LO BAT indicator will be lighted when the Battery Pack goes be ormal operating voltage. When the indicator turns on, the Model 172A/173A shouio be switched to LINE or OFF to permit recharging of the Pack.
c) The test point may be checked at any time using the Model 172A/173A or other measuring instruments. The voltages are summarized in Table 2-3.

IMPORTANT
The instrument must be operated in BAT mode in order to obtain a valid battery condition at test point "A". This will ensure that the batteries are supplying power to the instrument. If the voltage is measured when the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ is operated in the LINE mode, a different reading may be observed since the batteries are being charged.

TABLE 2-3.
Summary of Battery Voltage Levels (BAT mode)

| Test <br> Point | Acceptable Battery Levels <br> Range |  | Recharge <br> Normal | Battery <br> Tested |
| :---: | :---: | :---: | :---: | :---: |
| "A" | $19 \mathrm{~V} \rightarrow+20.5 \mathrm{~V}$ | +19.2 | 19 V | BT 402 |

3. How to Charge the Batteries. The Model 1728 provides builtin recharging circuitry. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ must be connected to line voltage. Recharging occurs at the most rapid rate when the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ is set to OFF. Typically, the recharge time is 2.5 hours per hour of discharge. After the batteries have been fully charged, either turn the instrument on with the LINE switch (trickle charge condition) or disconnect the line cord to prevent overcharging of the batteries.

## CAUTION



Overcharging the batteries will raise the internal temperature of the battery pack and may shorten the life of the batteries.

## SECTION 3. OPERATING INSTRUCTIONS

3-1. GENERAL. This section provides information needed to operate the Model 172A/173A for measurement of voltage, current and resistance.

3-2. HOW TO SELECT POWER. The Model I72A/I73A may be powered from line voltage or rechargeable nickel-cadmium batteries (when the Model 1728 is installed). The Model l72A/ I73A has a built-in line-voltage power supply and power cord.

NOTE
The accessory Model 1728 Recharqeable Battery Pack may be ordered at the time of purchase of the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ or may be purchased and field-installed at a later time if so desired. The Model 1728 features plug-in wiring and, as a result, no modifications need to be made to the Model 172A/l73A chassis,
a. How to Operate from Line Power. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ can be powered from line voltage over four ranges from a minimum of 90 V rms to a maximum of 250 V rms. Table $3-1$ summarizes the line voltages permitted.

1. Set the internal line voltage switch to either 117 V or 234 V .
2. Plug the line cord into source of line power.
3. Depress LINE pustbutton.

NOTE
Power on will be indicated by a lighted display with one or more digits and measurement unit showing.

TABLE 3-1.
How to Set Line Voltage

| Range <br> Desired | Switch <br> SOOI | Transformer <br> Modification* |
| :---: | :---: | :---: |
| $90-105 \mathrm{~V}$ 117 V Yes * <br> $105-125 \mathrm{~V}$ 117 V No <br> $210-250 \mathrm{~V}$ 234 V No |  |  |

*For this range, the leads must be rewired. See Schematic 29145 E Sheet 3 .
b. How to Operate from Battery Power.

1. Install the Model 1728 Rechargeable Battery Pack. (See Section 2, page 2-3.)
2. Depress BAT pushbutton.
3. If LO BAT indicator is lighted, the battery pack must be charged a minimum of 16 hours to provide fully charged operation of the Model 172A/173A.

## NOTE

To charge the Model 1728, release both LINE and BAT pushbuttons and connect the line cord to line power. If it is desired to use the Model 172A/173A immediately, depress LINE. The Model 172A/173A will be useable for measurements although the battery charging rate is decreased considerably.
4. If the LO BAT indicator is not lighted in BAT mode, the model $172 \mathrm{~A} / 173 \mathrm{~A}$ may be used for measurements.

## NOTE

The Model 1728 is shipped from the factory in uncharged condition. Therefore the Model 1728 should be installed and charged prior to use. After the Model 1728 has been charged for at least 16 hours, the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ can be powered continuously for at least 6 hours.

TABLE 3-2.
Summary of Operation in LINE and BAT Modes

| Button Depressed | Condition of Instrument |  |  |
| :---: | :---: | :---: | :---: |
|  | Line Power Connected 1728 not installed | Line Power Connected 1728 installed | Line Power Not Connected 1728 installed |
| LINE | ON | ON Battery trickle charged. | OFF |
| BAT | OFF | ON <br> Batteryslowly discharged. | ON |
| NE I THER <br> LINE NOR BAT | OFF | OFF <br> Battery charged at maximum rate. | OFF |

3-3. HOW TO SELECT FUNCTION. Function is selected by means of four pushbuttons: $D C / A C$, $V, A$ and $\Omega$.
a. V. This pushbutton must be used with $D C / A C$ to select either $D C$ voltage or $A C$ Voltage.

1. $D C$ Voltage. Depress $V$. Release $D C / A C$.
2. $A C$ Voltage. Depress $V$. Depress $D C / A C$.
b. A. This pushbutton must be used with $D C / A C$ to select either $D C$ current or $A C$ current.
3. $D C$ Current. Depress $A$. Release $D C / A C$.
4. $A C$ Current. Depress $A$. Depress $D C / A C$.
c. $D C / A C$. This pushbutton selects whether the selected voltage or current function will be $A C$ or $D C$. When depressed, $A C$ is selected.
d. $\Omega$. Depress $\Omega$ to measure resistance.

NOTE
$V$, $A$, and $\Omega$ pushbuttons are interlocked so that only one pushbutton is depressed at a time. However, it is possible to have all pushbuttons out which disconnects the input HI and L 0 terminals and no measurement can be made. (The voits or millivolts indicator will be lighted in this instance.) $\Omega$ overrides DC/AC. $V$ or A overrides HI/LO and 2 WIRE/4 WIRE.


FIGURE 3-1. Front Panel Pushbutton Selection.

3-4. HOW TO SELECT RANGE. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ provides automatic or manuai ranging. The AUTO/MAN pushbutton determines the ranging mode, where AUTO $=$ fully automatic ranging.
a. AUTO. When released, the Model I72A/l73A automatically selects the appropriate range in accord with the following rules.

1. When the dispiay exceeds 29999 the Model 172A/173A upranges (that is, it changes to less sensitivity and the decimal point moves appropriately).
2. When the display reaches 02599 the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ downranges (that is, it changes to greater sensitivity and the decimal point moves appropriately).
b. MAN. When depressed, the range is placed to hoid. The user can cause the Mode! $17 \overline{2 A / 73 A}$ to uprange or downrange by using the UP RANGE and DN RANGE pushbuttons.
3. When DN RANGE is momentarily depressed, the Model 172A/173A will downrange one decade of sensitivity. Each time the pushbutton is depressed and released, one downrange will occur until most sensitive range is obtained.
4. When UP RANGE is momentarily depressed, the Model 172A/173A will uprange one decade of sensitivity. Each time the pushbutton is depressed and released, one uprange will occur until least sensitive range is obtained.

3-5. HOW TO MEASURE VOLTAGE. The Model 172A/173A measures ac and dc voltage in five ranges: $0.3 \mathrm{~V}, 3 \mathrm{~V}, 30 \mathrm{~V}, 300 \mathrm{~V}$ and 1200 V DC (1000VAC).

CAUTION
Maximum input voltage depends on the range selected. Table 3-3 gives the maximum allowable continous input for each range on $A C$ and $D C$. Do not exceed these voltages or damage to the instrument will occur.

TABLE 3-3.
Maximum Allowable Continuous Input

| Range | AC Voltage (ACV) | DC Voltage (DCV) |
| ---: | :---: | :---: |
| 0.3 V | 1000 V rms | 1200 V peak: |
| 3 V | 1000 V rms | 1200 V peak: |
| 30 V | 1000 V rms | 1200 V peak |
| 300 V | 1000 V rms | 1200 V peak |
| 1000 V | 1000 V rms | 1200 V peak |

*Overload on manual range not to exceed 600 volts continuous or 1200 V for 3 seconds.
a. $D C$ Voltage. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ detects dc voltages from $\pm 10 \mathrm{microvolts/digit} \mathrm{to}$ $\pm 1 \overline{200}$ volts ( 1200.0 display). The maximum display is 29999 . When the display exceeds 29999, a 3 remains lighted, but all other digits are blanked. The display blinks above 1199.9 volts on the highest range.

1. Set to DC Volts.
2. Set to AUTO.
3. Connect the Signal to be measured between $H$ l and $L O$ terminals. (The terminals are designed to accept banana style plugs, such as Keithley part no. BG-5 or accessory test leads such as Model $1681 \mathrm{Clip}-0 n$ Test Leads.)
4. Observe the displayed digits, polarity sign, decimal point location, and measurement unit (mV or $V$ ). If no polarity $\operatorname{sign}$ is indicated, a positive polarity is implied.
b. AC Voltage. The Model 172A/173A detects ac voltages from 10 microvolts rms to 1000 volts (1000.0 display). The maximum display is 29999. When the display exceeds 29999 , a 3 remains lighted, but all other digits are blanked. The display blinks above 999.9 volts on the highest range.
5. Set to $A C$ Volts. (The AC indicator should be lighted.)
6. Set to AUTO.
7. Connect the signals to be measured between HI and LO terminais. (The terminals are designed to accept banana style plugs, such as Keithley part no. 8G-5 or accessory test leads such as Model 1681 Clip-On Test Leads.)
8. Observe the displayed digits, decimal point location, and measurement unit (mV or $V$ ).

3-6. HOW TO MEASURE CURRENT. (MODEL 172AONLY). The Model I72A measures ac and dc current in two ranges: 0.3 A , and 2 A . The current is limited by the current fuse even though the DMM is capable of displaying 2.9999A.

CAUTION
The Model 172A is protected by a 2 ampere fuse on all ranges. If the fuse is blown, a replacement Keithley Part No. FU-13 should be installed in the rear panel fuse holder. (See Figure 2-1).
a. DC Current. The Model 172 A detects dc currents from $\pm 10 \mathrm{mic}$ coamperes/digit to $\pm 2$ amperes. When the input exceeds 2 amperes, the current fuse will blow. When using the MAN mode it is possible to select $30 \mathrm{~A}, 300 \mathrm{~A}$ \& 3000 A Ranges, but 2 A Max is still the limit.

1. Set to $D C$ Amperes.
2. Set to Auto.
3. Connect the signal to be measured at the HI terminal.
4. Observe the displayed digits, polarity sign, decimal point location, and measurement unit (mA, or A). If no polarity sign is indicated, a positive polarity is implied. b. AC Current. The Model 172 A DMM detects ac currents from 10 microamperes rms/digit to 2 amperes rms. When the input exceeds 2 amperes, the current fuse will blow.
5. Set to AC Amperes. (The AC indicator should be lighted).
6. Set to Auto.
7. Connect the signal to be measured at the HI terminal.
8. Observe the displayed digits, decimal point location and measurement unit (AC $m A$ or $A C A$ ).


FIGURE 3-2. Typical Model 172A Current Display (DCmA).

3-7. HOW TO MEASURE CURRENT. (MODEL 173A ONLY.) The Model 173 A measures ac and de current in five ranges: $0.3 \mathrm{~mA}, 3 \mathrm{~mA}, 30 \mathrm{~mA}, 0.3 \mathrm{~A}$, and 3 A .

## CAUTION

The Model 173A DMM is protected by a 3 ampere fuse on all ranges. If the fuse is blown, a replacement Keithley Part No. FU-2 should be installed in the rear panel fuse holder. (See Figure 2-1).
a. DC Current. The Modell173A DMM detects dc currents from $\pm 10$ nanoamperes to $\pm 3$ amperes. The maximum display is 29999. When the display exceeds 29999, a 3 remains lighted, but all other digits are blanked.

1. Set to DC Amperes.
2. Set to AuTO.
3. Connect the signal to be measured at the HI terminal.
4. Observe the displayed digits, polarity sign, decimal point location, and measurement unit ( $\mu \mathrm{A}, \mathrm{mA}$, or A ). If no polarity sign is indicated, a positive polarity is implied.
b. AC Current. The Model I73ADMM detects ac currents from 10 namoamperes rms/digit to 3 amperes rms. The maximum display is 29999 . When the display exceeds 29999 , a 3 remains lighted, but all other digits are blanked.
5. Set to $A C$ Amperes. (The $A C$ indicator should be lighted.)
6. Set to AUTO.
7. Connect the signal to be measured at the Hl terminal.
8. Observe the displayed digits, decimal point location, and measurement unit (AC LA, $A C$ ma, or $A C A$ ).

figure 3-3. Typical Modell73A Current Display (ACmA).

3-8. HOW TO MEASURE RESISTANCE. The Model 172A/173A measures resistance from 10 milliohms/digit to 300 megohms. The maximum display is 29999. When the display exceeds 29999, a 3 remains lighted, but all other digits are blanked.
a. HI Ohms Measurement. When the HI/LO pushbutton is released (set to HI), the voltage developed across the resistance under test at full range is 3 volts. The Model 172A/ 173A measures from 100 ms to 300 megohms in Hl mode.

1. Set to HI Ohms.
2. Set to 2 WIRE.

NOTE
When the Model 172A/173A is set to 2 WIRE, the lower set of $H 1$ and LO input terminals is not connected. When set to 4 WIRE, the higherset of $H I$ and $L 0$ input terminals is used as "voltage sensing" terminals. See Section 3-9 for more detailed information.
3. Set to AUTO.
4. Connect the resistance under test between the upper set of HI and LO terminals.
5. Observe the displayed digits, decimal point location, and measurement unit ( $\Omega$, $K \Omega$, or $M \Omega$ ).
b. LO Ohms Measurement. When the HI/LO pushbutton is depressed (set to Lo), the voltage developed across the resistance under test at full range is $300 \mathrm{millivolts}$. Model $172 \mathrm{~A} / 173 \mathrm{~A}$ measures from $10 \mathrm{~m} \Omega$ to 30 megohms in $L 0$ mode.

1. Set to LO Ohms.
2. Set to 2 WIRE.
3. Set to AUTO.
4. Connect the resistance under test between the upper set of HI and LO terminals.
5. Observe the displayed digits, decimal point location, and measurement unit ( 0 , $K \Omega$, or $M \Omega$ ).

This illustration is typical of a 2 -terminal ohmmeter design.


When measuring resistance less than 1000 ohms it may be necessary to use the 4 -wire mode to eliminate the measuring error of the test leads. For example a pair of loft leads made from 18 AWG copper wire has 0.14 ohms resistance.

FIGURE 3-4. Typical 2 WIRE Resistance Measurement.

## 3-9. FURTHER MEASUREIMENT CONSIDERATIONS.

## a. DC Voltage Measurements.

1. Overloads. When the display exceeds $\pm 1200.0 \mathrm{~V}$ DC all digits blink to indicate an overload condition.
2. Input Resistance. Input resistance is $1,000 \mathrm{M} \Omega$ on the 300 mV and 3 V ranges: $10 \mathrm{M} \Omega$ on the $30 \mathrm{~V}, 300 \mathrm{~V}$, and 3000 V ranges. The effects of circuit loading should be considered when evaluating total accuracy of measurement. (See Accuracy.)
3. Accuracy. The Model 172A/173A accuracy is specified in terms of \% of reading and a \% of range. For a full range reading of 299.99 mV DC the accuracy of measurement would be $\pm(0.03 \mathrm{mV}+0.01 \mathrm{mV})$ or $\pm 0.04 \mathrm{mV}$. Measurements from relatively high source resistances could cause an additional reading error. The amount of error due to loading can be determined by the following relationship:
```
    % error = 100 x Rs \div(Rs + R1)
where Rs = source resistance in ohms
                            RI = input resistance of Model 172A/173A inohms
```

4. Self-Test Feature. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ has a bottcm cover voltage contact for functional check in DC Volts. To use this feature, connect the input HI terminai to circled 8 contact. Verify a display of approximately 5 volts de with $V$ depressed. To check dc current, depress $A$ and verify a display of $1.3 \mathrm{~mA}(172 \mathrm{~A})$; 1 mA (173A). b. AC Voltage Measurements
5. Overloads. When the display exceeds 1000.0 V AC (rms) all digits blink to indicate an overload condition.
6. Input impedance. The input impedance is 2 megohms shunted by less than 50 picofarads. The effects of circuit loading should be considered when evaluating the total accuracy of measurement. (See Accuracy.)
7. AC-to-DC Conversion. The Mode! 172A/173A operates as an average-reading voltmeter. calibrated in terms of the root-mean-square (rms) of a sine wave. The calibration is exact for sinusoidal waveforms in the specified frequency range.
8. Frequency Response. The frequency range given in the specifications is the minimum and maximum frequencies which accuracy is valid.
9. Accuracy. 172A/173A accuracy is specified in terms of \% of reading and so many digits. Measurements from relatively high source impedance could cause an additional reading error. The amount of error due to loading can be determined by the following relationship:

$$
\begin{aligned}
\% \text { error } & =100 \times \frac{Z s}{Z s+Z i n} \\
\text { where } Z s & =\text { source impedance } \\
Z \text { in } & =\text { effective input impedance of Model } 172 \mathrm{~A} / 173 \mathrm{~A}
\end{aligned}
$$

6. Self-Test Feature. The Model 172A/173A has a bottom cover voltage contact for functional check in $A C$ volts. To use this feature, connect the input Hl terminal to circled A contact. Verify a display of approximately 6 volts ac. To checx ac current, depress $A$ and verify a display of 1.2 mA .

NOTE
AC Self-test features are operable on line power only.

## c. Current Measurements.

1. Overloads. Fuses are as follows: Modell72A: 2A Model 173A: 3 A
2. Shunt Resistance. The Model 173 A develops approximately 300 millivolts across the input terminals at full range. The 172 A has $1.3 \Omega$ on all ranges.

For example, on the 300 milli-ampere range the shunt resistor is 1.3 ohm, which results in a voltage drop of $0.3 \times 1.3=390$ millivolts at full range.
3. Accuracy. 172A/173A accuracy is specified in terms of a of reading and so many digits. An additional reading error should be considered if the source resistance is not greater than 1000 times the shunt resistor. The amount of error can be determined by the following relationship:

$$
\begin{aligned}
\% \text { error } & =\frac{100 \times \operatorname{Rin}}{\text { Rs }+ \text { Rin }} \\
\text { where Rin } & =\text { shunt resistance of the Model } 172 \mathrm{~A} / 173 \mathrm{~A} \\
\text { Rs } & =\text { source resistance. }
\end{aligned}
$$

## d. Resistance Measurements.

1. Maximum Allowable Voltage input. The maximum input should not exceed 250 V rms sine wave or $\pm 250 \mathrm{~V} \mathrm{dc}$.
2. Polarity of 0hms. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ provides a positive voltage at the HI terminal.
3. Maximum Open-Circuit Voltage. When the HI and LO terminals are open in either Hi or LO ohms, the maximum voltage developed between $H I$ and $L 0$ is +5 volts.

This illustration is typical of a 4 -terminal measuring technique using a separate voltmeter and Current Source. The Model 172A/173A combines these features.


When using the $4-$ WIRE method, connect one pair of "current" leads to $\Omega$ SOURCE input. Connect a second pair of "voltage" leads to HI and LO. Then set to 4 WIRE.

Care should be taken to connect "current" leads and "voltage" leads properly. The LO terminal and $\Omega$ Source low must always connect to the same side of the unknown resistance.

FIGURE 3-5. Typical 4 WIRE Resistance Measurement.
4. Four-terminal Measurements. The 4 -WIRE mode connects the lower set of $\Omega$ SOURCE terminals to the DMM ohmmeter source. As shown in Figure $3-5$ the lower terminals are the current carrying terminals while the upper terminais are the voltage sensing terminals. This arrangement eliminates the error due to voltage drop across the cur-rent-carrying leads.
5. Semiconductor Diode and Transistor Testing. The Model 172A/173A can be used to test diodes and transistors to determine the relative condition of the device. For semiconductor diodes, the voltage applied must be sufficient to cause conduction in the forward direction. The "HI OHMS" mode provides a voltage up to 3 volts at a current upto 1 milliampere. Since the $H 1$ terminal is positive with respect to LO terminal, connections should be made as shown in figure $3^{-6}$ to cause forward conduction of diodes. Since the maximum current is available on the $3 \mathrm{~K} \Omega$ range, depress AUTO/MAN (Set to MAN) and manually range to the $3 \mathrm{k} \Omega$ range (down-range).
6. Self-Test Feature. The Model $172 \mathrm{~A} / 173 \mathrm{~A}$ has a bottom cover voltage contact for functional check in OHMS. To use this feature, place the DMM in OHM! and 2-WIRE mode. Connect input HI terminal to circled C contact. Verify a display of approximately 10 kilohms.


FIGURE 3-6. Semiconductor Diode and Transistor Testing.

3-10. HOW TO USE MODEL 172A/173A OFF-GROUND. The "LO" terminal can be operated off ground at potentials of up to $\pm 1400 \mathrm{~V}$. Isolation from the "Lo" terminal to power line ground is specified at $1000 \mathrm{M} \Omega$, or $10^{9} \Omega$ (shunted by 300 pF ). Typically, the isolation resistance from LO to GND is two decades greater than $10^{9} \Omega\left(10^{11} \Omega\right)$. Because of this excellent isolation, operating the Model 172A/173A off ground results in very little loading (from to to GND) of a floating source. At lo00V above ground, the Model 172A/ 173A will require, typically, only $10 n A$ from the source. The excellent isolation also accounts for the high common-mode rejection ratio of the Model 172A/173A. Even with the "HI" terminal driven and a source resistance of $1 \mathrm{k} \Omega$, 1000 VDC (from H| to GND) will produce typically only $10 \mu V$ DC error. This error voltage is determined directly from the ratio of the source resistance to the "isolation" resistance (See Figure 3-7).

$$
1 \simeq \frac{1000 \mathrm{~V}}{10^{11_{\Omega}}}=10^{-8} \mathrm{~A} \quad \quad V_{\text {across }} 1 \mathrm{k}=1 \times 1 \mathrm{k} \Omega=10^{-8} \times 10^{3}=10 \mathrm{uVDC}
$$

The "isolation" capacitance from LO to GND is important when AC common-mode signals are present. In the Model 172A/173A this capacitance is specified at 300 pF . At a frequency of $60 \mathrm{~Hz}, 300$ picofarads has a reactance of approximately $10 \mathrm{M} \Omega$. With the HI terminal driven and a source impedance of $1 \mathrm{k} \Omega$, a $1000 \mathrm{~V} \mathrm{p}-\mathrm{p}, 60 \mathrm{~Hz}$, common-mode signal will produce a voltage of only 100 mV p -p across the input terminals. This 100 mV $p-p$ signal will be further rejected by the input filter and $A-D$ converter so that the total rejection at the digital display is at least 120 dB (HI driven, $1 \mathrm{k} \Omega$ source impedance). For DC voltage measurements, rejection is much greater than specified when the Model 172A/173A LO terminal is driven, rather than the $H$ l terminal. Where there is a need for even greater isolation from LO to power ine ground, or where there is a need to float at potentials greater than 1400 volts above power line ground the Model 1728 Battery Pack should be used.


FIGURE 3-7. Use of Multimeter Off Ground.

3-11. HOW TO USE OPTIONAL PROBES AND SHUNTS.
a. Model 1600 High Voltage Probe. Set the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ to $D C$ volts and 30 volt range. The input resistance on the 30 volt range is 10 megohms so that no shunt resistor is needed. The Model 1682 has a 1000 :l division ratio. For maximum safety review the instructions furnished with the Model 1600 probe above 30 kV , switch to the 300 V range.

## CAUTION

The alligator clip (ground) must be connected to the source low so that high voltage is not applied between low and ground. Severe damage to the instrument will occur if the alligator clip is not connected.
b. Model 1682 RF Probe. Set the Model $172 A / 173 A$ to $D C$ volts and 30 volt range. The Model 1682 has a ivdc output corresponding to 1 V rms input over the range 100 kHz to 100 MHz .

## IMPORTANT

For use on the 3 volt range the banana plug adapter (with 10 megohm resistor) should be used since the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ input resistance is $>1000$ megonms on the 3 voit and 0.3 volt ranges.
c. Model 1685 Clamp-On AC Current Probe. Set the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ to $A C$ volts and 0.3 volt range. The Model 1685 provides a 0.1 volt rms output corresponding to a 1 ampere rms input. Review the instructions furnished with the Model 1685 to achieve best possible accuracy.
d. Model 1651 Current Shunt. Set the Model $172 A / 173 A$ to $A C$ or $D C$ volts (as appropriate) and 0.3 volt range. Connect the voltage leads to the Model 172A/173A input terminals. Connect separate leads (not furnished) between the source and the Model 1651 hex-head bolts. The Model 1651 shunt resistance is 0.001 ohm which produces a sensitivity of 1 millivolt per ampere.

3-12 HOW TO USE THE MODEL 1722 DIGITAL INTERFACE.
a. General. The Model 1722 provides binary coded decimal outputs (8421) and range control lines. Outputs are open-collector positive true unless otherwise specified. This accessory is available either "factory installed" or "field-installable". The Model 1722 consists of a two-layer circuit with card-edge and mating output connectors.

```
b. Installation.
```

1. Disconnect the Model 172A/I73A line cord from line voltage.
2. Turn the instrument over so that the bottom cover faces up.
3. Loosen four slotted screws on the bottom cover. The screws are captive, that is, they cannot be removed completely.
4. Turn over the instrument with the top cover facing up, taking care to hold the top and bottom covers together.
5. Carefully remove the top cover to gain access to the printed circuit board. There is one connection between the top cover and the main circuit board which must be temporarily removed in order to free the top cover.
6. Remove the Model 1728 Rechargeable Battery Pack (if installed). Carefully disconnect connectors from the mother board.

NOTE
The Models 1722 and 1728 cannot be installed on the Model 172A/173A cnassis at the same time.
7. Check to see that the four insulating spacers are in position on the circuit board as shown in Figure 3-9.
8. Place the Model 1722 on the spacers as shown in Figure 3-9.
9. Lift up the Model 1722 slightly to gain access to the Model 172A/173A mother board, and plug in connectors J1003, J1002, and Jl001 (in order given).
10. Connect ground return wire from the Model 1722 to the extra lug on transformer Tlol.
11. Replace the connections to the top cover.
12. Reinstall the top cover.
13. Turn the instrument over and tighten the four screws.
c. Connector Terminations. The Model 1722 uses two card-edge connectors Ploo6 (40pin) and Pllol (26-pin). Ribbon cable style of mating connectors may be used with these cardedge connectors as shown in Table 3-5.

TABLE 3-5.
Summary of Mating Connectors

|  | Manufacturer | Crimped Ribbon-Cable Styie |
| :---: | :---: | :---: |
| Pl101 | $3 M$ | $3462-0000$ |
| P1006 | $3 M$ | $3464-0000$ |



FIGURE 3-8. Model 1722 Digital Output Interface.


