103A WATTMETER

OPERATING AND MAINTENANCE MANUAL

Infratek

TABLE OF CONTENTS

1. Introduction and Specification
1.1. Introduction
1.2. The 103A Wattmeter
1.3. Options
1.4. Definition of Measured Quantities
1.5. Specifications

2. Operating Instructions
2.1. Introduction
2.2. Installation
2.3. Connecting to Line Power
2.4. Adjusting the Tilt Stand
2.5. Rack Mounting Kit
2.6. Operating Features
2.7. Front and Rear Panel Features
2.8. Display Features
2.9. Overrange Indication
2.10. Ranging
2.11. Coupling
2.12. Triggering
2.13. Reading Rates
2.14. Rear Panel Inputs

3. Measurement Consideration
3.1. Introduction
3.2. Input Overload Protection Limits
3.3. Measuring Voltage
3.4. Measuring Current
3.5. Measuring Power
3.6. Circuit Loading Error
3.7. True RMS Voltage and Current Measurement
3.8. Crest Factor
3.9. Combined AC and DC Measurement
3.10. Tutorial on Power Measurement
3.11. Power Contents of a Square Wave Signal

4. Remote Programming
4.1. Introduction
4.2. Capabilities
4.3. Bus Set-Up Procedure and Address Selection
4.4. Device-Dependent Command Set
4.5. Output Function Command Fn
4.6. Output Function Command Gn
4.7. Range Command In, Un
4.8. Display Command Dn
4.9. Mode Commands Cn
4.10. Set Command Sn
4.11. SRQ Mask Command Pn
4.12. Terminator Command Wn
4.13. Input Processing
4.14. Syntax Rules
4.15. Output Data
4.16. Service Requests
4.17. The Serial Poll Register
4.18. Interface Messages

5. Energy Measurement, Option 02
5.1. Introduction
5.2. Energy Converter (Option 02)
5.3. Scaling (Option 03)
5.3.1. Voltage Scaling
5.3.2. Current Scaling Using Current Transformers
5.3.3. Current Scaling Using External Current Shunts
5.4. Isolated Recorder Output A/V/W (Option 04)
5.5. Isolated Broad Band Recorder Output (Option 05)
5.6. Option Installation

6. Theory of Operation
6.1. Introduction
6.2. Overall Functional Description
6.3. Detailed Circuit Description
6.4. Current Amplifier
6.5. Voltage Amplifier

6.6. RMS Converter
6.6a. The Watt Converter
6.7. A/D Converter
6.8. Recorder Output Drivers
6.9. Digital Controller
6.10. Decoder
6.11. Key Board Encoder and Display Driver
6.12. Led Drivers
6.13. Power Supply
6.14. Isolated IEEE-488 Interface (Option 01)
6.15. Energy Converter (Option 02)
6.16. Recorder Output for Arms, Vrms, and Watt
6.17. Broad Band Recorder Output

7. Maintenance
7.1. Introduction
7.2. Disassembly Procedure
7.3. Top Cover Removal
7.4. Circuit Board Location
7.5. Main PCA Removal
7.6. Alignment Procedure
7.7. Current Amplifier DC Offset Adjustment
7.8. Voltage Amplifier DC Offset Adjustment
7.9. Watt Converter Offset Adjustment
7.10. Calibration Procedure
7.11. Frequency Response Alignment
7.12. Phase Equalization
7.13. Troubleshooting
7.14. Initial Troubleshooting Procedure
7.15. Digital Section Troubleshooting
7.16. Analog Section Troubleshooting
7.17. Power Supply Troubleshooting
7.18. Recorder Output Troubleshooting
7.19. IEEE-488 Interface
7.20. Energy Converter Troubleshooting
7.21. Scaling Troubleshooting

8. List of Replaceable Parts
9. Schematic Diagrams

1. INTRODUCTION AND SPECIFICATIONS

1.1 Introcuction

This manual provides complete operating instructions and service information for the 103A wattmeter.

1.2. The 103A Wattmeter

The Infratek 103A Digital Wattmeter is a high performance 6 digit instrument for general-purpose applications. Features of the basic 103A include:

- Power measurement
- True RMS voltage measurement
- True RMS current measurement up to 50A
- Highly legible vacuum fluorescent display
- Easy front panel operation
- Simple calibration, no internal adjustment
- 4-wire input

1.3. Options

A number of options are available for the 103A which can be easily installed at any time. The options include:

- IEEE-488 Interface (Option 01), featuring:
  Complete programmability
  Adapts to other installed options
  Simple command set
  Galvanically isolated

- Energy Converter (Option 02), featuring:
  Background energy computation
  Apparent power computation
  Power factor computation

- Scaling (Option 03), featuring:
  Current input scaling from current transformers
  Current input scaling from coaxial shunts
  Voltage input scaling

- Recorder output (Option 04), featuring:
  Output proportional to average power
  Output proportional to RMS current
  Output proportional to RMS voltage
  All three outputs galvanically isolated

- Broad band recorder output (Option 05), featuring:
  Output proportional to instantaneous power
  DC-10kHz bandwidth
  Galvanically isolated

1.4. Definition of Measured Quantities

The wattmeter determines rms-values of current and -voltage, power, and energy by means of converters. Power factor (PF) and apparent power (VA) are computed.

RMS current : $\left(\frac{1}{T}\int_0^T i^2\,dt\right)^{1/2}$

RMS voltage : $\left(\frac{1}{T}\int_0^T v^2\,dt\right)^{1/2}$

power : $\frac{1}{T}\int_0^T i\ v\ dt$

energy : $\int_0^{te} \text{power} \cdot dt$

apparent power: $\text{Arms} \cdot \text{Vrms}$

power factor : $\dfrac{\text{power}}{\text{Arms} \cdot \text{Vrms}}$

1.5 SPECIFICATIONS 103A

Current
Ranges: Input A: 3A, 30A; Rm= 10 mOhm; 40A cont., 50A 2 min.
Input B: 3mA, 30mA, 300mA; Rm= 10 Ohm; max. 0.7A cont.
Input C: 30mV, 300mV, 3V; Zin= 1 MOhm; max. 250V
Display: Fast rate 0-5000, slow rate 0-500000
Frequency
range: DC+AC-coupling: DC-100kHz; AC-coupling: 15Hz-100kHz
Accuracy: True RMS; inputs A,B,C; 1 year, 18-25 deg.C

Input A,B,C	(0.3% of input+0.1%FS)	15Hz-5kHz
Input A,B,C	(0.8% of input+0.2%FS)	5kHz-20kHz
Input B,C	(2% of input+0.3%FS)	DC,20kHz-100kHz
Input A,typ.	(3% of input+0.3%FS)	DC,20kHz-100kHz

Crest
factor: Exceeds 4:1 at Full Scale, increasing downscale
Temperat.
coeff: 0.01% of range/deg.C

Voltage
Ranges: 3V, 30V, 300V, 3000V*; max. 1000V RMS or 1400V peak
Display: Fast rate 0-5000, slow rate 0-50000
Frequency
range: DC+AC-coupling: DC-100kHz; AC-coupling: 15Hz-100kHz
Accuracy: True RMS, 1 year, 18-25 deg.C

(0.3% of input+0.1%FS)	15Hz-5kHz
(0.8% of input+0.2%FS)	5kHz-20kHz
(2% of input+0.3%FS)	DC,20kHz-100kHz

* Acc. limited to 1 min. operating time Vin>700V

Crest
factor: Exceeds 4:1 at Full Scale, increasing downscale
Temp.
coeff.: 0.01% of range/deg.C
Input
impedance:1MOhm, 20pF
Volt-Hertz
Product: 2'000'000VHz

Power
Ranges: Input A: 9W, 90W, 900W, 9kW, 90kW
Input B: 9mW, 90mW,....,90W, 900W
Input C: Ranges depend on external shunt in use
Display: Fast rate 0-9999, slow rate 0-999999
Max. Inp: As in current- and voltage section
Frequency
range: As in current- and voltage section
Accuracy: 1 year, 18-25 deg.C, power factor 0.5 to 1.0

Input A,B,C	(0.3% of input+0.1%FS)	10Hz-5kHz
Input A,B,C	(0.8% of input+0.2%FS)	5kHz-10kHz
Input B,C	(1% of input+0.4%FS)**	DC,10kHz-20kHz
Input B,C	(4% of input+0.5%FS)**	20kHz-100kHz
Input A	(2% of input+0.4%FS)**	DC,10kHz-20kHz
Input A,typ.	(4% of input+0.5%FS)**	20kHz-100kHz

Where not otherwise denoted: for power factor <0.5 multiply accuracy percentage figures by 2.
** Specified at power factor 1.

Temp.
coeff: 0.03% of range/deg.C

```
Crest
factor:    Same as for current- and voltage section
Apparent   Option 2: Add accuracy percentage figures given
Power:     for voltage and current.
Power      Option 2: Add accuracy percentage figures given
factor:    for power and apparent power.
Energy:    Option 2: Same accuracy percentage figures as
           given for power.

General
Input      Floating type 4-wire input. For linear operation the
type:      voltage difference between Lo-terminals may not excced
           8V peak. Max. voltage  between Lo-terminals is 250V.
Common     Common mode voltage: 700V peak from any input to earth.
mode:      Common mode rejection ratio:
           Current inputs: 140dB at 50/60Hz, 120dB at 1kHz
           Voltage input:  100dB at 50/60Hz, 80dB  at 1kHz
           Max. slew rate of Lo-terminal voltage: 150V/microsec.
Display:   6 digit, 12.5 vacuum fluorescent display. Green and
           red LED annunciators.
Control
functions:The 103A features 20 controls for voltage- and current
           range selection, for display selection, and for mode
           selection (AC- /AC+DC-coupling, auto, trig., and
           scaling).
Response
time:      For all functions 1 second to rated accuracy.
Ranging: Automatic or manual.
Temp.
range:     0-40 deg.C operating, -30 to 60 deg. C storage
Humitity: 80% RH from 0 to 35 deg.C
Warmup
time:      10 minutes to rated specification
Power:     220V (110V) +20%/-10%, 50-400Hz, 15VA
Size:      H x W x D; 132mm x 236mm x 300mm
Weight:    3.7kg

IEEE-488   Interface is galvanically isolated from 103A inputs.
interface:Option allows complete control and data output capa-
           bilities, and supports the following interface function
           subsets: SH1, AH1, T5, L4, SR1, RL1, DC1, and DT1.
Energy     Option allows simultaneous computation of energy (Wh),
converter:apparent power (VA), and power factor (PF).
Scaling:   Option allows scaling of voltage- and current input
           (range of scaling factor 0.0001 to 99999). All units
           are scaled and displayed accordingly. Option also allows
           current input switching to input C to operate from
           external coaxial- or standard shunts.
Recorder   Three isolated recorder outputs for RMS current, RMS
output:    voltage, and average power.
Broad band recorder output: Option allows measurement of instan-
           teneous power. Frequency response DC-10kHz. Output is
           galvanically isolated.
```

2. OPERATING INSTRUCTIONS

2.1. Introduction

This section provides operating instructions for the 103A. Refer to section 3 for measurement considerations.

2.2. Installation

The 103A has a rear panel power-line fuse in series with the input transformer. A 200mA, 250V slow-blow fuse is installed in the factory for operation from 200V to 250V. For operation with power-line voltages of 90V to 130V, the fuse must be replaced by a 400mA, 250V slow-blow fuse.

WARNING

To avoid electric shock, remove the power cord before replacing the line fuse.

2.3. Connecting to Line Power

WARNING

To avoid instrument damage, check that the rear panel line voltage selector is set to the correct line-voltage.
To avoid shock hazard, connect the 103A power cord to a power receptacle with earth ground.

The 103A accepts line power at 50Hz, 60Hz, or 400Hz.

2.4. Adjusting the Tilt Stand

At the bottom plate of the instrument are four tilt stands to adjust the viewing angle for bench-top use. To adjust their position, press in one end and rotate them to a stop position.

2.5. Rack Mounting Kit

You can mount the 103A in a standard 19-inch half rack panel using two rack ears. One rack ear is installed on each instrument side panel.

2.6. Operating Features

When the 103A is turned on, it performs an initialisation of its internal digital and analog circuitry. During start-up all display segments and all Leds are lit for approximately 1 second. The 103A determines the options installed and sets the internal option status accordingly. The 103A then assumes the following configuration:

- Display power
- Autorange input A (3000V 3V/30A 3A)
- AC-coupling
- 4 digit display (fast reading rate)
- Local (front panel) control

2.7. Front and Rear Panel Features

Front panel features are explained in Figure 2.1. Rear panel features are explained in Figure 2.2.Refer to section 3 for the definition of the measured quantities.
Note that the Wh, VA, and PF functions are available only with the energy converter option (option 02). Furthermore, the current- and voltage scaling function, and the current input switching to input C, are available only with the scaling option (option 03). If these options are absent, pressing any of these function buttons causes the 103A not to respond and to remain in the current state.

2.8. Display Features

The 103A features a 6 digit 12.5mm high vacuum fluorescent display. The units are displayed by Led annunciators to the right of the numeric field. The operating annunciators are explained in Figure 2.1.

2.9. Overrange Indication

An input is overrange if it exceeds the full scale display of the selected range or if the signal peaks exceed the linear operating range. This holds for the RMS converters as well as for the multiplier. When a display overrange occurs, the most significant digit and the decimal point are displayed. The remaining digits are blanked. When a peak signal overrange occurs the display flashes. When both, display overrange and peak signal overrange occurs, the most significant digit and the decimal point are flashed.

Scaling Procedure: Press TRIG → Press SCALE (current scaling factor is displayed) → Press controls 1- 6 and 11- 15 to set desired scaling factor → Press ENTER Arms to enter current scaling factor; Press ENTER Vrms to enter voltage scaling factor → Press TRIG to leave scaling mode.

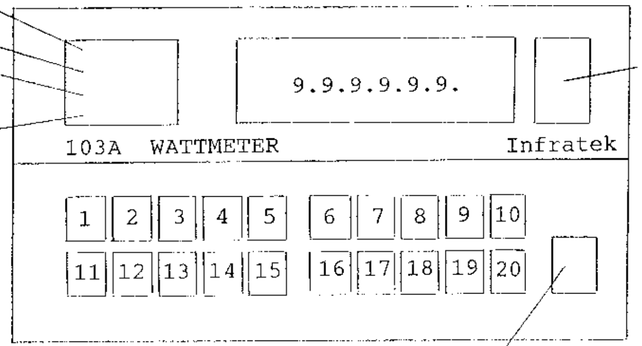
A Peak Overrange

V Peak Overrange

Scaling factor <> 1.00

Remote control active

Function and Units Annunciators



9: Display VA

10: Display Wh

16: Display Arms

17: Display Vrms

7: Display Watt

20: Display PF (power factor)

1- 4: Voltage ranges 3V, 30V, 300V, 3000V

5: AC + DC- coupling

6: Autorange, cycles between input A and input B

8: Enables trigger mode; leave trigger mode by pressing AUTO. Resets Wh-value to zero when Wh beeing displayed.

11- 13: Current ranges 3mA, 30mA, 300mA; input B

14- 15: Current ranges 3A, 30A; input A

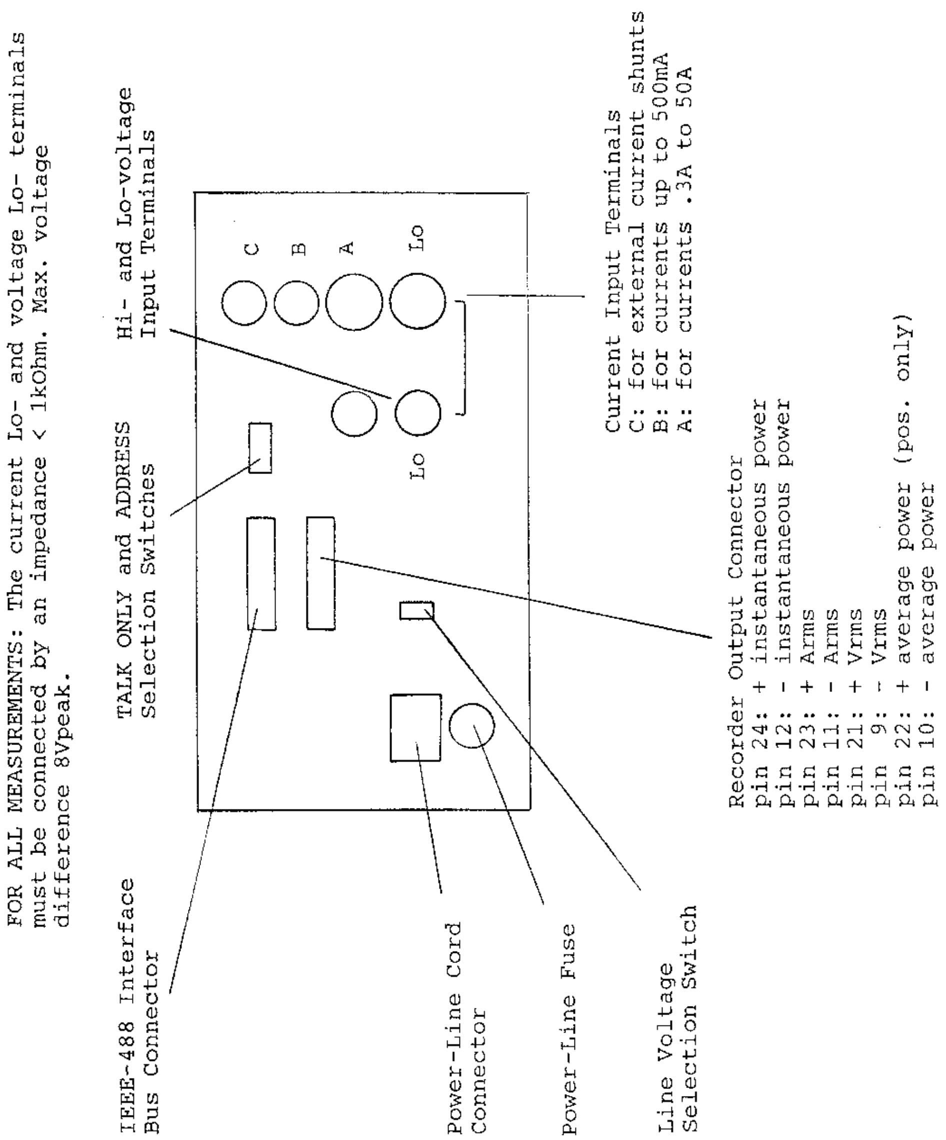
18: Toggles between 4- and 6- digit display

19: Toggles between inputs A,B and C (with scaling option)

Power switch. Initiates power-up self test and resets wattmeter to:
o W display; o Autorange input A;
o 4-digit display; o AC-coupling

Figure 2.1. Front Panel Features

Figure 2.2 Rear Panel Features



The only annunciators affected by overrange conditions are the A-PEAK OVER- and the V-PEAK OVER Led. They light up when current- or voltage peaks are overrange.

