PRECISION WATTMETER
MODEL 304B

OPERATING AND
MAINTENANCE MANUAL

Infratek

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1. INTRODUCTION AND SPECIFICATION

1.1. Introduction

This manual provides specifications, operating instructions, and service instructions for the 304B Three Phase Precision Wattmeter.

1.2. The 304B Three Phase Precision Power Analyzer

The model 304B Power Analyzer measures and computes 48 quantities simultaneously (on three phases). Four of these are displayed on the 40 character vacuum fluorescent display (selectable by front panel controls). The current- and voltage inputs are galvanically isolated and may float 1400V (peak) against each other and against ground. They cover the frequency range DC to 100kHz. Current and voltage are measured by converters. Power is determined by sampling the instantaneous values of current and voltage. Averaging can be selected in 4 steps. From current, voltage, and power the remaining quantities are computed. The 3-Phase Precision Power Analyzer is also capable to operate in a triggered mode. A measurement cycle starts to a front panel control input, or a trigger input from the rear panel or from the IEEE-488 interface. In triggered mode 46 quantities are determined within approximately 0.8 seconds. After measurement completion all quantities can be displayed or read over the interface bus.
The universal recorder output can be programmed from the front panel to output one out of 9 quantities (RMS current, RMS voltage, or power of phase 1, 2, or 3).
The multifunction recorder outputs 10 quantities simultaneously.
The IEEE-488 interface allows complete control of the instrument function.

1.3. Features

Features of the 304B include:

- 0.1 % accuracy
- Simultaneous measurement of 48 quantities on 3 phases
- Simultaneous display of 4 quantities
- Inputs galvanically isolated
- Wide frequency range, DC to 100kHz
- AC- or AC+DC-Coupling
- Versatile talk-only programming
- Timer function for energy summation
- Programmable for 3-Wattmeter or 2-Wattmeter measurement
- Individual scaling of voltage and current on each phase
- Non-volatile memory for programmed data

- Automatic or manual ranging
- 7 voltage ranges 2V, 6V, ..., 1000V
- 5 current plug-ins, 20mA to 150A per phase
- Simple to operate

Options: Frequency measurement, IEEE-488 interface, universal recorder output, Multifunction recorder output, standard and coaxial shunts.

1.4. Measured Quantities and their Definitions

The 304B measures simultaneously the following 48 quantities on phase 1, phase 2, and phase 3.

Current inputs (AC- and AC+DC-Coupling)

- True RMS
- Rectified Mean
- Mean
- Average currents of all 3 phases

Voltage inputs (AC- and AC+DC-Coupling)

- True RMS
- Rectified Mean
- Mean
- Average voltages of all 3 phases

Current and voltage inputs (AC- and AC + DC-Coupling)

- Power: P1, P2, P3, and $\sum$P1 + P2 + P3
- Apparent Power: S1, S2, S3, and ΣS1 + S2 + S3
- Magnitude of react. Power: Q1, Q2, Q3, and ΣQ1 + Q2 + Q3
- Power Factor: (Phase 1, 2, 3)
- Energy (positive and negative) of all 3 phases
- Magnitude of load impedance (phase 1, 2, 3)
- Resistive part of load impedance (phase 1, 2, 3)
- Correction of apparent power in 2-Wattmeter measurement

Mathematical Definitions

True RMS (A_r, V_r): $(1/nT \int_0^{nT} i^2\,dt)^{1/2}$, $(1/nT \int_0^{nT} v^2\,dt)^{1/2}$

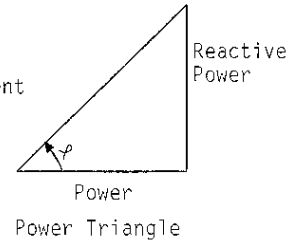
Rectified Mean(A_t, V_t): $1/nT \int_0^{nT} |i|\,dt$, $1/nT \int_0^{nT} |v|\,dt$