FIGURE 3-9. Installation of Model 1722.
table 3-6.
Summary of Digital Output at Pl006

| Pin No. | Signal | Pin No. | Signal |
| :---: | :--- | :--- | :--- |
| 1 | CASE GND | 21 | $10^{4}-2$ |
| 2 | COMMON | 22 | $10^{3}-2$ |
| 3 | COMMON | 23 | $10^{4}-1$ |
| 4 | COMMON | 24 | $10^{3}-1$ |
| 5 | COMMON | 25 | $10^{2}-8$ |
| 6 | PRINTER HOLD | 26 | $10^{1}-8$ |
| 7 | AUTOMODE | 27 | $10^{2}-4$ |
| 8 | VEXT | 28 | $10^{1}-4$ |
| 9 | R8 | 29 | $10^{2}-1$ |
| 10 | VOLTS | 30 | $10^{1}-2$ |
| 11 | AMPS | 31 | $10^{2}-1$ |
| 12 | R2 | 32 | $10^{1}-1$ |
| 13 | AC | 33 | $10^{0}-8$ |
| 14 | R1 | 34 | FLAG |
| -15 | $10^{3}-4$ |  |  |
| 16 | $10^{4}-8$ | 35 | FLAG |
| 17 | $10^{3}-8$ | $10^{2}-2$ |  |
| 18 | $10^{3}-4$ | 37 | OVERFLOW |
| 19 |  | 38 | $10^{2}-1$ |
| 20 |  | 39 | POLARITY |

TABLE 3-7.
Summary of Remote Commands at Pllol

| Pin No. | Command | Pin No. | Command |
| :---: | :---: | :---: | :---: |
| 1 | CASE GND* | 14 | RANGE STROBE |
| 2 | COMMON | 15 |  |
| 3 | COMMON | 16 | POLARITY $\overline{\text { STROBE }}$ |
| 4 | AUTORANGED STROBE | 17 | $\mathrm{R8}_{4}$ |
| 5 | TRIGGER MODE | 18 | $10^{4}$ STROBE |
| 6 | AUTOMODE S STROBE | 19 | TRIGGER |
| 7 | HOLD | 20 | 103 STROBE |
| 8 | OVERFLOW STROBE | 21 | FLAG RESET |
| 9 | LOAD RANGE | 22 | $10^{2}$ STROBE |
| 10 | FLAG/ $\overline{\text { FLAG }} \overline{\text { STROBE }}$ | 23 | TR\|GGER MODE DISABLE |
| 11 |  | 24 | 10 STR08E |
| 12 | FUNCTION STROBE | $25$ | AUTORANGED |
| 13 | R2 | 26 | $10^{\circ}$ STROBE |



FIGURE 3-10. Connector Pin Identification for P1006 and Pllol.


FIGURE 3-11. Card-Edge Connectors (Model 1727 Cable Set).
d. How to Select Vext Using Internal Jumper. The Model 1722 may be wired for use with internal or external voltage references and internal pull-up resistors. (See Figure 3-9).

1. Jumper $A$. When this jumper is installed, the pull-up resistors are connected to the external reference Vext (pin 8, pl006).
2. Jumper B. When this jumper is installed, the pull-up resistors are connected to the internal reference $(+5 \mathrm{~V})$.
3. Jumper $C$. When this jumper is installed, Vext is connected to internal +5 V reference. The pull-up resistors are not connected in this instance. The +5 volt reference is rated at 40 mA maximum.


FIGURE 3-12. Location of Jumpers and Pull-Ups on Model 1722.

TABLE 3-8.
Digital Output Lines Grouped By Function

| Name | $\begin{aligned} & \text { Plo06 } \\ & \text { Pin } \\ & \text { No. } \end{aligned}$ | P1101 <br> Pin <br> No. | Name | $\begin{gathered} \text { Plo06 } \\ \text { Pin } \\ \text { No. } \\ \hline \end{gathered}$ | $\begin{gathered} \text { Pllol } \\ \text { Pin } \\ \text { No. } \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| $10^{\circ}$ STROBE  <br>  $10^{0}-1$ <br> $10^{0}-2$  <br> $10^{0}-4$  <br>  $10^{0}-8$ | $\begin{aligned} & 39 \\ & 37 \\ & 35 \\ & 33 \\ & \hline \end{aligned}$ | 26 | FUNCTION $\overline{S T R O B E}$ <br>  - VOLTS <br>  $-A M P S$ <br>  $-A C$ <br>  $-O H M S$ | $\begin{aligned} & 10 \\ & 12 \\ & 14 \\ & 16 \\ & \hline \end{aligned}$ | 12 |
| $10^{1} \overline{\text { STROBE }}$ | 3 | 24 | OVERFLOW STROBE  <br>  -OVERFLOW | 38 | 8 |
| $10^{1}-1$ $10^{1}-2$ | 32 30 |  | AUTOMODE STROBE <br> -AUTOMODE  | 7 | 6 |
| $\begin{aligned} & 10^{1}-4 \\ & 10^{1}-8 \end{aligned}$ | $\begin{aligned} & 28 \\ & 26 \end{aligned}$ |  | AUTORANGED STROBE -AUTORANGED |  | $\begin{array}{r} 4 \\ 25 \end{array}$ |
| $10^{2}$ STROBE | -- | 22 | PRINTER HOLD | 6 |  |
| $10^{2-1}$ | 31 |  |  |  |  |
| 102-2 | 29 |  | TRIGGER MODE |  | 5 |
| $10^{2-4}$ | 27 |  | HOLD |  | 7 |
| 102-8 | 25 |  | LOAD RANGE |  | 9 |
| $10^{3} \overline{\text { STROBE }}$ | -- | 20 | R1 |  | 13 |
| 103-1 | 24 |  | R4 |  | 15 |
| $10^{3}-2$ | 22 |  | R8 |  | 17 |
| $10^{3}-4$ | 20 |  | TRIGGER |  | 19 |
| $10^{3}-8$ | 18 |  | FLAG RESET |  | 21 |
| $10^{4}$ STROBE | -- | 18 | TRIGGER MODE DISABLE |  | 23 |
| $10^{4-1}$ | 23 |  |  |  |  |
| $10^{4}-2$ | 21 |  | COMMON | 2,3,4,5 | 2,3 1 |
| $10^{4}-4$ | 19 |  | CASE |  |  |
| $10^{4}-8$ | 17 |  |  |  |  |
| POLARITY STROBE | -- | 16 | FLAG/ $\overrightarrow{F L A G}$ STROBE |  | 10 |
| RANGE STROBE | -- | 14 | $\frac{F L A G}{F L A G}$ | $\begin{aligned} & 36 \\ & 34 \\ & \hline \end{aligned}$ |  |
| -R1 | 13 |  | VEXT | 8 |  |
| -R4 | 11 |  |  |  |  |
| -R8 | 9 |  |  |  |  |

TABLE 3-9.
General Characteristics of Modei 1722 Digital Interface.
DIGITAL OUTPUTS:
Logic: BCD (8421) Open-collector positive true unless otherwise specified. Data: 4 full digits, 1 partial digit ( $0,1,2,3$ ) and exponential range code.

Function: 4-bit code ( $\Omega$, AC VOLTS, AMPS)
Polarity: HIGH $\equiv+$.
Overflow: LOW 三 > 29999.
Autorange: LOW $\equiv$ range change.
Automode: $\mathrm{HIGH} \equiv$ autorange mode.
FLAG ( $\overline{F L A G}$ ): HIGH (logic "O" $\equiv$ no output change occuring. Logic Levels: HIGH $\equiv$ open collector to output LO. LOW $\equiv$ closure to output LO. Output device (2N5134) greater than 20 V breakdown, $<0.5 \mathrm{~V}$ at 5 mA sink ( 3 TTL loads). Internal pull-up resistors may be installed on these open collector outputs. 4.7 K minimum value is recommended when using internal 5 volt power supply.
OUTPUT TIMING: Data is updated typically every 320 msec (non-trigger mode). Update time is typically 1.2 msec . Data will appear at an output only if its respective strobe is active. The FLAG will go low (Logic " $0^{\prime \prime}$ ') typically 2 msec before update and go high typically $100 \mathrm{\mu sec}$ after update. Data can be expected to be unchanging so long as the flag is high. If FLAG RESET is activated, the FLAG will reset (go to Logic " $0^{\prime \prime}$ ) until the end of the next data update.
REMOTE CONTROLS:
Strobe: Strobe lines permit word serializing in 4-bit increments or multiples thereof. HIGH inhibits controlled output lines from conduction, LOW enables conduction. Range In: 4-bit exponential code.
Load Range: Low enables remote ranging as set by Range code.
Hold: LOW inhibits display update, output update and autorange (A/D continues conversions).
Printer Hold: Same as hold but grouped with outputs for convenience in interfacing printer.
Trigger Mode: LOW enables TRIGGER control.
Trigger Mode Disable: LOW disables TRIGGER.
Trigger: LOW to HIGH transition initiates a new A/D conversion.
Flag Reset: LOW sets FLAG (FLAG) to LOW (HIGH).
Control Logic Levels \& Source Requirements: HIGH $\equiv$ either an open circuit or a voltage between +2.4 V and 5 V referred to output LO. LOW 三 closure to output LO within 0.8 V while sinking +1.6 miliamperes (1TTL load). When TRIGGER MODE, HOLD and LOAD RANGE code bits are all HIGH (inactive) the 172A/173A is under front panel control. These REMOTE CONTROL inputs have priority and will override any front panel setting once activated.
ISOLATION: All digital outputs and remote controls are isolated from 172A/173A analog input by $10^{9} \Omega$ and 500pF, 1200 VDC , 1000 V rms $A C$ maximum. All digital outputs and remote controls are isolated from chassis ground by $106 \Omega$ and $0.01 \mu \mathrm{~F} ; 250 \mathrm{~V}$ rms maximum.
e. Detailed Explanation of Model 1722.

TRIGGER MODE AND TRIGGER: (See Schematic 28248E)

HOLD:

LOAD RANGE:

REMOTE CONTROLS:

When TRIGGER MODE is active (Low), output data and display will not be updated. TRIGGER MODE enables TRIGGER. Conversion starts within 1.6 milliseconds after TRIGGER. Integration starts 120 milliseconds after start of conversion.

If either HOLD or PRINTER HOLD is low the output data and the display will not be updated and the FLAG will stay at HIGH (unless reset by FLAG RESET).

When LOAD RANGE is low the $172 \mathrm{~A} / 173 \mathrm{~A}$ will go to the range as set by the RANGE IN code (Table 3-10) at the beginning of the next conversion. As long as LOAD RANGE is held low, each instrument will remain on its programmed range overriding front panel UPRANGE, DOWNRANGE and AUTORANGE. RANGE $1 N$ codes programmed outside the limits of Table 3-10 will result in the nearest valid range to that programmed. LOAD RANGE will always cause a DMM range change. However, the display and output data will be held (not updated) during TRIGGER MODE or HOLD. Referring to timing schematic 282490,it is possible to just miss a REMOTE CONTROL update prior to data output. This can be misleading, especially in the case of HOLD. A HOLD just missed (unknown to the user), just before data begins to change, could result in erroneous data. To check if this occurred, it is suggested that the FLAG be examined no sooner than $10 \mu \mathrm{sec}$ after activation of the HOLD bit. If flag is low wait until it goes to HIGH before expecting the HOLD bit to have been accepted. Other REMOTE CONTROL bits such as TRIGGER MODE and TRIGGER, LOAD RANGE and the RANGE IN code can be kept active for longer than an output data update time, i.e. $>3.2 \mathrm{msec}$ to insure proper REMOTE CONTROL acceptance.

When in TRIGGER MODE and triggering into an autoranging condition, normal operation will give an output for each range encountered during the autorange. However, if this is undesirable the AUTORANGED output bit can be tied to TRIGGER MODE DISABLE and FLAG RESET. This will prevent the FLAG from being set and ignore further triggering until the final range is reached.
$V_{\text {ext }}:$

LINE GROUND:

GROUNDS:
Internal jumpers (user installed) select internal or external voltage reference for user-installed pullup resistors for all open-collector outputs, or applies internal $+5 V$ to $V$ ext (maximum external current load on internal +5 V is 40 mA ). Minimum pull-up resistor recommended is 4.7 K .

One pin on each output connector.

4 pins for digital outputs, 2 pins for remote control.

One $40-\mathrm{pin}$ card edge and one $26-$ pin card edge.

ENVIRONMFNT:

> Installed in a $172 \mathrm{~A} / 173 \mathrm{~A}$ : Operating $0^{\circ} \mathrm{C}$ to $55^{\circ} \mathrm{C}$, humidity $80 \% @ 35^{\circ} \mathrm{C}$. Storage: $-25^{\circ}$ to $+65^{\circ} \mathrm{C}$
f. Modifications to Model 172A/173A Specifications. When operating a 172A/173A with a 1722 in TRIGGER MODE, only the accuracy specifications for the top two onms ranges change as follows:

$$
\begin{array}{ll}
\text { HI } \Omega 300 \mathrm{M} \Omega \text { Range: } & \text { From } 1 \% \text { of reading to } 1.5 \% \text { of reading. } \\
\text { HI } \Omega 30 \mathrm{M} \Omega \text { Range: } & \text { From } 0.15 \% \text { of reading to } 0.2 \% \text { of reading. } \\
\text { LO } \Omega 30 M \Omega \text { Range: } & \text { From } 0.5 \% \text { of reading to } 1 \% \text { of reading. } \\
\text { LO } 3 M \Omega \text { Range: } & \text { From } 0.1 \% \text { of reading to } 0.15 \% \text { of reading. }
\end{array}
$$

Also when operating in TRIGGER MODE, repeatability of readings may be up to:
$0.5 \%$ on $300 \mathrm{M} \Omega \mathrm{Hi} \Omega$ and $30 \mathrm{M} \Omega$ Lo $\Omega$ ranges, and $0.05 \%$ on $30 M \Omega \mathrm{Hi} \Omega$ and $3 \mathrm{M} \Omega$ Lo $\Omega$ ranges.
Accuracy of all other ohms ranges and all other functions is not affected by the model 1722 when operating in TRIGGER MODE.

TABLE 3-10
MODEL 1722 RANGE \& FUNCTION CODING FOR MODEL 172A

| FUNCTION | OUTPUT <br> FUNCTION <br> CODE (1) | RANGE | OUTPUT <br> RANGE <br> CODE (1) | (EXP) | $\begin{aligned} & \text { INPUT } \\ & \text { RANGE } \\ & \text { CODE (1) (3) } \end{aligned}$ |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\checkmark$ A AC $\Omega$ |  | $R_{8} R_{4} R_{2} R_{1}$ |  | $\mathrm{R}_{8} \mathrm{R}_{4} \mathrm{R}_{2} \mathrm{R}_{1}$ |  |
| DC VOLTS | 1000 | $\begin{array}{r} 300 \mathrm{mV} \\ 3.0 \mathrm{~V} \\ 30 \\ 300 \\ 1200 \\ \hline 12 \mathrm{~V} \\ \hline \end{array}$ | $\begin{array}{llll}0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1\end{array}$ | $\begin{aligned} & 5 \\ & 6 \\ & 7 \\ & 8 \\ & 9 \\ & \hline \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \\ \hline \end{array}$ | Autorange |
| AC VOLTS | 1010 | $\begin{array}{r} 300 \mathrm{mV} \\ 3 \mathrm{~V} \\ 30 \\ 300 \\ 1000 \\ \hline \end{array}$ | $\begin{array}{llll} 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \\ \hline \end{array}$ | $\begin{aligned} & 5 \\ & 6 \\ & 7 \\ & 8 \\ & 9 \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{array}$ | AUTORANGE |
| DC AMPS | $1000^{(2)}$ | 300 mA 2 A | $\begin{array}{llll} 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ \hline \end{array}$ | $\begin{array}{r} 5 \\ 6 \\ \hline \end{array}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ \hline \end{array}$ | AUTORANGE |
| AC AMPS | $1010^{(2)}$ | $\begin{array}{r} 300 \mathrm{~mA} \\ 2 \mathrm{~A} \\ \hline \end{array}$ | $\begin{array}{llll} 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ \hline \end{array}$ | $\begin{array}{r} 5 \\ 6 \\ \hline \end{array}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ \hline \end{array}$ | AUTORANGE |
| LOW $\Omega$ | 0001 | $\begin{array}{r} 300 \Omega \\ 3 \mathrm{k} \Omega \\ 30 \mathrm{k} \Omega \\ 300 \mathrm{k} \Omega \\ 3 \mathrm{M} \Omega \\ 30 \mathrm{M} \Omega \\ \hline \end{array}$ | $\begin{array}{llll} 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ \hline \end{array}$ | $\begin{aligned} & 2 \\ & 3 \\ & 4 \\ & 5 \\ & 6 \\ & 7 \\ & \hline \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ \hline \end{array}$ | AUTORANGE |
| HI $\Omega$ | 0010 | $\begin{array}{rl} 3 \mathrm{k} \Omega \\ 30 \mathrm{k} \Omega \Omega \\ 300 \mathrm{k} \Omega \\ 3 \mathrm{M} \Omega \\ 30 & \mathrm{M} \Omega \\ 300 & \mathrm{~m} \Omega \\ \hline \end{array}$ | $\begin{array}{llll}0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0\end{array}$ | $\begin{aligned} & 3 \\ & 4 \\ & 5 \\ & 6 \\ & 7 \\ & 8 \\ & \hline \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \end{array}$ | AUTORANGE |

(1) Coding in this table is defined to be HIGH (POSITIVE) TRUE. "Il" = HIGH and "O"' = LOW. Refer to output and remate control logic levels for definitions of HIGH $\varepsilon$ LOW.
(2) Function code for Model 172A current is volts.
(3) Note that except for AUTORANGE CODE, INPUT $\&$ RANGE CODE is the compliment of the OUTPUT RANGE CODE, i.e. the INPUT RANGE CODE is the LOW TRUE BCD code of (EXP).

TABLE 3-11
MODEL 1722 RANGE $\varepsilon$ FUNCTION CODING FOR MODEL I73A
(Same as Table $3-10$ except as follows)

| FUNCTION | OUTPUT FUNCTION CODE (1) | RANGE | OUTPUT <br> RANGE <br> CODE (1) | (EXP) | INPUT <br> RANGE <br> CODE (1) (3) |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $V A A C \Omega$ |  | $R_{8} R_{4} R_{2} R_{1}$ |  | $\mathrm{R}_{8} \mathrm{R}_{4} \mathrm{R}_{2} \mathrm{R}$ |  |
| DC AMPS | 0100 | $\begin{array}{r} 300 \mu \mathrm{~A} \\ 3 \mathrm{~mA} \\ 30 \mathrm{~mA} \\ 300 \mathrm{~mA} \\ 3 \mathrm{~A} \\ \hline \end{array}$ | $\begin{array}{llll} 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \\ \hline \end{array}$ | $\begin{aligned} & 5 \\ & 6 \\ & 7 \\ & 8 \\ & 9 \\ & \hline \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{array}$ | AUTORANGE |
| AC AMPS | 0110 | $\begin{array}{r} 300 \mu \mathrm{~A} \\ 3 \mathrm{~mA} \\ 30 \mathrm{~mA} \\ 300 \mathrm{~mA} \\ 3 \mathrm{~A} \\ \hline \end{array}$ | $\begin{array}{llll} 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 1 \end{array}$ | $\begin{aligned} & 5 \\ & 6 \\ & 7 \\ & 8 \\ & 9 \\ & \hline \end{aligned}$ | $\begin{array}{llll} 1 & 1 & 1 & 1 \\ 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{array}$ | AUTORANGE |

## Digital Multimeter

Models 172A, 173A

3-13. COMMENTS RELATIVE TO THE MODEL 172A/173A SPECIFICATIONS. Above 1 ampere there is decrease in accuracy. This decrease in accuracy is due to self heating and the temperature coefficient of the resistors that are used in these currents. This degradation in accuracy will not exceed those values that are listed in the specification sheet. However, prolonged operation at the high currents (for instance, 2 amperes on the Model 172A, or 3 amperes on the Model 173A) may give temporary zero shifts because of the thermals whict are generated due to the self heating of the devices.

3-14. MODEL 1728 OPERATING TIPS. Although the manufacturers of the nickel cadmium batteries used in the 1728 claim that their cells can be charged at a $0 / 10$ rate indefinitely, once a cell is fully charged, the energy fed to the cell is converted to heat, which increases the temperature of the cell. If cells are overcharged at $\mathrm{C} / 10$ rate for extended periods of time (weeks), this may cause cell degradation. Keithley recommenas that the 1728 not be overcharged for extended periods to maximize useful battery life. Trick charging should have no effect on useful battery life. Nickel Cadmium batteries also exhibit a memory effect. If the 1728 is only used to operate the instrument for relatively short periods of time (l or 2 hours) the 1728 may not be able to provide the full operating time of 6 hours.

Do not operate the Multimeter in BAT mode after the LO BAT indicator is lighted. The discharge characteristic of Nickel Cadmium batteries is such that it maintains a fairly constant 1.2 V through most of its discharge cycle. At the end of the discharge curve the cell voltage drops fairly rapidly to zero volts. After a given ceil in the battery pack drops to zero it is reverse charged by the rest of the cells in series with it. Although the cells used in the 1728 are guaranteed by the manufacturer to withstand reverse charge for $10 \%$ of their discharge time, it is not a good practice to continually reverse charge cells, as more rapid cell degradation may occur.

The cells used in the 1728 should give a minimum of 250 discharge/charge cycles and typically 500 discharge/charge cycles. Thus, based on daily useage ( 5 day week, one per day) the battery pack should give a minimum of one year operation and typically two years Longer life should be expected for less frequent useage.

TABLE 3-12
Summary of Fuses and Miscellaneous Replaceable Parts

| ITEM | WHERE USED | KEITHLEY PART NO. |
| :---: | :---: | :---: |
| Fuse, $3 A B / 3 A G, 1 / 4 A$, Slo-Blo <br> Fuse, $3 \mathrm{AB} / 3 \mathrm{AG}, 1 / 8 \mathrm{~A}, \mathrm{Slo-Blo}$ <br> Fuse, $3 \mathrm{AB} / 3 \mathrm{AG}, 1 \mathrm{~A}, \mathrm{Slo-Blo}$ <br> Fuse, $3 A B / 3 A G, 2 A$ Quick <br> Fuse, $3 A B / 3 A G, 3 A$ Quick <br> Top Cover (less metalcal) <br> Bottom Cover (less metalcal) <br> Handle (less insert) <br> . . Insert <br> Rubber Foot | $117 V$ Line Volts 234 V Line Volts <br> Model 1728 <br> Model 172A Amperes <br> Model 173A Amperes | $\begin{aligned} & F U-17 \\ & F U-20 \\ & F U-10 \\ & F U-13 \\ & F U-2 \\ & 28969 C \\ & 28968 B \\ & 25729 D \\ & 26090 A \\ & F E-10 \end{aligned}$ |

## SECTION 4. ACCESSORIES

4-1. GENERAL. This section describes the various accessories and options available for use with the Model 172A/173A Digital Multimeter.

4-2. POWER OPTIONS. The Model 172A/173A can be powered by line voltage (105-125V standard) or rechargeable Battery Pack (Model 1728). Other line voltage ranges are avail able as described in Section 2. The Model 1728 is available factory-installed or fieldinstallable.

4-3. ISOLATED DIGITAL OUTPUT. The Model 1722 Digital Output Interface is available factory-installed or field-installable. Complete specifications are given in Section 3 (paragraph 3-12.)

## IMPORTANT

The Model 1722 , 1723 and 1728 cannot be installed and used at the same time since these options occupy the same location on the Model 172A/173A chassis.

4-4. RACK MOUNTING. The Model 172A/173A can be rack mounted in a full rack (19 inch width) in either a single or dual mounting configuration.

MODEL 1010 SINGLE RACK MOUNTING KIT

Description:
The Model 1010 is a single rack mounting kit with overall dimensions 5-1/4 in. (133 mm ) high and 19 in . ( 483 mm ) wide. The hardware included in this kit includes a 19 inch wide panel and other miscellaneous hardware.

## Application:

The Model 1010 adapts one Keithley Style "K" instrument for Standard $5-1 / 4 \mathrm{in}$. ( 133 mm ) $\times 19 \mathrm{in}$. ( 483 mm ) rack mounting with 11 in . ( 280 mm ) depth behind the front panel. For dual rack mounting of Style "K" instruments the Model 1017 Dual Rack Mounting Kit must be used.

Parts List:

| item <br> No. | Description | Qty <br> Req'd | Keithley <br> Part No. | Hlustration |
| :--- | :--- | :---: | :---: | :---: |
| 1 | Front Panel | 1 | 265950 |  |
| 2 | Support Plate (Shelf) | 1 | 26599 C |  |
| 3 | Bracket, Left Side | 1 | 266008 |  |
| 4 | Bracket, Right Side | 1 | 266018 |  |
| 5 | Slotted Screw, \#6-32 $\times 2-1 / 4 \mathrm{in}$. | 2 | - |  |
| 6 | Flat Washer, \#6 | 2 | - |  |
| 7 | Phillips Screw, \#8-32 $\times 1 / 2 \mathrm{in}$. | 10 | -- |  |

Assembly Instructions:

1. Using two Phillips Screws (Item 7) attach Support Plate (Item 2) to Front Panel (Item I).
2. Using four Phillips Screws (Item 7), attach left and right side Brackets (Items 3 and 4) to Front Panel (Item 1).
3. Using four Phillips Screws (Item 7), secure left and right side Brackets to Support Plate (1tem 2).
4. Assembly of rack hardware is complete except for mounting of instrument.
5. Rotate "handle" of Instrument so that handle is toward rear of Instrument. (Handle can be removed completely if desired by separating top and bottom covers.)
6. Remove two Slotted Screws ( $1-1 / 4 \mathrm{in}$. long) used to hold top and bottom covers together near front feet.
7. Position Instrument so that holes in bottom of Instrument align with two front holes on Support Plate.
8. Using two Slotted Screws (1tem 5) and two Flat Washers (Item 6), secure Instrument to Support Plate.


FIGURE 4-1. Model 1010 Single Rack Mounting Kit.

## Description:

The Model 1017 is a single/dual mounting kit with overall dimensions $5-1 / 4 \mathrm{in}$. ( 133 mm ) high and 19 in . ( 483 mm ) wide. The hardware included in this kit includes a 19 inch wide panel, and other miscellaneous hardware.

Application:
The Model 1017 adapts two Keithley Style ' $K$ '' instruments for Standard $5-1 / 4 \mathrm{in}$. (133 $\mathrm{mm}) \times 19 \mathrm{in}.(483 \mathrm{~mm})$ rack mounting with 11 in. ( 280 mm ) depth behind the front panel.

Parts List:

| Item No. | Description | $\begin{array}{r} \text { Qty } \\ \text { Req } \\ \hline \end{array}$ | Keithley Part No. | 1llustration |
| :---: | :---: | :---: | :---: | :---: |
| 1 | Front Panel | 1 | 280920 |  |
| 2 | Support Plate (Shelf) | 1 | 28094 C |  |
| 3 | Bracket, Left Side | 1 | 280968 |  |
| 4 | Bracket, Right Side | 1 | 28097B |  |
| 5 | Slotted Screw, $\# 6-32 \times 2-1 / 4 \mathrm{in}$. | 4 | -- | (19x) |
| 6 | Flat Washer, \#6 | 4 | -- | (6) |
| 7 | Phillips Screw, \#8-32 ${ }^{\text {P }}$ (1/2 in. | 4 | -- | Mux 8 |
|  | Blank Cover Plate | 1 | 280988 |  |
| 8 | Hole Plug | 2 | HP-20 | $\square$ |
| 9 | Kep Nut, \#8 | 5 | -- |  |

Assembly Instructions: (See Figure 42 , page 4-4.)