Caution: There is no additional overrange indication, other than described above, when inputs exceed maximum allowable values.

2.10. Ranging

Measurement ranges can be selected using either autorange (by pressing the AUTO control) or manual range (by pressing another range button). When the 103A is in autorange, then both, the voltage- and current path are in autorange. The 103A displays explicit units in every range, so that the display may be read directly. This is also true, when scaling is in use.

Autorange:

In autorange, the 103A goes to a higher range when the input exceeds 310000 counts, and goes to a lower range when the input falls below 30000 counts (approximate values).

Caution: A peak signal overload condition may occur without the 103A ranging to a higher range. In this case we recommend manual ranging.

The 103A is in autorange either at a current input A (3A/30A), or at current input B (3mA, 30mA, 300mA). Pressing the AUTO control switches autoranging between input A and B.
When using input C (for voltage inputs from external current shunts) autoranging is limited to the three current ranges 3mA/30mA/300mA (use appropriate scaling).

Manual Range:

In manual range, the 103A remains fixed in the selected range until you select another range or press AUTO.
In general, manual ranging gives better accuracy, when the overrange capabilities of the 103A are used.
Example: 380V line-to-line voltage can be measured on the 300V range (max. display up to 480V).

2.11. Coupling

In normal operating mode the voltage- and current inputs are AC-coupled. All signals above 10Hz are passed and processed in the instrument. When pressing the AC+DC-control the LED lights up indicating AC+DC-coupling. Signals from DC to 100kHz are passed and processed. This feature allows simple detection of DC-components.

The transient power measurements are performed by means of the broad band 103A recorder output, the 103A must be switched to AC+DC-coupling. If in this case AC-coupling is used false measurements result.

2.12. Triggering

Triggering causes the 103A to execute a measurement cycle and to display the result.
A measurement cycle is either triggered by pressing the TRIG control or by sending the trigger command from the interface.
When a measurement is triggered, the numeric field is blanked until the new readings are valied. During a measurement cycle all quantities are determined (A, V, W; option 02: VA, power factor). They can be displayed by pressing the appropriate front panel control.
The trigger mode is left by pressing the AUTO control.

2.13. Reading Rates

The RATE control allows you to select a medium display rate with 4 digit display and a slow display rate with 6 digit display.
The filter characteristic of the 103A is not changed.
When 4 digit display is selected and the decimal point goes beyond the 4. digit, the 103A must be switched to 6 digit display. This situation may arise when scaling with large scaling factors is in use.

2.14. Rear Panel Inputs

Lo-terminals:
The rear panel inputs for voltage and current are arranged in a 4-wire-connection. The 4-wire-input can be used to elimination power loss in long leads between load and wattmeter. A single constraint must be observed: the voltage difference between current-Lo-terminal and voltage-Lo-terminal must be less than 8V peak at all times. Nonlinear operation and internal overload results when this voltage difference is greater than 8V peak. A voltage difference between the Lo terminals of less than 250Vrms will do no harm to the wattmeter input.

For all measurements the two low terminals must be connected together either by long leads to and from the load or by a short jumper.
Make sure to always connect the Lo-input terminals of the wattmeter to the Lo-side of the load to be measured. Violation of this rule will expose the 103A to large common mode voltages, and if its slew rate is greater than 5V/microsecond, the wattmeter circuitry looses synchronisation. The 103A must be turned off and on again to start an initialisation.

Hi-voltage terminal:
The Hi-voltage terminal is connected to the Hi-side of the load.

Hi-current terminals (input A/input B)
The Hi-current terminal is connected in series with the load (on its Lo-side).

Hi-current terminal (input C, option)
Input C is for voltage inputs from external current shunts. When using input C, the same constraints for the Lo-terminals hold as explained in the beginning of this section (2.14).

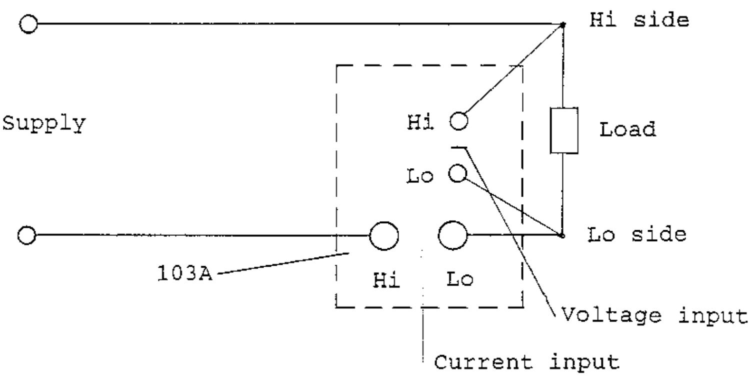


Figure 2.3. 103A Wattmeter Connection

3. MEASUREMENT CONSIDERATION

3.1. Introduction

This section discusses considerations and techniques to help you use the 103A effectively. Among other things, this section discusses sources of error which are an inherrent part of the power measurement process.
This section also discusses the benefits of 4-wire power measurements, and describes special considerations for making ac measurements.

3.2. Input Overload Protection Limits

WARNING

To avoid shock hazard and/or instrument damage, do not apply input potentials that exceed the input overload limits shown in table 3.1.

Table 3.1. Input Overload Limits

Function	Connectors	Maximum Input
Vrms	Input Hi and Lo	1000Vrms, 1400Vp
Arms, Input A	Input Hi and Lo	40Arms
Arms, Input B	Input Hi and Lo	0.7Arms
Arms, Input C	Input Hi and Lo	250V
All Functions	Diff.between Lo	250V
All Functions	Lo-terminals to earth	700Vp
All Functions	Lo-terminals to earth	5V/micro second

The 103A is protected against overloads up to the limits shown. Exceeding these limits may damage the instrument and/or pose a shock hazard.

3.3. Measuring Voltage

To measure voltage, select the desired function and connect the test leads as shown in Figure 3.1.

3.4. Measuring Current

To measure current, select the desired function and connect the test leads as shown in Figure 3.2.

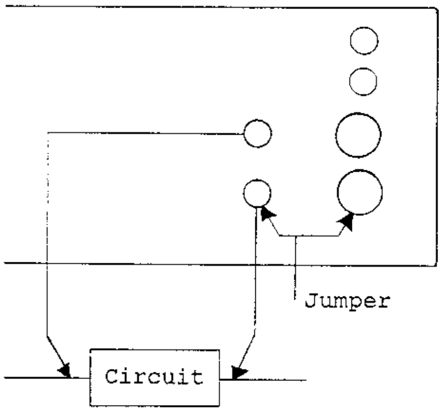


Figure 3.1. Measuring Voltage

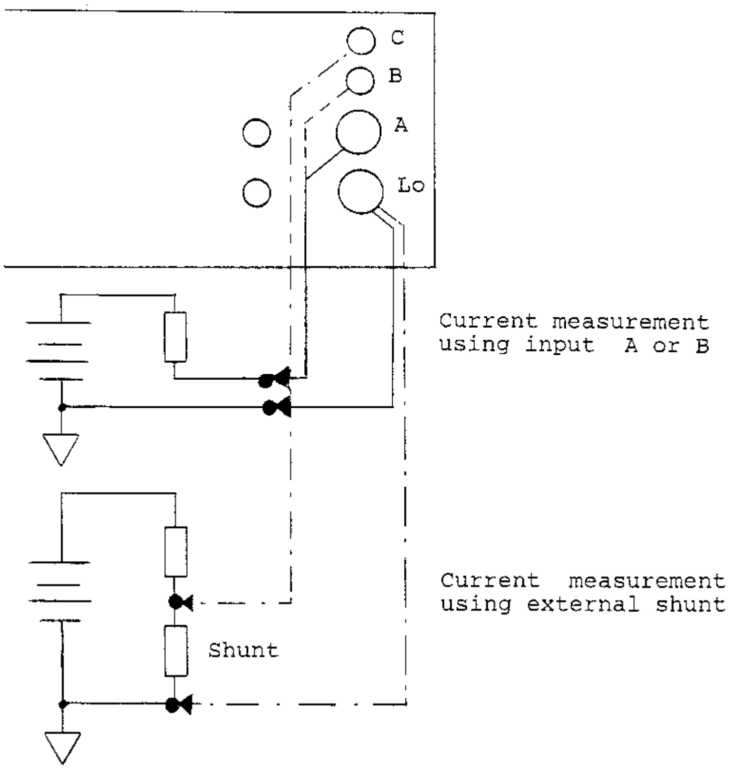


Figure 3.2. Measuring Current

3.5. Measuring Power

To measure power, select the desired function and connect the test leads as shown in Figures 3.3a/b.
Figure 3.3a shows the test lead connection when the power loss in the test leads is negligible.
Figure 3.3b shows the test lead connection making full use of the 4-wire power measurement, the power loss in the test leads is compensated for.

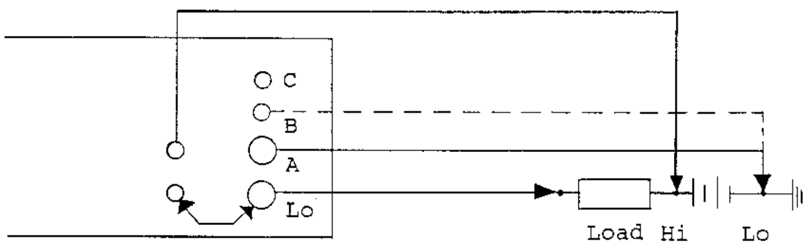


Figure 3.3a. Power Measurement not Using 4-Wire Connection

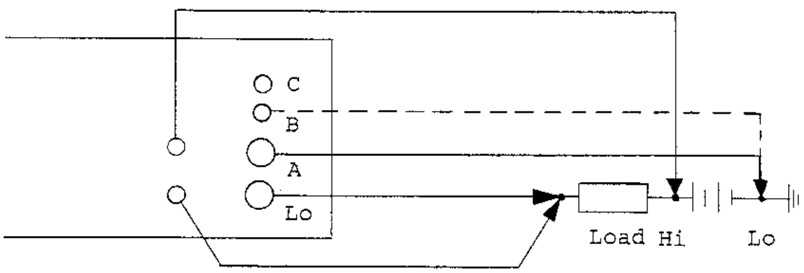


Figure 3.3b. 4-Wire Power Measurement

3.6. Circuit Loading Error

Whenever a wattmeter is connected to a circuit, the internal resistors of the wattmeter will load the circuit under test. Although the test lead power loss can be compensated for, there is no way to get around the power loss in the wattmeter input circuitry. Basically, the wattmeter input configuration is fixed, as shown in Figure 3.4.

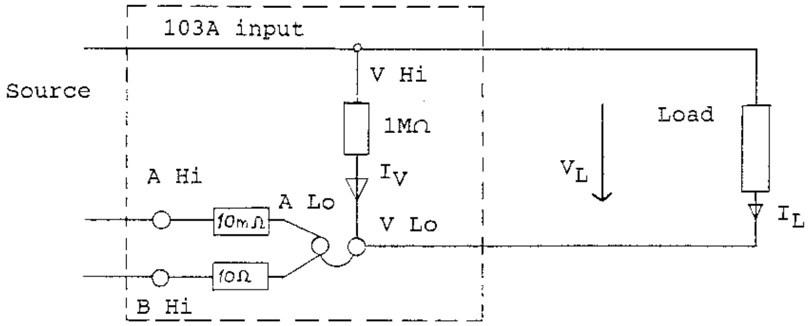


Figure 3.4. 103A Input Configuration

The current flowing in the 1MOhm voltage input resistor presents circuit loading, causing the main circuit loading error. For load resistors >1kOhm the current Iv flowing in the 1MOhm input resistor becomes >0.1% of the current Il flowing in the load. The current reading and the power reading of the 103A is in error as described below.

current display = Il + Iv (Il current in load)
power display = Pl + Pv (Pl power in load)

Approximate circuit loading error for resistive load Rl

Rl < 1kOhm current- and power error < 0.1%
Rl = 1kOhm current- and power error =+0.1%
Rl = 2kOhm current- and power error =+0.2%
Rl = 3kOhm current- and power error =+0.3%

3.7. True RMS Voltage and Current Measurement

In physical terms, the root mean square (rms) value of a waveform is the equivalent dc value that causes the same amount of heat to be dissipated in a resistor. The rms value provides a reliable basis for comparing dissimilar waveforms.
The 103A derives the rms value using analog computation. This means that the 103A readings represent rms values for all waveforms as long as the harmonics are within the bandwidth of the 103A.

By contrast, many meters in use today use average responding converters (rectified mean) and are rms calibrated for harmonic-free sinusoids. However, if a signal is not sinusoidal, average-responding meters do not display correct rms readings.

Figure 3.5. illustrates the relationship between different wave forms, and compares true rms values and rectified mean values. Also given are the crest factor and the form factor and their definitions.

Form factor = (rms value)/(rectified mean value)

Crest factor = (peak value)/(rms value)

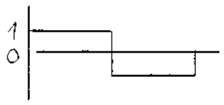
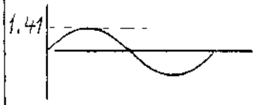
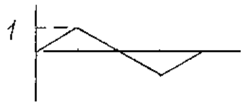
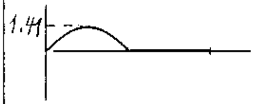
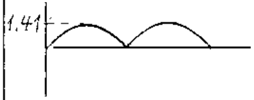
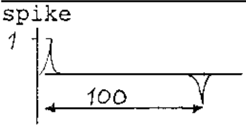
Waveform	RMS	Rectified mean	Crest factor	Form factor
	1.000	1.000	1.000	1.000
	1.000	0.9009	1.414	1.110
	0.577	0.499	1.732	1.155
	0.707	0.637	2.000	1.110
	1.000	0.9009	1.414	1.110
spike 			> 10	> 10

Figure 3.5. Comparison of Different Wave Forms

3.8. Crest Factor

Crest factors are useful for expressing the ability of an instrument to measure a variety of waveforms accurately. The crest factor of a waveform is the ratio of its peak value to its rms value. Quite often, there is a trade-off between crest factor and accuracy. The 103A has a full scale crest factor limit of 4.0 for current and voltage. With the 103A you can hardly make measurement errors due to crest factor overrange. There is a peak overrange indication for voltage and current, warning the user of crest factor overrange.

3.9. Combined AC and DC Measurements

The 103A determines the true rms value of signals with dc-components. Switch the 103A to AC+DC coupling. The 103A computes the following rms value:

$$V_{rms} = (V_{ac}^2 + V_{dc}^2)^{1/2}$$

The AC component can be determined by switching the 103A to AC coupling.

3.10. Tutorial on Power Measurement

Power measurement is a difficult measurement for several reasons. The instantaneous values of current and voltage must be multiplied without introducing phase errors. Normally, the gain of the current and voltage amplifiers must be switched over a wide range introducing phase errors at frequencies long before amplitude errors are observed. Finally, at low power factor a small value superimposed on a large value needs to me measured accuratly.
The following example demonstrates this situation: Irms·Vrms= 100VA, power factor = 0.01, power = 1W. If the user requires 1% accuracy on displayed power, he is actually asking for an instrument accuracy of 0.01%. Why? The multiplier must perform its operation on a background signal of 100VA within an error limit of 0.01W. This simply means an instrument accuracy of 0.01%.

Extreme conditions arise when power measurements on frequency inverters are performed. Current and voltage are totally dissimilar signals. The current is more or less sinusoidal, the voltage consists of a train of positive or negative pulses with weighted pulse duration. Voltage transients of more than 500V/us can be observed. Although the fundamental frequency of the flowing current is in the order of 50Hz, the wattmeter must cope with frequencies well over 100kHz. Low power factors further complicate the power measurement.

3.11. Power Contents of a Square Wave Signal

All Infratek wattmeters are broad band. The following discussion shows that accurate power measurements require broad band wattmeters.
We assume a square wave voltage and a square wave current working into a resistive load. We assume a fundamental frequency of 1kHz. To calculate the power contents of the harmonics the square wave signal for voltage and current is expressed in a Fourier series. From the expression for instantaneous power ($p=i \cdot v$), we determine the total power and assume the power contribution of the fundamental to be 100%. Doing this, we note that only products of the same frequency contribute to power. Table 3.2 shows the relative power content of the harmonics. It demonstrates

Fundamental	100%	1kHz
3. Harmonic	11%	3kHz
5. Harmonic	4%	5kHz
7. Harmonic	2%	7kHz
9. Harmonic	1.2%	9kHz
11. Harmonic	0.8%	11kHz

Table 3.2. Relative Power Content of a Square Wave

that accurate power measurements require broad band wattmeters. A band width of 11kHz would not suffice, since phase errors would introduce measurement errors.
At low power factors (inductive or capacitive loads) matters become worse. Phase errors of 1 degree may introduce 100% measurement error. A wattmeter bandwidth of at least 50kHz would be required.

4. REMOTE PROGRAMMING

4.1. Introduction

The IEEE-488 Interface turns the 103A into a fully programmable instrument for use with the IEEE-488 Interface bus. With the interface, the 103A can become part of an automated measurement system. The 103A can be under complete, interactive control from remote bus controller; or it can be set to the talk-only mode, connected to one or more listeners.

4.2. Capabilities

The IEEE-488 Interface provides remote control of the front panel controls except for the POWER. The Wh, PF, and VA controls are accesible only when the energy converter option (Option 02) is installed. Also, the scaling of current and voltage via the interface is accessible only, when the scaling option (Option 03) is installed. The interface is galvanically isolated from the input circuitry. The maximum allowable voltage difference between 103A Lo input terminals and IEEE-488 Interface is 500Vrms.

Warning: Voltage differences between 103A Lo-terminals and IEEE-488 Interface in excess of 500Vrms may cause damage or present shock hazard.

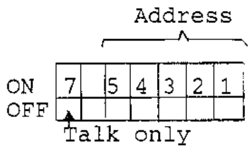
Other features include:

- Full talk/listen capability, including talk-only operation
- Comprehensive command set
- Fast measurement throughput
- Full remote/local capability
- Full serial pol capability, with bit-maskable SRQ
- Interface trigger
- Selectable output terminators
- Outputs 103A serial number

The 103A supports the following interface function subsets: SH1, AH1, L4, SR1, RL1, DC1, DT1, PP0, and C0.

4.3. Bus Set-Up Procedure and Address Selection

a) Turn the 103A Power switch OFF and set the rear panel address switch as shown below.



Address	A5	A4	A3	A2	A1
01	0	0	0	0	1
02	0	0	0	1	0
03	0	0	0	1	1
04	0	0	1	0	0
05	0	0	1	0	1
⋮				⋮	

b) Switch on the 103A
The Address of the 103A is factory set to Address 05 and talk-only mode off.

4.4. Device-Dependent Command Set

Device-dependent commands are the heart of the 103A remote control. They tell the 103A how and when to make measurements, when to put data on the bus, when and under what conditions to make service requests, and what data to put on the display. The complete set of device-dependent commands is listed in Figure 3.1. The commands are entered using upper case letters. For the 103A to receive them, they must be sent over the IEEE bus when the 103A is in remote and has been addressed as a listener.