Mean (A=, V=): $1/nT \int_0^{nT} i\,dt$, $1/nT \int_0^{nT} v\,dt$

Power (W): $1/nT \int_0^{nT} v \cdot i \cdot dt$

Average Voltage: (V1 + V2 + V3) /3
Average Current: (A1 + A2 + A3) /3

Apparent Power (VA) = I_{RMS} V_{RMS}



Power Triangle

Magnitude of reactive Power (VAR) = $I_{RMS} \cdot V_{RMS} \cdot \sin\varphi$

Power Factor (PF) = Power / Apparent Power

Energy (Wh) = $\int_0^t P1dt + \int_0^t P2dt + \int_0^t P3dt$ (P1 = Power Phase 1)

Magnitude of load impedance (|Z|) = V_{RMS} / I_{RMS}

Resistive part of load impedance (ReZ) = $\frac{V_{RMS}}{I_{RMS}} \cdot \cos\varphi$

ΣP = P1 + P2 + P3 (total power of phase 1, 2, and 3)

ΣS = S1 + S2 + S3 (total apparent power of phase 1, 2, and 3)

ΣQ = Q1 + Q2 + Q3 (total reactive power of phase 1, 2, and 3)

$\Sigma PF = \Sigma P / \Sigma S$ (average power factor)

2-Wattmeter measurements: (Use 2-Phases only)

$S_i = I_{rms}$ V_{rms}, Average Voltage/Current: x = x1+x2/2

ΣS = (S1+S2) $\sqrt{3}/2$; (S1+S3) $\sqrt{3}/2$; (S2+S3) $\sqrt{3}/2$

ΣP = (P1+P2); (P1+P3); (P2+P3)

ΣQ = |Q1| + |Q2|; |Q2| + |Q3|; |Q1| + |Q3|

1.5. SPECIFICATIONS

CURRENT

Ranges:

2A plug-in:	20mA, 60mA, 200mA, 600mA, 2A (1Ω)
10A plug-in:	200mA, 600mA, 2A, 6A, 20A[1]) (0.1Ω)
30A plug-in:	2A, 6A, 20A, 60A, ...[2]) (10mΩ)
150A plug-in:	0-200mA, 0-600mA, 0-2A, 0-6A, 0-20A, 0-60A, 0-150A
100A shunt:	20A, 60A, 200A, ...[3]) (1mΩ)
Voltage plug-in:	1mV=1A, range 0-20mV, ..., 0-2V

Maximum Save Input:

2A plug-in:	3A, 3 minutes
10A plug-in:	10A, 30 seconds
30A plug-in:	30A, 30 seconds
100A shunt:	200A, 30 seconds
Voltage plug-in:	20V max.

Display:	0-2045 for 2/20/200 ranges 0-6135 for 6/60/600 ranges
with scaling	0-99999
Frequency Range:	DC+AC-Coupling: DC-100kHz AC-Coupling: 15Hz-100kHz
Accuracy:	1 year, 18-25°C, all ranges

True RMS (Ar) Rect. Mean (At) Mean (A=)	±(0.1 % of input + 0.1 % of range) ±(0.1 % of input + 0.2 % of range)	40Hz-1000Hz DC:15Hz-40Hz 1kHz-20kHz
True RMS Mean Rect. Mean	±(2.0 % of input + 0.5 % of range)	20kHz-100kHz

1) 7A per phase cont. 2) 22A per phase cont. 3) 100A per phase cont.

*Detailed Specifications given in section 2.24

Crest Factor:	Exceeds 3:1 at 50 % full scale
Temp. Coefficient:	±(0.01 % of range) /°C

VOLTAGE

Ranges:	2V, 6V, 20V, 60V, 200V, 600V, 1000V[4])
Maximum Input:	All ranges: 1000V RMS or 1400V peak
Display:	0-2045 for 2V, 20V, 200V, 1000V ranges 0-6135 for 6V, 60V, 600V ranges
with scaling	0-99999

Frequency Range: DC+AC-Coupling: DC-100kHz
AC-Coupling: 15Hz-100kHz

Accuracy: 1 year, 18-25°C, all ranges

True RMS (Vr) Rect. Mean (Vt)	±(0.1 % of input + 0.1 % of range) ±(0.1 % of input + 0.2 % of range)	40Hz-1000Hz DC:15Hz-40Hz 1kHz-20kHz
Mean (V=)	±(0.3 % of input + 0.3 % of range)	20kHz-50kHz
True RMS Mean Rect. Mean	±(0.8 % of input + 0.4 % of range) ±(1.0 % of input + 0.4 % of range)	50kHz-100kHz

4) Accuracy limited to 1 minute operating time at voltages >700V.