1. Using four Phillips screws (Item 7) attach left and right hand Side Plates (ltems 3 and 4) to the Support Plate (1tem 2).
2. Using three Kep Nuts (Item 9) attach the Support Plate (Item 2) to Front Panel (Item 1).
3. Fasten the Side Plates to the Front Panel using two additional Kep Nuts (1tem 9).
4. Assembly of rack hardware is complete except for mounting of the instrument (s).
5. The plastic tilt bail/handle on each instrument must be removed before mounting. The top and bottom covers of the instrument must be disassembled in order to remove the handle. Loosen four screws on the bottom cover. of the instrument, lift off the top cover, and remove handle. Replace the top cover and tighten the four screws on the bottom cover.
6. Remove two slotted Screws ( $1-1 / 4 \mathrm{in}$. long) used to hold top and bottom covers together near the front feet on each instrument. These screws are captive and a needlenose pliers should be used to pull the screw out after it is loosened with a screwdriver.
7. Position the Instrument so that holes in the bottom of the Instrument align with the two front holes in the Support Plate.
8. Using two Slotted screws (1tem 5) and two Flat Washers (Item 6) secure the Instrument to the Support Plate.


FIGURE 42, Model 1017 Dual Rack Mounting Kit.

4-5. PROBE AND SHUNTS. The following probes and shunts extend the capabilities of the Model 172A/173A.

MODEL 1600 HIGH VOLTAGE PROBE
Description: The Model 1600 is a divider probe for measurement of high voltage up to 40 kilovolts dc. The probe is optimized for use with a dc voltmeter having 10 megohms input resistance.

MODEL 1682 RF PROBE
Description: The Model 1682 is an RF probe for measurement up to 100 MHz . The Model 1682 is optimized for use with a dc voltmeter having 10 Megohms input resistance.

MODEL 1685 CLAMP-ON AC CURRENT PROBE
Description; The Model 1685 is a clamp-on current probe for measurement of ac current up to 200 amperes. The Model 1685 is used with an AC voltmeter and provides an output of 0.1 volt rms per ampere.
$4-4$

MODEL 1651 CURRENT SHUNT
Description: The Model 1651 is a 0.001 ohm shunt for use with an $A C$ or $D C$ voltmeter having at least 100 microvolts resolution. The shunt is rated at up to 50 amperes.

4-6. CABLES AND CONNECTORS. The following cables and connection kits enable effective use of the Model 172A/173A.

MODEL 1683 UNIVERSAL TEST LEAD KIT
Description: The Model 1683 is a set of flexible test leads, 40 in . (1m) in length, with interchangeable screw-on adapters.

MODEL 1681 CLIP-ON TEST LEAD KIT
Description: The Model 1681 is a set of test leads, 48 in . ( $1,2 \mathrm{~m}$ ) in length, terminated by a banana plug and spring-action clip-on probe.

MODEL 1727 DIGITAL OUTPUT CABLE SET
Description: The Model 1727 is a cable set consisting of 26 - and 40 - conductor ribbon cable terminated by mating card-edge connectors to the model 1722. The Model 1727-3 is 3 feet long ( 1 m ), and the Model $1727-10$ is ten feet long ( $3,1 \mathrm{~m}$ ).

MODEL 7004 SHIELDED CABLE
Description: The Model 7004 cable is a shielded cable, 42 inches ( $1,1 \mathrm{~m}$ ) long and is terminated by 2 tinned leads plus shield. Two banana plug adapters are furnished for use with Models 172A/173A.

Application: The Model 7004 cable is useful when making low-level voltage connections to the Model $702 / 7029$ Low-Voltage Scanner, both analog INPUT and OUTPUT. The shield may be connected to the GUARD terminal.

4-7. MISCELLANEOUS.

MODEL IT25A MAINTENANCE KIT
Description: The Model 1725A contains a specially punched calibration cover for accessability to adjustment controls on the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ chassis. The kit also contain test leads and a copy of this manual.

Description: The Model $702 / 7029$ is a ten-channel low-voltage scanner. The 702/7029 can be used for manual, scan, or remote scanning operation.

CHANNELS: 10 channels per scanner mainframe (multiple scanner mainframes may be connected for up to 100 channels).

## CONTROL MODES (FRONT PANEL SELECTABLE):

All-Off: No Channel selected.
Manual: Channel selected by front panel switch.
Scan: Channeis sequentially selected at a rate determined by front panel control. Initial channel may be preset.
Remote: Channel randomly selected using 4-line BCD code, or sequentially selected at remote clock rate

SCAN RATE: Variable from nominally 0.1 to 10 seconds per channe! by front panel control. Scan rate using remote clock is timited only by relay clasure time.
DISPLAY: Single digit front panel LED display identities channel selected.
DIGITAL INPUT AND DIGITAL OUTPUT: TTL intertace lines provide for remote channel selection, clock, and control of All-Off mode. Output data includes present channel address. mainframe tdentification, clock. and relay ready. The (digital) Common may be lloated up to $\pm 30$ volts peak with respect 10 (chassis) Ground.
ENVIRONMENT: $0^{\circ} \mathrm{C}-50^{\circ} \mathrm{C}, 0 \%$ to $80 \%$ relative humidity up to $35^{\circ} \mathrm{C}$.
POWER: $90-125$ or $200-250$ volts (switch sefected), $50-60 \mathrm{~Hz}, 15$ watts.
CONNECTORS:
Digital Input, Digital Output (rear): 26-pin 3M Part No. 34291002.

Common, Ground (rear): Binding posts.
Scanner Plug-in Card (rear): Internal connector mates with plug-in card edge.
Analog Inputs, Output, and Guard (rear): Clamp-lype barrer strips for use with \#14 to 22 AWG wire.
Scanner Maintrame: Card edge mates with Scanner Mainframe internal connector.

SIGNAL INPUTS: 10 channeis per card
SWITCHING CONFIGURATION: Guarded. 2-pole. break betore make.
RELAY CLOSURE TIME: Less than 5 miliseconds.
EXPECTED LJFE: $10^{8}$ closures per channel
SIGNAL LEVEL: 10 volts peak. 10 miliamperes peak with a resistive load for expected hite Absolute maximum peak in. stantaneous ratings: 200 volts. 100 miltamperes or 2 vollamperes with a resistive load
THERMAL OFFSET (LABORATORY ENVIRONMENT): LESS than 3 microvolts from input to output when copper wires are used.
SIGNAL PATH RESISTANCE: Initially less than 0.5 ohm per pole; less than 2 ohms at end of life.
ISOLATION: Guarded interchannel resistance is nominaliy $10^{12}$ ohms at room temperature, and guaranteed greater than 10:0 ohms at environmental extremes. Unguarded capacitance is less than 10 picofarads between any iwo signal terminals
GUARDING: Guard surrounds all anatog signal paths Each 10. channel scanner piug-in card in multi-scanner systems may have a separate guard voltage.
MAXIMUM LEVELS: 200 volts peak between signal line parrs or from signal lines to guard or Maintrame (digital) Common 100 volls peak between guard and Mainirame (digital) Com. mon.
DIMENSIONS, WEIGHT: Style $M$ 3-1/2 in halt-rack, overall bench size 4 in . high $\times 8-3 / 4 \mathrm{in}$. wide $\times 15-1 / 4 \mathrm{in}$. deep ( $100 \times$ $220 \times 385 \mathrm{~mm})$. Net weight 8 pounds ( 3.5 kg ).
ACCESSORIES SUPPLIED: Model 7021-2 System interconnect Cable.
ACCESSORIES AVAILABLE:
Model 7021-2 System Interconnect Cable: 2 loot ( 0.6 m ) cable interconnects scanners for multiple. scanner operation ( $n-1$ used tor interconnecting n scanners). 40 foot ( 12 m ) maximum recommended total system cable length (extra)

## MODEL 750 PRINTER WITH MODEL 7501-1722 PRINTER INTERFACE

Description: The Model 750 is an 18 -column printer which is plug-to-plug compatible with the Model 172A/173A.
COLUMNS: 18 (see Drum Diagram).
DECIMAL POINT: 13 decimal points: 9 are floating and print to right of number (columns 6 through 10.12 through 15).
FRONT PANEL CONTROLS: Power: Run; Manual Print; Paper Feed; Print Interval.
PRINT RATE: Print Interval control provides intervals from 1 sec.fline to 10 sec ./line, continuously adiustable. In the External position, up to $2 \frac{1}{2}$ print commands/sec. are accepted.
DATA INPUT: Parallel BCD (8421) high true (low true with removal of jumper). Floating decimal points are low true only. Compatibte Logic: TTL. DTL or open collector; inputs are 2 TTL loads (floating decima! points, 1 TYL load).
CONTROL INPUTS: External Print; Red Print; Motor Oft: Remote Standby; Continuous Print: Inhibit.
Compatible Logic: TTL. DTL or open collector: inputs are 2 TTL loads (External Print and Continuous Print. 3 TTL loads). Inputs are low true, except External Print requires low-to-high transition.
CONTROL OUTPUT: Printer-in-Cycle (PIC); End-of-Print Data Hold; Manual Print; Print Twice.

Output Logic: TTL; can drive 8 TTL loads (PIC. 4 TTL laads). Outputs are high true: except End-ot-Print is 3 ms pulse. Printer-in-Cycle and Data Hold are low true
INPUT/OUTPUT (I/O) CONNECTIONS: Two 50-pin recessed card-edge connectors: $1 / O$ A for data inpul. columns 1 through 10; 1/O B for accessories and/or additional data. columns 11 through 18 (see Drum Diagram).
ISOLATION: Input Lo to chassis ground greater than $10^{7}$ ohms. Lo may be floated up to 350 volts peak with respect 10 chassis ground.
PAPER: $21 / 4$ in tan-fold or roll.
RIBBON: Black/red. $1 / 2$ in. wide.
ENVIRONMENT: $0^{\circ} \mathrm{C}$ to $50^{\circ} \mathrm{C} .0 \%$ to $80 \%$ relative numidity at up $1035^{\circ} \mathrm{C}$
POWER: 90-110, 105-125, 200-240 volts (switch selected). 50-60 $\mathrm{Hz}, 30$ watts ( 40 watts with accessortes)
DIMENSIONS, WEIGHT: Style 0. 7 in half-rack, overall bench size $7^{1 / 2}$ in. nigh $\times 8^{1 / 2}$ in. wide $\times 15^{1 / 4}$ in. deep $(190 \times 220 \times 390$ $\mathrm{mm})$. Net Weight, 16 pounds $(7 \mathrm{~kg})$
ACCESSORIES FURNISHED: One ribbon (installed), one pack fanfold paper.

SECTION 5. THEORY OF OPERATION.

5-1. GENERAL. This section contains circuit descriptions for the Model 172A/173A, Model 1728 Battery Pack option and Model 1722 Digital Interface option. (It should be noted that the Theory of Operation for the Model 1723, IEEE Standard 488 Bus Interface option is provided under separate cover, see Model 1723 Instruction Manual.) The descriptions contained in this section are broken down into the following major categories.
a. Overall Operation.
b. Input Signal Conditioning.
c. A/D Converter and Digital Circuits.
d. Display Board.
e. Power Supply.
f. Battery Pack (Model 1728).
g. Digital Interface (Model 1722).

5-2. OVERALL OPERATION. The overall signal flow of the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ DMM is shown in Figure 5-1.
a. Input Signal Conditioning. An input to the DMM (a resistance, a do voltage or current, or an ac voltage or current) is applied to the appropriate signal conditioning circuit. The output from the signal conditioning circuit is a filtered dc voltage in the range of either 0 to $\pm 3$ volts or 0 to $\pm 300 \mathrm{millivolts}$, which is directly proportional to the input signal within the measurement range.
b. A/D Converter and Digital Circuits. The $A / D$ converter changes the voltage out of the signal conditioning circuitry into digital pulses by the charge balance technique, and these pulses are accumulated by the digital circuitry during the measurement conversion period. At the end of this period, the digital circuitry uses the total count to determine the correct polarity and value of the digitized input signal, which is then displayed with the appropriate polarity, range, decimal point location and function on the LED display. The $A / D$ converter auto calibrates and autozeros itself, as well as the signal conditioning circuitry, to obtain a high measurement accuracy.
c. Digital Interface Options. The display information of the Model 172A/173A can alsc be made available as an output by using either the Model 1722 Digital Interface or the Model 1723 IEEE Standard 488 Bus Interface. Both of these optically isolated options cal also be used to program range, trigger a conversion, or hold the reading of the Model 172A/173A.
d. Power Supply. The power supply furnishes regulated dc voltages for all of the DMM circuitry, and receives its power from either the ac line or the optional Model 1728 Rechargeable Battery Pack.

5-3. INPUT SIGNAL CONDITIONING. Most of the input signal conditioning circuitry is contained on the main printed circuit board (mother board) PC-466 and shown on schematic 29145 E (Sheet 1). These circuits consist of input switching, an ohms converter, a dc attenuator, an ac/dc converter, a clamp and an active filter. The current to voltage $(1 / V)$ converter circuitry is located on the current board PC-406 for the Model 173 A and mounted on a shield for Model l72A. Both circuits are shown on Schematic 274780.


FIGURE 5-I. Overall Block Diaqram of Model I72A/173A.


FIGURE 5-2. Simplified Block Diagram of Signal Conditioning Circuits.
a. Overall Operation. Signal routing in the signal conditioning circuitry is essentially as shown in the simplified block diagram (Figure 5-2). Front panel switching selects the applicable path for the input signal. For example, an ac current input would be routed through switch "A" to the $1 / V$ converter. The ac voltage output from the $1 / V$ converter would be routed through the "V" switch and the "DC/AC" switch to the AC/DC converter, and the dc voltage output of this circuit would then be routed to the $A D$ converter through the clamp and active filter. The required switching and signal conditioning for an ohms or voltage input can also be readily determined from the diagram, and is left to the user. The front panel switching and signal conditioning circuits will be described in greater detail in the following paragraphs.
b. Switching. Front panel pushbutton switches control power, function and ranging for the Model $1 \overline{72 A / 1} 73 A$. A summary of the switching is given in Table 5-1. Additional information on function selection and range selection switching is given in Paragraphs $5-3 i$ and $3 j$, respectively.

TABLE 5-1.
Summary of Pushbutton Switching.


TABLE 5-1. (CON'T)
Summary of Pushbutton Switching.

\begin{tabular}{|c|c|c|c|}
\hline SW: \({ }^{-\mathrm{CH}}\) \& STYLE \& SETTING \& REMARKS \\
\hline V \& *Interlock \& in \& DMM is set to \(V\) mode. Overrides \(A\) and \(\Omega\) functions due to interlocked pushbuttons. \\
\hline A \& :Inter lock \& In \& DMM is set to \(A\) mode. Overrides \(V\) and \(\Omega\) functions due to interlocked pushbuttons. \\
\hline \(\Omega\) \& *Inter lock \& In \& \begin{tabular}{l}
DMM is set to \(\Omega\) mode. Overrides \(V\) and \(A\) functions due to interlocked pushbuttons, also overrides \(D C / A C\) switch. \\
*NOTE \\
If \(V, A\), and \(\Omega\) pushbuttons are OUT simultaneously, no function will be selected, the input terminals will be open-circuited, and the DMM will display \(V\). The displayed reading is meaningless.
\end{tabular} \\
\hline DC/AC \& Push-Push \& In \& DMM is set to measure \(A C\) (either \(V\) or \(A\) ). Not functional when set to \(\Omega\). \\
\hline DC/AC \& Push-Push \& Out \& DMM is set to measure DC (either Vor A). \\
\hline \begin{tabular}{l}
HI/LO \% * \\
HI/LO \% \%
\end{tabular} \& \begin{tabular}{l}
Push-Push \\
Push-Push
\end{tabular} \& \[
\begin{aligned}
\& \text { In } \\
\& \text { Out }
\end{aligned}
\] \& DMM is set to low ohms function. DMM is set to high ohms function. \\
\hline 2 WIRE/4 WIRE**
2 WIRE/4 WIRE** \& Push-Push
Push-Push \& in

Out \& | DMM is set for $4-$ WIRE ohms measurements. Upper pair of terminals are used for voltage sensing. Lower pair of terminals are used for ohms source. Lower pair of terminals are useable only in 4 -WIRE a mode and are open circuited for all other conditions. |
| :--- |
| DMM is set for conventional 2-WIRE ohms measurements. Upper pair of terminals must be used. Lower pair of terminals are opencircuited. | <br>

\hline \& \& \& | $\therefore \div \text { NOTE }$ |
| :--- |
| Only functional when set to $\Omega$. | <br>

\hline
\end{tabular}

1) The de attenuator is shown on the simplified schematic (Figure 5-3). On the 300 mv and $3 V$ ranges, $K 202$ is de-energized as shown and no attenuation occurs. Above $\pm 3$ volts, K202 will energize. This means that the output on the 30 V and 300 V ranges will be $1 / 100$ of the input as derived from the following equation.

$$
\frac{100 K}{150 K+9.75 M+100 K}=\frac{1}{100}
$$

2) For 1200 voltrange, switch $Q 206$ will also be on, which makes the output $1 / 1000$ of the input. Thus, for all dc ranges, a full scale dc voltage input will result in either a $\pm 3$ volt or $\pm 300$ millivolt output from the attenuator, and the $A / D$ converter gain (buffer) will be XI or X10 accordingly. Table 5-2 lists the respective gains for dc voltage (and ac voltage) ranges.

TABLE 5-2.
Gain Chart For $A C / D C$ Voltage.

|  |  |  | RANGE CONTROL LINES |  |
| ---: | :---: | :---: | :---: | :---: |
| RANGE | ATTENUATION | A/D GAIN | RLD | H |
| 300 mV | $\vdots 1$ | $\times 10$ | +8 V | -12 V |
| 3 V | $\div 1$ | $\times 1$ | +8 V | -12 V |
| 30 V | $\div 100$ | $\times 10$ | 0 V | -12 V |
| 300 | V | $: 100$ | $\times 1$ | 0 V |
| 1000 V | $: 1000$ | $\times 1$ | -12 V |  |

## d. $A C / D C$ Converter.

1) The basic transfer function of the $A C / D C$ converter is a shown on the simplified schematic (Figure 5-4). The resistor values were selected so the lvacrms in $=-1 V \mathrm{VA}_{\mathrm{OU}}{ }^{-}$ Above 3 volts, feedback resistance ( $R_{f}$ ) is reduced to keep the output always less than - 3 Vdc . The dc output is a half-wave rectified sine wave, and the converter is average responding, calibrated to the rms value of a sine wave.
2) $C_{\text {, }}$ blocks dc inputs, and the dc offset voltage of the amplifier is autozeroed of $C_{4}$, $R$ and $C$ provide some output filtering, along with the active filter (to be descrit later.)
3) In actual circuit operation (as shown on Schematic 29145E, Sheet 1) feedback resistance of U 201 is controlled by K201 and K101. With both relays de-energized as shown, the overall gain of the ac/dc converter is unity (i.e. I VACrms input =-lVdc, With only K201 energized, gain is $\div 100$, and with both relays energized gain is $\div 1000$. The relays are controlled by the relay drivers shown in the lower left corner of the schematic. The relay drivers are, in turn, controlled by signals from the RLD and H lines from LSI circuit U901. See Table 5-2 for gain chart of the ac voltage ranges.


FIGURE 5-3. Simplified Schematic of DC Attenuator.


FIGURE 5-4. Simplified Schematic of AC/DC Converter.

## e. Current-to-Voltage (I/V) Converter.

1) Model 173A I/V Converter. The converter is shown on the simplified schematic (Figure 5-5). An input current is converted to a voltage directly proportional to the input current by measuring the voltage drop across a resistance placed in series with the current. This is accomplished by closing the appropriate range relay (K50l through K505) to give an output voltage between 0 and $300 \mathrm{millivolts} .\mathrm{For} \mathrm{example:} \mathrm{Consider}$ that K 503 is closed. The current will now flow through $9 \Omega+0.9 \Omega+0.1 \Omega=10 \Omega$, and $30 \mathrm{~mA}=300 \mathrm{mV}$. Since a dc current is converted to a dc voltage and an ac current is converted to an ac voltage, the output of the $I / V$ converter is routed through either the $D C$ attenuator circuit or the $A C / D C$ converter before being applied to the $A / D$ converter. Signal routing is controlled by the $D C / A C$ pushbutton and the gains employed are the same as those given in Table $5-2$ for the 300 mV range. Input protection for the I/V converter consists of a 3 ampere medium acting fuse (F501) and a diode bridge (CR50 The fuse is rear panel accessible. CR501 limits the voltage to 2 diode: drops in either positive or negative polarity. Unity gain buffer amplifier U50l guards the center connections of the diodes so that less than one digit error is introduced on the $300 \mu \mathrm{~A}$ range, which has 10 nanoampere sensitivity. Refer to Schematic 274780 for the remainde of this discussion. Range control lines ( $A, B$ and $C$ from LSI chip UODI) autorange the Model 173A current function. The lines are decoded by the BCD to decimal decoder U502 (See Table 5-3). The output from U502 turns on the applicable relay driver transistor to energize its range relay. Diodes are used to block the range lines when -12 V is applied and input dividers are used to drop +8 V to +5 volts for application to 4502. Spike suppression diodes are used across the relay coils to prevent damage to the relay drivers. Potentiometers R506, R509 and R512 provide adjustments for calibrating the I/V converter. With the exception of the fuse, all of the $1 / V$ converter circuitry is physically located on current PC-406 and shown on Component Layout diagram 27884 C in Section 7.

TABIE 5-3.
173 A Current Ranging.

|  |  |  | $\begin{array}{c}\text { RANGE LINE } \\ \text { RANGE } \\ \text { ACA E DCA }\end{array}$ |  | $\begin{array}{c}\text { RANGE } \\ \text { RESISTANCE }\end{array}$ |
| :---: | :---: | :---: | :---: | :---: | :---: |
| RELAY |  |  |  |  |  |
| OPERATED |  |  |  |  |  |$)$

2) Model 172A I/V Converter. This current converter (shown in Figure 5-6) consists of a 1 ohm resistor (R154) and a 2 A protection fuse (F501). The input current passes through the resistor developing an output voltage from 0 to 2 voits. For example: a 475 mA input will produce an output voltage of 475 mV . Since an ac current input will produce an ac voltage and a dc input will produce a dc voltage, the output of the $1 / V$ converter is routed through either the $D C$ attenuator or the $A C / D C$ converter before beir applied to the $A / D$ converter. Routing is controlled by the position of the $D C / A C$ pushbutton, and the gains used are the same as those given in Table 5-2 for the 300 mV ( 300 n


FIGURE 5-5. Simplified Schematic of 173A $1 / \mathrm{V}$ Converter.


FIGURE 5-6. Simplified Schematic of Model I72A I/V Converter.
and $3 V(2 A)$ ranges. $F 501$ is accessible from the rear panel and $R 514$ is mounted on a shield above the display board. The circuit is shown at the bottom of Schematic 27478D, which also contains the I/V converter for the Model 173A.
f. Ohms Converter.

1) The ohms converter circuit basically consists of a current generator and summing amplifier. Simplified operation for the two wire ohms configuration is shown in Figure 5-7.
2) The current is generated by applying either 3.34 or .334 volts (Ohms Cal. Voltage) from buffer amplifier UlOl to the Range resistors. The unknown resistances (Rx) is placed in the feedback loop of the summing amplifier (U202) to force the current through the unknown resistor. Thus, the output signal to the $A / D$ converter for an on range measurement can be determined by the equation $-V_{o d c}=1 \cdot R_{X}$. The current flowing through $R_{x}$ is determined by the equation $1=$ Vohms CAL.

## Range

Six decade currents are generated by the six combinations of the three range resistors and two levels of ohms cal voltage. Example: $\frac{.334 \mathrm{~V}}{334}=1 \mu \mathrm{~A}$. This current is used on 300 K . $L O \Omega$ range and $3 M H I \Omega$ range ( 3 V max.) $334 \mathrm{~K}=$
3) See Table 5-4 for ohms ranges. High ohms puts the $A / D$ converter on the 3 volt range, allowing 6 resistance ranges which can turn on semiconductor junctions for on scale readings. Low ohms puts the $A / D$ converter on the 300 mV range, allowing 6 resis tance ranges which do not turn on semiconductor junctions for on scale readings.
4) There are time and temperature drifts associated with amplifiers UlOl and U202. These effects are compensated for by the $A / D$ converter. The reference used to calibrate the $A / D$ converter in $\Omega$ function is the output of UlOl. Therefore, any drift in UlOl is compensated for every conversion cycle. The negative input of $U 202$ is what "autozera't 1 is calibrated to every conversion cycle. Therefore, ohms current stability is a function only of the stability of the Range resistor. The lead drop in the high terminal of the ohms source amplifier is compensated for by connecting it to "autozero" 2 when in the onms mode. "Auto-zero" 2 is the zero for the input signal. In 2 -wire ohms the leads connect at the front panel binding post. Therefore, a 4 -terminal ohms system exists up to the front panel terminals. See A/D converter discussion for a more thorough explanation of error correction.
5) The ohms converter circuit has been further simplified and redrawn to show the 4-Wire ohms configuration in Figure 5-8.
a. As previously described, the circuit measures a resistor by putting a constant current through $R x$ and measuring the voltage drop across $R x$, which is accomplished by putting $R x$ in the feedback of a summing amplifier ( $\Omega$ AMP) whose input is a reference ( $\Omega$ Vref) voltage through an input resistor ( $R \Omega$ ).
b. $A Z-1, A C A L, A Z-2, \varepsilon A / D$ Signal are the $4 \mathrm{~A} / D$ inputs. This $A / D$ operation compensates for time $\varepsilon$ temperature variation of $\Omega V R e f$ and $\Omega$ Amp, as well as compensating for lead resistance. The $A / D$ looks at each of these inputs in the time sequence as follows:

1) $A Z-1$ looks at $\Omega$ AMP input for 40 ms and stores this zero level.
2) ACAL looks at $\Omega$ VREF for 40 ms and calibrates itself to the difference between $A Z-1$ and $A C A L$. Thus, it is calibrated to the voltage across $R \Omega$. Since $R \Omega$ is a fixed stable resistor the value of 1 is now known. Since 1 flows through $R x$ the calibration is fixed.
3) AZ-2 looks at the voltage at the top of $R x$ for 40 ms . This is defined as the zero level for signal measurement and is stored in $A / D$.


FIGURE 5-7. Simplified Ohms Converter, Two-Wire Ohms Configuration.