4.5. Output Function Command Fn

The output function command tells the 103A which quantity to load in the output buffer. When the 103A is addressed to talk, it will put the contents of the output buffer on the bus.

Example	Explanation
"F0"	The output buffer will be loaded with the value of rms current, e.g. 30.7856mA
"F4"	When Option 02 is installed, the 103A outputs the value of energy, e.g. 18152.2 Wh. If Option 02 is not installed, "F4" will be ignored.

4.6. Output Function Command Gn

The G1 command copies the 103A current range, voltage range, SRQ mask, and terminator selected into the output buffer in the format shown below. The output format of G2, G3, and G4 is also shown below.

103A IEEE-488 INTERFACE COMMANDS

Output Function Commands

F0	Arms	,RMS current	
F1	Vrms	,RMS voltage	
F2	W	,power	default
F3	VA	,apparent power	
F4	Wh	,energy	
F5	PF	,power factor	
G1	Get range I,U; SRQ mask; termin.;		
G2	Get current scaling factor		
G3	Get voltage scaling factor		
G4	Get instrument serial number		

Range Commands

I0	3mA	U0	3V
I1	30mA	U1	30V
I2	300mA	U2	300V
I3	3 A	U3	3000V
I4	30A		

Mode Commands

C0	Autorange 3A, 30A	default
C1	Autorange 3mA,30mA,300mA	
C2	AC-coupling	default
C3	AC+DC-coupling	
C4	Triggered measurement on	
C5	Trigger measurement	
C6	Triggered measurement off	
C7	4 digit display	default
C8	6 digit display	
C9	Wh reset	

Display Commands

D0	Arms display	
D1	Vrms display	
D2	W display	default
D3	VA display	
D4	Wh display	
D5	PF display	

Set Commands

S1 xxxx.xx	Set current scaling factor: e.g. xxxx.xx = 1000.85
S2 xxxx.xx	Set voltage scaling factor: e.g. xxxx.xx = 20
S3	Select inputs A,B to C, C to A,B; toggels

SRQ Mask Command

P0	SRQ disabled
P1	SRQ on current over
P2	SRQ on voltage over
P3	SRQ on current or voltage over
P4	SRQ on power over
P5	SRQ on current or power over
P6	SRQ on voltage or power over
P7	SRQ on current,voltage or power over
P8	SRQ on data available

Terminator Commands

W1	CR/LF/EOI
W2	CR/LF
W3	EOI only
W4	disable terminators

Typical command strings for HP9816 PC and HP-85 calculator.
The address of the 103A Wattmeter is 5.

```
CLEAR 7                    ;Clear port
CLEAR 705                  ;Clear 103A to default functions
OUTPUT 705;"D0 C8"         ;Display Arms, 6 digits
  FOR I=1 TO 8
    OUTPUT 705;"F0"        ;Setup for current output
    ENTER 705; R,R$        ;Read data from 103A
    PRINT I;R;R$           ;HP-85 display
  NEXT I
OUTPUT 705;"S1 100.5"      ;Scale current by 100.5
```

Figure 3.1. Device-Dependent Command Set

Command	Output String	Meaning
G1	frst	f=0-4 as in I-range commands r=0-3 as in U-range commands s=0-8 as in SRQ-mask commands t=1-4 as in terminator commands
G2	SF A=1.00000	Current scaling factor
G3	SF V=1.00000	Voltage scaling factor
G4	103A SN 8047258	Serial number

4.7. Range Commands In, Un

The range commands tell the 103A which current and voltage range to select. A range command automatically terminates 103A autorange setting. The range setting can be read using the G1 command.

4.8. Display Command

The display commands duplicate the right hand side of the function controls below the display. When Option 02 is installed, the display commands D3, D4,and D5 are executed, otherwise they are ignored.

Example	Explanation
"D1"	Display of Vrms
"D5"	When Option 02 is installed, the power factor will be displayed.

4.9. Mode Commands

The mode commands C0, ..., C9 duplicate part of the controls below the display.

Example	Explanation
"C0C2C8C9"	Selects autorange for voltage and current input A (3A, 30A), AC-coupling, 6 digit display, and resets the energy reading to zero.

4.10. Set Commands Sn

The set commands are accessible when the scaling option (Option 03) is installed.

Example	Explanation
"S1 100.2"	Sets current scaling factor to 100.2. Maximum 6 digits with or without decimal point are allowed. "S1" must be followed by a space.
"S2 100"	Sets voltage scaling factor to 100.
"S3"	Toggles inputs between input A/B and input C.

4.11. SRQ Mask Command Pn

The SRQ mask commands P0 through P8 are used to program the 103A to make service requests on user-specified conditions.

Example	Explanation
"P7"	SRQ on current, voltage or power over.

4.12. Terminator Command Wn

The terminator commands select what terminators the 103A appends to every output string. The terminators are: Carriage Return (CR), Line Feed (LF), and EOI (End Or Identify). CR and LF are ASCII control codes, sent over the data bus just like output data. EOI is a uniline message which is sent simultaneously with the last character in the output string. Normally, each output string is terminated with CR followed by LF and EOI.
The terminator selection can be read using the G1 command. The 103A sets to W1 on power-up.

4.13. Input Processing

An input string can contain as many commands as required. The only exception are the S1 and S2 commands. Commands are executed in the sequence they are received. Commands which are not recognized by the 103A will be ignored. A command string must be terminated with CR (Carriage Return), and LF (Line Feed), EOI is optional. Most controllers finish a command string with a CR LF pair. If a controller does not have this feature, the programmer must transmit a terminator explicitely.
The 103A accepts alphabetic characters in upper case. Spaces are ignored, unless a space is required as in S1 and S2.
The exception to the input processing are the numeric set commands S1 and S2. Only one set command may be sent at a time, because a programming command goes with a numeric field.

Example for HP85 Controller

```
OUTPUT 705;"S1 50.08";   current scaling 50.08
OUTPUT 705;"S2  0.5 ";   voltage scaling  0.5
```

4.14. Syntax Rules

Two syntax rules should be followed when writing input command strings. They are:

Rule 1: Read output data only once.

To prevent old data from being read a second time by mistake, the output buffer is always cleared after it has been read. If the output buffer is read twice without an intervening output command, the 103A will not respond to the second attempt to read the output buffer. However, if the 103A is in talk-only, no intervening command is necessary.

Rule 2: Use no more than one output command per input command string.

If an input command string contains more than one output command, only the data from the last command can be read.

4.15. Output Data

The following describes the data that can be loaded into the 103A output buffer and sent to the interface bus. It describes how and when data is loaded into the output buffer, and the types of output data.
The 103A can also send data to the IEEE-488 bus from the serial poll register.
The 103A is programmed to send output data when it receives an output command, e.g. "F2". The data are not actually loaded on the interface bus until the controller addresses the 103A as a talker. This is done by sending the interface message MTA (My Talk Address). The types of output data are shown in Figure 4.2. Numeric data, including units, are sent to the IEEE-488 bus in the same format as displayed on the display. When data are overrange the suffix "OVER" is appended to the data. When data are called for which are not available because the option is not installed the 103A outputs "NO OPTION".
Status data is the output in response to G1, G2, G3, and G4 commands. The data is formatted as shown in Figure 4.2.
The terminators appended to numeric data and status data are user-selectable by the terminator commands W1...W4.

Output Data Type		Format Examples
Numeric data	3.00000mA	Measured value
	5.07823mA OVER	Overrange
	221.782V	Measured value
	3.80100Wh	Measured value
Instrument Configuration Data	G1: 3221	→ Terminator W1, SRQ P2
		→ 300V range
		→ 3A range
	G2: SF A=50.0000	
	G3: SF V=1.00000	
	G4: 103A SN 8047823	
Output from SRQ	P1: decimal 65	SRQ on current over

Figure 4.2. Output Data Types

4.16. Service Requests

Service requests let bus instruments get the attention of the system controller. The requests are sent over the SRQ line. If more than one instrument on the bus is capable of sending service requests,the controller can learn which one made the request by taking a serial poll. The 103A responds to the poll by sending the contents of its serial poll register. The serial poll register indicates whether or not the device requests service, and if so, the reason for the request.
The 103A may be programmed to make a service request on user-specified conditions. The conditions are specified by entering a value for the service request mask.

4.17. The Serial Poll Register

The serial poll register is a binary-coded register which contains eight bits, as illustrated in Figure 4.3. The controller can read the 103A serial poll register by taking a serial poll. Because serial poll data is loaded directly on the bus, reading the serial poll register leaves data in the output buffer intact.
The eight bits of the serial poll register are described below. Note that the SRQ mask uses bits 1 through 4 to set bit 7 (the RQS bit). Bit 7 sets the SRQ line true, which generates a service request. Bits 1 through 4 are set, depending on the selected SRQ mask P0...P8, as follows:

selected SRQ mask	decimal value bit 1 through 4
P0	0 SRQ disabled
P1	1 SRQ on current over
:	:
P8	8 SRQ on data available

Bit:	8	7	6	5	4	3	2	1
	0	SRQ	0	0	4 bits used for SRQ generation			
Decimal		64	32	16	8	4	2	1

Figure 4.3. Serial Poll Register

Taking a serial poll clears bit 7 of the serial poll register. Bits 1 through 4 are also set when no SRQ is desired (P0 user-specified). In this case bit 7 is not set and the service request line is not set true.

4.18. Interface Messages

The interface messages understood by the 103A are the following three main classes described in IEEE-488 Standard: address messages, universal commands, and addressed commands. All interface messages described here originate at the controller.

Address Messages

MLA:	My Listen Address	- Addresses a device to listen
MTA:	My Talk Address	- Addresses a device to talk
UNL:	Unlisten	- Addresses all listeners to unlisten
UNT:	Untalk	- Addresses all talkers to untalk

Universal Commands

ATN: Attention - A uniline message which causes the 103A to interpret multiline messages as interface messages. When false, multiline messages are interpreted as device-dependent messages.

REN: Remote Enable - A uniline message which, when received with MLA, switches the 103A to remote. In remote the 103A front panel controls are deactivated.

DCL: Device Clear - A multiline message which is loaded into the input buffer. DCL sets the 103A to the following operating conditions:
- Autorange on, input A
- Display Watt
- AC-coupling

SPE: Serial Poll Enable - A multiline message which causes the serial poll data (rather than the output buffer data) to be transferred on the bus once ATN becomes false.

SPD: Serial Poll Disable - Removes the serial poll enable state.

Addressed Commands

GTL: Go To Local - Causes the 103A to switch to local (front panel) control.

SDC: Selected Device Clear - Identical to DCL, but is accepted by current listeners only.

4.19. Talk - Only Mode

The talk-only mode lets the user take advantage of the remote capability of the 103A without having to use an instrument controller.
To put the 103A in the talk-only mode:

1. Turn the 103A power switch off.
2. Set the rear panel Talk Only switch (bit 7 of address switch) to the up-position (on).
3. Connect the 103A via the IEEE-488 bus to your data receiving device (listener hand-shake capabilities are required).
4. Turn the 103A power switch on.
5. Configure the 103A with the frontpanel controlls. (The 103A can also be operated in the Talk-Only Mode when in remote).

The 103A reads the Talk-Only bit switch on power-up and sends data every 20 measurement cycles (in intervalls of approx. 10 seconds). The data transmitted are those specified by the output function commands F0 through F2, (Option 02, F0...F5).

5. OPTIONS

5.1. Introduction

Option 01, the IEEE-488 Interface, is described in section 4. This section describes the energy converter (Option 02), the Current and voltage scaling (Option 03), the recorder output for Arms, Vrms, Watt (Option 04), and the broad band recorder output for instantaneous power (Option 05).
The installation procedure for all options is described in section 5.6.

5.2. Energy Converter (Option 02)

When the energy converter is installed, the 103A sets the internal status accordingly on power-up. Three additional functions Wh (energy), VA (apparent power), and PF (power factor) are now available, and also can be transmitted over the IEEE-488 Interface bus.
Positive or negative energy is computed from measured power and elapsed time increments. To start an energy measurement, the stored energy value must first be set to zero. This is done as follows: Display Wh and press the TRIG/Wh-RESET control. From now on the energy is computed, and can be viewed on the display if desired. We recommend to use manual ranging and keep the current and voltage ranges fixed during an energy measurement.
When the 103A is switched to triggered operation,the energy value is no larger valid. In triggered mode the time base gets lost.
The apparent power and the power factor are computed from the equations given in section 1.4.

5.3. Scaling (Option 03)

When the scaling option is installed, the 103A-scaling functions, including input switching to input C, is activated.
Current- and voltage inputs can be multiplied by scaling factors in the range 0.0001 to 999999. All quantities (A, V, W, VA, Wh) are scaled and displayed accordingly.
On power-up the current and voltage scaling factor is set to 1.0. when after power-up one or both scaling factors are set to some other value than 1.0, the "SCALING ON" annunicator lights up.

The procedure to change the scaling factor is as follows:

1. Press TRIG.
2. Press SCALE. The current scaling factor is now displayed and the unit-annunciator "A" is turned on. The 103A is now ready to accept another current scaling factor. For current scaling factor change proceed with step 3. For voltage scaling factor change proceed to step 4.

3. Enter the current scaling factor using the number field below the display (left hand side). Maximum 6 digits can be entered, the decimal point is set by the AUTO control. Numbers can be entered with or without decimal point (Note that the display is still showing the old scaling factor). To store the new current scaling factor press ENTER Arms. Now the new current scaling factor is displayed.
   To leave the scaling procedure press the TRIG control.
4. To display the voltage scaling factor press SCALE. The voltage scaling factor is now displayed including the annunciator "V". Enter the voltage scaling factor using the number field below the display. Maximum 6 digits can be entered, the decimal point is set by the AUTO control. To store the new voltage scaling factor press ENTER Vrms. Now the new voltage scaling factor is displayed.
   To leave the scaling procedure press the TRIG control.

The scaling factors can be viewed at any time by pressing the TRIG control and the SCALE control. SCALE toggles the display between current scaling factor and voltage scaling factor.

5.3.1. Voltage Scaling

Voltage scaling becomes necessary when external voltage step-up or step-down transformers, or external voltage deviders are used. The external circuit may be loaded by the 103A 1MOhm input impedance. In case of circuit loading the scaling factor has to be corrected accordingly.
The external circuit connection must fullfill two conditions:
1. The Lo terminals must be connected together (max. 8V difference), and 2. the displayed power value must be positive.
Figure 5.1. shows the circuit connection using a voltage transformer.

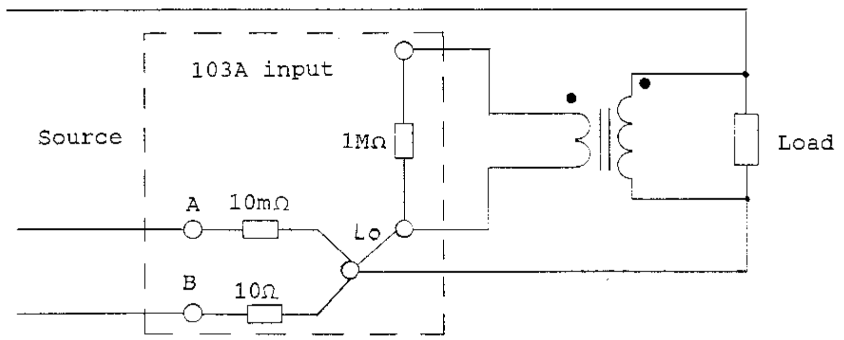


Figure 5.1. Circuit Connection Using Voltage Transformer

5.3.2. Current Scaling Using Current Transformers

Depending on the output current range of the current transformer the 103A- or B-input can be used. The burden voltage is Ix0.01Ohm for the A-input and Ix10Ohm for the B-input. The current scaling factor to be entered is simply the current transfer ration, e.g.100:5 enter 20.0.
The external circuit connection must fullfill two conditions:
1. The Lo terminals must be connected together (max. 8V difference), and 2. the displayed power value must be positive. Figure 5.2. shows the circuit connection using a current transformer.

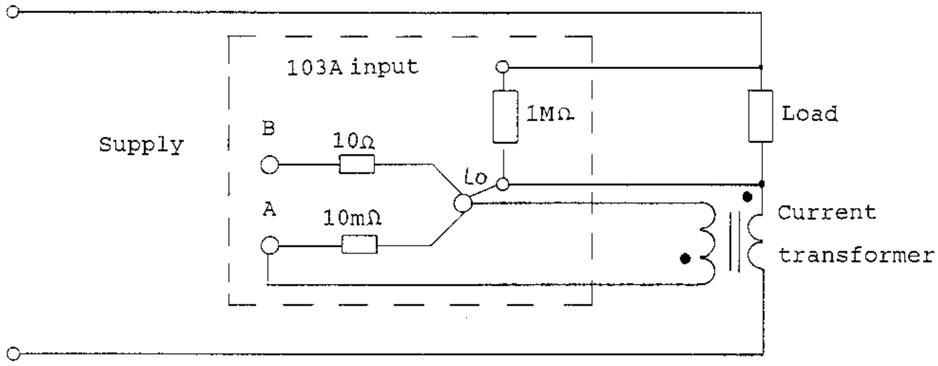


Figure 5.2. Circuit Connection Using Current Transformer

5.3.3. Current Scaling Using External Current Shunts

To make full use of the 103A bandwidth at high currents, it is advantageous to utilize coaxial current shunts (also called current viewing resistors). When current shunts are used, the 103A current input is switched to input C. The shunt voltage is then applied between Lo current input terminal and input terminal C. When the 103A is switched to input C, the current ranges are limited to 3mA, 30mA, and 300mA. The 103A selects the current ranges as shown in Figure 5.3.

Shunt voltage	103A range	shunt voltage before overload
30mV	3mA	approx. 48mV
300mV	30mA	approx. 480mV
3V	300mA	approx. 4.8V
Wattmeter sensitivity = 3mA/30mV=0.1mA/mV=0.1A/V		

Figure 5.3. Shunt Voltage and Current Range

When input C is active, the 3A and 30A ranges can not be selected (manual and auto ranging).

Warning: When the 103A is switched to input C, there is no indication that input C is active other than current range limitting to 3mA, 30mA, and 300mA.

The following examples demonstrate how to calculate the scaling factor for external coaxial shunts.

Example 1: A coaxial current shunt with resistance Rm=0.10102Ohm for maximum 20A is used.

Shunt sensitivity = 1/0.10102Ohm=9.89903A/V

$$\text{Scaling factor} = \frac{\text{Shunt sensitivity}}{\text{Wattmeter sensitivity}} = \frac{9.89903\text{A/V}}{0.1\text{A/V}} = 98.9903$$

At maximum shunt current of 20A, the shunt voltage is 2.02V.The 103A will operate in the 300mA range and will display 20.0A.