Crest Factor: Exceeds 3:1 at 50 % full scale

Temp. Coefficient: ±(0.01 % of range) /°C

Input Impedance: 1Mohm / 20pF

Volt-Hertz Product: 1×10^7VHz

POWER

Ranges: (Power ranges result by multiplying current range x voltage range)
2A plug-in: 40mW, 120mW, 360mW, ..., 2000W per phase
10A plug-in: 400mW, 1200mW, ..., 20kW per phase
30A plug-in: 4W, 12W, ..., 60kW per phase
100A shunt: 40W, 120W, ..., 200kW per phase
Voltage plug-in for external shunts: Power ranges depend on shunt resistance

Display (10A plug-in) with scaling: 0-418.2mW, 0-1254mW, 0-3.764W etc. per phase
0-999999

Maximum Input: As in current and voltage section

Frequency Range: DC+AC-Coupling: DC-100kHz
AC-Coupling: 15Hz-100kHz

Temp. Coefficient: ±(0.02 % of range) /°C

Overload: Voltage and current levels exceeding the linear operating range for power measurement are indicated by "I-UP" and "U-UP" Led and by display blanking.

Accuracy: 1 year, 18-25°C, power factor 0.5 to 1.0, all ranges

Continuous sampling	±(0.1 % of input + 0.1 % of range)	40Hz-400Hz
	±(0.1 % of input + 0.2 % of range)	15Hz-40Hz, 400Hz-1kHz
AVG=2	±(0.2 % of input + 0.35 % of range)	DC
Random sampling AVG=4	±(0.5 % of input + 0.3 % of range)	DC-20kHz
	±(1.0 % of input + 0.5 % of range)	20kHz-60kHz
	±(2.0 % of input + 0.8 % of range)	60kHz-100kHz

Accuracy limited to 1 minute operating time at voltage >700V, and currents >7A (10A plug-in), >22A (30A plug-in), and >100A (100A shunt).

For power factor <0.5 multiply accuracy percentage figures by 2.

Apparent Power: Add accuracy percentage figures given for RMS voltage and RMS current.

Magnitude of reactive Power: Add percentage figures given for RMS voltage, RMS current, power and apparent power. For power factors from 0.8 to 1.0 multiply accuracy percentage figures by 2.

Power Factor: Add accuracy percentage figures given for power and apparent power.

Energy: Continuous sampling: 0.4 % of reading
Random sampling: 1 % of reading, DC-20kHz; 3 % of reading 20kHz-100kHz.

Magnitude of load impedance: Add accuracy percentage figures given for RMS voltage and RMS current.

Resistive part of load impedance: Add accuracy percentage figures given for RMS voltage, RMS current and power factor.

General

Input type:	Floating type, inputs are galvanically isolated. Isolation voltage 3kV/50Hz for 1 minute.
Common Mode:	Current input 120dB at 50/60Hz
Rejection:	Voltage input 100dB at 50/60Hz
Display:	40 character, 5mm high vaccum fluorescent display. Four quantities including sign and units are simultaneously displayed. The selected averaging 1, 2, 3, or 4 is always shown in the last character (to the right of the display).
Controls:	The controls below the display are defined in the section "mathematical definition" of the manual. The three controls PF/(I/U), Wh, and |Z|/ReZ have double function purpose. The control PF/(I/U) allows viewing of the selected current and voltage range. The control field to the left of the display is for the selection of the ranging and coupling mode. The control field to the right of the display is for the selection of the sampling mode and run/hold mode. The two controls Phase 1, 2, 3, and Σ P, S, Q are for the selection of the display quantities. The sampling mode "CONT SAMPLING" is provided for signals below 1kHz, and "RAND SAMPLING" is provided for signals above 1kHz.
Response time:	Current and voltage: 1 second to rated accuracy. Power and related quantities: response time depends on sampling mode and averaging. Min. 0.8 sec. (cont. sampling, AVG=1), max. 20 sec. (rand. sampling, AVG=4).
Ranging:	Automatic for current and voltage section, or manual with up-range- and downrange control.
Warm-up time:	2 minutes for reading within specified accuracy.
Power:	220V (110V) +20 %/-10% 50-60Hz/48VA
Size:	H x W x D; 132mm x 450mm x 300mm
Weight:	7.8kg