FIGURE 5-8. Four-Wire Ohms Measuring Technique.
4) A/D Signal looks at the bottom of Rx for 200 milliseconds . The A/D thus measure the difference between $A / D$ Signal and $A Z-2$ without polarity sign. The voltage across Rx is displayed.
c. The measurement is essentially a ratio measurement between the voltage across $R x$ and the voltage across $R \Omega$.
d. Note that the voltage at the top of $R x$ is essentially at signal 10 of the instrument ( $\pm$ תAMP offset and lead resistance drop) and the voltage at the bottom of $R x$ is negative. Thus, the high impedance terminal is guarded and relative fast response is achieved at high resistance values.
5) Refer to sheet 1 of Schematic 29145 E for the remainder of the ohms converter circuit discussion. The ohms switching FET Qllo is driven by the c-iine, Qlos is driven from the $\mathrm{A}-\mathrm{line}$ and Q 107 is driven from the $\mathrm{B}-1$ ine. These lines are also used and decoded to operate the Modell73A autoranging current. When on, Q110 switches the gain of $\mathrm{Ul01}$ from one to ten. Q105 and Q107 switch-in the range resistors. Each resistor consists of an adjustment potentiometer, a fixed resistor and the on resistance of a FET (no FET for $33.4 \mathrm{M} \Omega$ ). Amplifier U202 is a FET indut amplifier. This amplifier is overload protected by Qlob base emitter junction connected to signal ground, and Ql08 base emitter junction connected through Ql09 clamp transistor. Thus, the input swing is clamped. Very large voltage excursions on the output side of U202 are allowed (by action of Q205 and CR205. Under normal operating conditions Q205 is operated in the saturated mode. However, under overlo. conditions, Q205 becomes a current source with its collector to emitter breakdown handling large voltage excursions when signals are positive with respect to the ohms source high. Conversely, if signals are negative with respect to ohms source high, CR205 reverse biases, cutting off that portion of the circuit. All of these high voltages will cause current to flow through R205 (120K?) which is connected to the +15 volt supply. The maximum limitation of 250 volts rms is a function of the power rating of R205 (a 1/2-watt resistor), and Q205's 400 volt breakdown.

TABLE 5-4. OHMS RANGES

| RANGE |  | RANGE | REF | OHMS | RANGE LINES |  |  |
| ---: | ---: | :---: | :---: | :---: | :---: | :---: | :---: |
| $H 1 \Omega$ | LO | R | $V_{1}$ | CURRENT | $A$ | $B$ | $C$ |
| 3 K | $300 \Omega$ | 3.34 K | 3.34 V | 1 mA | +8 V | -12 V | +8 V |
| 30 K | 3 K | 3.34 K | .334 V | $100 \mu \mathrm{~A}$ | +8 V | -12 V | -12 V |
| 300 K | 30 K | 334 K | 3.34 V | $10 \mu \mathrm{~A}$ | -12 V | +8 V | +8 V |
| 3 M | 300 K | 334 K | .334 V | $1 \mu \mathrm{~V}$ | -12 V | +8 V | -12 V |
| 30 M | 3 M | 33.4 M | 3.34 V | 100 nA | -12 V | -12 V | +3 V |
| 300 M | 30 M | 33.4 M | .334 V | 10 nA | -12 V | -12 V | -12 V |

9. Clamp Circuit (Figure 5-9).
1) The clamp prevents damage to the input circuitry of the $A / D$ converter and the active filter by limiting the maximum input voltage to approximately plus and minus 5 volts. It also functions in conjunction with the 150 Kohm resistor (R217) and 0.01 Li capacitor (C209) in the dc attenuator to eliminate any relay arcing whenever high volt. age inputs are applied to the instrument during range switching. Low leakage FETS are used to minimize leakage current.


FIGURE 5-9. Simplified Schematic of Clamp.


FIGURE 5-10. Simplified Schematic of Active Filter.
2) As shown on Sheet 1 of Schematic 29145E, the -5 volts is supplied to Q703 by zener diode VR701 and resistor R710, which is connected to -15 volts.
h. Active Filter (Figure 5-10).

1) The DC filter is used in front of the $A / D$ converter on all functions. The component values used in the circuit provide $250: 1$ attenuation to 50 Hz on dc volts, and 1700:l filtering on ac volts output at 50 Hz . Minimum rise time is achieved without overshoot by having the following component relationships: $C 702=C 701, R 604=R 603$, $R^{*}+R 707=1.5(R 603)$ and $C 702=1.5(C 601)$. The filter requires an input resistance of $200 \mathrm{~K} \Omega$, $49.9 \mathrm{~K} \Omega$ of which is R 707 . The other $150 \mathrm{~K} \Omega$ comes from various sources, dependent upon range and function, as given in Table 5-5. The $200 \mathrm{~K} \Omega$ is also maintained so that the effect of $A / D$ converter input current is autozeroed out (see $A / D$ converter discussion, Paragraph 5-4). The filter does not contribute any dc offsets to the signal path. They are blocked by $C 702$ and C701. C903 (not shown) provides frequency compensation for $U 602$.

TABLE 5-5.
Active Filter input Components.

i. Range Selection. Ranging is accomplished by RSA \& RSB lines going to LSI circuit U901. They are controlled by the front panel switches AUTO/MAN, DN $\varepsilon$ UP, according to Table 5-6. RSA \& RSB are edge sensitive, causing range changes when their levels are changed. This causes one uprange or one downrange per button push.

TABLE 5-6.
Range Selection.

| Range AUTO/MAN | witc DN | UP | $\begin{aligned} & \text { Rang } \\ & \text { RSA } \end{aligned}$ | $\begin{aligned} & \text { ines } \\ & \text { RSB } \\ & \hline \end{aligned}$ | ACTION |
| :---: | :---: | :---: | :---: | :---: | :---: |
| OUT | X | $X$ | OV | $+8 \mathrm{~V}$ | AUTORANGE |
| IN | OUT | OUT | OV | OV | HOLDRANGE |
| IN | IN | OUT | +8V | OV | DOWNRANGE |
| IN | OUT | IN | $+8 \mathrm{~V}$ | $+8 \mathrm{~V}$ | UPRANGE |
| $X=$ DON'T CARE |  |  |  |  |  |

j. Function Switching.

TABLE 5-7.
Function Selection.

| FUNCTION | V | $$ |  |  | HI/LO | $\Omega$ | FUNCT AC/DC | LINES (U901) VI |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| DCV * | IN | OUT | OUT | OUT | x | +8V | $+8 \mathrm{~V}$ | +8V |
| DCI | IN | OUT | IN | OUT | X | +8V | $+8 \mathrm{~V}$ | +8V OV |
| ACV | OUT | IN | OUT | OUT | x | +8V | OV | + $8 \mathrm{~V} \mathrm{~V}^{+8}(172 A)$ |
| ACI | OUT | IN | IN | OUT | x | $+8 \mathrm{~V}$ | OV | OV (173A) |
| HIS | OUT | OUT | X | IN | OUT | OV | OV | +8V |
| LOS | OUT | out | x | IN | IN | ov | +8V | $+8 \mathrm{~V}$ |

Function selection is accomplished by connecting function lines $\Omega, A C / D C, \varepsilon$ VI according to Table 5-7. The function lines are level sensitive.


FIGURE 5-12. Simplified Block Diagram of A/D Converter.

- 5-4. A/D CONVERTER AND DIGITAL CIRCUITS. (Schematic 29145E, Sheet 2).
a. Introduction. A simplified block diagram of the A/D Converter and Digital circuits is shown in Figure 5-11. The $A / D$ converter generates a digital pulse train which over a specified time period is directly proportional to the dc voltage applied. It has the capability to measure its own offsets and gain errors as well as those of circuitry in front of it (i.e., ac/dc converter, dc attenuator and ohms converter). The converter then cancels the effect of these errors by storing appropriate correction voltages in autozero and auto-calibrate storage. A conversion cycle consists of four different operating modes, as shown in Figure 5-12. During each mode, a different input is connected to the $A / D$ buffer. The difference voltage between $A C A L$ and $A Z-1$ is the calibration voltage, while the difference between signal integrate and $A Z-2$ is the measured voltage. The converter uses the charge balancing conversion technique, and polarity detection is accomplished digitally. Almost all of the digital tasks are handled by a custom large scale integration (LSI) circuit. Note: details of the operation of the LSl chip will not be given in the $A / D$ converter discussion. However, various of its outputs which are necessary for the operation of the remainder of the $A / D$ converter will be referred to when necessary.
b. Charge-Balancing Technique. The charge-balancing converter of the Model 172A/173A is built around an active integrating circuit and a comparator circuit which at first glance may appear similar to a dual-slope converter. However, its operation is quite different. In the charge balance converter, the net charge for an integrating cycle (charge/discharge cycle) is zero, and the digital output from the converter is a function of the number of integrating cycles that occur during the measurement conversion period (signal integrate). The number of integrating cycles in turn, depend upon the level of the input signal. In the Model $172 A / 173 A$, the input to the $A / D$ converter is offset to handle bipolar input signals and the number of integrating cycles (output counts) increases as the input voltage increases in the positive direction. For example: on the 3VDC range, a -3 volt input would produce zero counts, zero volts ( 30,000 counts) and $+3 V$ ( 60,000 counts). It can be seen from the example that a minus $s i g n$ would have to be displayed from 0 to 30,000 counts and that 30,000 counts would have to be subtracted in order to display zero with a zero volt input. Both of these tasks are handled by the digital circuits.


FIGURE 5-12. A/D Converter System Timing.
c. Basic Operation of the $A / D$ Converter. The four basic operating modes of the $A / D$ converter are described as follows:

1) AZ-1. The buffer input is connected to reference low (signal LO in $V$ and $A$ functions), or summing junction of the ohms amplifier in $\Omega$ function. The switching rate for zero input is forced into the current switch drivers. The comparator output applies a de correction voltage to auto-zero storage. This voltage is stored and applied to the active integrator forming a negative feedback loop which quickly stabilizes.
2) Auto-Calibrate. In this mode, the buffer input is connected to the reference (3.3444 Vdc in $V$ and $A$ functions, or the ohms reference in $\Omega$ ). Auto-zero storage continues to apply AZ-l correction voltage to the active integrator. The current switch drivers are forced to switch at the appropriate rate for reference input, and a dc correction voltage from the comparator is applied to auto-cal storage. This correction voltage is stored and continually applied to the reference current source which changes the reference current removed from the active integrator, completing another negative feedback loop.
3) AZ-2. The same procedure as $A Z-1$ is followed, with the exception that the buffer is connected to input $L 0$ (zero circuit for $d c \vee$ and $A$ functions, ac/dc converter for ac $V$ and $A$, or input HI for $\Omega$ ).
4) Signal Integrate. The buffer is connected to signal input (dc attenuator output for dc $V$ and $A$, ac/dc converter output in ac $V$ and $A$, or input $L 0$ in $\Omega$ ). AZ-2 and ACAL voltages are still applied, which provide compensation for zero and gain errors. The A/D conversion is now made, and displayed during the next conversion cycle.
d. A/D Buffer. The buffer (shown in Simplified Schematic, Figure 5-13) performs two functions. It has four multiplexing JFET switches ( Sl through S 4 ) that connect the necessary inputs to the $A / D$ converter to provide the four basic modes of operation. The driving signals ( $Z_{1}, Z_{2}, R$ and NS) for the multiplexing switches come from LSI circuit 4901. The second function of the buffer is to provide two gains ( $x \mid$ and $x \mid 0$ ) which give $3 V$ and $0.3 V$ ranges, respectively. Buffer gain during $A Z-1$ and $A C A L$ is $x 1$ for $V, A$ and every other $\Omega$ range. Buffer gain during AZ-2 is the same as signal integrate, which is $\times 10$ on $300 \mathrm{mV}, 30 \mathrm{~V}, \mathrm{~L} 0 \Omega, 300 \mathrm{~mA}$ on 172 A and all current ranges of 173 A . A gain of $\times 1$ is used elsewhere. LSI chip 4901 controls $S 5$ and $S 6$ (Q702 and Q701) via the Gl0 line.


FIGURE 5-13. Simplified Schematic of $A / D$ Buffer.


FIGURE 5-14. Simplified Schematic of the A/D Converter.
e. A/D Converter Simplified Schematic Description (Figure 5-14).

1) The active integrator, reference current switch and driver, comparator, $A Z$ and ACAL storage circuits are shown on the simplified schematic diagram. After the buffer, the $A / D$ converter becomes unipolar, using only one reference current. Since bipolar inputs are applied to $R_{i}$, the nominal value of $I_{z}$ is such that if $V_{i n}=-3$ volts, $I_{z}-1$ in $\geq 0$. Thus, -3 volts is zero counts, 0 volts is 30,000 counts and +3 volts is 60,000 counts. The LSI circuit (U901) counts in this way, providing digital polarity sensing. It should be noted that a 60,000 count span is used as described above, with counts produced by the clock during signal integrate. This is done so that LSI circuit can detect overrange conditions in both polarities and to permit a signal settling time,

- after connecting it to the buffer, before beginning the conversion.

2) Charge balance $A / D$ conversion is used. With this conversion method, the resulting output pulse train has the property that its average frequency over a given time period is proportional to the average of the input voltage over the same time period. Thus, the digital output is a representation of the true integral of the analog input over any specificed sampling time. The basic converter consists of the active integrator, comparator, current switch driver, reference current switch and the reference current source. For this description, assume that the charge on the integrating capacitor (ci) is such that the output of $\mathrm{U6O4}$ is initially at some positive level. As the input signal current ( 1 in ) is integrated by the capacitor, the output of 4605 ramps negative and eventually becomes more negative than the comparator threshold. The comparator output goes to logic zero, which is inverted to logic 1 by the inverter and applied to the " $D$ " input of the flip flop. At the next positive going edge of the Clock, this "one" is latched by the flip flop and appears as the set output $Q R$, and the $\mathbb{Q}$ output of the flip flop turns on the current switch. The reference current $I_{r}$ is forced to flow out of the integrating capacitor, discharging it, and the output of 0604 crosses the comparator threshold in the positive direction. This results in a logic 0 at the " $D$ " input of the flip flop and the next positive going edge of the CLOCK signal resets the flip flop, which terminates the pulse on the QR line and turns off the current switch. The converter will remain in this state until the next time that the integrator voltage crosses the threshold of the comparator in the negative direction. For relative large values of the input, the time required for the capacitor to be recharged to the point where the comparator threshold is exceeded will be relatively short and the integration cycle (charging - discharging cycle) described will occur at a high frequency. Conversely, with lower values of input current, the charging time of the integrator will be longer and the events described will occur at a lower rate. Thus, the repetition rate of current pulses (and digital output pulses) is a function of input current. It should be noted that the current switch driver circuitry shown has been greatly simplifit for this discussion. In actual operation, the current pulse is limited in time to onehalf of the output pulse on the QR line, and is turned on and off by a $90^{\circ}$ out of phase clock which centers the current pulse on the digital output pulse to eliminate edge problems. Since the amount of current removed from the integrating capacitor during each discharge cycle is equal to the product of $I_{r}$ and one-half clock period, the current pulses are uniform in size. The total charge removed from the capacitor in any given time period is equal to the total charge that flowed in (within a resolution of one discharge increment). The uniformity of size of the reference current pulse guarantees that the total number of such pulses is proportional to the time-integral of the input current.
3) The auto-zero correction is always applied to the active integrator, but during $A Z-1$ and $A Z-2$, the switch $S_{z}$ is closed which allows correction of the auto-zero signal. The rest of the time it is stored on capacitor $C_{a}$. The correction signal is generated by forced switching of the current source at the "zero" input rate. Since the input is offset, this equates to a midscale current input. The correction signal is the de level developed at the output of the comparator by $R_{f}$ and filtered by $C_{f}$. Auto-zero correction is supplied as negative feedback to the integrator input. Auto-zero correction can be considered as a contribution to input current since it affects the charge portion of the integration cycle.
4) The auto-calibrate correction is continually applied to the reference current circuit. $\mathrm{S}_{\mathrm{c}}$ is closed during Auto-Cal to update the correction voltage, and is stored on capacitor $C_{c}$. Auto-Calibrate correction is generated similiarly to auto-zero correction, with the exception that forced current switching is done at the full-scale current input rate. Auto-calibrate correction varies $I_{r}$ and thus, sets the amount of charge removed from $C_{i}$ during the discharge cycle since the source "on' time is fixed at one-half the clock period.
5) In the reference current circuit, the base of $Q_{r}$ is referenced to ground and the emitter resistor $R_{2}$ connects to a negative voltage $(-V)$. The current through $\mathrm{R}_{\mathrm{r}}(1)$ is approximately equal to $I_{r}+I_{c}$ (neglecting base current of $Q_{r}$ ). Since 1 is constanc, $I_{r}$ will vary inversely with respect to a change of $I_{c}$.
6) The reference current switch consists of two diodes, and is controlled by the current switch driver circuitry. Reference current is removed from the summing junction of the active integrator when $D_{1}$ is conducting. When $\bar{Q}$ of the $D$ flip flop is high, $D_{2}$ conducts cutting off $D_{1}$. The $Q$ output of the flip flop is the digital pulse train proportional to the output. The circuitry which forces predetermined switching rates during $A Z-1, A Z-2$ and $A C A L$ is not shown.
f. Oscillator. The oscillator (shown in Figure 5-15) is crystal controlled and operates at approximately 669 kHz . It is divided down $2: 1$ to produce the $A / D$ converter clock. The oscillator runs at twice the clock rate for the following two reasons:
7) It allows the current switch to be on only one-half of the clock period, so that there is always an off time even when the current switch is on for consecutive clock cycles. This eliminates a gross nonlineraty problem from the charge-balance A/D converter.
8) It allows the current to be switched on and off with a $90^{\circ}$ phase shifted clock sigr. (generated by the oscillator) so that there will be no timing problems with the edges of the current pulses.


FIGURE 5-15. Simplified Schematic of 669 kHz Oscillator.


FIGURE 5-16. Simplified Schematic of Reference Supply.
g. Reference Supply. Although not actually a part of the A/D converter circuitry, the reference supply (shown in Figure 5-16) furnishes the stable known voltages required to auto calibrate the $A / D$ converter. These voltages are also used in the ohms converter circuitry. The heart of the reference supply is a stable, low temperature coefficient zener diode. It is driven from a constant current (nominally 7.5 mA ) developed by amplifier U601. With the zener current well regulated, it is immune to power supply variations The output divider resistors are part of a precision resistor network which provides very stable reference voltages. R606 and the input resistors of the divider are specially selected (depending on the zener voltage) to provide a nominal $200 \mu \mathrm{~A}$ of current to the divider. The zener voltage is between 6.15 and 6.5 volts, with the resistors matched accordingly.
h. Digital Section. The digital section is composed almost entirely of the custom LSI circuit UGO1. Tt keeps track of the function and range, allows auto or manual ranging generates the display information, controls the $A / D$ converter timing, provides ranging lines for the signal conditioning circuitry, and provides information for the optional digital interfaces, as well as controlling them.

5-5. DISPLAY BOARD, SCHEMATIC 27404D.
a. This schematic shows the display digits, the LED function indicators, all display drivers and multiplex timing generator. The entire display, including minus sign and function indicators, is fully multiplexed. This is accomplished with six time slots (timing mux). The mux times are generated by shift register $U 301$ whose inputs come from the LSI circuit (U901, Schematic 29145E). These time slots are referred to as ${ }_{0},{ }^{t} 1$, $t_{2}, t_{3}, t_{4}, t_{5}$. The common anodes of each digit and the common anodes of the function indicators are driven from the appropriate mux line, see Figure 5-17. These mux times occur in the operating digital interfaces (see Section 5-8, 1722). The mux times occur in the sequence $t_{0}$ thru $t_{5}$, $t_{0}$ and $t_{1}$ are 383 microseconds each, and $t_{2}$ thru $t_{5}$ are 191 microseconds each. One complete mux cycle is 1.53 milliseconds .
b. The data mux lines, $a, b, c, d, e, f, g$, and dp drive the cathodes of the display segments and the function indicators. See Table 5-8. The data mux lines are generated in the LSI circuit U901, Sheet 3 of Schematic 29145E.
c. The 10,000 digit only indicates 1,2 , or 3 in overrange. If the 10,000 digit is zero, it is blanked by the data mux lines. It is necessary to operate the function indicator and minus sign twice as long as the digits. Since "Ac" and "-" are activated during $t$, the 10,000 digit time, $t$ is as long as $t 0$. To keep the 10,000 digit the same brightness as the other digits, $a, b, c, d, e$ and $g$ data mux lines for this digit are on for half of $t, t i m e$.
d. The anode driver transistors are saturating switches (Q301 thru Q306). The segment driver transistors are emitter followers (Q307 thru Q314). R302A thru R302H are current limiting resistors. Segment current is approximately 30 milliamperes peak. R $303 \& \subset 301$ decouple current spikes from the 5 volt power supply. $C 302$ decouples U301 from power supply. CR301 and R304 prevent parasitic oscillation of segment driver transistors.

5-6. POWER SUPPLY, SCHEMATIC 29145E. Sheet three of this schematic contains the voltage regulators, line transformer, line voltage switching and power switching for the Models 172A/173A. There are four separate integrated circuit voltage regulators used. VROO3 provides the regulated +15 volts and the -15 volt regulator is VROO2. These two regulators deliver the $\pm 15$ volts used by most of the circuitry in the 172A/173A. In addition, the regulated +15 volts is supplied to the input of the +8 volt regulator (VROO4) and the regulated -15 volts is supplied to Zener diode VR801 via R801 to develop - 12 volts. Both of these voltages $(+8$ and -12 ) are fed to the LSI chip (U901). The -12 volts is also fed direct to the Switch Driver circuitry and the +8 volts is fed indirectly to this circuitry by the pullup resistors associated with U901. The two 15 volt regulators receive either $\pm 29.5$ volts (unregulated) from the line transformer (TOOI) and full-wave rectifier (CROO1), or $\pm 19.2$ volts from the batteries in the Model 1728 Battery Pack. The unregulated voltages are higher than the regulators need because they are used to recharge the battery pack. If the instrument is off, but the ilne cord powered, unregulated voltages are fed direct to the Battery pack connectors ( $\mathrm{P} 401,402$ ). There is also a +5 volt regulator (VROOI). This regulator is used to drive the display, the digital logic circuitry in the $A / D$ converter, and all relays. This +5 volts is also used to drive the Optical Isolator circuitry whenever the Model 1722/1723 Interface Option is installed in the 172A/173A.
If a Model 1728 battery pack is installed in the Model 172A/173A the batteries of the Model 1728 will be charged through the unregulated voltages. When the instrument is Iine powered, resistors, R005, R006 and R007 feed the charge inputs on the battery pack. These resistors drop the charging current down to the trickle charge level. As previously mentioned, the 8 volt regulator, VROO4, gets its input from the regulated +15 volt output of VROO3. The input for VROOI ( 5 V regulator) is derived from transformer secondary 7 and 8 , full-wave rectifier CROO2 and ROO3. This unregulated +14.5

TABLE 5-8.
Display Data MUX Lines.

| 8 LINES | DRIVES DISPLAY SEGMENT OF INDICATOR LIGHT DURING |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  | $\mathrm{t}_{5}$ | $t_{4}$ | $t_{3}$ | $\mathrm{t}_{2}$ | ${ }^{\text {, }}$ | ${ }^{\text {to }}$ |
| a | a | a | a | a | a for last $\frac{1}{2}$ of $t_{1}$, Off other half | $\begin{array}{r} \mathrm{mV} \text { indicator-173 } \mathrm{A} \\ \mathrm{mV} / \mathrm{mA} \text { indicator-172 } \mathrm{A} \end{array}$ |
| $b$ | $b$ | b | b | $b$ | $b$ for last $\frac{1}{2}$ of $t_{1}$, Off other half. | $V$ indicator-173 A $V / A$ indicator-172 A |
| c | c | c | c | c | c Same as above. | $\begin{array}{r} \mu \mathrm{A} \text { indicator-173A } \\ \text { not used-172 } \end{array}$ |
| d | d | d | d | d | d Same as above. | $\begin{array}{r} \text { mA indicator-173A } \\ \text { not used-172 } \end{array}$ |
| e | e | e | e | e | e Same as above. | A indicator-173A not used-172 A |
| f | $f$ | $f$ | $f$ | f | AC indicator all of $t$ | $\Omega$ indicator |
| 9 | 9 | 9 | 9 | 9 | $g$ for last $i_{2}$ of $t_{1}$ Off other half | $k \Omega$ indicator |
| $d p$ | dp | $d p$ | $d p$ | dp | "'-l' indicator <br> All of $t_{1}$ | M $\Omega$ indicator |



FIGURE 5-17. Digital Display Multiplex Scheme.
also charges the 8.4 V batteries. In BAT mode, the $\pm 19.2$ volts and the +8.4 volts from the batteries connect to the input terminals of VROO2, VROO3 and VROOI. The line switch applies ac voltage from the transformer to the Model 1722 for its regulated 5 volt supply Thus, turning the 172A or 173A off also turns off the 1722.
Transformer T001 has two internal shields, one secondary shield tied to pin 10 , and one primary shield tied to power ground. This shielding provides line isolation. When the dual primary of TOO1 is tied in parallel by switch S001, the Model 172A/173A is connected for 117 volt operation. Switch 5001 also puts these primaries in series, for 230 volt operation, as indicated on the schematic. Provision for 100 volt line is interchanging connections 5 and 6 and connections 2 and 3 on the primaries. This is a physical wiring change that must be made on the printed circuit board, and is a factory option.
There are two connectors for the Model 1728 battery pack, P402 and P401. The self-check terminals are on the bottom of the instrument. There is an "ac" self-check, "dc" selfcheck and an "ohms" self-check. Connect from the appropriate self-check terminal to the input high terminal to exercise the instrument. The self-check is not accurate, the voltages and currents are only approximate. A battery test point ("A") on the bottom of the instrument allows checking of the +19.2 volt battery in the Model 1728. Normally the low battery light will indicate when the batteries have become low and need recharging. However, the test point could be used to troubleshoot for a defective cell.