Example 2: A coaxial current shunt with resistance Rm=0.009984Ohm for maximum 55A is used.

$$\text{Scaling factor} = \frac{(1/0.009984)\text{A/V}}{0.1\text{A/V}} = 1001.6$$

At maximum current of 55A the shunt voltage is 0.549V.The 103A will operate (unfortunately) at the low end of the 300mA range, displaying 55.0A.
Choosing the optimal shunt resistance allows the 103A to operate in its best operating range (70 to 160% of full scale).
Figure 5.4. shows the 103A input wiring using external shunts.

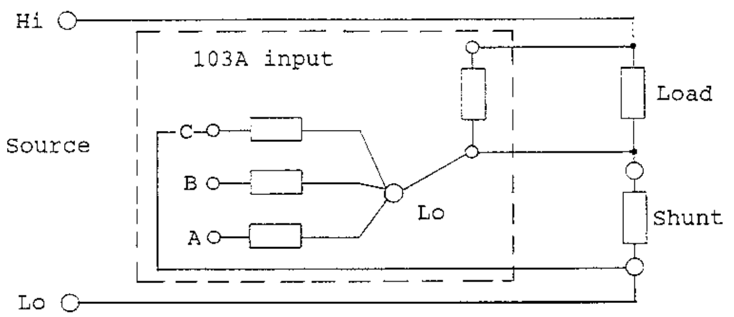


Figure 5.4. Circuit Connection Using External Current Shunts

5.4. Isolated Recorder Output A/V/W (Option 04)

Option 04 features three recorder outputs for rms-current, rms-voltage, and average power. The three recorder outputs are isolated from the 103A input, from the IEEE-488-Interface, and from the broad band recorder output. Furthermore, the three recorder outputs are isolated from each other,and if desired can be connected to a common potential. Figure 5.5. gives specific data of the three outputs.

Specification	Arms	Vrms	Watt
Output/pin Nr	A^+/A-;23/11	V+/V-;21/9	W+/W-;22/10
Output impedance	200Ohm	200Ohm	200Ohm
Accuracy	0.5%FS	0.5%FS	0.5%FS
V-A-display 3000/300000	+3V	+3V	
W-display +9000/+900000			+3V
Minimum output	+5V	+5V	+5V
Response time	1s	1s	1s
Input Output Isolation	2000Vpeak	2000Vpeak	2000Vpeak
Short Circuit Current	U/200Ohm	U/200Ohm	U/200Ohm

Note: Rms current as well as rms voltage are average values and are always positive. On the other hand, average power can become negative by either wrong input connection or by power reversal. In this case, the negative power value will not be transmitted to the recorder output, the output goes to zero.

5.5. Isolated Broad Band Recorder Output (Option 05)

This unique option can be used to measure instantaneous power for complex current- and voltage waveforms, or can be used to measure transient power (maximum and minimum) during a start-up cycle. Valuable information can be obtained from the resulting power waveform.
Option 05 can even be used to multiply two signals: Apply the first signal to the voltage input of the 103A, and apply the second signal to the C input of the current input of the 103A. The broad band recorder output is the precisely scaled product of the two.
Figure 5.6. shows the specification of the broad band recorder output.

Specification	Option 05
Output /pin	P^+/P-; 24/12
Output impedance	0.5Ohm
W-display 9000/900000	min. 0V, max. 6V, average 3V
Maximum Output	±9V peak
Frequency range	DC-10kHz (-3dB at 10kHz)
Accuracy	0.5%FS
Short Circuit Current	20mA

Figure 5.6. Specification Broad Band Recorder Output

Note: For all transient power measurement use AC+DC coupling.

Figure 5.7. shows for several current and voltage waveforms the resulting power waveforms.

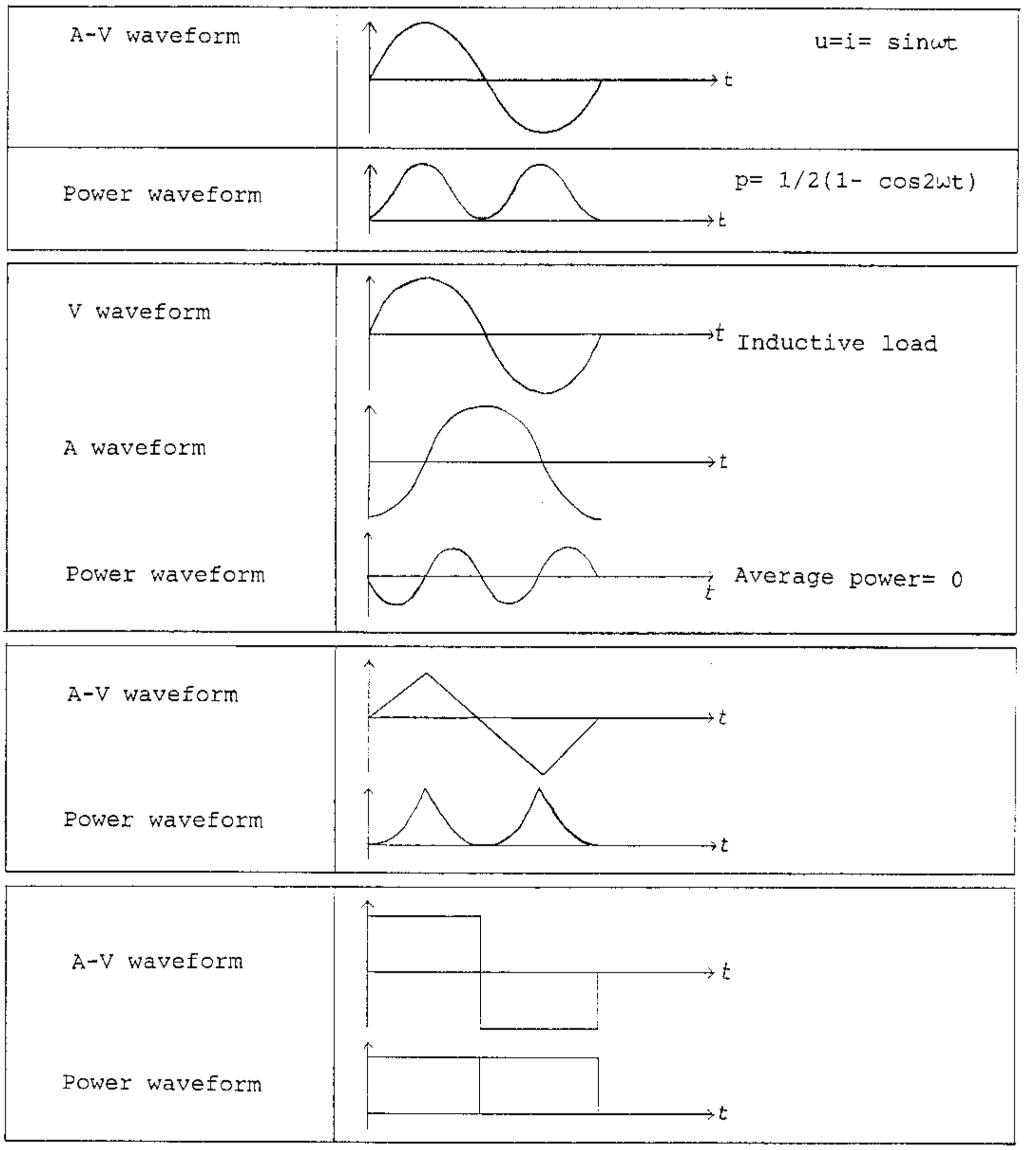


Figure 5.7. Current-, Voltage-, and Power Waveform

5.6. Option Installation

For option installation remove all connections to 103A inputs and disconnect the power-line cord.

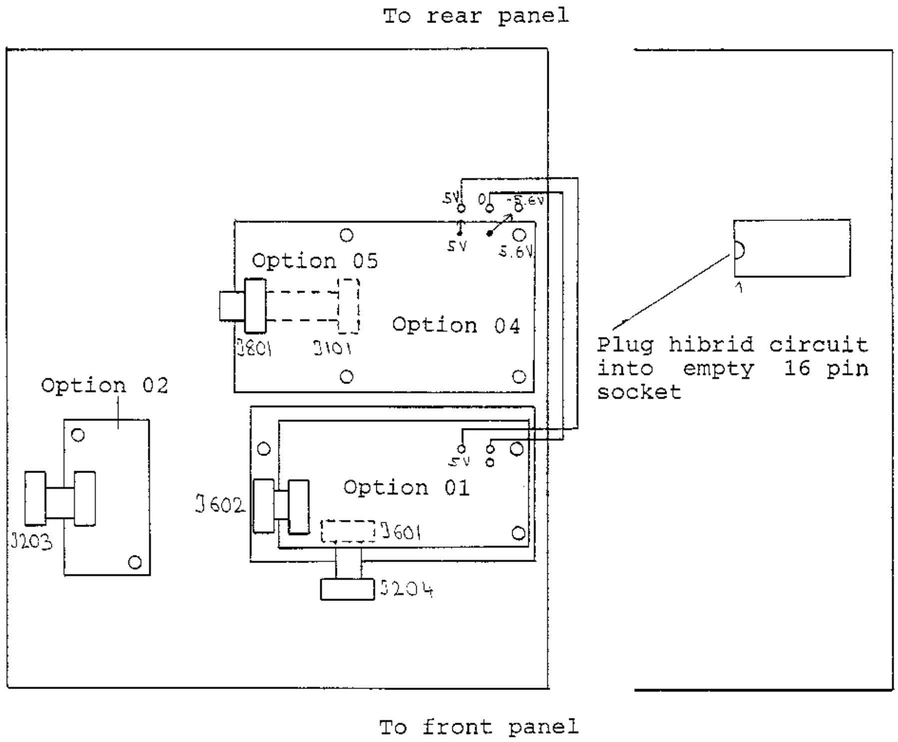


Figure 5.8.a) Installation of option 01, option 02, option 04, and option 05.

Figure 5.8.b) Installation of option 03.

6. THEORY OF OPERATION

6.1. Introduction

This section presents an overall functional description of the 103A, followed by detailed circuit description. The description is supported by the schematic diagrams in section 9.

6.2. Overall Functional Description

The functional block diagram of the 103A is shown in Figure 6.1.
The basic signal path flows from left to right. The inputs are sensed at the input terminals, scaled, converted, directed to the A/D converter circuit, the digital representation transmitted via the internal bus to the digital controller, and sent to the display.
The current amplifier and the voltage amplifier constitute the "front end" of the wattmeter. The current amplifier senses the current in the current sensing resistors and produces a proportional signal for all functions. Its output is applied to the rms converter and the watt converter which both produce an equivalent dc voltage. The voltage amplifier senses the voltage in the devider circuit. The amplifier output is applied to the voltage rms converter, and also to the watt converter.
The multiplexer selects one out of three signals and presents it to the A/D converter.
The microprocessor (digital controller) controls the operation of virtually every part of the 103A. It configures the instrument for each function and range, triggers the A/D converter, controls the multiplexer, reads the appropriate latches, calculates the results, sends data to and reads data from the display controller, and communicates with the IEEE-488 Interface.
The main power supply provides supply voltages to all parts of the instrument including the display.
All outputs of the 103A are isolated from the main electronics. Shock hazards are eliminated.

6.3. Detailed Circuit Description

The following paragraphs give a detailed circuit description of the functional blocks in Figure 6.1. The discriptions follow the part designations of the schematic diagrams of section 9. Pins are designated by the respective integrated circuit (e.g. U101-7 for U202 pin 7).

6.4. Current Amplifier

The voltage drop accross the current sensing resistors at input A or B, or at input C (external shunt) is amplified in U1. The gains are 100/10/1 when input B or C are used. When input A is used the gains are 100 and 10. The input switching from input A to input B is accomplished by relay S7. Input switching to input C is accomplished by relay S9. Gain 100 of amplifier U1 is set by relay

S5. Similarly, S6 sets gain 1 and gain 10.
The output U1-10 is decoupled in U2 and then applied to the rms converter U3 and the multiplexer U101. The input signal is AC or AC+DC coupled by relay S6. U2 performs phase correction at high frequencies.

6.5. Voltage Amplifier

The voltage from the input devider R23, R24, and R25 is amplified in U4. The gain switching (100, 10, 1) is accomplished by relays S1, S2, and S3, and the AC- and AC+DC coupling is controlled by relay S4. U5 performs phase correction at high frequencies.

6.6. RMS Converters

U3 and U6 are analogue computing rms converters. The AC- or DC input signal at pin 13 is converted to a DC signal which would produce the same power as the input signal. The outputs of the rms converters are always positive. The components around U6 are used for signal low pass filtering. The time constant of the low pass filter is approximately 0.5 seconds.

6.6a The Watt Converter

U102 and the four amplifiers U103 comprise the watt converter. The current signal output at U2-6 and the voltage signal output at U5-6 are applied via the autozero multiplexer U101 to the analogue computing watt converter U102. U102 formes the product of current and voltage and feeds a current proportional to the product to amplifier U103-12,13,14. Its output is a voltage proportional to instantaneous power. U103-3,2,1 performs low pass filtering, its output is a voltage proportional to average power. U103-5,6,7 is a signal inverter. U103-9,10,8 together with U101 generates the autozero signal to control the watt converter null. U101 samples the watt converter output with zero input and stores the error signal in C102.

6.7. A/D Converter

The four signals Ir (rms current), Ur (rms voltage), Pp (positive power), and Pn (negative power) are selected by multiplexer U105, fed to amplifier U107, and are in U108 digitally converted. U108 is controlled by the microprocessor U201. U201 reads the A/D output via the data bus D0...D7. The multiplexer is controlled by latch U106.

6.8. Recorder Output Drivers

The signals for the recorder outputs are generated by the three amplifiers U104-(1,2,3),(5,6,7), and (8,9,10). These signals are fed to connector J101. The signal Pm at J101 is used for the broad band recorder output (option 05).

6.9. Digital Controller

U201 does all the controlling of the digital components. It reads the program from U203 and U204, it stores data in U205 and 206, it addresses the digital circuits, and finally, it performs the computing required.6.10.

6.10. Decoder

U208, U209, U210, U10, U11, and U12 are used for circuit addressing. They address memory space U204-U206, the key board encoder/display driver U207, the A/D converter U108, and the latches U8, U106, U109, and U306 through U308.

6.11. Key Board Encoder and Display Driver

U207 scans the 20 front panel controls S300 through S319 and when a key is depressed is its number stored in U207. U207 then sends an IRQ to U109-3. The digital controller reads the data from U207 and takes appropriate action.
U207 also sends display data to the decoders U301 and U302. It performs the multiplexing of the six digits including the decimal points. U303 and U304 are high voltage drivers for the vacuum fluorescent display.

6.12 LED Drivers

U306, U307, and U308 are the drivers for the 24 front panel LEDs. The three latches are addressed by U210. The data are sent from the microprocessor via the data bus.

6.13. Power Supply

The power supply provides the outputs +5V, ±15V, +30V, +(7-8)V, 3.3V, and the isolated output +5V, and -5.6V.
The ±15V supply is for the analogue circuits, the +5V is for the digital circuits, the +30V is for the display drivers, the 3.3V for the vacuum fluorescent display, and the +5V/-5.6V for the isolated outputs (recorder and interface). VR401 through VR405 are voltage regulators.

6.14. Isolated IEEE-488 Interface (Option 01)

To avoid hazardous potentials at the interface output a bidirectional bus isolator is put between the 103A and the interface output circuit.
The potential isolation is achieved by the bus isolators U602 through U605. U601 and U606 are bidirectional bus transceivers on the 103A input side, and U607 and U608 are the transceivers on the 103A output side. J602 is connected to the interface connector J501. The interface controller U503 manages the signal flow between 103A and external system controller. U501 and U502 are bus transceivers to communicate with the external interface controller. U504 is the address latch. On 103A start-up, its contents is read and stored by the microprocessor.

6.15. Energy Converter (Option 02)

The energy converter determines the time increment for the energy computation. The time increment is derived from the microprocessor clock.

6.16. Recorder Output for Arms, Vrms, and Watt

The three signals proportional to Arms, Vrms, and Watt are generated by the quad operational amplifier U104. The signals are taken off connector J101 and transmitted to J801 on the recorder output print. The DC current isolator T801 receives a current proportional to Arms and reflects this current to the output side. The voltage drop accross the output resistor network is adjusted to be 3Vdc at full scale current range.
Similarly, the DC current isolator T802 transmits Vrms to the output side and T803 transmits Watt to the output side. The three output signals are galvanically isolated from the 103A input and main electronics and also galvanically isolated from each other. Only positive currents can be transmitted to the output.

6.17. Broad Band Recorder Output

The broad band recorder output transmits the signal proportional to instantaneous power to the 103A output. The isolation amplifier U801 accomplishes signal isolation. The output side of U102 receives its supply from the DC/DC converter comprised of Q801-Q805, T804, and voltage regulators VR801, VR802.

> Note: The broad band recorder output and the IEEE-interface have common potentials. The Lo-side of the recorder output is approximately 5.6V below IEEE-488 interface ground.
> When using both, the interface and the recorder output, make sure that the external equipment does not short this potential difference.

Block Diagram

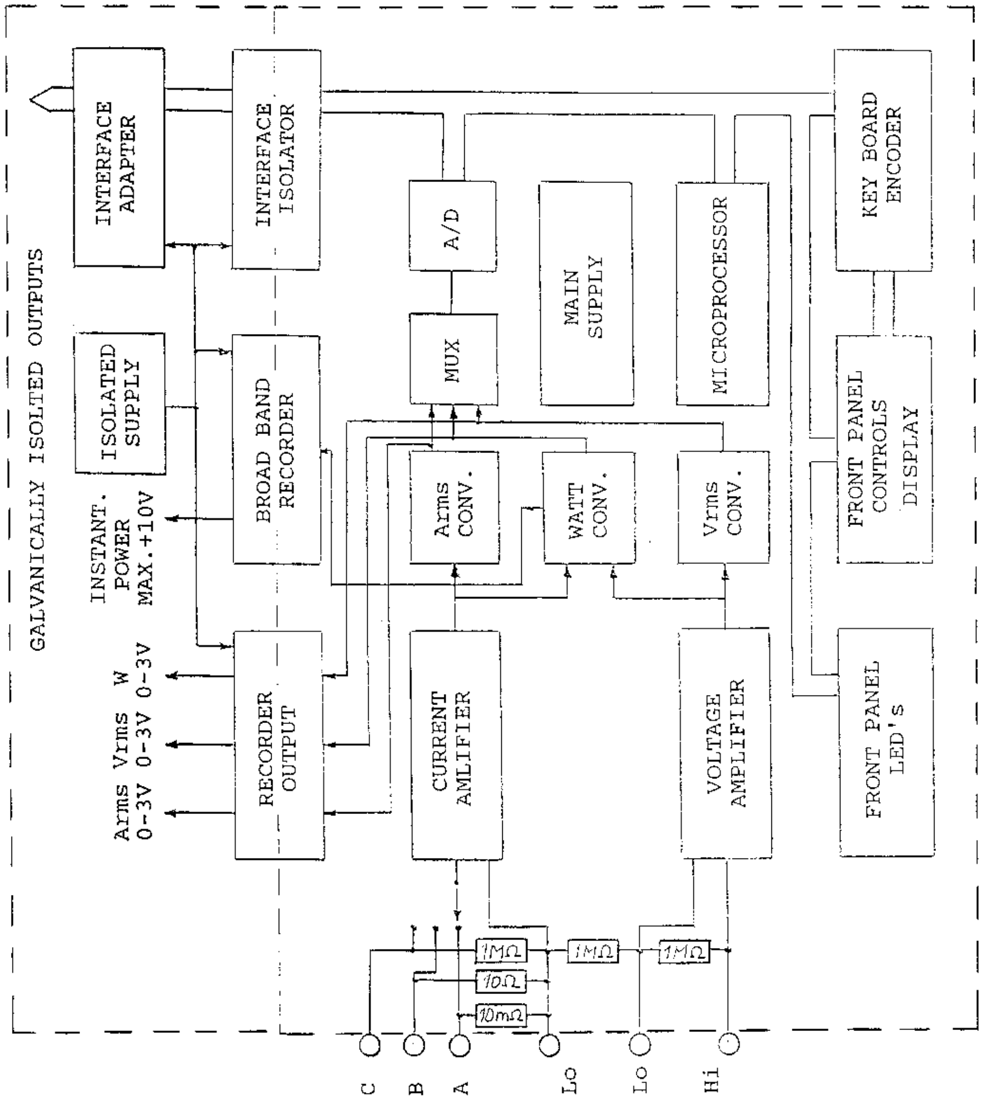


Figure 6.1. Block Diagram 103A

7. MAINTENANCE

Warning These service instructions are for use by qualified personnel only. To avoid electric shock, do not perform any procedures in this section unless you are qualified to do so.