5-7. MODEL 1728 RECHARGEABLE BATTERY PACK, SCHEMATIC 26758C. The Model 1728 provides $\pm 19.2$ volts and +8.4 volts from nickel-cadmium batteries. BT401 and BT402 are 19.2 volt, . 45 AH nickel cadmium packs which are fused by IA, 3 AG sio-Blo fuses. BT403 is an 8.4 V pack composed of seven 1.2 volt "C" cells and is also fused by a $1 \mathrm{~A}, 3 \mathrm{AG}$, slo-Blo fuse. The Model 1728 has a built-in recharging circuit which operates from $\pm 29.5 \mathrm{~V}$ (unregulated) supplied by the DMM line-power supply.
a. BT401 charging. BT401 is charged via.a constant current from Q401. Diodes CR401 and CR402 and resistor R402 place a diode drop across R401. The resulting current is the maximum charging current. Diode CR403 prevents the battery from supplying current through Q401. The maximum charging current occurs only when the DMM is set to OFF. A trickle charge is maintained when the DMM is line operated. The reduced current is obtained by inserting a limiting resistor in series with the charging circuit (not shown on Schematic 26758C). In full charge, the batteries are charged at a c/10 rate ( 45 mA for BR401 \& BT $402, \& 200 \mathrm{~mA}$ for BT403). When trickle charged, the charge rate varies according to 1 ine voltage $\varepsilon$ battery condition from a minimum of $\mathrm{C} / 100$ rate to a maximum of $\mathrm{C} / 20$ rate. Thus, trickle charge may never fully charge the batteries, but is intender to put sufficient charge into them for short intermittent use.
B. BT402 \& BT403 Charging. BT402 \& BT403 are charged via constant currents from Q 402 or 0403 , respectively. These circuits operate similarly to the above circuit, except that they are powered by unregulated $\pm 29.5 \mathrm{~V}$.
c. Low Battery Detector. This circuit monitors the voltage of all three batteries in the Model 1728, and provides a drive signal to turn on the front panel low battery indicator if either battery's voltage drops below a predetermined level. The approximate levels are: BT403 $(+7.2 \mathrm{~V})$, BT401 ( 17.1 V ) and BT402 ( $-17 . \mathrm{V}$ ). These levels were selected to ensure that a low battery indication will be given before operation of the associated regulator circuits in the DMM can be adversely affected. The heart of the detector circuit is U401, which is connected as an open-loop comparator. Low voltage detection for each battery is described as follows:

1) BT403. The threshold of the comparator is set at approximately +7.2 volts by a divider consisting of $R 407$ and 2410 connected between the regulated +15 volts and


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common. BT403 is connected to the inverting input of U403 through fuse F403 and resistor R408. When the voltage of $B T 403$ drops below the comparator threshold, the comparator output switches positive, turning on the low battery indicator.
2) BT402. For detecting a low voltage condition of BT402, a divider consisting of R411 and R412, and a NPN transistor (Q404) is used along with the comparator. The emitter of Q 404 is connected to the regulated -15 volts, and its base level is set by the divider connected between common and BT402 through fuse F402. With the voltage of BT402 at -19.2 volts, the base-emitter junction of $Q 404$ is reverse biased by approx imately 1 volt. When the voltage drops below approximately -17.1 volts, Q 404 is turne on, dropping the inverting input of $U 401$ below the threshold voltage and the low batte indicator is turned on by the output of U401.
3) BT4OI. Low voltage detection of BT4OI is similar to that described for BT4O2, with the exception that when $Q 405$ is turned on the threshold voltage of $U 401$ is raised above the +8.4 volts supplied by BT 401 . The result is the same. The output of $\mathbf{U 4 0 1}$ switches positive, turning on the low battery indicator.
4) It should be noted that the switching levels described above can vary slightly, because of the $\pm 5 \%$ tolerance of the regulated power supplies in the DMM.

## 5-8. MODEL 1722 DIGITAL INTERFACE.

a. Overall Block Diagram. As shown in Figure 5-18, Serial data from the DMM and its assoclated clock Thes are first isolated. Bidirectional data line SERDAT is then split Output data DOWNDAT goes to the output register block where it is converted to parallel form and then to the output buffers. The clock lines go to the control block which decides where the data is going, out or in, and also generates the flag. Control input data and strobes are first buffered by the input buffer block. The strobes go to the output buffer to gate the outputs. The control, data inputs go to the input register and control block where they are converted from parallel to serial form and sent to the isolation block. The input register and control block also decides, based on control data input, whether there is to be an output update. Power isolation for the 1722 is provided by transformer T1001 which is powered by a secondary winding of the DMM power trans former.
b. Signal Isolation. (See Schematic 27902E). The bidirectional data line (SERDAT) a the two clock lines (SERCLK and INCLK), each drive an emitter follower (Q1035, Q1037 or Q1036) whose load is an LED in its respective opto-isolator (U1019, Ul021 and U1020). The outputs of these opto-isolators are pulled up by R1009, R1012 and R1009, respectivel U1018 is driven by Q1034 in a similar manner to the three opto-isolators just mentioned, and its output pullup is on the DMM mainframe.
c. Power Supply. Low voltage ac from the secondary of the DMM transformer is supplie via pins $B$ and $C$ on Jl001. Switching for the power for T1001, provided at J1003 Pins A. and $B$, comes via the DMM mainframe through its Power ON switch. The secondary of T1001 is rectified, filtered and run through an integrated circuit ( +5 V regulator TR1001) whose output is filtered by C1015, C 1002, C1003, C1004, C1014. The core of T1001 is connected to chassis ground by a green wire to a screw on the DMM mainframe or transforr Also common mode filtering is performed by R1008 and Cl006 connected between output low and chassis ground.
d. Control Block. UPCLK, the isolated form of INCLK, is run to the t.rigger input of Elol7 timer. A buffered version of UPCLK is also run via diode gate CRIOO2 to the threshhold input of $\mathrm{U1017}$. U1017 is such that its output will go high when a falling edge goes into trigger. A filter made up of R1007 and C1008 will try to charae, however since this threshhold is clamped low through diode CRIOO2, it will not be able to time
out in the time period of the clock pulses on INCLK until the last rising edge of INCLK, at which time it will clock out at 30 microseconds. Therefore, UPTIME, the output of U1017, will be length of the INCLK pulse stream plus approximately 30 microseconds. This is the time in which data will be flowing from the 1722 to the DMM. The beginning of a conversion is started by clocking DOWNCLK with UPTIME in flip-flop Ul015A. The beginning of downtime also defines the time when the flag is set high, that is, when data has finished being updated. Setting the flag low during data change time, or resetting the flag, is accomplished in two ways: FR or UPDATE. Downtime also gates DOWNCLK thru U1014C \& Ul014D where it is called GATECLK and goes to the output register.
e. Output Register. The output register is made up of shift registers Ul008A \& B, $1009 A \& B, 1010 A \& B, 1011 A \& B$. It is a $32-b i t$ shift register, of which only 30 are used. Serial data enters Ul 1008 B and is clocked through all of the shift registers by the parallel clock, GATECLK. At the end of the clocking time all 30 bits have been shifted in and are presented in parallel to the output buffer.
f. Output Drive and Buffer. Parallel data on the output registers goes to output gates 41001 thru 1007 and 41012 and 1013. Here, the data is gated with the output strobes through drive transistors (Q1001 thru 1030) to the output connector P1006.
g. Input Buffers. Strobelines are buffered by $U 1101$ and UllO2 and go out to the output drive and buffer block. Remote control inputs are buffered by 41104 , Ullll, Ullo5. U1104 is a Schmitt trigger, which is put on certain control lines to prevent false triggering (see Schematic 28019ㄷ).

NOTE
Additional information concerning the operation of the Model 1722 is given in Section 3. This additional information is referenced to three timing diagrams provided in Section 7 (Timing Diagrams: 28247E, 28248 E and 28249 E ).

## SECTION 6. MAINTENANCE.

6-1. GENERAL. This section contains information necessary to maintain the instrument. Included are procedures for electrical Performance Verification, Adjustment/Calibration, Troubleshooting, and Fuse Replacement.

6-2. REQUIRED TEST EQUIPMENT. Recommended test equipment for Performance Verification is given in Table 6-1. Test equipment for Adjustment/Calibration is given in Table 6-6. Alternate test equipment may be substituted if specifications equal or exceed the stated characteristics.

TABLE 6-1.
List of Test Equipment for Performance Verification.

| ITEM | DESCRIPTION | SPECIFICATION | MFR | MFR MODEL |
| :---: | :---: | :---: | :---: | :---: |
| A | DC Calibrator | $\begin{aligned} & \pm 0.2 \mathrm{~V} \text { through } \pm 1000 \mathrm{Vdc} \\ & \pm 0.002 \% \text { or } 20 \mu \mathrm{~V} \end{aligned}$ | FLUKE | 343A |
| B | AC Calibrator | 0.2 through 20 V rms $\pm 0.022 \%+10 \mathrm{VV}$ | HP | 745A |
| c | High Voltage Amplifier (Used with Model 745A) | 200 V through 1000.0 v rms $\pm 0.04 \%$ | HP | 746A |
| D | Decade Resistor | $\begin{aligned} & 2 \mathrm{~K} \Omega \text { through } 10 \mathrm{M} \Omega \\ & \pm 0.01 \% \end{aligned}$ | ESI | DB62 |
|  |  | 200M ${ }^{\text {¢ }} \pm 0.1 \%$ | CADDOCK | MG750 |
| E | Current Source | 200 $\mu \mathrm{A}$ through 20 mA $\pm 0.006 \%$ | fluke | 33308 |
|  |  | 200 mA and $2 \mathrm{~A} \pm 0.02 \%$ | FLUKE | 382A |
| F | Ohmmeter | $10^{7} \Omega \pm 1 \% \quad 10^{9} \Omega \pm 5 \%$ | KI | 616 |
| G | IM $\Omega$ Resistor | $\geq 1 / 8 \mathrm{~W}, \pm 1 \%$ tolerance | KI | R-88-1M $\Omega$ |

6-3. PERFORMANCE VERIFICATION. Performance Verification should be performed by qualified personnel using accurate and reliable test equipment as given in Table 6-1. Use the following procedures to verify basic operation and accuracy of the instrument. All measurements should be made at an ambient temperature within the range of $20^{\circ} \mathrm{C}$ to $30^{\circ} \mathrm{C}$ and with a relative humidity of less than $80 \%$. If the instrument is out of specification at any point, perform a complete calibration as given in Paragraph 6-4. If the instrument is "IN WARRANTY", contact your Keithley representative or the factory.

## NOTE

This procedure is intended to verify only the basic accuracy of the Model 172A/ 173A in voltage, current, and resistance modes. Test equipment accuracy should be $X 5$ better than the measurement accuracy. In many cases the equipment listed in Table $6-1$ is not $X 5$ better, because such equipment is not readily available. For this reason, the expected error contribution of the listed test equipment is
given in the performance verification tables and should be added to the specified accuracy tolerance of the instrument to obtain the allowable readings. The listed "Source Error" assumes that the test equipment has been calibrated to the manufacturer's specifications.
a. Initial Conditions. Before beginning the verification procedure, the instrument must meet the following conditions:

1) If the instrument has been subjected to extremes of temperature, allow internal temperatures to stabilize for one hour minimum at the environmental conditions specified in Paragraph 6-3.
2) Turn on the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ and allow it to stabilize for one hour. The instrit ment may be powered from either line power or from battery pack power, as long as the battery pack has been fully charged as described in Paragraph 2-3b.

WARNING

$+1$Some procedures require the use of high voltage. Take care to prevent contact with live circuits which could cause electrical shock resulting in severe bodily injury or death.
b. Input Resistance Check. (DC VOLTS).

1) Select $D C V$ function.
2) Select MAN and 3 volt range.
3) Connect the $D C$ Calibrator (A) to the Model 172A/173A.
4) Apply 1 volt dc to the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ and record the reading.
5) Connect the 1 Megohm resistor (G) between calibrator HI and input HI of 172A/173A.
6) Apply 1 volt de to Model $172 \mathrm{~A} / 173 \mathrm{~A}$ and verify that the displayed reading is within 10 digits of the reading in step 4. This verifies that the input resistance is $>10^{9} \Omega$.
7) Select the 30 volt $D C$ range using UP RANGE pushbutton.
8) Measure the input resistance between HI and LO using ohmmeter (F).
9) Input resistance should be $10 \cdot$ megohms $\pm 2-1 / 2 \%$.
C. DC Voltage Accuracy Check.
10) Set to $D C$ Volts and AUTO.
11) Connect the $D C$ Calibrator ( $A$ ) to the instrument.
12) Set the DC Calibrator to the output specified in Table 6-2.
13) Verify that the instrument reading is within the limits specified.
14) Repeat steps 3) and 4) with negative voltages.

TABLE 6-2.
DC Voltage Performance Check.

| RANGE | APPLIED VOLTAGE | NOMINAL DISPLAY | TOLERANCE (SPECIFIED ACCURACY) IN DIGITS $\#=$ |  |  | SOURCE ERROR*: |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | $\begin{aligned} & 24 \mathrm{hr},{ }^{\circ} \mathrm{C} \\ & 25 \pm{ }^{\circ} \end{aligned}$ | $\begin{gathered} 20 \\ 6 \mathrm{mo} \end{gathered}$ | $\overline{0^{\circ} \mathrm{C}}$ <br> 1 year |  |
| 300 mV | $\pm 0.20000 \mathrm{Vdc}$ | $\pm 200.00 \mathrm{mVdc}$ | $\pm 3 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 3 V | $\pm 2.0000 \mathrm{Vdc}$ | $\pm 2.0000 \mathrm{Vdc}$ | $\pm 3 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 0.4 \mathrm{~d}$ |
| 30 V | $\pm 20.000 \mathrm{Vdc}$ | $\pm 20.000 \mathrm{Vdc}$ | $\pm 3 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 0.4 \mathrm{~d}$ |
| 300 V | $\pm 200.00 \mathrm{Vdc}$ | $\pm 200.00 \mathrm{Vdc}$ | $\pm 3 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 4 \mathrm{~d}$ | $\pm 0.4 \mathrm{~d}$ |
| 1000 V | $\pm 1000.0 \mathrm{Vdc}$ | $\pm 1000.0 \mathrm{Vdc}$ | $\pm 2 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ | $\pm 3 \mathrm{~d}$ | $\pm 0.2 \mathrm{~d}$ |

* The Manufacturer's specified uncertainty of the DC Calibrator (A). If this calibrator is used, add uncertainty to the 172A/173A tolerance to obtain the allowable reading. For example, the allowable 1 year $20^{\circ}$ to $30^{\circ} \mathrm{C}$ reading on the 300 mV range would be 199.96 to 200.04 with a zero source error. Including the source uncertainty, the reading would be 199.94 to 200.06 .
** Tolerances above one half digit have been rounded off to the next higher digit because of the approximate 0.5 digit flash point of the least significant digit of the display.
d. AC Voltage Accuracy Check.

1) Select $A C$ Volts and AUTO.
2) Connect the $A C$ Calibrator ( $B$ ) to the instrument. Set the calibrator frequency to 20 kHz .
3) Apply 200 mVac to the instrument. The reading must be within the limits specified in Table 6-3.
4) For the 3 and 30 volt ranges, apply the required voltages stated in Table 6-3 and verify that the readings are within specifications.
5) To check the 300 and 1000 volt ranges, connect the High Voltage Amplifier (c) to the output of the AC Calibrator per the manufacturer's instructions. Connect the amplifier output to the Model 172A/173A input terminals. Set the calibrator to supply 200.00 Vrms at 20 kHz for checking the 300 V range, and 1000.0 Vrms at 10 kHz to check the 1000 V range. Verify that the readings are within the specified limits in Table 6-3.
6) To check accuracy at 50 Hz , apply the voltage specified in Table 6-3 for the 30 V range and verify that the reading is within the specified limits.
7) To check accuracy at 100 kHz , apply the voltage specified in Table 6-3 for the 200 mV range and verify that the reading is within specified limits.

TABLE 6-3.
$A C$ Voltage Performance Check.


## e. Resistance Accuracy Check.

1) Select $\Omega, \mathrm{HI}$ and 2 WIRE.
2) Select AUTO.
3) Connect the Decade Resistor ( $D$ ) to the instrument input terminals. Set the decade resistor to zero and record the resistance of the test leads. Subtract the lead resistance from the resistance reading on the Model 172A/173A in the following steps.
4) Set the decade resistor to the resistance values given in Table 6-4. Verify that the readings are within specified limits for HI ohms.
5) Select $L 0$ ohms and repeat the decade resistor settings given in Table 6-4. Verify that the readings are within specified limits for L0 ohms.

TABLE 6-4.
Resistance Performance Check.

| Range | RESISTANCE SETTING | NOMINAL display | TOLERANCE (SPECIFIED ACCURACY) IN DIGITS $20^{\circ}$ to $30^{\circ} \mathrm{C}$ |  | SOURCE ERROR |
| :---: | :---: | :---: | :---: | :---: | :---: |
|  |  |  | HI | 10 |  |
| $300 \Omega$ | $200.00 \Omega$ | 200.00 |  | $\pm 8$ digits | $\pm 2$ digits |
| $3 \mathrm{~K} \Omega$ | $2.0000 \mathrm{~K} \Omega$ | 2.0000 | $\pm 8$ digits | $\pm 8 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 30k $\Omega$ | $20.000 \mathrm{~K} \Omega$ | 20.000 | $\pm 8 \mathrm{~d}$ | $\pm 8 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 300ks | $200.00 \mathrm{~K} \Omega$ | 200.00 | $\pm 8 \mathrm{~d}$ | $\pm 10 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 3M, | 2.0000 k | 2.0000 | $\pm 11 \mathrm{~d}$ | $\pm 31 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 30M8 | $20.000 \mathrm{M} \Omega$ | 20.000 | $\pm 37 \mathrm{~d}$ | $\pm 160 \mathrm{~d}$ | $\pm 2 \mathrm{~d}$ |
| 300M 8 | $200.00 \mathrm{M} \Omega$ | 200.00 | $\pm 30 \mathrm{id}$ |  | $\pm 20 \mathrm{~d}$ |
| * Manufacturer's specified uncertainty for the Decade Resistor (D) and the 0.1\% 200Ms resistor. Add uncertainty to the Tolerance to obtain allowable reading if these items are used for the accuracy check. |  |  |  |  |  |

f. Current Accuracy Check (Model 173 A Only).

1) Select $D C$ and $A$.
2) Select Auto.
3) Connect Current Source (E) to the instrument input terminals.
4) Set the current source to the currents given in. Table 6-5. Verify that each reading is within specified limits.

TABLE 6-5.
DC Current Accuracy Check (Model 173A Only).

| RANGE | CURRENT <br> APPLIED | NOMINAL <br> DISPLAY | TOLERANCE (SPECIFIED <br> ACCURACY) <br> IN DIGITS <br> $20^{\circ}$ to $30^{\circ} \mathrm{C}$ | SOURCE <br> ERROR* |
| :---: | :---: | :---: | :---: | :--- |
| 300 A | $\pm 200.00 \mathrm{~A}$ | 200.00 | $\pm 22$ digits | $\pm 1 \mathrm{digit}$ |
| 3 mA | $\pm 2.0000 \mathrm{~mA}$ | 2.0000 | $\pm 22$ digits | $\pm 1 \mathrm{digit}$ |
| 30 mA | $\pm 20.000 \mathrm{~mA}$ | 20.000 | $\pm 22$ digits | $\pm 1 \mathrm{digit}$ |
| 300 mA | $\pm 200.00 \mathrm{~mA}$ | 200.00 | $\pm 22$ digits | $\pm 4 \mathrm{digit}$ |
| 3 A | $\pm 2.0000 \mathrm{~A}$ | 2.0000 | $\pm 22$ digits $* *$ | $\pm 4 \mathrm{digit}$ |

* Manufacturer's specified uncertainty for Current Sources (E). If these sources are used, add uncertainty to Tolerance to obtain allowable reading.
** Self heating effects of currents greater than 1 ampere can double the percentage of reading error (i.e., prolonged application of >lA can cause tolerance to increase to $\pm 42$ digits).
g. Current Accuracy Check (Model 172A Only).

1) Select $D C$ and $A$.
2) Select AUTO.
3) Connect Current Source (E) to the instrument input terminals.
4) Set the current source to 200 mA . Verify a reading of 199.48 to 200.52 mA . .
5) Set the current source to $1 \mathrm{~A}:$ Verify a reading of 0.9973 to $1.0027 \mathrm{~A} \%$.
*NOTE
Readings do not account for source inaccuracy. Add $0.02 \%$ uncertainty to reading if Current Source (E) is used (i.e., $\pm 4$ digits to step 4 and $\pm 2$ digits to step 5).

TABLE 6-5.
Recommended Test Equipment For Calibration.

| ITEM | DESCRIPTION | SPECIFICATION | MFR | MODEL |
| :---: | :---: | :---: | :---: | :---: |
| A | DC Calibrator | $\begin{aligned} & +2.90000 \mathrm{~V},+29.0000 \mathrm{~V},+290.000 \mathrm{~V} \\ & +1000.00 \mathrm{~V} \text {, to within } 20 \mathrm{ppm} \end{aligned}$ | Fluke | $343 A$ |
| B | AC Calibrator | $\begin{aligned} & \text { IV @ } 1 \mathrm{kHz} \\ & \text { IV, } 100 \mathrm{~V} @ 5 \mathrm{kHz} \end{aligned}$ | HP | 745A |
| C | Decade Resistor | $2 \mathrm{~K} \Omega$ through $10 \mathrm{M} \Omega \pm 0.01 \%$ | ESI | RS 725 |
| D | Current Source* | $1 \mathrm{~A}, 100 \mathrm{~mA}, 10 \mathrm{~mA} \pm 0.02 \%$ | Fluke | 383A |
| $E$ | DMM | $1.0000 \mathrm{~V} \pm 0.001 \%$ | KI | 5900 |
| F | Test Circuit | $\left.\begin{array}{l} \text { Resistor, } 2 M \Omega \\ \text { Capacitor, } 1 \mu F \end{array}\right] \text { Paralleled }$ | $\begin{aligned} & \mathrm{KI} \\ & \mathrm{KI} \end{aligned}$ | $\begin{aligned} & R-253-21 \\ & C-215-1 \end{aligned}$ |

*NOTE
An alternate Current Source may be assembled using a precision $1 \Omega$ resistor stabilized at constant temperature, and a Keithley Model 227 which has been adjusted to obtain a 1.0000 V reading across the $1 \Omega$ resistor. Use DMM (E) to accurately monitor the voltage drop.

6-4. CALIBRATION REQUIREMENTS. In general, calibration should be performed yearly (every 12 months) or whenever the Performance Verification (in this section) indicates that the Model $172 A / 173 \mathrm{~A}$ is out of specifications. It should be noted that if it is desired to make dc voltage measurements to the 6 month or 24 hour accuracy specification, the calibration cycle will have to be shortened accordingly. If any step in the Calibration Procedure cannot be performed properly, refer to Troubleshooting information in this section, or contact your keithley representative or the factory as described in the Verification Procedure.

NOTE
Calibration should be performed by qualified personnel using accurate and reliable test equipment.
a. Recommended Test Equipment. Recommended test equipment for calibration is listed in Table 6-9. Alternate test may be used. However, the accuracy of the test equipment must be at least five times better than the Model 172A/173A specifications, or equal to Table 6-1 specifications. For example, to achieve a dc accuracy of $0.015 \%$, the calibration source accuracy should be no worse than $0.003 \%$ total. There are several exceptions where other than five times better accuracy is required and these exceptions are noted in the calibration procedure.
b. Environmental Conditions. Calibration should be performed under laboratory conditions having an ambient temperature of $25^{\circ} \mathrm{C} \pm 1^{\circ} \mathrm{C}$, and a relative humidity of less than $30 \%$. If calibration is not done at $25^{\circ} \mathrm{C}$, a $\pm 5^{\circ} \mathrm{C}$ temperature range around that temperature is allowed, but this will result in a shift of the specification temperature range. For example, if calibration is performed at $23^{\circ} \mathrm{C}$, the stated 1 year $20^{\circ}-30^{\circ} \mathrm{C}$ accuracy specification will then be 1 year $18^{\circ}-28^{\circ} \mathrm{C}$. If the instrument has been subjected to temperatures outside of the calibration temperature range, or to higher than $80 \%$ relative humidity, allow one hour minimum for the instrument to stabilize at the specified calibration environmental conditions before beginning the calibration procedure.
;-5. PREPARATION FOR CALIBRATION. Preparation of the Model 172A/I73A for calibration :onsists of installing the Model 1725 A calibration cover and allowing a sufficient time "or the instrument to warm up after installation of the calibration cover.
a. Installation of the Model 1725A Calibration Cover. Calibration should be performed using the Model 1725A calibration cover. This cover permits access to the Model 172A/ .73A adjustments, while allowing the instrument to reach normal internal operating tempsrature. Install the cover as follows:

## WARNING

\&
Disconnect the line cord before removing the top cover. To discharge voltage on capacitors, depress the LINE pushbutton after disconnecting the line cord.

1) Turn off power and disconnect the line cord.
2) Turn the instrument over so that the bottom cover is facing up, loosen the four screws in the bottom panel. These screws are held captive by rubber 0 -rings.
3) Hold the top and bottom covers together to prevent their separation and turn the DMM over to normal position.
4) Carefully lift off the top cover and disconnect the connector from the wires going to the rear panel (current fuse).
5) If the Model 1722 or 1723 Digital Interface is installed, disconnect its connections to the DMM motherboard and remove interface board(s) along with the instrument top cover.
6) If the Model 1728 Battery Pack is installed, disconnect its connectors as shown in Figure 2-3 and remove the battery pack from the DMM.
7) Connect P503 from the calibration cover current fuse to $\mathbf{J 5 0 3}$ from the Model 172A/ 173A current board, and position the calibration cover in place on the Model 172A/173A.
b. Warm Up. Connect the line cord and turn power on the instrument by depressing the LINE pushbutton. Allow a one hour warm-up time before beginning the calibration procedure.

6-6. CALIBRATION PROCEDURE. The calibration/adjustment of the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ consists of performing the procedures outlined as follows:

1. Precalibration.
2. $D C$ voltage calibration.
3. $A C$ voltage calibration.
4. Ohms calibration.
5. DC current calibration (Model 173A only).

Precalibration and $D C$ voltage calibration must be done in that order. After completing precalibration and $D C$ voltage calibration, $A C$ voltage, ohms and $D C$ current calibration can be interchanged with each other if desired. Since adjustments within a procedure are interrelated and dependent on prior calibration steps, they must be done only in the order given to ensure proper calibration of the instrument. The circled numbers within the procedures indicate the given order of adjustments for the complete calibration. These numbers are also repeated in Figure 6-1, which shows the adjustment locations by procedural grouping (ie., precalibration, $D C$ voltage calibration and etc.) and serves as an aid to perform the calibration procedure using the calibration cover. Perform the following adjustments to calibrate the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ and restore its operation to specified limits.

## WARNING



Some procedures require the use of high voltage. Take care to prevent contact with live circuits which could cause electrical shock resulting in injury or death. Use an insulated tool when making adjustments.
a. Precalibration.

1) Input Current Adjustment.
a. Set the DMM to MAN; 300 mV DC range.

NOTE
The input short used in the following steps should be no more than $10 \mathrm{~m} \Omega$ ( $10^{-2 \Omega}$ ). This can be verified by observing no more than a ligit increase when switching from $3 K \Omega$ LO range to $300 \Omega$ LO range. The short should also have low thermal EMFs, which can be determined by reversing the connections on the de 300 mV range and observing that there is no change in the zero reading.
b. Connect a short between input HI and LO.
c. Record the reading on the DMM.
d. Remove the short and connect the Test circuit (F) across input $H 1$ and $L O$.

fRONT PANEL

FIGURE 6-1. Location of Calibration Adjustments.
(1) e. Adjust potentiometer R714 (input current) to obtain the same reading as in step c. (Minimize physical movement around input as this will cause a shift in the reading.)
f. Repeat steps b. thrue. to assure equal readings (within $\pm 1$ digit is acceptable.

NOTE
Each digit difference between input shorted and $2 M \Omega \| 1 \mu F$ applied is 5 picoamperes dc
2) Ohms Zero Adjustment.
a. Set the DMM to 2-WIRE and LO ohms.
b. Select $3 \mathrm{~K} \Omega$ range.
c. Apply short between input HI and LO .
2)d. Adjust potentiometer R713 (ohms zero) for a zero or zero flashing one reading on the DMM.
e. Select $30 \mathrm{~K} \Omega$ range.
f. Slightly readjust R 713 to obtain a zero or zero flashing one reading.
b. $D C$ Voltage Calibration.

1) Zero Adjustments.
a. Select $D C V 300 \mathrm{mV}$ range.
b. Connect the $D C$ Calibrator ( $A$ ) to the input terminals.

NOTE
It may be necessary to compensate for dc offset of the $D C$ Calibrator. For example, if the dc offset is $-2 \mu V$ dc then the DC Calibrator should be adjusted $+2 \mu \mathrm{~V}$ to compensate for the offset. Use a Keithley Model 155 to determine calibrator offset
c. Set the DC Calibrator to apply $+100 \mu \mathrm{~V}$, $\pm 1 \mu \mathrm{~V}$ to DMM input.
(3)d. Adjust potentiometer R2O4 ( 300 mV zero) for a 00.10 reading on DMM.
e. Select 30Vdc range.
f. Set the DC Calibrator to apply $+10 \mathrm{mV} \pm 100 \mu \mathrm{~V}$ to $D M M$ input.
4) g. Adjust potentiometer R207 (30V zero) for a 0.010 reading on DMM.
2) Full range Adjustments.
a. Connect the $D C$ Calibrator to the input terminals.
b. Set the instrument to the range given in Table 6-7.
c. Set the DC Calibrator to provide the "Applied Input" given in Table 6-10.
d. Adjust the control given in Table 6-10 to achieve the specified display.

NOTE
Perform the calibration in the exact order given.

TABLE 6-7.
Full Range $D C$ Calibration

| RANGE | APPLIED INPUT | CONTROL | DISPLAY <br> REQUIRED |
| ---: | :--- | :---: | :--- |
| 3 V | $+2.9 \mathrm{~V} \pm 0.003 \%$ | (5) 2.9 V CAL (R610) | 2.9000 |
| 300 V | $+290 \mathrm{~V} \pm 0.003 \%$ | ( |  |
| 30 V | 29 V ADJ (R209) | 290.00 |  |
| 1200 V | $1000 \mathrm{~V} \pm 0.003 \%$ | ( 1 KV ADJ (R214) | 1000.0 |

c. $A C$ Voltage Calibration.

1) Select $A C V$ and MAN ranging.
2) Connect $A C$ Calibrator ( $B$ ) to the input terminals.
3) $I V$ at 1 kHz Adjustment.
a. Select $3 V$ range.
b. Apply 1 Vac $\pm 0.04 \%$ at 1 kHz .
9)c. Adjust potentiometer R104 (iV, 1 kHz ) for a $1.0000 \pm 1$ digit reading.
4) 100 V at 50 kHz Adjustment.
a. Select 300 V range.
b. Apply $100 \mathrm{~V} \pm 0.1 \%$ at 50 kHz .
(10)c. Adjust variable capacitor C 204 ( $100 \mathrm{~V}, 50 \mathrm{kHz}$ ) for a $100.00 \pm 3$ digit reading.
5) 1 V at 50 kHz Adjustment.
a. Select $3 V$ range
b. Apply IVac $\pm 0.1 \%$ at 50 kHz .
(11) c. Adjust variable capacitor ( 2201 ( $1 \mathrm{~V}, 50 \mathrm{kHz}$ ) for a $1.0000 \pm 3$ digit reading.
d. Ohms Calibration.
l) IOM $\Omega$ Adjustment.
a. Select $\Omega$ (ohms) and MAN ranging.
b. Select $30 \mathrm{M} \Omega \mathrm{HI}$ range, 2 wire.
c. Connect a $10 M \Omega \pm 0.03 \%$ resistor between input upper terminals. (Decade
resistor (C) may be used, it has $0.01 \%$ accuracy.)
(12) d. Adjust potentiometer R115 (IOM HI ) for a 10.00 reading on the display.
e. Select $30 M \Omega$ LO range; record the change in digits from lOM $\Omega \mathrm{HI}$ range.
(13) f. Adjust potentiometer R211 (10M $L 0$ ) for $10 M \Omega+1 / 10 \Delta$ digits.

EXAMPLE: If $10 M \Omega$ LO was reading 9.850 ( $\Delta$ digits $=150$ ), adjust for a reading of 10.015 ( $1 / 10 \Delta$ digits $=15$ digits).
g. Repeat steps d. through f. until the reading is $10.000 \pm 2$ digits on $\mathrm{HI} \Omega$ and $10.000 \pm 10$ digits on LOR.
2) $290 \mathrm{~K} \Omega$ Adjustment.
a. Select $300 \mathrm{~K} \Omega \mathrm{HI}, 2$ wire.
b. Connect the decade resistor (c) between input (upper) terminals. Set decade resistor for $290.000 \mathrm{k} \Omega$.
(14)c. Adjust potentiometer R116 (290K $\Omega$ ) for a reading of $290.00 \pm 1$ digit.
3) $2.9 \mathrm{~K} \Omega \mathrm{Adjustment}$.
a. Select $3 \mathrm{~K} \Omega \mathrm{H} / \Omega, 4$ wire.
b. Connect the decade resistor to the instrument using the 2 -wire configuration.

Set the decade resistor to $2.9000 \mathrm{~K} \Omega$.
(15) c. Adjust potentiometer R117 (2.9K $\Omega$ ) for a reading of $2.9000 \pm 1$ digit.
e. DC Current Calibration (Model 173A Only).

1) 1 Ampere Adjustment.
a. Select DCA and MAN ranging.
b. Select $3 A$ range.
c. Connect the current source ( $D$ ) to the Model 173 A and apply +1 ampere.
(16) d. Adjust potentiometer R512 (1A) for a reading of $1.0000 \pm 1$ digit.
2) 100 mA Adjustment.
a. Set the current source for 100.00 mA .
b. Select 300 mA range.
(17)c. Adjust potentiometer R 509 ( 100 mA ) for a reading of $100.00 \pm 1$ digit.
3) 10 mA Adjustment.
a. Set the current source for 10.00 mA .
b. Select 30 mA range.
(18)c. Adjust potentiometer R506 ( 10 mA ) for a reading of $10.000 \pm 1$ digit.
f. Current Calibration for Model 172A. No adjustments can be made. Primary component which determines accuracy is resistor RST4 ( $1 \Omega, 0.1 \%, 10 \mathrm{~W}, \mathrm{WW}$ ).


FIGURE 6-2. Location of Connectors and Test Points.

- 6-7. TROUBLESHOOTING AND REPAIR. The troubleshooting and repair information in this section is intended only for qualified personnel having a basic understanding of analog and digital principles and components used in a precision electronic test instrument. Since most repairs (or replacement of parts) will require that the unit be recalibrated or its performance reverified, a facility having calibration test equipment may also be required. If the required personnel or facilities are not available, or if doubt exists the Keithley representative in your area should be contacted in the event repair of the instrument is needed. If it has been determined that you have the means to properly repair and return the Model $172 \mathrm{~A} / 173 \mathrm{~A}$ to service, the following instructions may prove useful to help you isolate the fault or make the repair. It is strongly recommended that the following instructions be read carefully and that the Theory of Operation and Calibration Procedure both be reviewed, before any attempt is made to repair the Model 172A/173A.


## NOTE

For instruments that are still under warranty, (less than 12 months since date of shipment), if the instrument's performance is outside of specifications at any point or if abnormal operation is indicated, contact your keithley representati or the factory before attempting any troubleshooting or repair, other than fuse replacement.
a. Disassembly. If there is a need to remove the top cover and partially disassemble the Model 172A/173A for troubleshooting or to replace a part, the following procedure should be followed:

## WARNING

$+$
Disconnect the line cord before removing the top cover. To discharge voltage on capacitors, depress the LINE pushbutton after disconnecting the line cord.

1) Turn off power and disconnect the line cord.
2) Turn the instrument over so that the bottom cover is facing up, loosen the four screws in the bottom panel. These screws are held captive by rubber $0-r i n g s$.
3) Holt the top and bottom covers together to prevent their separation and turn the DMM over to normal position.
4) Carefully lift off the top cover and disconnect the connector, from the wires going to the rear panel (current fuse).
5) If the Model 1722 or 1723 Digital Interface is installed, disconnect its connectors to the DMM motherboard and remove interface board(s) along with the instrument top cover. (See figure 3-9).
6) If the Model 1728 Battery Pack is installed, disconnect its connectors as shown in Figure 2-3 and remove the battery pack from the DMM.

NOTE
If the RF shield on the main printed circuit board is removed and replaced, recalibration of the $A C$ voltage circuits may be required. If the position of the shield is disturbed during troubleshooting or repair, perform the $A C$ voltage verification check to determine whether recalibration is needed.
7) The main printed circuit board RF shield is held in place by 4 spring clips. Remove the shield only if absolutely necessary, as its removal and replacement may necessitate recalibrating the $A C$ voltage circuit.
8) To gain access to the display board components (or to remove the display board), first, remove the current board (173A) or the display board RF shield (172A) by disconnecting its connector to the main printed circuit board and removing the 2 attaching screws.
b. Special Handling of Static Sensitive Devices. C/MOS devices are designed to function at very low voltage levels for low power consumption. For this reason, a normal static charge build up on your person or clothing can be sufficient to destroy these devices. The following steps list the static sensitive devices in your instrument, or its options, and provide instructions on how to avoid damaging them when they must be remo'ed/replaced.

1) Static sensitive devices:

Keithley Part Number

## Reference Designation

U1015, U1106
U803, U1014, U1107
U502
U1008 thru U1011
Ul001 thru Ul007, Ul012, UlO13, Ullo9
4805, Ullll
Ullol thru Ullo3, Ullos
U901
U603
2) The above integrated circuits should be handled and transported only in protective containers. Typically they will be received in metal tubes or static protective foam. Keep the devices in their original containers until ready for use.
3) Remove the devices from their protective containers only at a properly grounded work bench or table, and only after grounding yourself by using a wrist strap.
4) Handle the devices only by the body. Do not touch the pins.
5) Any printed circuit board into which a device is to be inserted must also be grounded to the bench or table.
6) Use only anti-static type solder suckers.
7) Use only grounded tip soldering irons.
8) After soldering the device into the board, or properly inserting it into the mating receptacle, the device is adequately•protected and normal handing can be resumed.
c. Troubleshooting Hints. Table 6-8 describes the Symptoms and Probable Cause for a variety of possible malfunctions. It is beyond the scope of this Instruction Manual to list all possible symptoms, therefore, it is suggested that you contact the Keithley representative in your area, or the Factory, in the event your instrument needs repair.

TABLE 6-8.
Troubleshooting Hints

\begin{tabular}{|c|c|c|c|c|}
\hline \& ттом \& \& bable cause \& CORRECTIVE ACTION \\
\hline \& No display (LINE mode) \& 1) \& \begin{tabular}{l}
Line voltage switch (SOOI) set incorrectly. \\
Fuse FOOI is missing or open. \\
Line voltage connector \(J 1007\) improperly connected to pc board at P1007.
\end{tabular} \& \begin{tabular}{l}
Check connection to line power. Check LINE switch setting to conform to line voltage availabl See Figure 6-2. Check fuse Check fuse. Replace with proper rating. \\
Check connection to pc board as shown in Figure 6-2.
\end{tabular} \\
\hline \multirow[t]{3}{*}{b)

c)} \& \multirow[t]{3}{*}{No display. (BAT mode)} \& 4) \& Batteries need recharging. (Check for LO BAT indication.) \& Connect instrument to line power Release LINE. <br>
\hline \& \& 2) \& Battery fuses blown. Batteries improperly installed on battery pack. \& Check F401, F402 and F403. Check battery pack for proper polarity on all batteries. See Figure 2-3. <br>

\hline \& \& 1) \& | Battery cables improperly installed. |
| :--- |
| Display cable P301 not | \& Check battery connections at P402 and P401 as in Figure 2-3. Check plug P301 and mating <br>

\hline \multirow[t]{3}{*}{c)} \& \multirow[t]{3}{*}{No display (All modes)} \& I) \& properly connected. \& connector J301. Make certain al pins are making proper contact (pins should not be bent). Chec for proper orientation of the connector. <br>
\hline \& \& 2) \& LSI module improperly installed. \& Check U901 for proper installation. Make certain all pins are making contact (pins should not be bent). <br>
\hline \& \& \& Power supply malfunction. \& Check power supply voltages as described in Table 6-9. <br>
\hline \multicolumn{2}{|l|}{d) Display is blank, or some segment on.} \& \& Clock waveform is missing \& Check pin 4 of LSI UgOI for a clock waveform of approx. 334 swinging between +4 V and $\emptyset \mathrm{V}$. waveform is present, LSI UgOl is probably faulty. If waveform is not present, integrated circuits U804, U805 or Crystal Y901 may be faulty. <br>
\hline
\end{tabular}

TABLE 6-8 (CON'T)
e) One display bar missing on all digits.
f) One digit missing.
g) 10,000 digit missing. (except if reading is less than 10,000 counts)
h) Function indicator off.
i) Faulty reading on $\Omega$ function.
j) Faulty reading on Current function.
k) Faulty reading on all functions.

1) Faulty connection between P301 \& J301.
2) Cathode driver circuitry faulty. See schematic 27404D
3) Faulty connection between P301 \& J301.
4) Anode drive circuitry faulty. See schematic 27404 D .

Q301

Transistor Q306

1) DMM set for 4 WIRE ohms and $\Omega$ SOURCE terminals are not connected.
2) DMM set for 4 WIRE ohms but leads are reversed. Current fuse F 501 is blown.
A/D converter circuitry. See schematic 29145E, Sheet 2.

Check plug P301 and mating connector J301. Make certain all pins are making contact.
'a'" bar: Check R302 pin 14 for signal. When 'ON', voltage should be approx. +1.8V.
'b" bar: Check R302 Pin 16
"c' bar: Check R302 pin 15
"d" bar: Check R302 pin 9
"e" bar: Check R302 pin 12
"f" bar: Check R302 pin 10
"g" bar: Check R302 pin 13
decimal point: Check R302 pin 11
Check plug P301 and mating connector J301.
If units digit missing, check collector of Q305 for signal. When 'ON', voltage should be approx. 4.8 V . If tems digit missing, check collector of Q304. If hundreds digit missing, check collector Q303. If thousands digit, minus sign and function indicator missing, check collector Q302.
On 10,000 digit, check collector Q301. If no signals are present problem could be transistor or integrated circuit U301.

Set to 2 WIRE.

Connect HI input to the same side of unknown as the $+\Omega$ SOURCE Lead Replace fuse on rear panel.

Check for proper Capture Range of A/D converter as described in Table 6-10.

TABLE 6-9
Line Power Checks

| Step | Item/Component | Required Condition | Remarks |
| :---: | :---: | :---: | :---: |
| 1 | S001 Line Voltage switch*. | Must be set to 230 V or 115 V as appropriate. |  |
| 2 | FOOI Line Fuse * | Continuity. |  |
| 3 | J/P1007* | Properly mated. |  |
| 4 | Pl008 line cord | Plugged into live receptacle. |  |
| 5 |  | Turn on power (Line switch). | NOTE: Output from CROO2 should be $\geqq+12.6 \mathrm{~V}$. out put from CROOI $\geq \pm 26 \mathrm{~V}$. |
| 6 | +5V pad* | +5volts $\pm 5 \%$. | Output of VROOI. |
| 7 | +8V pad* | +8volts $\pm 5 \%$ | Output of VR004, input to VROOI. |
| 8 | +15V pad* | +15volts $\pm 5 \%$ | Output of VR003. |
| 9 | -12V pad** | $-12 \mathrm{volts} \pm 5 \%$ | VR801 \& R801 |
| 10 | -15V pad** | -15 volts $\pm 5 \%$ | Output of VROO2 |
|  |  |  | NOTE: Hot regulator may indicate shorted load. |

On main printed circuit board (See Figure 6-2 for location, and see sheet 3 of Schematic 29145 f for circuit details).


FIGURE 6-3. Waveform for Capture Range Check.

TABLE 6-10
A/D Converter Capture Range Check

| Step | (tem/Component | Required Condition | Remarks |
| :---: | :---: | :---: | :---: |
| 1 | 28623A Test Lead (Part of 1725 A maintenance Kit) | a) Connect plug such that Black lead to TP801; Red lead to TP802. <br> b) Connect terminal of red lead to oscilloscope EXT. TRIGGER. <br> c) Connect terminal of black lead to oscilloscope VERTICAL INPUT. | See Figure 6-2. |
| 2 | 28622A Test Lead ( $\mathrm{P} / 0$ 1725A) | a) Connect plug (Green wire) to Plool, Pin A. <br> b) Connect terminal of green wire to oscilloscope GND. | See Figure 6-2. |
| 3 | Oscilloscope Controls | a) TRIGGER: +, DC coupled. <br> b) VERTICAL: DC, $0.5 \mathrm{~V} /$ division. <br> c) TIME BASE: $20 \mathrm{mS} /$ division. |  |
| 4 | $\left\{\begin{array}{l} 172 \mathrm{~A} / 173 \mathrm{~A} \\ \text { Settings } \end{array}\right.$ | a) Turn on power. <br> b) Set to MAN; 300 mVDC range. <br> c) Short INPUT HI to LO. |  |
| 5 | Check waveform, Figure 6-3. | All signals $A Z 1, A C A L \& A Z 2$ should be +lVdc $\pm$ IVdc. | If one or more correction signals ( $A Z 1, A C A L, A Z 2$ ) are out of capture range, See sheet 2 of Schematic' 29145E for circuit details. Note: There is some interaction between circuits. |

6-8. FUSE REPLACEMENT. With the exception of the current fuse, all fuses are located internally in the Model 172A/173A. To replace the current fuse, proceed to step $g$. To replace an internal fuse, proceed as follows:

Disconnect the line cord before removing the case cover.
a. Turn off power and disconnect the line cord.
b. Turn the DMM bottom side up and loosen the four screws in the bottom cover. These screws are held captive by rubber 0 -rings..
c. Hold the top and bottom covers together to prevent their separation and turn the DMM over to normal position.
d. Lift off the top cover.
e. Replacement of Battery Pack fuses. F401, F402 and F403.

1) Leave the Battery pack in place and connected.
2) Remove either F 401 , F 402 or F 403 (shown in Figure 2-2) and replace it with a $1 \mathrm{~A}, 250 \mathrm{~V}$, 3AG SLO-BLO fuse (Keithley part number fu-10).
3) Reinstall top cover.
f. Replacement of Line Fuse FOO .
4) Once the top cover is removed, FOOL is accessible without removing any other components.
5) Remove FOOI, shown Figure 6-2, and replace it with a $1 / 4 \mathrm{~A}, 250 \mathrm{~V}$, 3AG SLO-BLO fuse (Keithley part number FU-17) for 117 V line operation, or a $1 / 8 \mathrm{~A}, 250 \mathrm{~V}, 3 \mathrm{AG}$ SLO-BLO fuse (Keithley part number FU-20) for 230 V line operation.
6) Reinstall top cover.
g. Current Fuse F501.
7) The current fuse in accessible from the rear panel as shown in figure 2-1.
8) Replace F501 as follows:

Model 173A: 3A, 250V, 3AG (Keithley \#FU-2).
Model 172A: 2A, 250V, 3AG (Keithley \#FU-13).


Do not install fuses with higher ratings than specified. Instrument damage may occur.

## SECTION 7. REPLACEABLE PARTS.

7-1. GENERAL. This section contains information necessary for ordering replacement parts. Included, to assist you in locating and identifying components, are CrossReference Tables, the Replaceable Parts List, llustrations, Component Layout Diagrams and Schematics. Also included are instructions telling you how to order parts and obtain Factory Service. These items are further described in the following paragraphs.

7-2. ORDERING INFORMATION. Where possible, standard component parts have been used in your instrument. These parts may be ordered directly from the manufacturer by using the manufacturer's part number, or ordered from your keithley representative or the factory by using the Keithley part number. Both of these part numbers are included in the Replaceable Parts List, where applicable. It should be noted that in some instances, standard parts are used, but they are either specially selected or matched. These items are identified in the parts list only by Keithley part number and must be ordered from Keithley to ensure that they meet critical circuit requirements. A degradation of the instruments performance will result if these items are replaced with standard components. To place an order or to obtain additional information concerning replacement parts, contact your Keithley representative or the Factory. When ordering, include the following information:
a. Instrument Model Number.
b. Instrument Serial Number.
c. Part Description.
d. Circuit Designation (where applicable).
e. Keithley Part Number.

7-3. FACTORY SERVICE. If the instrument is to be returned to the factory for service, please complete the service form which follows this section and return it with the instrument. Package the instrument for shipment in its original shipping carton, or if it is not available, use a suitable substitute container that is rigid. When a substitute container is used, wrap the instrument in paper or plastic sheeting and surround it with at least four inches of excelsio- or other shock-absorbing material. See the inside of the front cover for the address of the Factory, or other Service Centel

7-4. REPLACEABLE PARTS LIST. This list is arranged in alphabetical order of the schematic circuit designation of the components and includes the following information:
a. Circuit Designation.
b. Description of Part.
c. Three letter Manufacturer's code (this code is used to access the cross-reference list of manufacturers, Table 7-1).
d. Manufacturer's designation (part number).
e. Keithley part number.

In addition to the columnar information above, heading information is contained within the parts list that identifies the applicable schematic and component layout diagrams.

7-5. CROSS-REFERENCE OF MANUFACTURERS. Table 7-1 provides a cross-reference list of manufacturers. The list is arranged in alphabetical order of the three letter manufacturer's codes given in the Replaceable Parts List. The Table includes the manufacturer's name, address and 5-digit federal supply code.

7-6. COVERS AND PANELS. Covers, panels and other miscellaneous items such as the condensed operating instruction label (a metalcal) are not included in the Replaceable Parts List. These items are shown in Figure 7-1 and listed in Table 7-2. Order these parts by using the applicable Keithley part numbers given.

7-7. COMPONENT DESIGNATIONS FOR PC-446. Table 7-3 is a cross-reference listing of the components on the main printed circuit PC-446, which can be used in conjunction with the Component Layout Diagram 28795D (Page 7-32) to physically locate a component when its circuit designation is known. The listing is arranged in the alphabetical order of the circuit designations and includes the item number and zone location of the components, referenced to the Component Layout diagram. Table 7-3 is located on Page 7-31.

7-8. SCHEMATICS.
a. PC-446, input Signal Conditioning. (29145E, Sheet 1 of 3, Page 7-28). This schematic describes the input switching, ac/dc conversion, filtering, attenuating, relay drivers and ohms source.
b. PC-446, A/D Converter (29145E, Sheet 2 of 3, Page 7-29). This schematic describes the analog-to-digital converter and the reference supply circuitry.
c. PC-446, Power Supply (29145E, Sheet 3 of 3, Page 7-30). This schematic describes the line power supply and the digital section. (See schematic 26758 C for the Model 1728 Rechargeable Battery Pack.)
d. PC-403, Display (27404D, Page 7-34). This schematic describes the display driver circuitry. Circuit designation series is 300 .
e. Current Circuitry (274780, Page 7-35). This schematic describes the current circuitry for both the Models 172A and 173A. Circuit designation series is 500 . (PC-406 Model 173A oniy).
f. Model 1728 Rechargeable Battery Pack (26758C, Page 7-36), . Circuit designation series is 400.
q. PC-415, Model 1722 Digital Interface, Bottom (27902E, Page 7-37). This schematic describes the Model 1722 circuitry. Circuit designation series is 1000 .
h. PC-416, Model 1722 Digital Interface, Upper (28019E, Page 7-38). This schematic describes the Model 1722 circuitry. Circuit designation series is 1100 .
i. Timing diagrams for Model 1722.

1) 28247E, Page 7-40.
2) 28248 E , Page $7-40$.
3) 28249 D , Page $7-41$.

7-9. COMPONENT LAYOUTS. Component layout diagrams are used to illustrate the component parts of the printed circuit boards used in the Model 172A/173A, the optional Model 1728 Battery Pack and the optional Model 1722 Digital Interface. The component layouts for Model 1728 and Model 1722 identify the parts by circuit designation which relate directly to the Replaceable Parts List. The other component layouts use item numbers to identify
the parts which relate to a tabular listing contained on the face of the diagrams, or in some cases the listing is on a second sheet. The tabular listing provides a crossreference to the schematic circuit designation and includes the Keithley part number for convenience.
a. Model 172A/173A PC-446, Component Layout No. 287950 (Sheet 1 and 2, Page 7-32 and 7-33).
b. Display Board PC-403, Component Layout No. 27879C (Page 7-34).
c. Current Board (173A only) PC-406 Component Layout No. 27884C (Page 7-35).
d. Model 1728 Battery Pack, Component Layout, Figure 7-2 (Page 7-36).
e. Model 1722 PC-415, Component Layout, Figure 7-3 (Page 7-39).
f. Model 1722 PC-416, Component Layout, Figure 7-4 (Page 7-39).


FIGURE 7-1. Top and Bottom Cover Assembly.

TABLE 7-1.
Cross-Reference of Manufacturers

| MFR. CODE | NAME AND ADORESS | FEDERAL SUPPLY CODE | MFR. <br> CODE | NAME AND ADDRESS | FEDERAL SUPPLY CODE |
| :---: | :---: | :---: | :---: | :---: | :---: |
| A-B | Allen-Bradley Corp. <br> Milwaukee, WI 53204 | 01121 | $\mathrm{H}-\mathrm{P}$ | Hewlett Packard Palo Alto, CA 94304 | 07263 |
| AMP | Amp Inc. Harrisburg, PA 17105 | 00779 | INT | Intersil Inc. Cupertino, CA 95014 | 32293 |
| BEC | Beckman inst. Inc. Fullerton, CA 92634 | 73138 | ITT | ITT Semiconductors Lawrence, MA 01841 |  |
| BRG | Berg Electronics Inc. <br> New Cumberland, PA 17070 | 22526 | I RC | IRC Division Burlington, IA 52601 | 07716 |
| BUS | Bussman Mfg. Div. St. Louis, MO. 63017 | 71400 | GLD | Gould Inc. <br> St. Paul, MN 55165 | 52431 |
| $c-1$ | Components, Inc. <br> Biddeford, ME 04005 | 06751 | K-I | Keithley Instruments, Inc. Cleveland, Ohio 44139 | 80164 |
| C-W | Continental-Wirt Elec. Warminster, PA 18974 | 79727 | L-F | Littlefuse, Inc. <br> Des Plaines, IL 60016 | 75915 |
| $C A D$ | Caddock <br> Riverside, CA 92507 | 19647 | MOL | Molex <br> Downers Grove, IL 60515 | 27264 |
| CCC | Coto Coil Co. <br> Providence, RI 02905 |  | MIC | Miconics Industries <br> Plainsview, NY 11803 | 21200 |
| CL. $B$ | Centralab Division Milwaukee, WI 53201 | 71590 | MOT | Motorola Semi Prod. Inc. Phoenix, AZ 85008 | 04713 |
| DIC | Dickson Elec. Corp. Scottsdale, AZ 85252 | 12954 | MMM | 3M Company <br> St. Paul, MN 55101 |  |
| DLE | Dale Electronics Inc. Columbus, NE 68601 | 91637 | NAT | National Semi. Corp. <br> Santa Clara, CA 95051 | 27014 |
| DTN | Dielettron (Consolidated) New York City, NY 10013 |  | NEL | Northern Engr. Labs Burlington, WI 53105 | 00815 |
| ECI | Electro Cube Inc. <br> San Gabriel, CA 91776 | 14752 | OHM | Ohmite Mfg. Co. <br> Skokie, IL 60076 |  |
| EDI | Electronic Devices, Inc. Yonkers, NY 10710 |  | P\&B | Potter \& Brumfield Princeton, IN 47670 |  |
| EFJ | E.F. Johnson Co. Waseca, MN 56093 | 74970 | POM | Pomona Electric <br> Pomona, CA 91766 | 05276 |
| ERI | Erie Technological Prod. Erie, PA 16512 | 72982 | QTN | Q-Tron <br> Santa Ana, CA 92705 |  |
| F-I | Fairchild Instruments Mountain View, CA 94043 | 07263 | RCA | RCA Corporation Moorestown, NJ 08050 | 02734 |

TABLE 7-1 (CON'T)
Cross-Reference of Manufacturers

| MFR: <br> CODE | NAME AND ADDRESS | FEDERAL <br> SUPPLY <br> CODE | MFR. <br> CODE | NAME AND ADDRESS |
| :--- | :--- | :--- | :--- | :--- | :---: |

7-10. SPARE PARTS KIT. A Kit is available that contains a complement of spare parts which will maintain up to ten Model 172A/I73A DMMs. Specify Keithley Part Number 30116 when ordering.