7.1. Introduction

This section presents maintenance information for the 103A. This section also includes an alignement procedure and a calibration procedure.

7.2. Disassembly Procedure

Warning To avoid electric shock, remove the power cord and test leads before disassembling the instrument.

7.3. Top Cover Removal

1. Remove the front and rear panel screws along the top edge.
2. Remove the two screws along the top edge on left and right hand side panel.
3. Lift the top cover from the case.

7.4. Circuit Board Location

The main circuits including the options are located on the main printed circuit board assembly. The options are installed on spacers and connected to the main PCA by cables.
Parts of the display, all LED drivers, and all function control switches are located on the front panel PCA.
The rear panel assembly carries the line transformer,the line selection switch, and the input connectors.

7.5. Main PCA Removal

The main printed circuit board assembly is attached to the side panels by 8 self locking spacers (4 on each side).
Unscrew the front and the rear panel. Squeeze the top of the self locking nylon spacers. Starting at a corner, lift the main PCA upwards and unlock the self locking spacers one by one.

7.6. Alignement Procedure

To attain maximum accuracy, the 103A must be properly aligned before calibration. Measure all offsets with respect to current amplifier ground potential.
Allow 10 minutes warm-up time before proceeding to the next steps.

7.7. Current Amplifier DC Offset Adjustment

1. Select AC+DC coupling, 3mA current range.
   Adjust P3 for 0mV at U2-6.
2. Select AC+DC coupling, 300mA current range.
   Adjust P4 for 0mV at U2-6.
3. Repeat steps 1 through 2 until readings converge.

7.8. Voltage Amplifier DC Offset Adjustment

1. Select AC+DC coupling, 3V range, short input Lo-terminals together.
   Adjust P8 for 0mV at U5-6.
2. Select AC+DC coupling, 300V range.
   Adjust P9 for 0mV at U5-6.
3. Repeat steps 1 through 2 until readings converge.

7.9. Watt Converter Offset Adjustment

1. Select AC coupling, 3V range, 300mA range.
   Apply 3Vrms/130Hz to voltage input.
   Adjust P102 for minimum AC voltage at U103-14 (use oscilloscope).
2. Select AC coupling, 30mA range, 300V range.
   Apply 30mArms/130Hz to current input B.
   Adjust P101 for minimum AC voltage at U103-14 (use oscilloscope).
3. Repeat steps 1 through 2 once ore twice.
4. Check offset voltages at:
   U103-14, Offset, maximum +3mV
   U103- 1, Offset, maximum +3mV
   U103- 7, Offset, maximum +5mV

7.10. Calibration Procedure

For calibration a wide range of voltages and currents are required. For the whole calibration procedure use 130Hz sinusoidal signals. Select AC coupling.
Select the polarity of the inputs such that a positive display for power results. Through all the calibration procedure, the Lo terminals must be connected together.

1. 30mA, 3V, Watt calibration:
Select 30mA- and 3V range. Apply 30mA and 3V to the 103A input.

1.1 Switch the CAL switch S201 to the front position, wait 1 second and press the 30mA range button. The calibration factor for the 30mA range is now displayed. Switch S201 back to its rear position. The 30mA range is now calibrated.

1.2 Switch S201 to the front position, wait one second and press the 3V range button. The calibration factor factor for the 3V range is now displayed. Switch S201 back to its rear position. The 3V range is calibrated.

1.3 Apply 3mA/0.3V to the 103A input.
The current and voltage readings should be within +0.1% (on 30mA/3V ranges).
Adjust P105 if deviations are greater than 0.1%.

1.4 If the setting of P105 had to be changed, repeat steps 1.1 and 1.2.

1.5 Power calibration. Select 30mA/3V ranges and apply 3mA/3V at 130Hz and 0 degree phase shift between current and voltage.
Switch S201 to front position, wait 1 second and press the "W" control. The calibration factor for Watt is now displayed. Switch S201 back to its rear position. Power for all ranges is now calibrated.

1.6 Apply 3mA/0.3V. The display should be 0.9mW $^{+}$0.1%.
Deviations can be adjusted with potentiometer P104. If large adjustments are necessary, repeat step 1.5.

2. 30V calibration:
Select 30V range. Apply 30V.
Switch S201 to front position. Wait 1 second, press 30V range control, and set S201 again to rear position.

3. 300V and 3000V calibration:
Select 300V range. Apply 300V.
Switch S201 to front position. Wait 1 second, press the 300V control, and set S201 again to rear position. (The 3000V range is now calibrated).

4. 3mA calibration:
Select 3mA range. Apply 3mA.
Switch S201 to front position. Wait 1 second, press the 3mA control, and set S201 to rear position.

5. 300mA calibration:
Select 300mA range. Apply 300mA.
Switch S201 to front position. Wait 1 second, press the 300mA control, and set S201 to rear position.

6. 3A calibration: (Input A)
Select 3A range. Apply 3A.
Switch S201 to front position. Wait 1 second, press the 3A control, and set S201 to rear position.

7. 30A calibration:
   Select 30A. Apply 30A.
   Switch S201 to front position. Wait 1 second, press the 30A control, and set S201 to rear position.
   If 30A are not available proceed as follows: Disconnect A-input-cable from main print. Apply a voltage between current Lo and pin A on main print. The required voltage is calculated from V=300mV(R1/0.01Ohm). 0.01Ohm is the nominal value , and R1 is the measured value of R1 and is written on the inner side of the rear panel.

8. Shunt input C calibration:
   Switch to input C (only when option 03 installed).
   Switch to 30mA range and apply 300mV between current Lo and input C.
   Switch S201 to front position, wait 1 second, press AB--C control and set S201 again to rear position.

This concludes the calibration procedure for the 103A wattmeter.

7.11. Frequency Response Alignment

The frequency response may have to be readjusted when either U1 or U4 was replaced. The signals at U2-6 and U5-6 are adjusted to be -1% at 100kHz using the following potentiometers:

3V	range	adjust potentiometer P7
30V	range	adjust potentiometer P6
300V	range	adjust potentiometer P5
3000V	range	no adjustment

3mA	range	adjust potentiometer P2
30mA	range	adjust potentiometer P1
300mA	range	no adjustment

For the 3A range adjustment, the compensation coil mounted on the input measuring resistor R1 is formed to set the amplitude at U2-6 to within $\pm$5% (specified up to 20kHz).

7.12. Phase Equalization

Set 30V/30mA ranges, set Watt display. Use a good ohmic load and apply a 100kHz voltage and current signal to the 103A input. Measure the outputs U2-6 and U5-6 with an oscilloscope and adjust the phase difference between them to zero using P11 and P10.

7.13. Troubleshooting

The 103A is designed to be efficiently maintained and repaired. All integrated circuits are socketed. Most of the troubleshooting can be done with basic electronic troubleshooting equipment such as a multimeter and an oscilloscope. The troubleshooting of the digital section is probably most efficiently done by exchanging the (socketed) integrated circuits.

7.14. Initial Troubleshooting Procedure

When a problem occurs in the 103A, first verify the problem is actually in the instrument. If the problem occurs when the instrument is in a system, check to see if the same problem exists when under local control. If the malfunction does not involve the IEEE-488 option or the recorder output option, remove the options from the instrument before proceeding.
A failure in the instrument may cause the 103A to display random patterns or nothing at all. If in addition, none of the front panel LED's are lighted, start troubleshooting by checking the power supply for proper levels and for oscillations.
If all of the supplies are working correctly, check the 1MHz clock of the microprocessor. Check the "CAL" switch, it must be set to the rear position.

7.15. Digital Section Troubleshooting

The troubleshooting of the digital circuits is best performed by replacing integrated circuits.
If a problem occurs with front panel LED's, check the decoder U210, and the latches U306, U307, and U308.
If a problem occurs with the vacuum fluorescent display, check U209-7, U10-10, U11-8, U207, U301, U302, U303, and U304.
If a problem occurs with the microprocessor, check U201, U203, U204, U205, and U206.
If a problem occurs with gain selection, check U7, U8, U9-6.
If a problem occurs with the front panel controls, check U207, U301, and U305.
When an installed option is not recognized by the 103A, check 109.
If the watt converter exhibits an unstable null, the error could be in the integrated circuit U106.
When no data, or false data are displayed, check the reference at pin 10 of U108, or replace U108.

7.16. Analog Section Troubleshooting

Monitor the outputs U1-10 and U4-10 and switch ranges. Amplifiers U2 and U5 have a gain of 1. The rms converters U3 and U6 convert an AC input signal to a positive output signal (pin 6/14).
If an error occurs in the watt converter, check the output U103-14. To a sinusoidal current and voltage input, the signal at U103-

(positive watt input and no phase shift between current and voltage).
If an error occurs in the watt converter autozero, check the multiplexer U101 and U103-8.

7.17. Power Supply Troubleshooting

Check the rear panel fuse. If none of the supply voltages is present, check the input section of the transformer. If just one of the supply voltages is not present, check the appropriate voltage regulator.

7.18. Recorder Output Troubleshooting

If one of the recorder outputs Arms, Vrms, or Watt is not operative, check U104. For full scale display, the voltage at R137, R138, and R139 must be 3V. If these voltages are correct, check the DC current isolators T801-T803.
If a problem occurs with the broad band recorder output, check U801. Check the supply voltages $\pm$12V at the output side of U801.

7.19. IEEE-488 Interface

Check the supply voltages at the bus isolator input side and output side. Check the voltage levels at the address selector switches R501-R508 and make sure levels correspond with the address selector switches. Check the 1MHz clock signal at U608-13. Proceed by replacing integrated circuits U601, U606, U607, U608, U501, U502, U503, and U504.

7.20. Energy Converter Troubleshooting

If a problem occurs in the energy converter, check U701, U702, and U703.

7.21. Scaling Troubleshooting

If a problem occurs, check the hibrid circuit "scaling". The problem could also be caused by a malfunction of U206.
If a problem occurs with input switching, A,B--C check U7 and U8.

8. LIST OF REPLACEABLE PARTS

Main PCA

C1, C18	Cap., Cer., 100pF, 5%, 100V
C2, C19	Cap., Cer., 1000pF+33OpF, 5%, 100V
C3, C20	Cap., Polyst., 100pF, 1%, 63V
C8, C25	Cap., Cer., 68pF, 5%, 100V
C16	Cap., Cer., 1000pF, 5%, 100V
C7, C24, C104	Cap., Polypr., 1nF, 5%, 100V
C4, C5, C21, C22, C14, C15 C31, C32, C102, C103, C109 C112, C113, C404	Cap., Polypr. 100uF, 5%, 100V
C17	Cap., Cer., 390pF, 5%, 100V
C6, C23, C12, C13 C29, C30, C105, C106	Cap., Polypr., 220nF, 5%, 100V
C9, C10, C11, C26, C27 C28, C101, C107, C108 C110, C111, C203, C204, C402 C406, C408, C410	Cap., Tant., 1.5uF, 35V
C201, C202	Cap., Cer., 22pF, 5%, 100V
C401	Cap., Electrol., 4700uF, 25V
C403, C405, C407, C409	Cap., Electrol., 1000uF, 40V
C411	Cap., Electrol., 100uF, 35V
D1-D14	1N4148, Si Diode
D406, D407	WO2, Bridge Rectifier
D401-D405	1N4002, Si Diode
J101, J202, J203	2-Row-Connector 14 pin
J201, J204	2-Row-Connector 20 pin
P1, P6	Pot., 5kOhm, Bourns 3296W
P2, P7	Pot., 200 Ohm, Bourns 3296W
P3, P11, P8, P9	Pot., 100kOhm, Bourns 3296W
P4, P10	Pot., 2kOhm, Bourns 3296W
P5	Pot., 1kOhm, Bourns 3296W
P101-P105	Pot., 500kOhm, Bourns 3296W
Q1	ZTX450, Si Trans. npn
R1	0.01Ohm Dale, 50W, 1%
R2	10Ohm Dale, 10W, 1%
R3-R22, R24-R40 R101-R139, R201-R204	M.F.Resistor, 1%, 0.4W, 250V
R23	Res., Phil, VR68, 5%, 1W, 7000V
S401	Voltage Range Selector
S1-S9	Relay FBR22D06P, FUJITSU
T401	Line Transformer 103A
U1, U5	AMP05FX, Amplifier PMI
U2, U5, U107	OP43GP, Amplifier PMI
U3, U6	AD637J, RMS Converter
U101, U105	DG212, Analog Switch MAXIM
U102	RC4200A, Raytheon
U103	TL074BC, Quad Amplifier
U104	OP400FY, Quad Amplifier
U106, U109, U8	74HC373, Octal Latch
U7	SN75423, Relay driver
U108	HADC574ZCC, 12bit A/D Converter
U201	MC6809C, Motorola

U202	74HCT245B, Bus Transceiver
U203, U204	2764, 8k EPROM
U205	6116P, RAM
U206	2804, EEPROM
U207	P8279, Key Board Encoder
U208, U209	74HC138, Decoder
U9, U10	74HC04, Hex Inverter
U11, U12	74HC32, Quad OR
U210	74HC08, Quad AND
VR401,405	LM340T-5, 5V Regulator
VR402,403	LM340T-15, 15V Regulator
VR404	LM7915CT, -15V Reguator
Z1, Z3	8.2V Zener, 0.5W
Z2, Z4, Z102	12 V Zener, 0.5W
Z101	9.1V Zener, 0.5W
Z401	15V Zener, 0.5W

Display PCA

D301-303	1N4148 Si Diode
J302	2-Row-Connector 14 pin
J301	2-Row-Connector 20 pin
LD301-308	MV54124 Led green, rectangular
LD309-324	GL-3NG5 green/GL-3PR5 red, LED
RN 301-RN303	9x100Ohm Resistor Network
S301-320	Print Switch ITT KSA
U301	74HC259E Latch
U302	74LS248N Decoder BCD/7 Segment
U303, U304	MSL 912 VFD Driver
U305	74HC04 Hex inverter
U306-308	74HC373 Octal Latch
VFD1	Vacuum Fluorescent Display FUTAB 6-LT-15C

Various Parts

MP01	Rear Panel assembly
MP02	Front Panel
MP03	Power Switch 10A/250V
MP04	Case 103A, KM7

Options

Bus Isolator PCA

C601, C602	Cap., Polypr., 1nF, 100V
C603	Cap., Tantal, 1.5uF, 35V
J601, 602	2-Row-Connector 20 pol.
Q601	2N3904, npn Si Transistor
Q602	2N3906, pnp Si Transistor
R601-603	M.F.Resistor, 1%, 0.4W, 250V
U601, 606, 607, 608	74HC245, Bus Transceiver
U603-605	N1600, Quad Bus Isolator
U602	N1601, Dual Bus Isolator

IEEE-488 interface PCA

J501	Cable Assembly, Interface to Isolator
J502	Cable Assembly, Interface to 24 pol. Amphenol
J503	Cable Assembly, Interface to Address Switch
R501-508	M.F.Resistor, 4.75k, 1%, 250V
U501-502	MC3447L, Line Driver
U503	MC68488, Interface Adapter
U504	74HC373, Octal Latch

Energy Converter PCA

J701	2-Row-Connector, 14 pol.
U701	74HC373
U702	74HC4040
U703	CD4020

Recorder Output PCA

C801, 802, 805, 806 C813, 814	Cap., Polypr., 100nF, 5%, 100V
C803, C804	Cap., Cer., 270pF, 5%, 100V
C807, 811, 812	Cap., Tantal, 10uF, 35V
C808, 809	Cap., Cer., 22pF, 5%, 100V
C810	Cap., Polypr., 1nF, 5%, 100V
D801-804	EGP10D, Fast Recovery Diode
D805	1N4148, Si Diode
J801, 802	2-Row-Connector 14 pol.
P801	Pot., 20kOhm, Bourns 3296W
P802	Pot., 1kOhm, Bourns 3296W
P803-805	Pot., 200Ohm, Bourns 3296W
Q801, 804	ZTX109C, npn Transistor
Q802	ZTX452, npn Transistor
Q803	ZTX552, pnp Transistor
Q805	IRF510, MOSFET Power Transistor
R803-816	M.F.Resistor, 1%, 0.4W, 250V
T801-803	DC Current Isolator
VR801	LM78L12, +12V Regulator
VR802	LM79L12, -12V Regulator
Z801	BZX55C15, 15V Zener
Z802	BZX55C56, 56V Zener

9. SCHEMATICS DIAGRAM

Figure	Title
9.1/2	Voltage- and Current Amplifier PCA
9.3/4	Watt- and A/D Converter
9.5/6	Microprocessor PCA
9.7/8	Power Supply PCA
9.9/10	Display PCA
9.11/12	Bus Isolator PCA
9.13/14	IEEE-488 Interface
9.15/16	Energy Converter PCA
9.17/18	Recorder Output PCA