TABLE 7-2.
COVERS, PANELS AND MISCELLANEOUS

| DESCRIPTION | KEITHLEY <br> PART NUMBER |
| :---: | :---: |
| Top Cover (less metalcal) <br> : : Metalcal for top cover <br> Bot tom Cover (less metalcals) <br> - Metalcal, operating instructions <br> - Metalcal, rear panel <br> Handle (less insert) <br> - Insert (2 req'd) <br> Spacer (4 req'd) <br> Rubber foot ( 4 req'd) <br> Front Panel - Model 172A <br> Front Panel - Model 173A <br> "O"' Ring (Used to hold display board, 4 req'd) <br> Metalcal, minus sign <br> " 0 "' Ring (Used to hold bottom cover screws captive, 4 req'd) | $\begin{aligned} & 28969 \mathrm{C} \\ & M C-254 \\ & 289688 \\ & M C-262 \\ & M C-235 \\ & 25729 D \\ & 26090 A \\ & 25762 B \\ & F E-10 \\ & 29837 C \\ & 29839 C \\ & G A-18 \\ & M C-231 \\ & G A-3 \end{aligned}$ |

## REPLACEABLE PARTS

## BATTERIES (BT)

"400" SERIES (Schematic 26758C)

| Circuit Desig. | Description | Mfr. Code | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: | :---: |
| BT401 | Multicell, 19.2V, Nickel-Cadmium | GLD | 403041 | BA-31 |
| BT402 | Multicell, 19.2V, Nickel-Cadmium | GLD | 403041 | BA-31 |
| BT403 | Set of Seven "C' cells, 8.4 Volts | -- | -- | : |
| * | Nickel-Cadmium, "C'" cell, 1.2 volts (used for BT403; seven required) | GLD | $2.05 C B$ | BA-30 |

CAPACITORS (C)

| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Coscription | Keithley |

"000" SERIES (Schematic 29145E)
(PC-Board 446)
(PC-Board 446)


## "100" SERIES (Schematic 29145E) (PC-Board 446)

Cl01 $418 \mathrm{pF}, 500 \mathrm{~V}, \mathrm{MICA}$. . . . . . . MIC
C102 . $56 \mu \mathrm{~F}, 50 \mathrm{~V}, \mathrm{MPC} .$. . . . . . . ECI
C103 8820pF, $1 \%$, Poly. . . . . . . . DTN
C104 3.3 10 F, 20V, ETT . . . . . . . . . C-I
C105 10 $10 \mathrm{~F}, 20 \mathrm{~V}$, ETT. . . . . . . . . . C-I
C 106 330pF, 6.3 V DC, $\pm 20 \%$, ETT . . . . K-I
C107 100pF, 1000V, CerD. . . . . . . . CLB
C108 $330 \mathrm{pF}, 6.3 \mathrm{~V}$ DC, $\pm 20 \%$, ETT . . . . K-I

| DM15RF418pFF03 | $C-278-418 p$ |
| :--- | :--- |
| 650B1A564 | $C-201-.56$ |
| 8820pF-63V. $1 \%$ | $C-299-8820$ |
| TD1-20-225-20 | $C-179-3.3$ |
| TD2-20-106-20 | $C-179-10$ |
|  | $C-333-330$ |
| DD-101 | $C-64-100 p$ |
|  | $C-333-330$ |

CAPACITORS (C) (CON'T)

| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Description | Codeithley |

## "200" SERIES (Schematic 29145E) <br> (PC-Board 446)

" 600 " Series (Schematic 29145E) (PC-Board 446)
. $1 \mu \mathrm{~F}, 10 \%$, 200VDC . . . . . . . TRW

33pF, 1000V, CerD . . . . . . . . CLB
. $22 \mu \mathrm{~F}, 50 \mathrm{~V}$, MPC . . . . . . . . . ECl
.015, 200V, Poly. . . . . . . . . ECI
$1 \mu \mathrm{~F}, 16 \mathrm{VDC}$. . . . . . . . . . . CLB
6.8pF, 50VDC . . . . . . . . . . ERI

150pF, 1000V, CerD. . . . . . . . CLB
.015, 200 V , Poly. . . . . . . . . ECI
$1 \mu \mathrm{~F}, 16 \mathrm{VDC}$. . . . . . . . . . . . CLB
$.22 \mu \mathrm{~F}, 10 \%$, 200VDC. . . . . . . . TRW
2200 pF , 1000 V , CerD . . . . . . . CLB

| $\begin{aligned} & 1-200-10-\times 363 U W \\ & D D-330 \end{aligned}$ | $\begin{aligned} & c-269-.1 \\ & c-64-33 p \end{aligned}$ |
| :---: | :---: |
| X363UW022 | C-269-. 22 |
| 10SS-D22 | c-64-2200p |
| 625B1A224J | C-201-. 22 |
| 62581C153 | C-221-.015 |
| UK16-104 | c-238-. 1 |
| 301-000СОН0639C | c-282-6.8p |
| DD-151 | C-64-150p |
| 62581C153 | C-221-.015 |
| UK16-104 | C-238-1 |

## "700" SERIES (Schematic 29145E) <br> (PC-Board 446)

.25-1.5pF, 2000V, Teflon Trimmer. EFJ .05 $\mu \mathrm{F}$, 1000V. . . . . . . . . . . SPG
3pF, 50VDC . . . . . . . . . . . ERI
.25-1.5pF, 2000V, Tefion Trimmer. EFJ
10 1 F, 20V, ETT. . . . . . . . . . C-I
. $1 \mu \mathrm{~F}, \mathrm{l}$ V V , CerD . . . . . . . . . CLB
1500pF, 500V, Poly. . . . . . . . CLB
1000pF, 500V, Poly. . . . . . . . CLB
. $01 \mu \mathrm{~F}, \mathrm{l} 200 \mathrm{~V}$. . . . . . . . . . . STD
. $1 \mu \mathrm{~F}, 50 \mathrm{~V}, \mathrm{MPC}$. . . . . . . . . ECI

273-101
41C169AB
301-000C0J0309C
273-101
TD2-20-106-20
UK16-104
CPR-1500J
CPR-1000J
PYW-R. 01
625B1A103-J

## "300" SERIES (Schematic 27404D)


'500' SERIES (Schematic 274780)

## CAPACITORS (C) (CON'T)

| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Description | Code |

"800" SERIES (Schematic 29145E)
(PC-Board 446)

$19001 "$ SERIES (Schematic 29145)
(PC-Board 446)
C901
47pF, 1000V, CerD
CLB
DD-470
C-64-47pF
"1000" SERIES (Schematic 27902E, PC-415)

"1100" SERIES (Schematic 28019E, PC-416)

C1101 $0.01 \mu \mathrm{~F}, 16 \mathrm{~V}$, CerD. . . . . . . . . . CLB
Cllo2 0.01 $\mu \mathrm{F}, 16 \mathrm{~V}$, CerD. . . . . . . . . . CLB
C1103 $1.2 \mu \mathrm{~F}, 20 \%, 20 \mathrm{~V} . \quad$. . . . . . . . . $\mathrm{C}-1$
Cll04 0.01 $\mu \mathrm{F}, 16 \mathrm{~V}$, CerD.
0.01 LF, 6 , CerD. . . . . . . . . . CLB

Cllo5 0.01 $\mu \mathrm{F}, 16 \mathrm{~V}$, CerD. . . . . . . . . . CLB
Cll06 $220 \mathrm{pF}, 1000 \mathrm{~V}$, CerD . . . . . . . . . CLB
Cllo7 $1000 \mathrm{pF}, 1000 \mathrm{~V}, \mathrm{CerD}$. . . . . . . . ERI

UK16-103
UK16-103
TDI-20-125-20
UK16-103
UK16-103
DD-221
808-000-25RO-102K

C-238-0.01M
$\mathrm{C}-238-0.01 \mathrm{M}$
C-179-1.2M
C-238-0.01M
C-238-0.01M
C-64-220P
C-64-1000P

```
    DIODES (CR)
"000"' SERIES (Schematic 29145)
    (PC-Board 446)
```



```
"100" SERIES (Schematic 29145E)
(PC-Board 446)
```



CR201
CR202
CR203
CR204
CR205
CR206

CR301


Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$. . . . . . MOT IN4006 RF-38
" 400 " SERIES (Schematic 26758C)

| CR401 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$. . . . . . . T-1 | 1N914 | RF-28 |
| :---: | :---: | :---: | :---: |
| CR402 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$. . . . . . . T-1 | IN914 | RF-28 |
| CR403 | Rectifier, $1 \mathrm{~A}, 800 \mathrm{~V}$. . . . . . . MOT | 1N4006 | RF-38 |
| CR404 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V} . . . . . . . ~ T-1$ | IN914 | RF-28 |
| CR405 | Rectifier, 75 mA , 75V. . . . . . . T-I | 1N914 | RF-28 |
| CR406 | Rectifier, $1 \mathrm{~A}, 800 \mathrm{~V}$. . . . . . . MOT | 1N4006 | RF-38 |
| CR407 | Rectifier, 75 mA , 75V. . . . . . . T-I | 1N914 | RF-28 |
| CR408 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$. . . . . . . T-I | IN914 | RF-28 |
| CR409 | Rectifier, $1 \mathrm{~A}, 800 \mathrm{~V}$. . . . . . . M0T | 1N4006 | RF-38 |
| CR410 | Rectifier, 75 mA , 75V. . . . . . . T-1 | IN914 | RF-28 |

## DIODES (CR)

| Circuit | Mfr. | Mfr. | Keithley |
| :--- | :--- | :--- | :--- |
| Desig. | Description | Code | Desig. |

" 500 " SERIES (Schematic 274780)

| CR501 | Bridge Rec | diode, 5A, 50V EDI | PE05 | RF-48 |
| :---: | :---: | :---: | :---: | :---: |
| CR502 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | 1 N914 | RF-28 |
| CR503 | Rectifier, 75 mA , | 75 V . . . . . . T-1 | 1 N914 | RF-28 |
| CR504 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | IN914 | RF-28 |
| CR505 | Rectifier, 75 mA , | 75V . . . . . . . T-1 | 1N914 | RF-28 |
| CR506 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | 1N914 | RF-28 |
| CR507 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | iN914 | RF-28 |
| CR508 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | 1 N914 | RF-28 |
| CR509 | Rectifier, 75 mA , | 75V. . . . . . . T-1 | 1 N914 | RF-28 |

" 600 " SERIES (Schematic 29145E)
(PC-Board 446)

| CR601 | Rectifier, 75mA, 75v | 1 N914 | RF-28 |
| :---: | :---: | :---: | :---: |
| CR602 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | 1N914 | RF-28 |
| CR603 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | 1 N914 | RF-28 |
| CR604 | Rectifier, 75mA, 75 V | 1 1914 | RF-28 |
| CR605 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | 1N914 | RF-2 |


| CR701 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-I | 1N914 | RF-28 |
| :---: | :---: | :---: | :---: | :---: |
| CR702 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . T-1 | 1N914 | RF-28 |
| CR703 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-1 | IN914 | RF-28 |
| CR704 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - $\mathrm{T}-\mathrm{I}$ | 1 N914 | RF-28 |
| CR705 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-1 | 1N914 | RF-28 |
| CR706 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-1 | 1N914 | RF-28 |
| CR707 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . . T-I | 1N914 | RF-28 |
| CR708 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . . T-I | 1N914 | RF-28 |
| CR709 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-I | 1 N914 | RF-28 |
| CR710 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | - T-1 | 1N914 | RF-28 |
| CR711 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . . . T-I | 1 N 914 | RF-28 |
| CR712 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . . . . . T-1 | 1N914 | RF-28 |
| CR713 | Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$ | . T-I | IN914 | RF-28 |

CR801
Rectifier, $75 \mathrm{~mA}, 75 \mathrm{~V}$
1N914
RF-28

## DIODES (CR)

| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Description | Code |

" 1000 " SERIES (Schematic 27902E, PC-415)

"300" SERIES (Schematic 27404D)

"و00" SERIES (Schematic 28656E)
DS901 Pilot Light, Light Emitting Diode. H-P HP5082-4494 PL-63

FUSES (F)
" 0001 " SERIES (Schematic 29145E)
(PC-Board 446)


| Circuit Desig. | Description $\quad \begin{gathered}\text { Mfr. } \\ \text { Code }\end{gathered}$ | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: |
| $J 301$ | Socket, 14-Pin DIP. . . . . . . T-I | C931402 | S0-70 |
| "400' SERIES (Schematic 26758C) |  |  |  |
| J401 | 5-pins . . . . . . . . . . . M0L | 2139-5 | CS-287-5 |
| J402 | 5-pins . . . . . . . . . . . . MOL | 2139-5 | CS-287-5 |
| "500" SERIES (Schematic 274780) |  |  |  |
| 501 | 5-pin Housing. . . . . . . . . . BRG | 20370 65039 C | $\begin{aligned} & C S-251 \\ & C S-310 \end{aligned}$ |
| J502 | 8-pin Housing. - . . . . • • • • BRG | 63-06-1023 |  |
| J503 | 2-pin Housing. (Model 173 A only) ${ }^{\text {Female Contacts ( } 2 \text { req'd for } 5503 \text { ) MOL }}$ | 02-06-5103 | CS-328 |
| -- | Female Contacts (12 for J501, J502) BRG | 47439 | CS-236 |

## CONNECTORS (J) (CON'T)

| Circuit | Description | Mfr. <br> Desig. | Mfr. <br> Codeithley <br> Desig. |
| :--- | :--- | :--- | :--- |


| J1001 | Housing, 5-pins (mates with CS-236). | BRG | 20370 | CS-2.51 |
| :--- | :--- | :--- | :--- | :--- | :--- |
| J1002 | Housing, 6-pins. |  |  |  |
| J1003 | Housing, 2-pins, MINI-PV. . . . . . . | BRG | $65043-093$ | CS-335 |
|  | CS |  |  |  |

> "1000" SERIES (Schematic 29145E) (PC-Board 446)

| 11001 | Housing, 5-Pins (Mates with CS-236) | BRG | 20370 | CS-251 |
| :---: | :---: | :---: | :---: | :---: |
| J1002 | Housing, 6-Pins . . . | - BRG | 65043-093 | CS-335 |
| J1003 | Housing, 2-Pins MINI-PV | - BRG | 65039-035 | CS-266 |
| J1004 | NOT USED |  |  |  |
| J1005 | NOT USED |  |  |  |
| J1006 | NOT USED |  |  |  |
| J1007 | Connector, Housing. | MOL | 2139-3 | C5-287-3 |
| J1008 | NOT USED |  |  |  |
| J1009 | Banana Jack, Red. | POM | 1581 | BJ-11-2 |
| J1010 | Banana Jack, Black. | POM | 1581 | BJ-22-0 |
| J1011 | Banana Jack, Red. | - POM | 1581 | BJ-11-2 |
| J1012 | Banana Jack, Black. | . POM | 1581 | BJ-11-0 |

## "ll00" SERIES (Schematic 28019E)



RELAYS (K)

## "100"' SERIES (Schematic 29145E)

 (PC-Board 446)| Circuit Desig. | Description | Mfr. Code | Mfr. Desig. | Keithley <br> Part No. |
| :---: | :---: | :---: | :---: | :---: |
| K101 | 5V, Reed Type | COT | UF-40097 | RL-56 |
|  | " 200 " SERIES (Schematic (PC-Board 446) | 29145E) |  |  |
| K201 | Contact . . . . . . . . . . . . . . | CCC | SPECIAL <br> R10-E3738-1 | $\begin{aligned} & \text { RL- } 57 \\ & \text { RL- } 51 \end{aligned}$ |
| K202 | Relay . . . . . . . . . . . . . . . | P\&B | R10-E3738-1 | RL-51 |


| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Kescription | Code |

"500" SERIES (Schematic 27478D)

| K501 | Relay, Reed, $0.5 A$, Form A. . . . . WAB | $1170-3-1$ | RL-44 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- |
| K502 | Relay, Reed, 0.5A, Form A. . . . . . WAB | $1170-3-1$ | RL-44 |
| K503 | Relay, Reed, 0.5A, Form A. . . . . . WAB | $1170-3-1$ | RL-44 |
| K504 | Relay, Reed, 1.5A, Form A. . . . . . QTN | H5AlM-S20 | RL-50 |
| K505 | Relay, Reed, 3A. . . . . . . . . . . WAB | $1170-2-1$ | RL-49 |

CONNECTORS (P)
"300" SERIES (Schematic 29145E)
(PC-Board 446)

| Circuit <br> Desig. | Description | Mfr. <br> Code | Mfr. <br> Desig. | Keithley <br> Part No. |
| :--- | :--- | :--- | :--- | :--- |
| Assembly Cable. . . . . . . . . |  |  |  |  |

"400" SERIES (Schematic 29145E)
(PC-Board 446)


## CONNECTORS (P) (CON'T)

| Circuit | Mfr. | Mfr. |
| :--- | :--- | :--- |
| Desig. | Coscription | Keithley |

"1000" SERIES (Schematic 27902E, PC-415)


P1101 Card-edge, 26-pin (part of Model 1727) . . . . . . MMM 3462-0000 C5-294-1

TRANSISTORS (Q)
"100" SERIES (Schematic 29154E) (PC-Board 446)

| Circuit Desig. | Description | Mfr. Code | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: | :---: |
| Q101 | NPN, Case TO-92 | MOT | 2N5089 | TG-62 |
| Q102 | PNP, Silicon, Case T0-92. | MOT | 2N5089 | TG-61 |
| Q103 | PNP, Silicon, Case ro-92. | MOT | 2N5087 | TG-61 |
| Q104 | NPN, Switch . | MOT | 2N3904 | TG-47 |
| Q105 | FET, Case T0-18 (*Selected TG-88) | INT | 1 TS 3538 | 28250A |
| Q106 | Transistor, NON, Case T0-106. . . | K-1 | --- | 28234 A |
| Q107 | N-Chan, JFET. . | K-1 | --- | TG-128 |
| Q108 | Transistor, NPN, Case T0-106. . | K-1 | --- | 28234 A |
| Q109 | PNP, Silicon, Case T0-92. . | MOT | 2N5087 | TG-61 |
| Q110 | N-Chan, JFET. | INT | ITE4392 | TG-77 |

$" 200 "$ SERIES (Schematic 29154E)
(PC-Board 446)

Q201
Q202
Q203
Q204
Q205
Q206

PNP, silicon. . . . . . . . . . . MOT
NPN, Case . . . . . . . . . . . . F-I
PNP, Silicon, TO-92 Case. . . . . MOT
N -Chan, JFET. . . . . . . . . . . INT
NPN, Case TO-5. . . . . . . . . . RCA
N -Chan, JFET, Case T0-92. . . . . K-I

2N3906
2N3643
2N3905
ITE4392
2N3439

TG-84
TG-123
TG-53
TG-77
TG-93
TG-128

| Circuit Desig. | Description $\begin{aligned} & \text { Mfr. } \\ & \text { Code }\end{aligned}$ | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: |
|  | "300'" SERIES (Schematic 274040) |  |  |
| Q301 | PNP, Case T0-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q302 | PNP, Case T0-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q303 | PNP, Case T0-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q304 | PNP, Case TO-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q305 | PNP, Case T0-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q306 | PNP, Case T0-106 . . . . . . . . . F-I | 2N4355 | TG-90 |
| Q307 | PNP, Case R-110. . . . . . . . . F-I | \$17638 | TG-33 |
| Q308 | PNP, Case R-110. . . . . . . . . F-I | S 17638 | TG-33 |
| Q309 | PNP, Case R-110. . . . . . . . . F-1 | S17638 | TG-33 |
| Q310 | PNP, Case R-110. . . . . . . . . F-I | S 17638 | TG-33 |
| Q311 | PNP, Case R-110. . . . . . . . . F-I | 517638 | TG-33 |
| Q312 | PNP, Case R-110. . . . . . . . . F-1 | S17638 | TG-33 |
| Q313 | PNP, Case R-110. . . . . . . . . F-I | 517638 | TG-33 |
| Q314 | PNP, Case R-110. . . . . . . . F-I | S17638 | TG-33 |
| 1"400'1 SERIES (Schematic 26758C) |  |  |  |
| Q401 | PNP, Case T0-5 . . . . . . . . . . RCA | 2N4032 | TG-92 |
| - Q402 | NPN, Case TO-39. . . . . . . . . . MOT | 2N3300S | TG-117 |
| Q403 | PNP, Case T0-5 . . . . . . . . . RCA | 2N4032 | TG-92 |
| Q404 | NPN, Case TO-106 . . . . . . . . . F-I | 2N3565 | TG-39 |
| Q405 | PNP, Case T0-92 MOT | 2N5087 | TG-61 |
| " 500 " SERIES (Schematic 29145E) (PC-Board 446) |  |  |  |
| Q501 | Transistor Array - 14-Pin DIP . . RCA | CA3086 | $1 c-53$ |
| Q502 | NPN, Case TO-106. . . . . . . . . F-I | 2N5134 | TG-65 |
| " 600 " SERIES (Schematic 29145E) (PC-Board 446) |  |  |  |
| Q601 | N -Chan, JFET. . . . . . . . $\mathrm{K}-1$ |  | $T G-128$ |
| Q602 | Transistor, TG-128, (Selected). . K-I |  | 28958 A |
| Q603 |  | ----- | TG-128 |
| 0604 | Transistor, TG-128, (Selected). . K-I | ----- | 28958 A |

## TRANSISTORS ( 0 )

Circuit Desig.
Mfr. Mfr.
Code Desig.