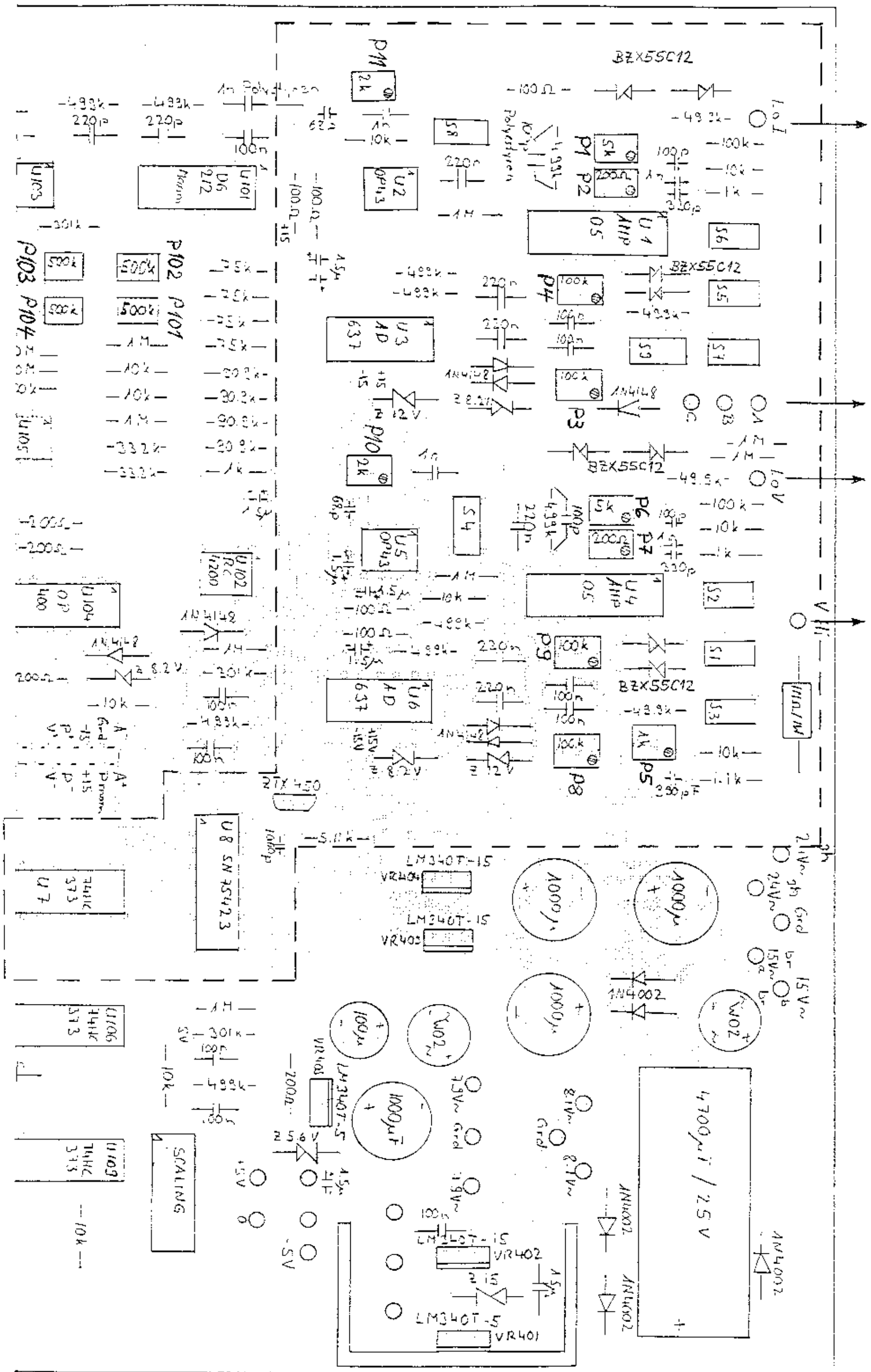


Figure 9.1. Voltage- and Current Amplifier PCA

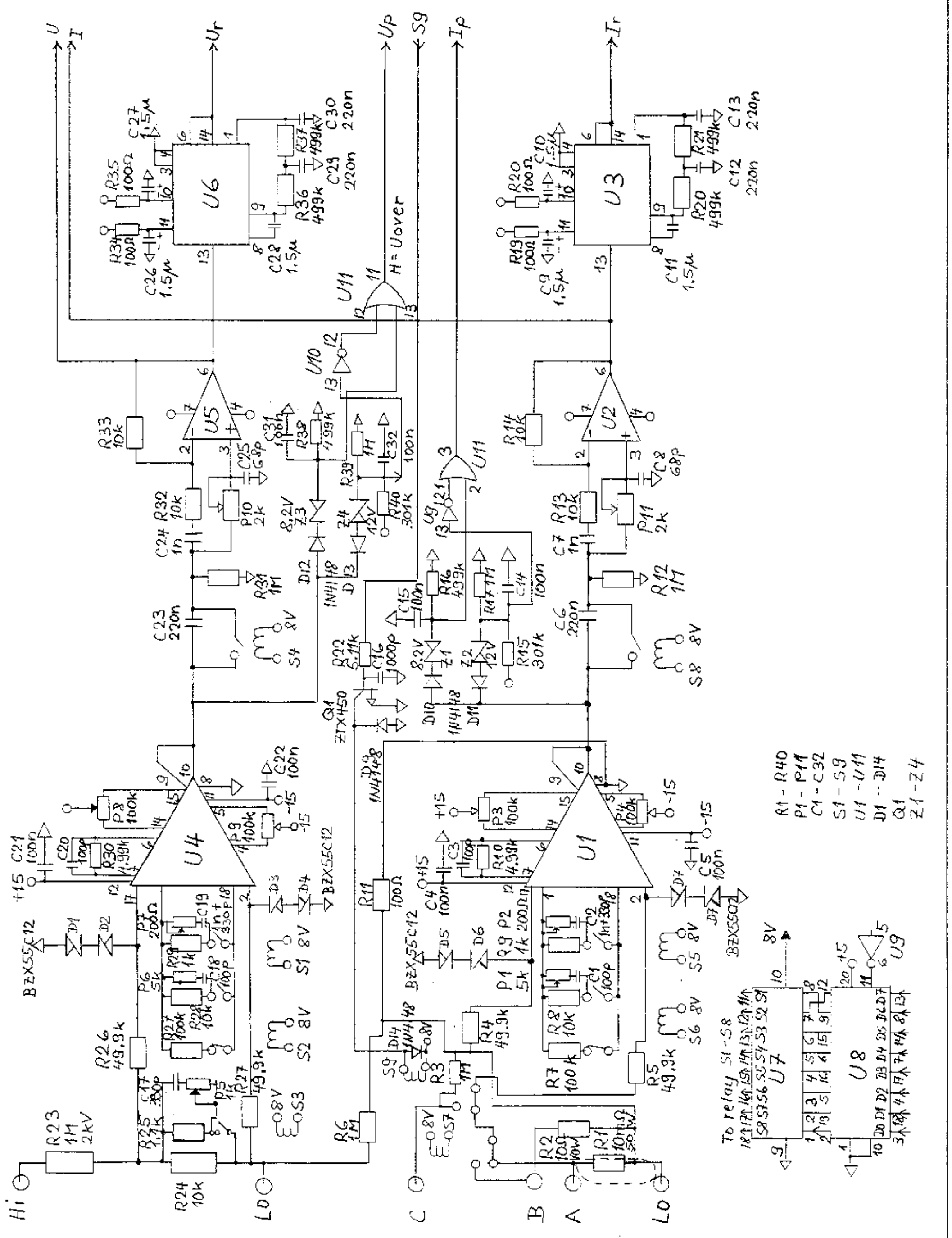


Figure 9.2. Voltage- and Current Amplifier PCA

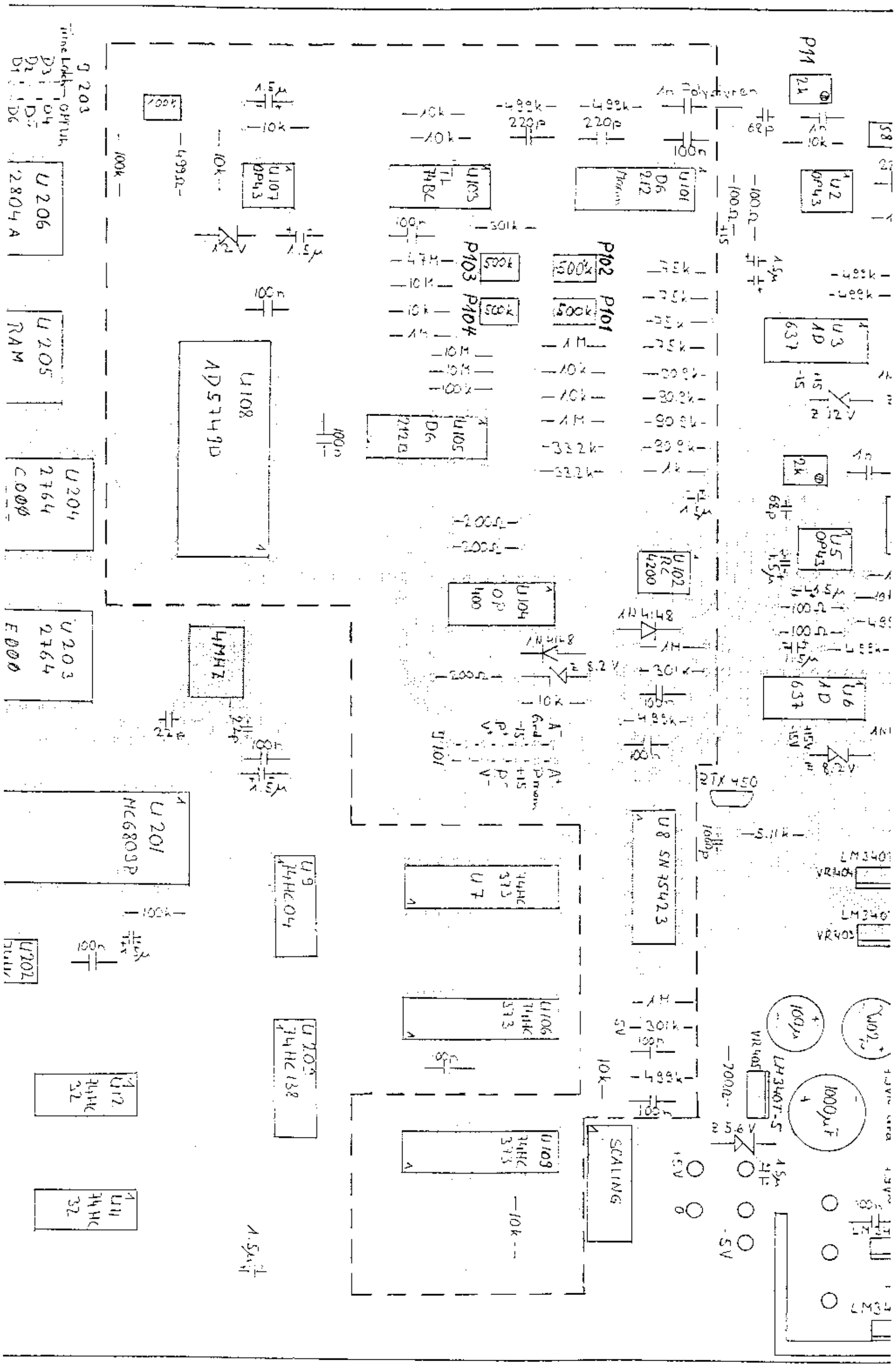
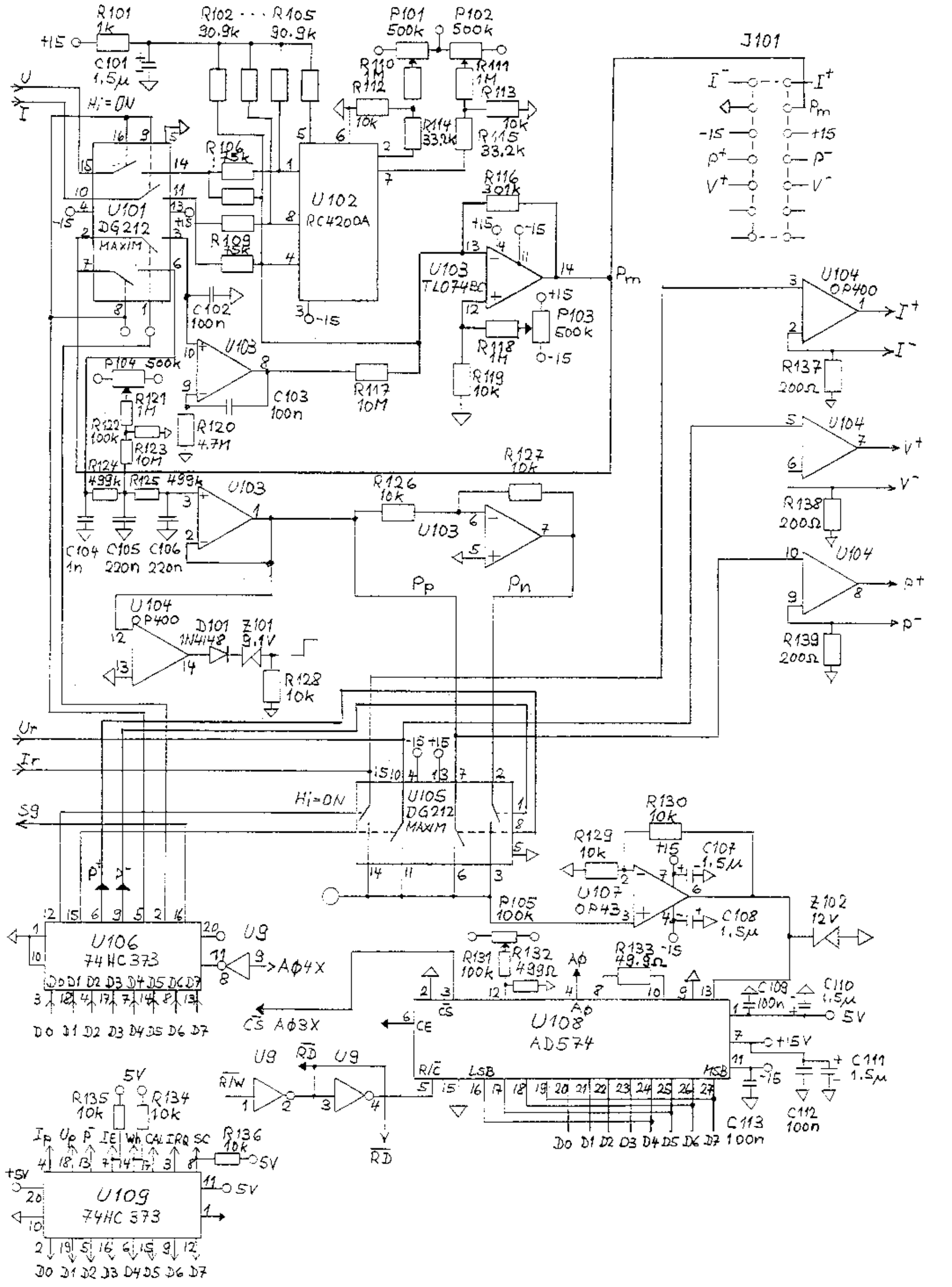


Figure 9.3. Watt- and A/D Converter PCA



R101 - R139
C101 - C113
P101 - P105
D101
Z101 - Z102
U101 - U109
J101

Figure 9.4. Watt- and A/D Converter PCA

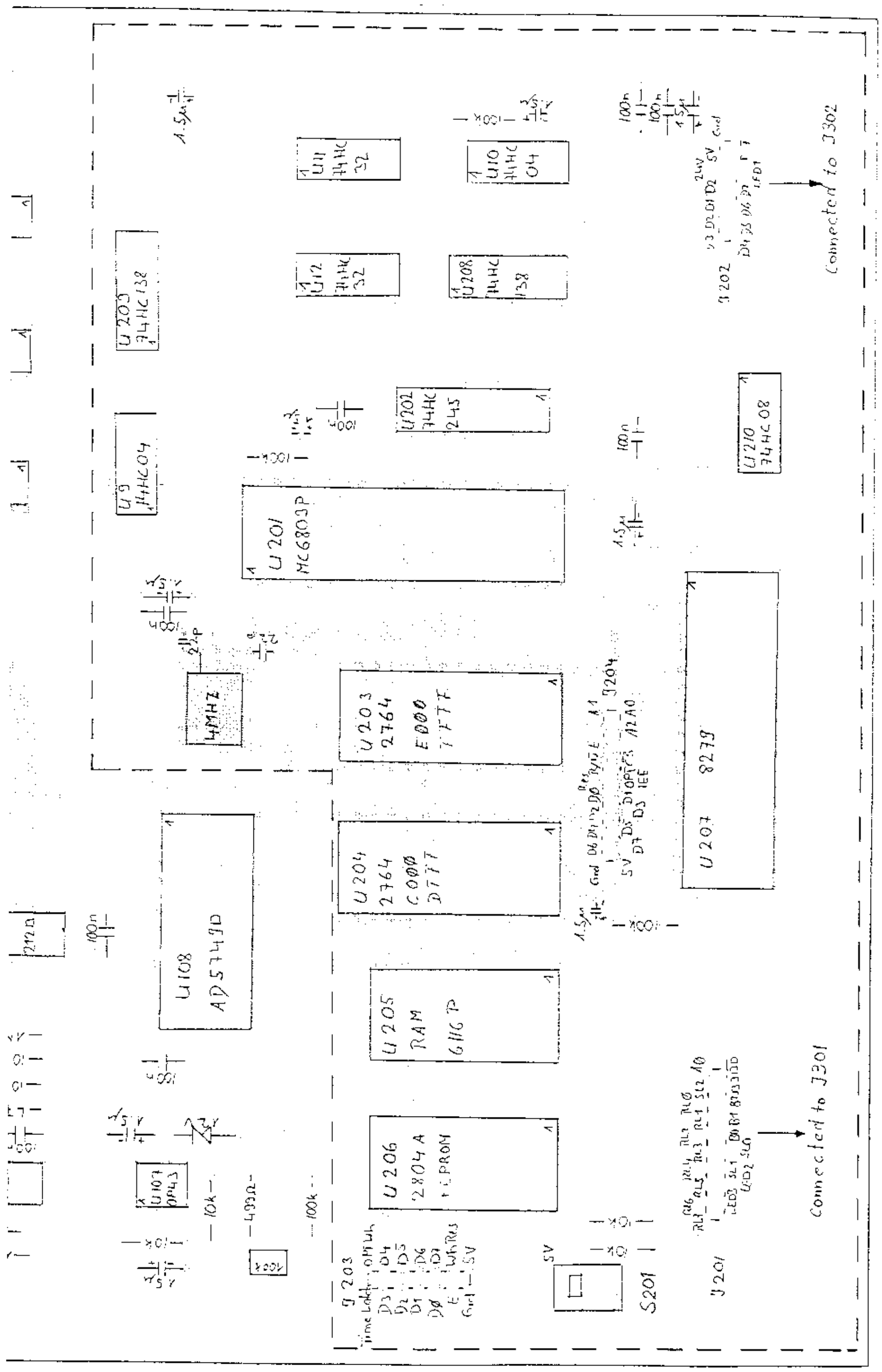
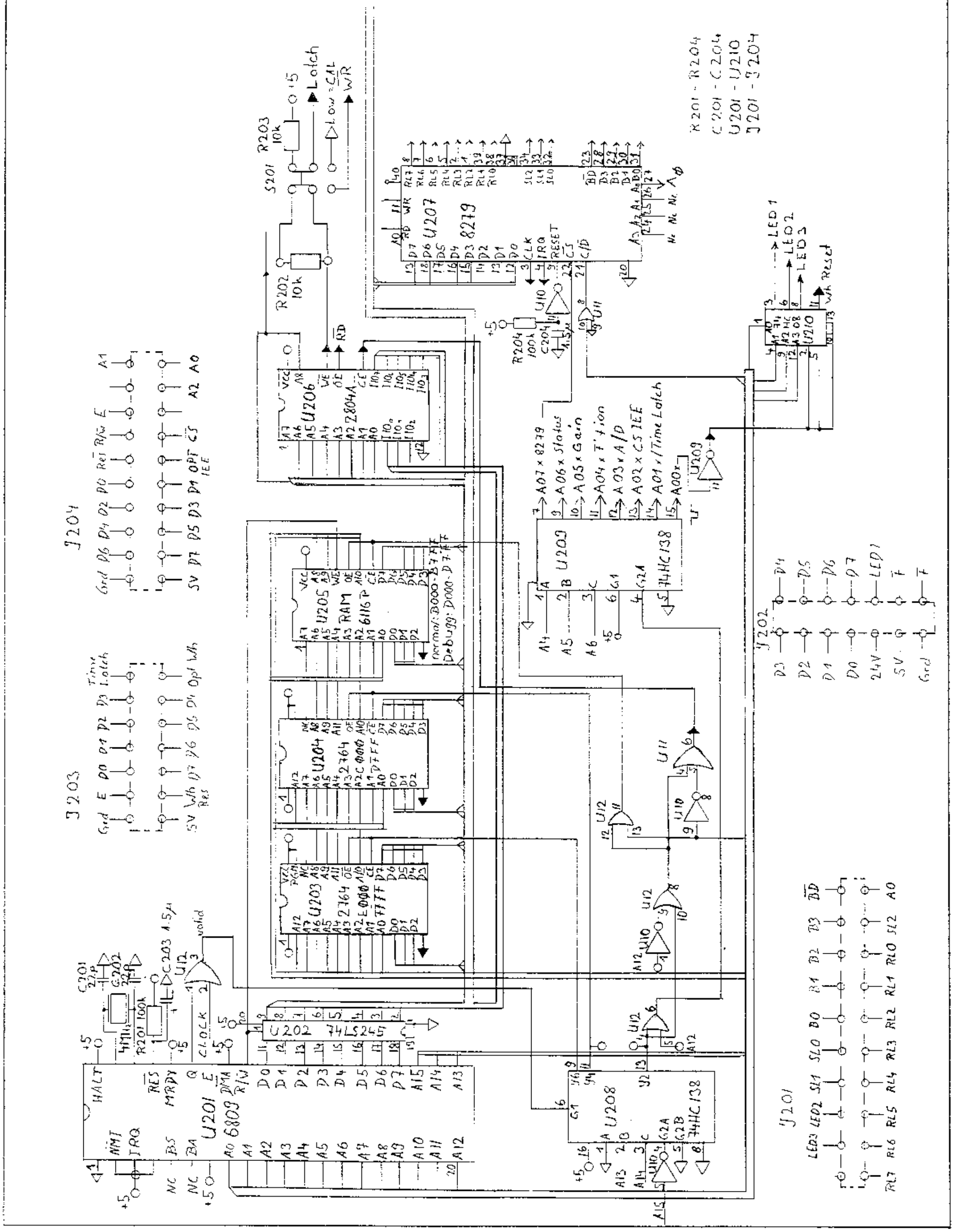


Figure 9.5. Microprocessor PCA

Figure 9.6. Microprocessor PCA



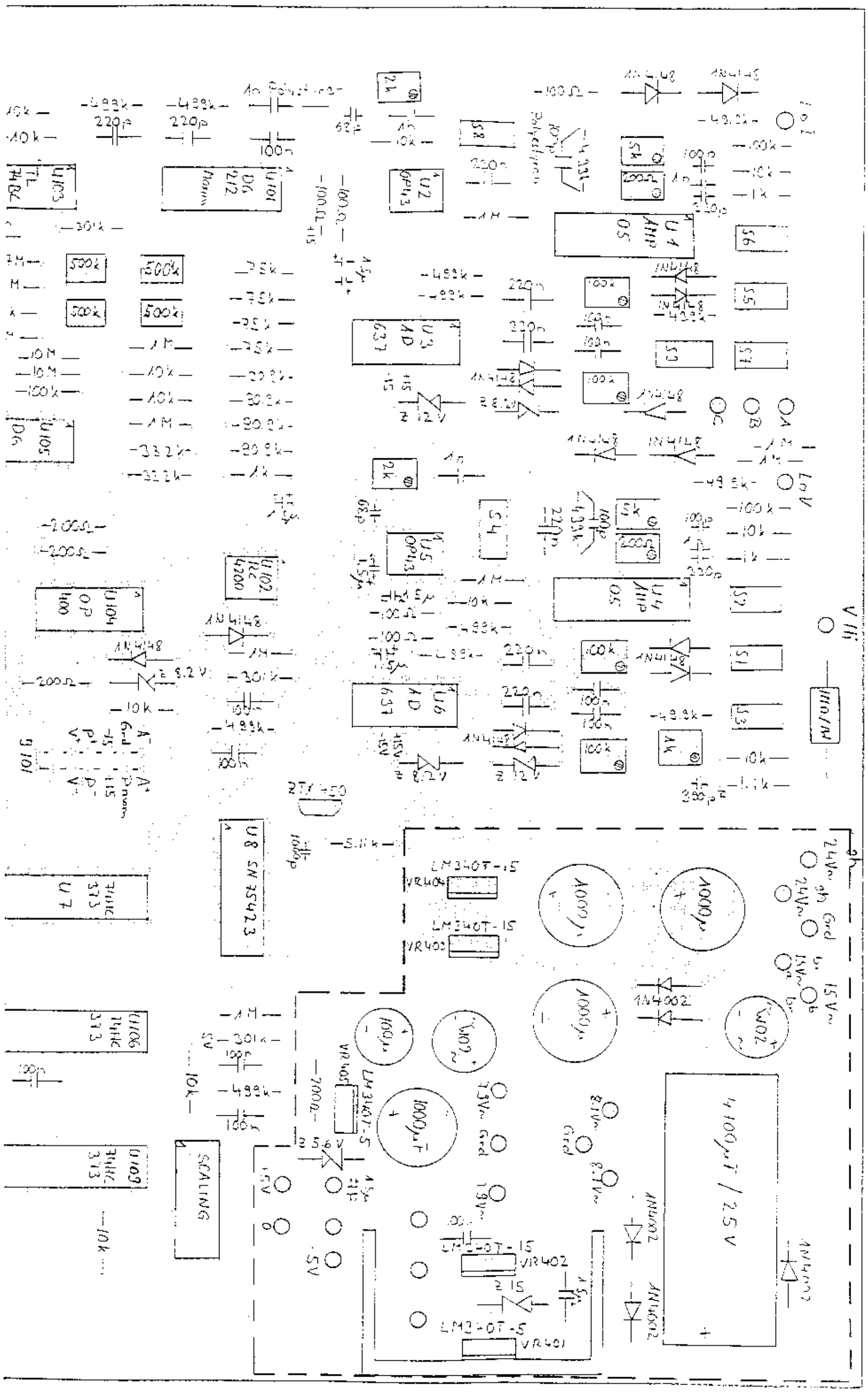


Figure 9.7. Power Supply PCA

C401 - C411
S401
VR401 - VR405
D401 - D405
Z401

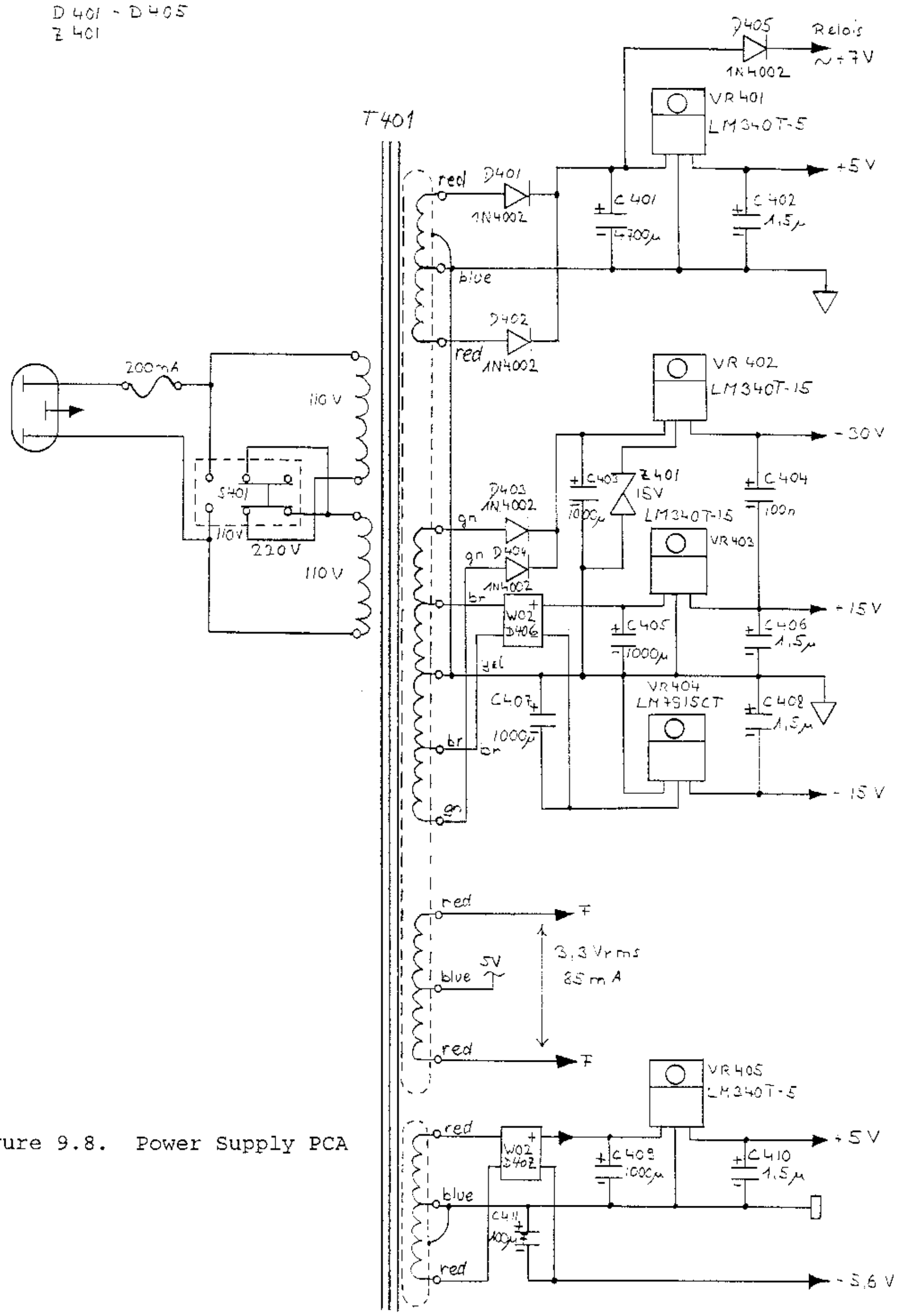


Figure 9.8. Power Supply PCA

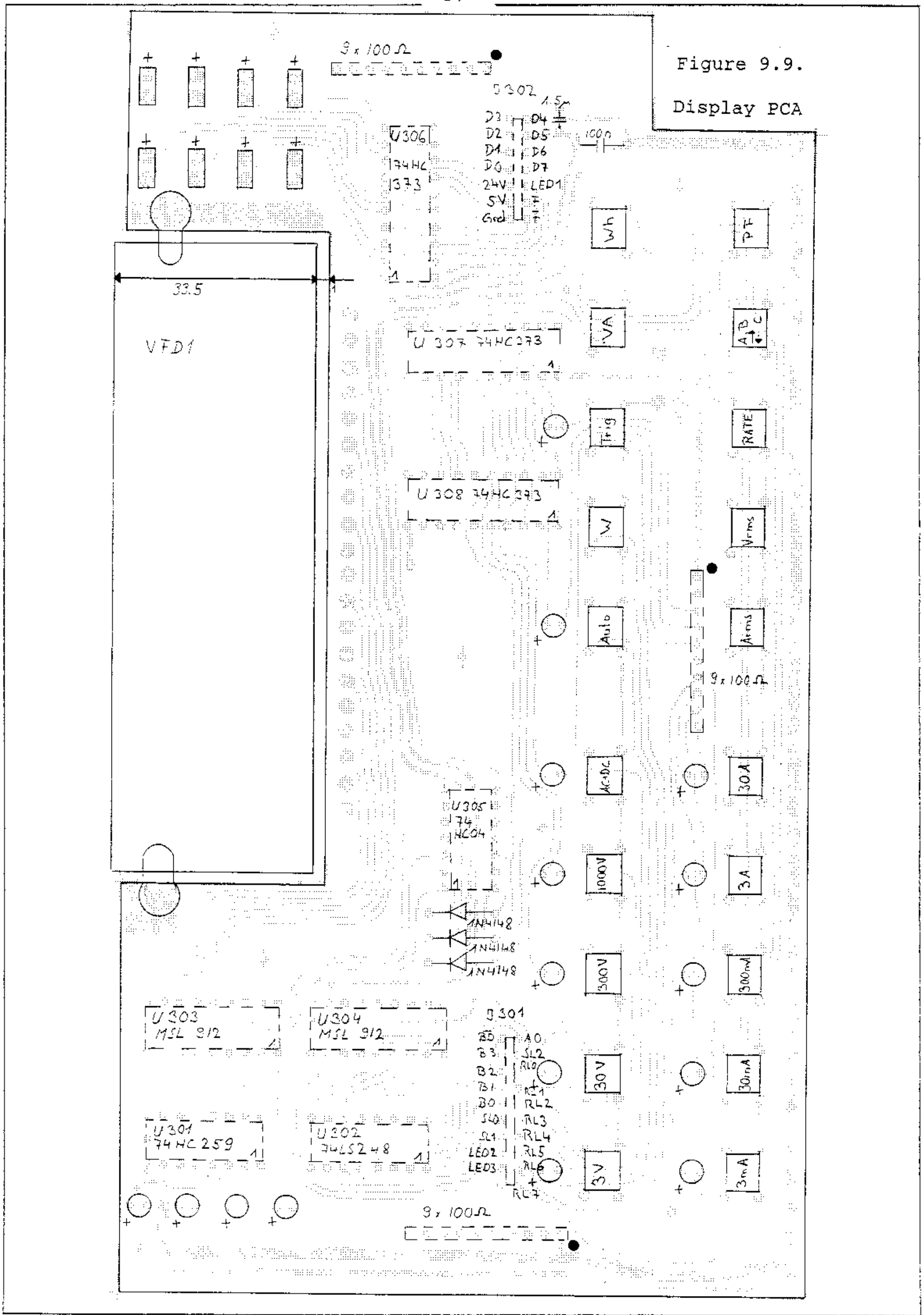
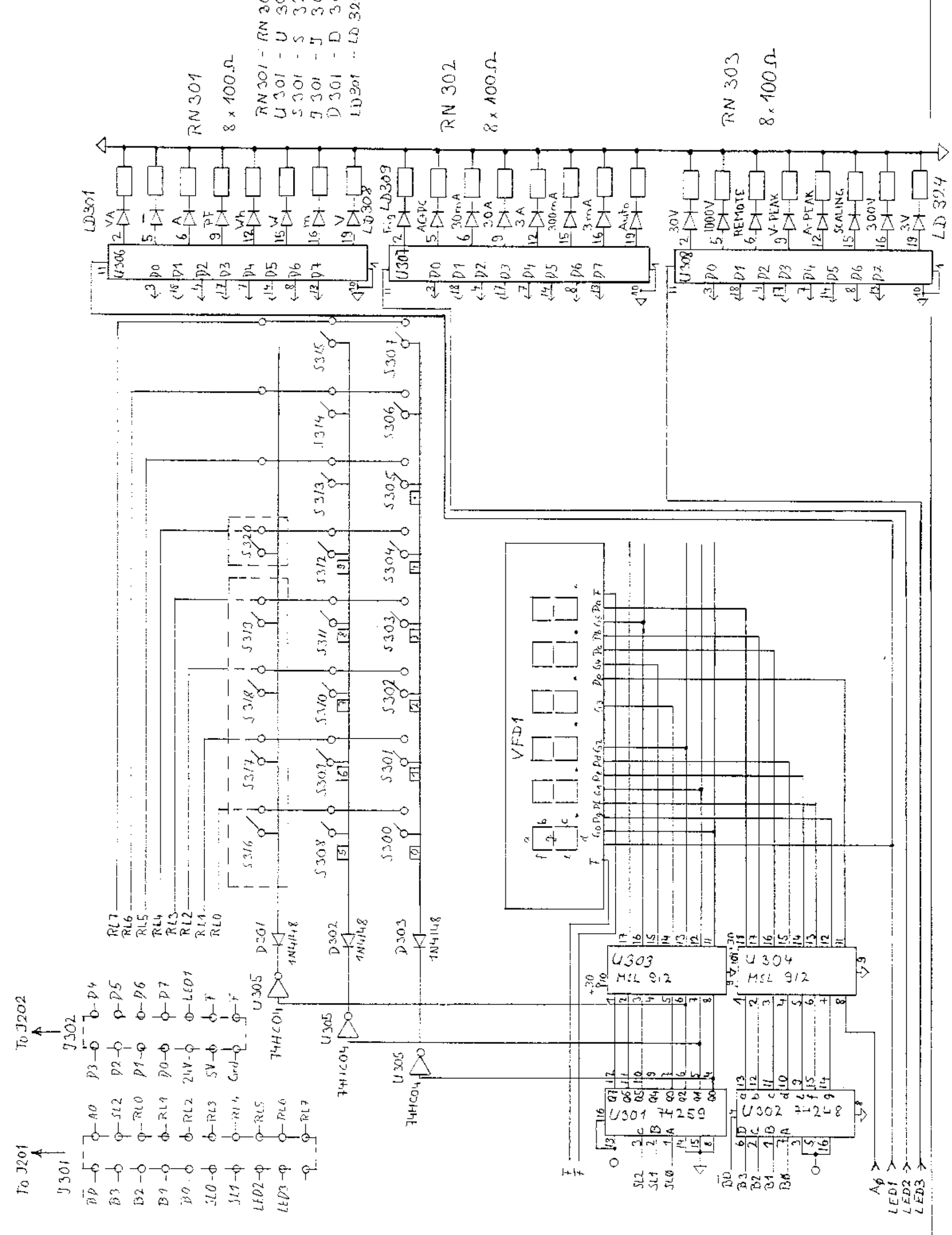


Figure 9.9.