Keithley
Part No.
"700" SERIES (Schematic 29145E)
(PC-Board 446)

Q701
Q702
Q703
Q704
Q705
Q706
Q707
Q708
Q709
Q710
Q711
0712
0713
0714

N-Chan, JFET. . . . . . . . . . . K-I
N-Chan, JFET. . . . . . . . . . . K-I
N-Chan, JFET. . . . . . . . . . . K-1
N-Chan, JFET. . . . . . . . . . . K-I
N -Chan, JFET.
$k-1$
PNP, Silicon, TO-92
MOT
N-Chan, JFET. . . . . . . . . . . K-1
N -Chan, JFET.
K-I
Transistor, NPN, CASE TO-106 INT
INT
N -Chan, JFET.
K-I
N-Chan, JFET
K-1
Transistor, NPN, Case TO-106. . . K-I
PNP, Silicon, TO-92
MOT

| ---- | TG-128 |
| :---: | :---: |
| ----- | TG-128 |
| ----- | TG-128 |
| ----- | TG-128 |
| ----- | TG-128 |
| 2N3905 | TG-53 |
| ----- | TG-128 |
| ----- | TG-128 |
| 2N3565 | 28234A |
| 2N3565 | 28234 A |
| --.-- | TG-128 |
|  | TG-128 |
|  | 28234A |
| 2N3905 | TG-53 |

"1000" SERIES (Schematic 27902E, PC-415)

Q1001
Q1002
Q1003
Q1004
Q1005
Q1006
Q1007
Q1008
Q1009
Q1010
Q1011
Q1012
Q1013
Q1014 Q1015 Q1016 Q1017 Q1018 Q1019 Q1020 Q1021 Q1022 Q1023 Q1024 Q1025


TRANSISTORS (Q) (CON'T)

| Circuit Desig. | Description |  | Mfr. Code | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Q1026 | NPN, Case T0-106. | . . . . . . . | F-1 | 2N5134 | TG-65 |
| Q1027 | NPN, Case T0-106. | - | F-I | 2N5134 | TG-65 |
| Q1028 | NPN, Case T0-106. | . . . . . . . | F-I | 2N5134 | TG-65 |
| Q1029 | NPN, Case T0-106. | . . . . . . | F-1 | 2N5134 | TG-65 |
| Q1030 | NPN, Case T0-106. | . . . . . . | F-I | 2N5134 | TG-65 |
| Q1031 | NPN, Case T0-106. | . . . . . . | $F-1$ | 2N5134 | TG-65 |
| Q1032 | NPN, Case T0-106. | . . . . . . . | F-1 | 2N5134 | TG-65 |
| Q1033 | NPN, Case T0-106. | . . . . . . . | F-I | 2N5134 | TG-65 |
| Q1034 | PNP, Case R-110 | . . . . . . . | F-1 | S17638 | TG-33 |
| Q1035 | PNP, Case R-110 | . . . . . . . | $\mathrm{F}-1$ | S17638 | TG-33 |
| Q1036 | PNP, Case R-110 | . . . . . |  | 517638 | TG-33 |
| Q1037 | PNP, Case R-110 | - . | F-I | S17638 | TG-33 |

"1100" SERIES (Schematic 280I9E)
Q1101 NPN, Case TO-106. . . . . . . F-I 2N5134 TG-65

## RESISTORS (R) <br> "000" SERIES (Schematic 29145E) <br> (PC-Board 446)

| Circuit Desig. | Description $\begin{aligned} & \text { Mfr. } \\ & \text { Code }\end{aligned}$ | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: |
| R001 | $6.8 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}, \mathrm{Comp}$, . . . . A-B | CB-682-10\% | $\mathrm{R}-76-6.8 \mathrm{~K}$ |
| R002 | $5.1 \mathrm{k} \Omega, 10 \%$, $1 / 4 \mathrm{~W}$, Comp. . . . . $\mathrm{A}-\mathrm{B}$ | CB | R-76-5.1K |
| R003 | 158, 5\%, 5W, WW . . . . . . . . OHM | 4565 | R-257-15 |
| R004 | NOT USED |  |  |
| R005 | 680 , $10 \%$, $1 / 2 \mathrm{~W}$, Comp . . . . . . A-B | EB-681-10\% | R-1-680 |
| R006 | 680R, $10 \%$, 1/2W, Comp . . . . . A-B | EB-681-10\% | R-1-680 |
| R007 | 100 , 10\%, 1/2W, Comp . . . . . . A-B | GB-101-10\% | R-2-100 |
| "100" SERIES (Schematic 29145E) (PC-Board 446) |  |  |  |
| R101 | SELECTED k -1 |  | 293170 |
| R102 | K102, 103, 202 and 203. . . . . K-I |  | R-266 |
| R103 | are a matched set . . . . . . K-I |  | R-266 |
| R104 | 50ת, 0.5W, VAR. . . . . . . . . BEC | 72PMR-50 | RP-97-50 |
| R105 |  | 1/8, . $1 \%, \mathrm{C}-5$ | R-241-2191 |
| R106 | 150K $\Omega, 10 \%, 1 / 4 \mathrm{~W}, \mathrm{Comp}$. . . . . A-B | CB | R-76-150K |
| R107 | 240K, $10 \%$, $1 / 4 \mathrm{~W}$, Comp. . . . . . A-B | CB | R-76-240 |
| R108 | Thick Film Resistor Network . . . K-I |  | TF-72 |
| R109 |  | 1/8, 1\%, c-5 | R-241-249 |
| R110 | 10K $\Omega$, 10\%, 1/4W, Comp . . . . . A-B | CB-103-10\% | R-76-10K |

RESISTORS (R) (CON'T)


R201
R202
R203
R204
R205
R206
R207
R208
R209
R210
R211
R212
R213
R214
R215
R216
R217
R218

Selected . . . . . . . . . . . . K-I

| ----- | $\begin{aligned} & 293170 \\ & R-266 \end{aligned}$ |
| :---: | :---: |
|  | R-266 |
| 72PMR-200K | RP-97-200K |
| EB-XXX-10\% | $R-1-120 K$ |
| $\begin{aligned} & \text { 72PMR-200K } \\ & \text { CEA-TO-49.9K } \end{aligned}$ | $\begin{aligned} & R P-97-200 K \\ & R-88-49.9 K \end{aligned}$ |
| 72PMR-500 | $\begin{aligned} & R P-97-500 \\ & T F-67 \end{aligned}$ |
| 72PMR | RP-97-200K |
| CB | R-76-33 |
| CB-2R7-10\% | R-76-2.7 |
| 72PMR-10 | RP-97-100 |
|  | TF-75 |
| EB-27K-10\% | R-1-27K |
| MS 281 | R-247-150K |
| CB | R-76-33K |

R102, 103, 202 and 203. . . . . . K-I
are a matched set . . . . . . . . K-I
$200 \mathrm{~K} \Omega, 0.5 \mathrm{~W}, \mathrm{POT}$. . . . . . . . BEC
120K $\Omega$, $10 \%$, $1 / 2 \mathrm{~W}$, Comp. . . . . . $\mathrm{A}-\mathrm{B}$
Thick Film Resistor Network . . . K-l
$200 \mathrm{~K} \Omega, 0.5 \mathrm{~W}$, POT. . . . . . . . . BEC
$49.9 \mathrm{~K} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . IRC
$500 \Omega, 0.5 \mathrm{~W}, \mathrm{POT}$. . . . . . . . . BEC
Thick Film Resistor Network . . . K-I
$200 \mathrm{~K} \Omega, 0.5 \mathrm{~W}, \mathrm{POT}$. . . . . . . . . BEC
$33 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}, \mathrm{Comp}$. . . . . . A-B
$2.7 \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
100』, 0.5W, VAR . . . . . . . . . BEC
Thick Film Resistor Network . . . K-l
$27 \mathrm{~K} \Omega, 10 \%, 1 / 2 \mathrm{~W}$, Comp . . . . . A-B $150 \mathrm{~K} \Omega, 1 \%, 8 \mathrm{~W} . . . . . . . . . . C A D$ $33 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
"300" SERIES (Schematic 274040)


RESISTORS(R) (CON'T)

| Circuit | Mfr. | Mfr. | Keithley |
| :--- | :--- | :--- | :--- |
| Desig. | Description | Code | Desig. |

" 400 " SERIES (Schematic 26758C)

R401
R402
R403
R404
R405
R406
R407
R408
R409
R410
R411
R412
R413
R414
13.7 $8,1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$

IRC
$A-B$
A-B
IRC
A-B
$A-B$
IRC
$A-B$
$A-B$
IRC
IRC
IRC
IRC
IRC

| CEA-TO-13.7 | $R-88-13.7$ |
| :--- | :--- |
| EB- $123-10 \%$ | $R-1-12 K$ |
| EB-123-10\% | $R-1-12 K$ |
| CEA-TO-13.7 | $R-88-13.7$ |
| EB-3R3-10\% | $R-1-3.3$ |
| EB-152-10\% | $R-1-1.5 \mathrm{~K}$ |
| CEA-TO-71.5K | $R-88-71.5 \mathrm{~K}$ |
| CB-104-10\% | $R-76-100 \mathrm{~K}$ |
| CB-222-10\% | $R-76-2.2 \mathrm{~K}$ |
| CEA-T0-76.8K | $R-88-76.8 \mathrm{~K}$ |
| CEA-TO-499K | $R-88-499 \mathrm{~K}$ |
| CEA-TO-100K | $R-88-100 \mathrm{~K}$ |
| CEA-TO-110K | $R-88-110 \mathrm{~K}$ |
| CEA-TO-499K | $R-88-499 \mathrm{~K}$ |

"500" SERIES (Schematic 28067D)

R501
R502
R503
R504
R505
R506
$R 507$
R508
R509
R 510
R511
R512
R513
R514

R515
R516
R517
2. $2 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W} . .$. . . . . . $A-B$

900 ת, 0.05\%, $1 / 2 \mathrm{~W}$. . . . . . . IRC
$90 \Omega, 0.05 \%, 1 / 8 \mathrm{~W} . . . . \quad . \quad . \quad . \quad$ IRC
$9.1 \Omega, 0.5 \%, 1 / 2 W$. . . . . . . . TEP
$499 \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF} . . . . . \quad . \quad$ IRC
$2 \mathrm{~K} \Omega, 0.5 \mathrm{~W}, \mathrm{Var} .$. . . . . . . BEC
$0.91 \Omega, 0.5 \%, 5 W$. . . . . . . . . TEP
$40.2 \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . . IRC
200 , 0.5W, Var. . . . . . . . . BEC
$0.102 \Omega, 0.5 \%, 10 W$. . . . . . . TEP
$2.7 \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
$10 \Omega, 0.5 \mathrm{~W}$, Var. . . . . . . . . . BEC
Thick Film Resistor Network. . . . K-I
$1 \Omega, 0.1 \%$, 1OW . . . . . . . . . . TEP
R502-R513 used on Model 173A only. R514 used on Model 172A only.
$30.1 \mathrm{~K} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . . IRC
30.1K $\Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF} \cdot$. . . . . IRC
$30.1 \mathrm{~K} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF} \cdot . \cdot$. . . IRC

CB
MAR6-900
MAR6-90』
TS.5S-9.1 $\Omega$
CEA-T0-499
72PMR-10K
TS5-0.91
CEA-TO-40. 2
72PMR-IK
TS 10-0.102 $\Omega$
CB-2R7-10\%
72PMR-10
--
TS-10W

CEA-30.1K-1\%
CEA-30.1K-1\%
CEA-30. $1 \mathrm{~K}-1 \%$

R-76-2.2K
R-236-900
R-236-90
R-237-9.1
R-88-499
RP-97-2K
R-238-. 91
R-88-40.2
RP-97-200
R-239-. 102
R-76-2.7
RP-97-10
TF-4 4
R-256-1

R-88-30.1K
R-88-30.1K
R-88-30.1K

## RESISTORS (R) (CON'T)

| Circuit | Mfr. | Mfr. | Keithley |
| :--- | :--- | :--- | :--- |
| Desig. | Coscription | Desig. | Part No. |

## "600"' SERIES (Schematic 29145E) (PC-Board 446)

$13.44 \mathrm{~K} \Omega, 0.5 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF} . . . . . \mathrm{DLE}$
$5.76 \mathrm{~K} \Omega, 0.5 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . DLE
133K $\Omega$, 1\%, 1/8W, MtF. . . . . . . IRC
133Kת, 1\%, 1/8W, MtF. . . . . . . IRC
Part of 28959B. . . . . . . . . . K-I
Part of 28959B. . . . . . . . . . K-I NOT USED
$15 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
15K $\Omega$, 10\%, 1/4W, Comp . . . . . . A-B
100 , 5\%, 500VDC. . . . . . . . BEC
NOT USED
10ת, 0.5W, POT. . . . . . . . . . BEC
$7.5 \mathrm{~K} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . . IRC
$22 \mathrm{~K} \Omega, 10 \%$, $1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
Thick Film Resistor Network . . . K-I
Thick Film Resistor Network . . . K-I
$13.98 \mathrm{~K} \Omega$, Matched Set. . . . . . . TEL
$15 \mathrm{~K} \Omega$, Matched Set . . . . . . . . TEL
$18.04 \mathrm{~K} \Omega$, Matched Set. . . . . . . TEL
2K $\Omega$, Matched Set. . . . . . . . . TEL
$900 \Omega, 0.1 \%, 1 / 10200 \mathrm{~V}$. . . . . . TRW
$1.67 \mathrm{~K} \Omega, 0.1 \%, 1 / 10,200 \mathrm{~V} . . . . . \mathrm{TRW}$

MFF-1/8-13.44K
MFF-1/8-5.76K
CEA-TO-133K
CEA-TO-133K
--..-
-.---
CB
CB
72PMR-100K
72PMR-500
CEA-TO-7.5K
CB-223-10\%
-----
-----
---.
----
-----
MAR 5
MAR 5

## " 700 " SERIES (Schematic 29145E) <br> (PC-Board 446)

R701 $15 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . A-B

R703
R704
R705
R706
R707
R708
R709
R710
R711
R712
R713
R714
R715

R702 22K, 10\%, 1/4W, Comp . . . . . . A-B
$22 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . : . . . . A-B
150Kת, 1\%, 1/8W, MtF. . . . . . . IRC
$10 \mathrm{~K} \Omega$, $10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
$7.5 \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . . IRC
49.9K $\Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. . . . . . IRC
$210 \mathrm{~K} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF} . . . . . . . \mid R C$
$10 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
$47 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
Thick Film Resistor Network . . . K-I
Thick Film Resistor Network . . . K-I
200K $\Omega$, 0.5W, POT. . . . . . . . . BEC
200K $\Omega$, 0.5W, POT. . . . . . . . . BEC
$1 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp. . . . . . . A-B

CB
CB-223-10\%
CB-223-10\%
CEA-TO-150K
CB-103-10\%
CEA-TO-7.5K
CEA-T0-49.9K
CEA-TO-210K
CB-103-10\%
CB
-----
-----
72PMR-200K
72PMR-200K
CB
$R-246-13.44 K$
$R-246-5.76 K$
$R-88-133 K$
$R-88-133 K$
$R-246-\%$
$R-246-\%$
$R-76-15 K$
$R-76-15 K$
$R P-114-100$
$R P-97-10$
$R-88-7.5 K$
$R-76-22 K$
$T F-70$
$T F-69$
$R-273-13.98 K$
$R-273-15 K$
$R-272-18.04 K$
$R-272-2 K$
$R-263-900$
$R-263-1.67 K$

R-246-13.44K
R-246-5.76K
R-88-133K
R-88-133K
R-246-*
R-246-:
R-76-15K
R-76-15K
RP-114-100
RP-97-10
R-88-7.5K
R-76-22K
TF-70
TF-69
R-273-13.98K
R-273-15K
R-272-18.04K
R-272-2K
R-263-1.67K

$$
\begin{aligned}
& R-76-15 K \\
& R-76-22 K \\
& R-76-22 K \\
& R-88-150 K \\
& R-76-10 K \\
& R-88-7.5 K \\
& R-88-49.9 K \\
& R-88-210 K \\
& R-76-10 K \\
& R-76-47 K \\
& T F-60 \\
& T F-60 \\
& R P-97-200 K \\
& R P-97-200 K \\
& R-76-1 K
\end{aligned}
$$

RESISTORS (R) (CON'T)

| Circuit Desig. | Description | Mfr. <br> Code | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: | :---: |



## "900" SERIES (Schematic 29145E) <br> (PC-Board 446)

R901
Thick Film Resistor . . . . . . . K-I
10K $\Omega$, $10 \%$, $1 / 4 \mathrm{~W}$, Comp . . . . . A-B
$22 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
$22 \mathrm{~K} \Omega, 10 \%, 1 / 4 \mathrm{~W}$, Comp . . . . . . A-B
NOT USED
$120 \mathrm{~K} \Omega, 5 \%, 2 \mathrm{~W}$, WW . . . . . . . . TRW

## TF-68

$C B-103-10 \% \quad R-76-10 K$
CB-223-10\% R-76-22K
CB-223-10\% R-76-22K
BWH

R-201-120

R1001
R1002
R1003
R1004
R1005
R1006
R1007
R1008
R1009
R1010
R1011
R1012
R1013
R1014
R1015
R1016

Resistor Network, Thick Film, . . K-I
$k-1$
$K-I$
Resistor Network, Thick Film . . . K-1
$K-1$
$\mathrm{K}-1$
A-B

| $32.4 \mathrm{k} \Omega, 1 \%, 1 / 8 \mathrm{~W}, \mathrm{MtF}$. |
| :--- |
| $\mathrm{M} \Omega, 10 \%, 1 / 4 \mathrm{~W}$ Como. . . . . . 1 RC |

$3.9 \mathrm{k} \Omega, 10 \%$, $1 / 4 \mathrm{~W}$, Comp. . . . . . A-B
$A-B$
I RC
A-B
IRC
IRC
I RC
A-B
"1100"' SERIES (Schematic 28019E)
RIIOI
R1102
R1103
R1104
R1105
R1106

- R1107
"800" SERIES (Schematic 29145E)
(PC-Board 446)
"1000"' SERIES (Schematic 27902E)

| CEA-TO-1IK $\Omega$ | $R-88-11 \mathrm{~K}$ |
| :---: | :--- |
| - | $\mathrm{TF}-54$ |
| - | $\mathrm{TF}-54$ |
| - | $\mathrm{TF}-54$ |
| - | $\mathrm{TF}-54$ |
| CEA-TO-6.5K $\Omega$ | $\mathrm{R}-88-6.5 \mathrm{~K}$ |
| CEA-TO-10K $\Omega$ | $\mathrm{R}-88-10 \mathrm{~K}$ |


|  | SWITCHES (S) <br> " 000 " SERIES (Schematic 29145E) (PC-Board 446) |  |
| :---: | :---: | :---: |
| S001 | Switch, Slide, DPDT . . . . . . . C-W GF326-0006 | SW-397 |
|  | "700" SERIES (Schematic 29145E) <br> (PC-Board 446) |  |
| S701 | Switch, Cutting . . . . . . . . K-I -- | 28799B |
|  | TRANSFORMERS (T) <br> " 000 " SERIES (Schematic 29145E) (PC-Board 446) |  |
| T001 | Transformer . . . . . . . . . . . K-1 ----- | TR-163 |
|  | "1000" SERIES (Schematic 27902E) |  |
| T1001 | Transformer . . . . . . . . . . K-I | TR-164 |
|  | integrated circuits (u) <br> "100" SERIES (Schematic 29145E) (PC-Board 446) |  |
| Circuit Desig. |  Mfr. <br> Description <br> Code <br> Mfr. <br> Desig. | Keithley Part No. |
| 4101 | Op. Amp. 8-Pin DIP. . . . . . . INT LM308PA | $\begin{gathered} 10-199 \text { is } \\ \text { IC. } 78 \end{gathered}$ |
|  | '200'' SERIES (Schematic 29145E) |  |
| $\begin{aligned} & \text { U2O1 } \\ & \text { U202 } \end{aligned}$ | Op. Amp. CASE T0-99 . . . . . . . F-I UAF356HC Op. Amp. 8-Pin CASE TO-5. . . . . K-I | $\begin{aligned} & 1 C-152 \\ & \text { IC-132 } \end{aligned}$ |
|  | "300" SERIES (Schematic 274040) |  |
| U301 | $\begin{aligned} & \text { 8-Bit Parallel-Out Serial Shift } \\ & \text { Register, } 14 \text {-Pin DIP. . . . . T-I SN74LSI64 } \end{aligned}$ | 1--127 |
|  | "400" SERIES (Schematic 26758C) |  |
| U401 | Operational Amplifier, 8-pin DIP . F-1 U9T7741393 | $1 \mathrm{C}-42$ |
|  | "500" SERIES (Schematic 274780) |  |
| U501 | Operational Amplifier, 8-pin DIP. INT LM308PA | 1C-99 |
| U502 | COS/MOS BCD-TO-DECIMAL decoder, <br> 16-pin DIP. . . . . . . . . . RCA CD4028AE | 1c-135 |

INTEGRATED CIRCUITS (U) (CON'T)

| Circuit <br> Desig. | Description | Mfr. <br> Code |
| :--- | :--- | :--- |

## ' 600 ' SERIES (Schematic 29145E) (PC-Board 446)

| U601 | Op. Amp. 8-Pin DIP. . . . . . . . F-1 | U917741393 | 1c-176 |
| :---: | :---: | :---: | :---: |
| 0602 | Op. Amp. 8-Pin DIP. . . . . . . . INT | LM308PA | 1C-99 |
| U603 | Selected 1C-153....... . . K-1 |  | 28090A |
| U604 | Op. Amp. 8-Pin DIP. . . . . . . . NAT | LM30IAN | 1C-24 |
| U605 | Voltage Comparator. . . . . . . . NAT | LM311N | 1C-173 |
| " 700 " SERIES (Schematic 29145E) (PC-Board 446) |  |  |  |

4701
U702
JFET, Input Output. . . . . . . . NAT
LM351N
IC-176
Op. Amp. 8-Pin, Case T0-5 . . . . NAT LHOO42CH
" 800 ' SERIES (Schematic 29145E)
(PC-Board 446)


| Quad 2-1nput AND, 14-pin DIP. | RCA | CD40818E | 1C-138 |
| :---: | :---: | :---: | :---: |
| Quad 2-Input AND, 14-pin DIP. | . RCA | CD40818E | 1c-138 |
| Quad 2-1nput AND, 14-pin DIP. | . RCA | CD408JBE | 1c-138 |
| Quad 2-Input AND, 14-pin DIP. | RCA | CD4081BE | IC-138 |
| Quad 2-Input AND, 14-pin DIP. | RCA | CD4081BE | 1c-138 |
| Quad 2-Input AND, 14-pin DIP. | RCA | CD4081BE | 1c-138 |
| Quad 2-Input AND, 14-pin DIP. | RCA | CD408IBE | 16-138 |
| COS/MOS Dual 4 -Stage Static Shift |  |  |  |
| Register. . . . . . . . . | RCA | CD4015AE | 1-136 |
| COS/MOS Dual 4-Stage Static Shift Register. | RCA | CD4015AE | IC-136 |
| COS/MOS Dual 4-Stage Static Shift Register | . RCA | CD4015AE | IC-136 |
| COS/MOS Dual 4-Stage Static Shift |  |  |  |
| Register. | . RCA | CD4015AE | 1c-136 |
| Quad 2-Input AND, 14-pin DIP. | RCA | CD4081BE | 1c-138 |
| Quad 2-1nput AND, 14-pin DIP. | RCA | CD4081BE | 1c-138 |
| Quad 2-Input NOR, 14-pin DIP. | RCA | CD4001AE | IC-108 |
| Dual D-Type Flip-Flop, 14-pin DIP | RCA | CD4013AE | 1c-103 |


| Circuit Desig. | Description $\begin{gathered}\text { Mfr. } \\ \text { Code }\end{gathered}$ | Mfr. Desig. | Keithley Part No. |
| :---: | :---: | :---: | :---: |
| U1016 | COS/MOS Hex Inverter, 14-pin DIP. . . . . . RCA | CD4069BE | 1C-139 |
| 41017 | Timing Logic, 8-pin DIP. . . . . . . . SIG | NE555V | 1C-71 |
| U1018 | Optically-coupled Isolator, 8-pin DIP. . H-P | HP 5082-4351 | 1C-142 |
| 41019 | Optically-coupled Isolator, 8-pin DIP . . . H-P | HP 5082-4351 | $1 \mathrm{C}-142$ |
| U1020 | Optically-coupled Isolator, 8-pin DIP. . . H-P | HP 5082-4351 | IC-142 |
| U1021 | Optically-coupled Isolator, 8-pin DIP . . . H-P | HP 5082-4351 | 1C-142 |
| "1100" SERIES (Schematic 28019E) |  |  |  |
| U1101 | Hex Inverters, Open Collector Output. . . . TEXAS | SN74LSOSN | 1c-141 |
| U1102 | Hex Inverters, Open Collector Output.. . . TEXAS | SN74LSO5N | \|c-14| |
| U1103 | Hex Inverters, Open Collector Output.. . . TEXAS | SN74LSO5N | 1C-141 |
| U11104 | Positive-NAND Gates and Inverters/ <br> Totem-pole outputs <br> TEXAS | SN74LS14N | 15-137 |
| U1105 | Hex Inverters, Open Collector Output . . . TEXAS | SN74LSO5N | $1 \mathrm{C}-141$ |
| U 1106 | Dual D-Type Flip-Flop, 14-pin DIP. . . . . RCA | CD4013AE | 1c-103 |
| U1107 | Quad 2-Input NOR, 14-pin DIP. . . . . . RCA | CD4001AE | 1c-108 |
| U1108 | COS/MOS 8-Stage Static Shift <br> Register | CD4021AE | $1 C-130$ |
| U1109 | Quad 2-Input AND, 14-pin DIP . . . . . . RCA | CD4081BE | IC-138 |
| U1110 | COS/MOS Dual 4 Input NAND Gates. . . . . . RCA | CD4012AE | $1 \mathrm{C}-140$ |
| U1111 | Six cos/mos Hex Inverter . . . . . . . . . RCA | CD4069BE | IC-139 |

VOLTAGE REOULATORS (VR)
"000" SERIES (Schematic 29145E)





TABLE 7-3
COMPONENT DESIGNATIONS FOR PC-446 (MODEL 172A/173A)

| Circuit <br> Desig./Item No. |  | Location Code | Circu Desig | Item No. | Location Code | Circu Desig | I tem | Location Code |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| COOI | 38 | 83 | c801 | 21 | C5 | J1006 | - | - |
| c002 | 12 | B3 | C802 | 35 | C5 | J1007 | - | B4 |
| C003 | 18 | C3 | C901 | 289 | D5 | $J 1008$ | - | - |
| C004 | 19 | B3 | C902 | 292 | 05 | $J 1009$ | 4 | 62 |
| c005 | 20 | C3 | C902 | 292 |  | $J 1010$ | 2 | G1 |
| C006 | 31 | 84 | CROO 1 | 189 | B1 | J1011 | 5 | G2 |
| c007 | 30 | ${ }^{6} 4$ | CROO2 | 188 | B3 | 11012 | 3 | G1 |
| c008 | 24 | B4 |  |  |  |  |  |  |
| C009 | 50 | B5 | CRIO1 CRIO2 | 167 | C2 | K101 | 192 | C2 |
| coso | 49 | B5 | CR102 | 165 164 | C2 | K20.1 | 193 | D2 |
| coll | 17 | ${ }^{6} 4$ | CR104 | 164 163 | D2 | K202 | 191 | E2 |
| CO12 | 13 | C5 |  |  |  | P401 | 57 | E5 |
| C10) | 43 | 01 | CR201 | 166 162 | D2 | P402 | 56 | 85 |
| C102 | 27 | C2 | CR203 | 161 | E2 | P501 | 61 |  |
| C103 | 284 | 02 | CR204 | 173 | E2 | P502 | 62 | E1 |
| C104 $C 105$ | 14 16 | C2 $C 2$ | CR205 | 190 | D3 | P1001 | 60 | c2 |
| C106 | 52 | C2 | CR206 | 169 | D3 | P1002 | 63 | E5 |
| C107 | 7 | C3 | CR601 | 182 | C3 | P1003 | 58 | E5 |
| C201 | 23 | 01 | CR602 | 181 | C4 | P1004 | 55 | 84 |
| C202 | 51 | E1 | CR603 | 184 | $\mathrm{CH}_{4}$ | Q101 | 234 | C2 |
| C203 | 45 | D2 | CR604 | 183 180 | $\mathrm{CL}_{4}$ | Q102 | 232 | C2 |
| C204 | 22 | E2 | CR605 | :80 | C4 | Q103 | 231 | C2 |
| C205 | 15 | 02 | CR701 | ;68 | D3 | Q104 | 227 | D2 |
| C206 | 32 | 02 | CR702 | 170 | 03 | Q105 | 240 | D2 |
| C207 | 11 | 02 | CR703 | 171 | D3 | Q106 | 223 | D2 |
| C208 | 10 | E2 | CR704 | 172 | E3 | Q107 | 238 | D2 |
| C209 | 48 | F2 | CR705 | 174 | 04 | Q108 | 222 | D2 |
| C210 | 25 | E3 | CR706 | 178 | E4 | Q109 | 233 | D3 |
| C601 | 39 | 03 | CR707 | 283 | 04 | Q110 | 236 | D3 |
| C602 | 6 | 03 | CR708 | 185 | E4 | Q20: | 237 | 02 |
| C603 | 42 | C4 | CR709 CR710 | 186 187 187 | E4 | Q202 | 242 | E2 |
| c604 | 285 | C3 | CR711 | 177 | E4 | Q203 | 228 | E2 |
| C505 | 26 | $\mathrm{C}_{4}$ | CR712 | 175 | E4 | Q204 | 235 | E2 |
| 6606 | 29 | 04 | CR713 | 176 | -4 | Q205 | 241 | D3 |
| 6607 | 33 | 04 | CR713 | 176 | - 4 | Q206 | 239 | E3 |
| C608 | 44 | C4 | CR801 | 179 | 65 |  |  |  |
| 6609 | 8 | C4 | DS90! | 101 | F5 | Q602 | 255 | C4 |
| 6610 611 | 28 34 | 04 04 | FOO 1 | 71872 | 35 | Q603 | 250 | C4 |
|  |  |  |  | 71.6 | 35 | Q604 | 254 | C4 |
| 701 | 40 | 03 | J301 | 207 | 05 | 0701 | 247 | 04 |
| 702 | 41 9 | 53 | 11001 | - |  | Q702 | 248 | 04 |
| 704 | 46 | 04 | $J 1002$ | こ | - | Q703 | 252 | E3 |
| 705 | 47 | D4 | $J 1003$ | - | - | Q704 | 253 | E4 |
| 706 | 37 | E4 | $J 1004$ | - | - | Q705 | 249 | 04 |
| 707 | 36 | EL | J1005 | - | - | Q706 | 229 | 04 |

TABLE 7-3. (CONTINUED).