Display PCA

Figure 9.10. Display PCA



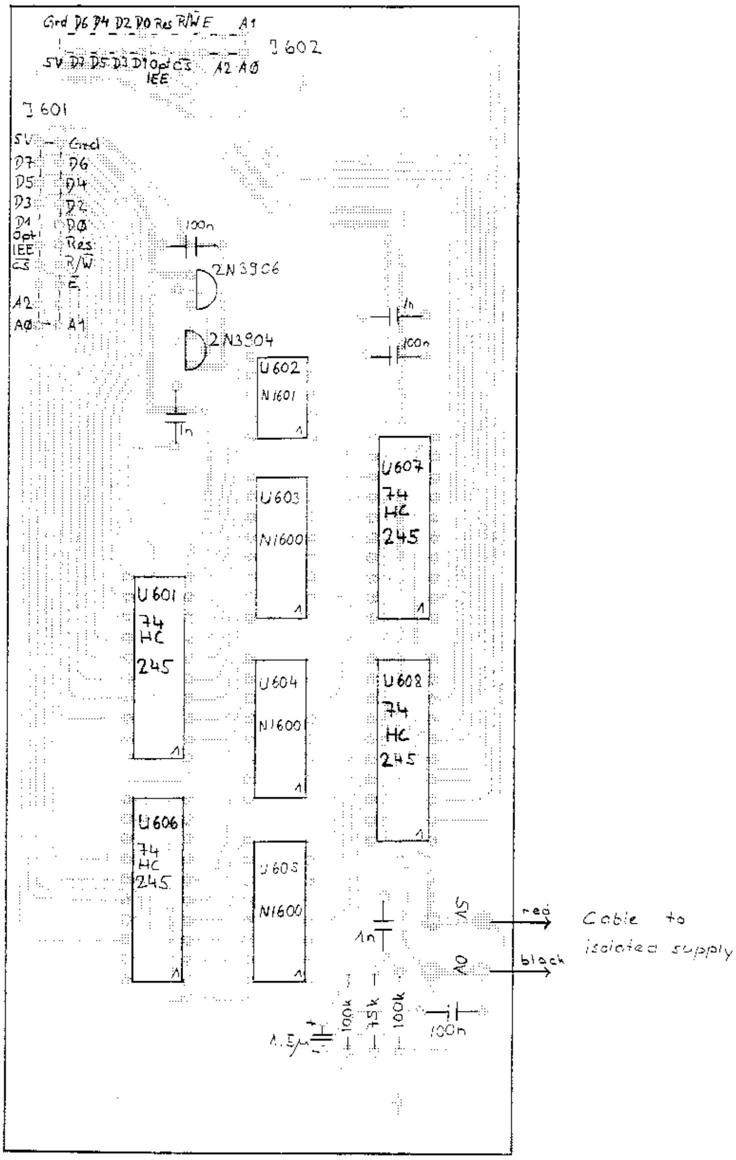


Figure 9.11. Bus Isolator PCA

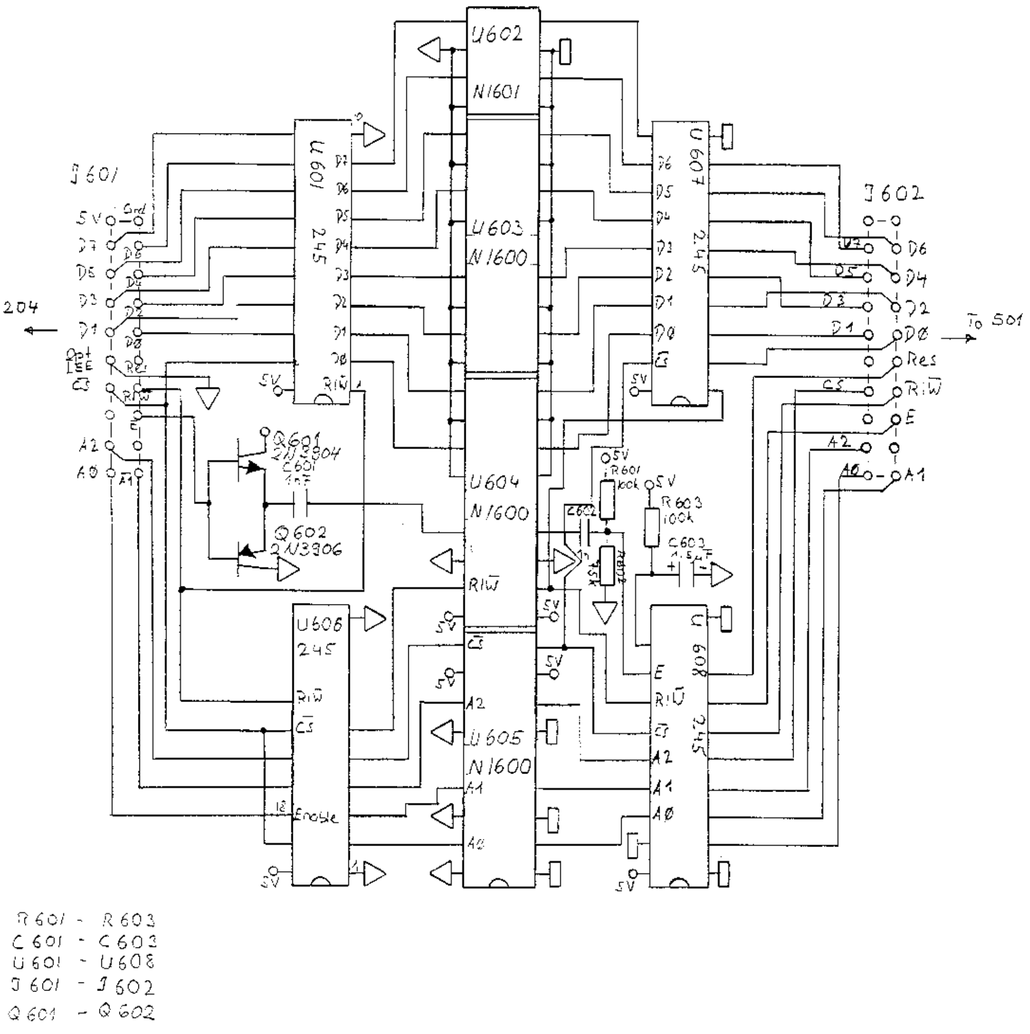


Figure 9.12. Bus Isolator PCA

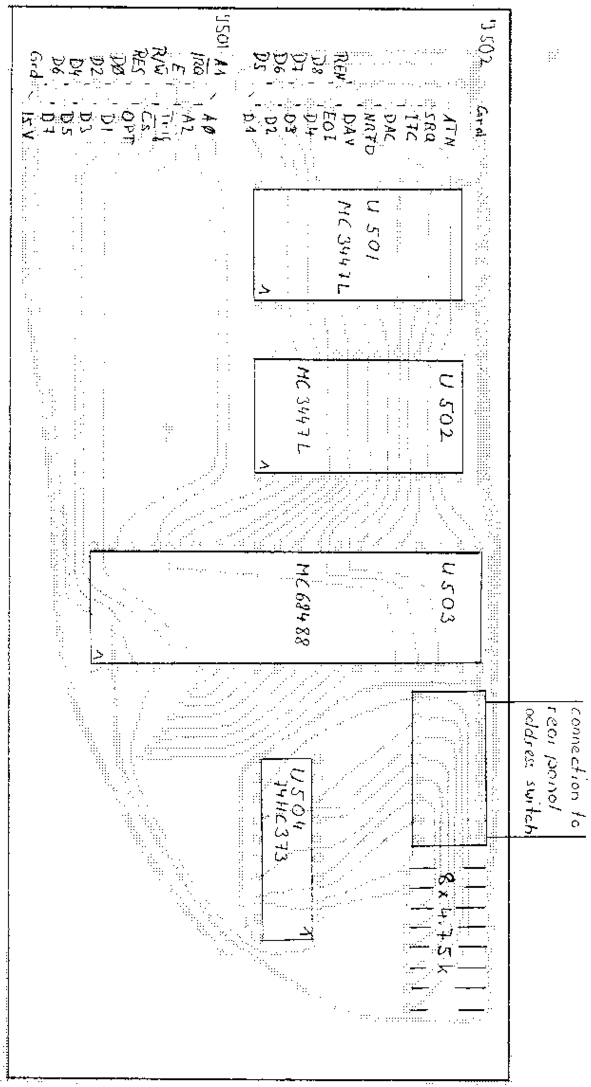


Figure 9.13. IEEE-488 Interface PCA

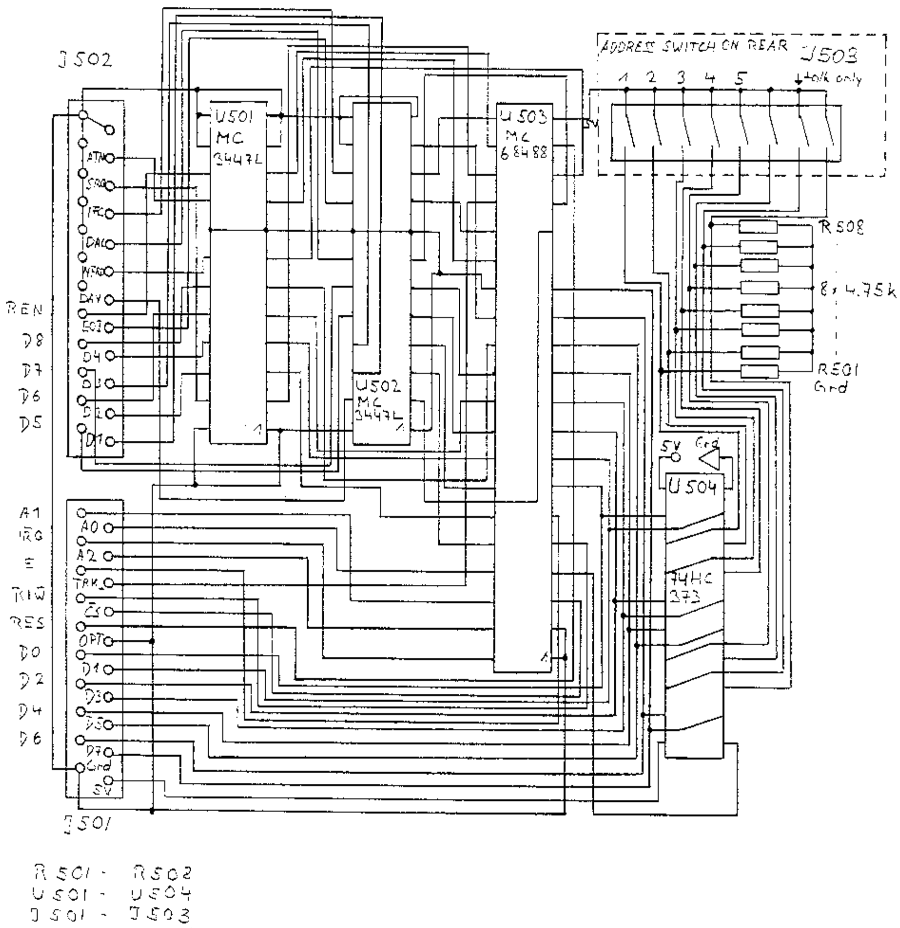


Figure 9.14. IEEE-488 Interface PCA

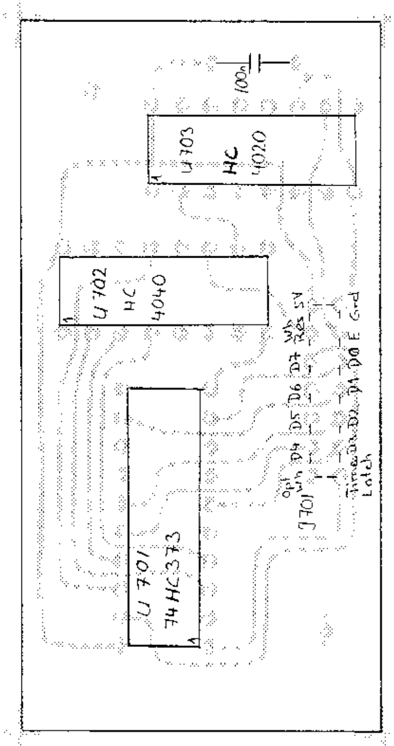
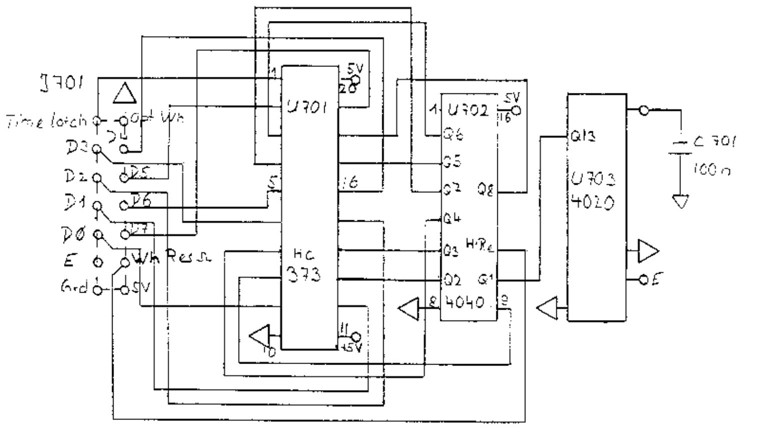


Figure 9.15. Energy Converter PCA



C 701
J 701
U 701 - U 703

Figure 9.16. Energy Converter PCA

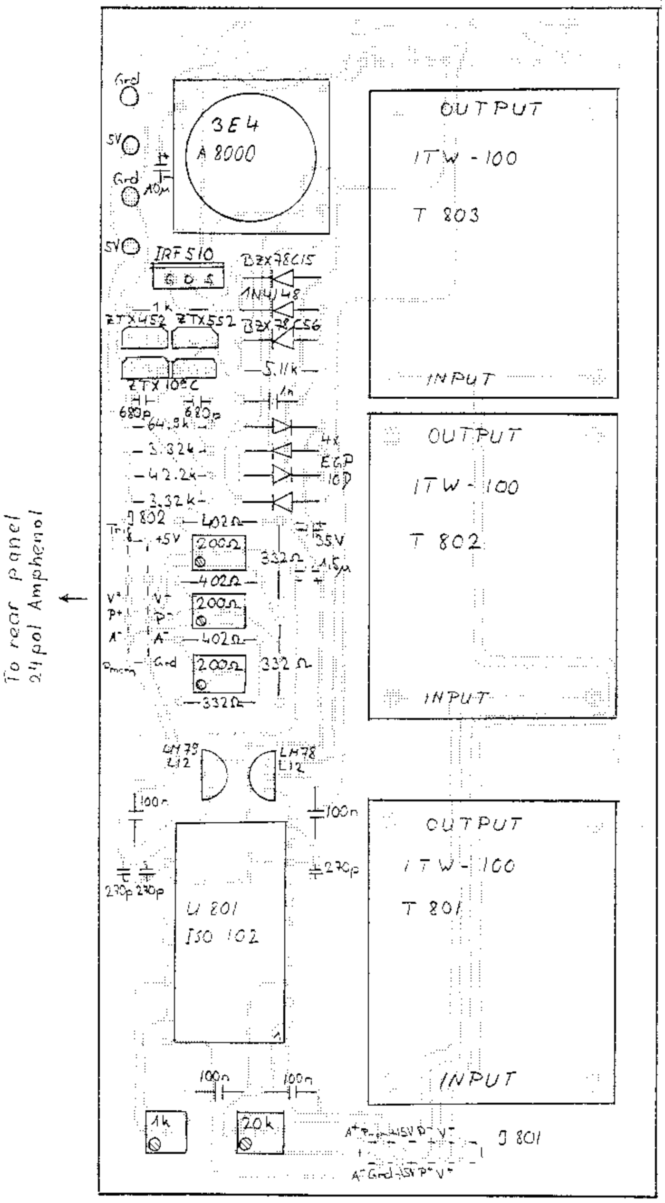
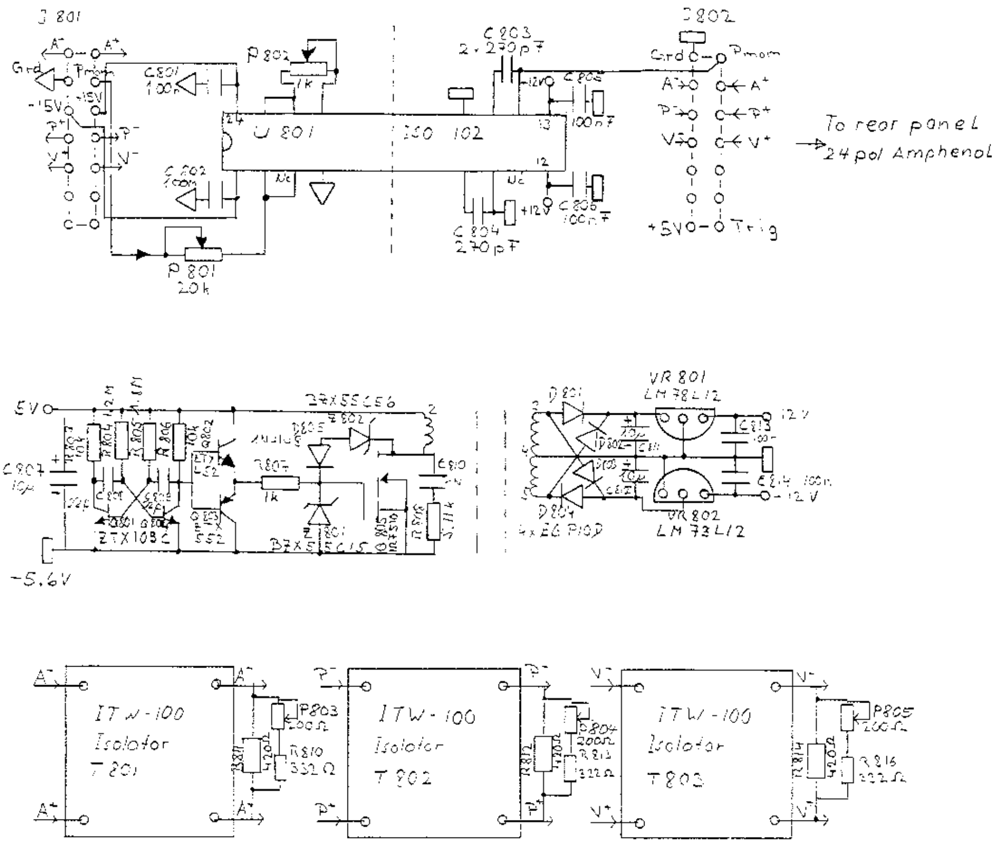
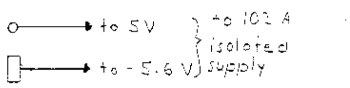


Figure 9.17. Recorder Output PCA





R803 - R816
C801 - C814
U801
T801 - T803
VR801 - VR802
Q801 - Q805
D801 - D805
Z801 - Z802
J801 - J802

Figure 9.18. Recorder Output PCA