Recorder Outputs:	The recorder option outputs a user-selectable analog signal proportional to RMS current, RMS voltage, or power. ±2V output for fullscale display. The quantity to be output is front panel selectable. The multifunction recorder (Option 08) outputs 10 signals proportional to 3 x Arms, 3 x Vrms, 3 x W, and W. The signal range is 0-2V. Positive W-display is required. Accuracy 0.4%.
IEEE-488 Interface Functions:	The option allows complete control and data output capability, and supports the following interface function subsets: SH1, AH1, T5, L4, SR1, RL1, DC1, DT1, E1, TPO, and CO.
Frequency Measurement:	Frequency of current signal phase 1 is measured. 10Hz-8kHz. Accuracy 0.2 % ±4Hz.

Specifications subject to change without notice.

1.6. Summary of Programming Functions

Setting Scaling Factors:

Select "HOLD" ⟶ Press "SCALE" ⟶ Press "SCALE A" or "SCALE V" ⟶ Set scaling factor from keyboard numbers ⟶ Press "ENTER" Press "RUN".

Setting 3-Wattmeter or 2-Wattmeter Configuration:

Select "HOLD" ⟶ Press "SCALE" ⟶ Press "AVG" (Display toggels 2-W to 3-W configuration) ⟶ Press "RUN".

Setting Energy Timer Function and Time:

Select "HOLD" ⟶ Press "SCALE" ⟶ Press "WhRES" (The timer function is activated when /T is displayed and deactivated when /- is displayed) ⟶ Press "RUN".

Setting Time:

Select "HOLD" ⟶ Press "SCALE" ⟶ Press "Σ" (Talk-only setting and time are displayed) ⟶ Press "ENTER" ⟶ Set time in seconds from keyboard numbers ⟶ Press "ENTER".

Setting Talk-only Output Functions:

Select "HOLD" ⟶ Press "SCALE" ⟶ Press " Σ " (Talk-only setting and time are displayed) ⟶ Press all those function keys (Ar, Az, Vr, W ...) you want to output to your printer ⟶ Press "ENTER" (The new set of output functions is now displayed) ⟶ Select time in seconds from keyboard numbers ⟶ Press "ENTER".

2. OPERATING INSTRUCTIONS

2.1. Introduction

This section provides instructions for installing and operating the 304B. Refer to section 2.16. for measurement considerations.

2.2. Installation

The 304B has a rear panel power-line fuse in series with the power supply. A 250mA, 250V slo-blo fuse is installed in the factory and the voltage selector switch is set for 195V-250V operation. For operation with power-line voltages of 98V to 125V, the fuse must be replaced by a 500mA, 250V slo-blo fuse and the voltage selector switch set for 98V to 125V operation.

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

2.3. Connecting to Line Power

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

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 304B in a standard 19-inch rack panel using the two rack ears. One rack ear is installed on each instrument side panel.

2.6. Operating Features

When the 304B is turned on, it performs an initialisation of its internal digital circuitry. It then reads in the type of current

plug-in in use, determines the options installed, and sets the internal status. The 304B then assumes the following configuration:

Autorange: Starting in the 1000V range and in the highest current range
Continuous Sampling
Run (Continuous measurement)
AC-Coupling
Averaging 1
Display of phase-1-values: I_{RMS}, U_{RMS}, P, Power Factor

NOTE: When the current plug-in is changed, the 304B must be turned off. A new initialisation is required.

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 1.4. for the definition of the measured quantities.

2.8. Display Features

The 304B features a 40 character vacuum fluorescent display. In the normal RUN- or HOLD-mode four quantities including units are displayed. These quantities are selected in the control field below the display. The last character of the display shows the selected averaging indicated by numbers 1, 2, 3, or 4.

2.9. Overrange / Underrange Indication

A current or voltage input is overrange if it exceeds the full scale of that range or if the instantaneous peak values exceed the operating range of the A/D-converters. The 304B indicates an input (phase 1, phase 2, or phase 3) is overrange by lighting the I-UP or U-UP Led in the range control field and by blanking the corresponding quantity on the display. When the input falls below 30 % of selected range the I-DOWN or the U-DOWN Led is lighted.

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

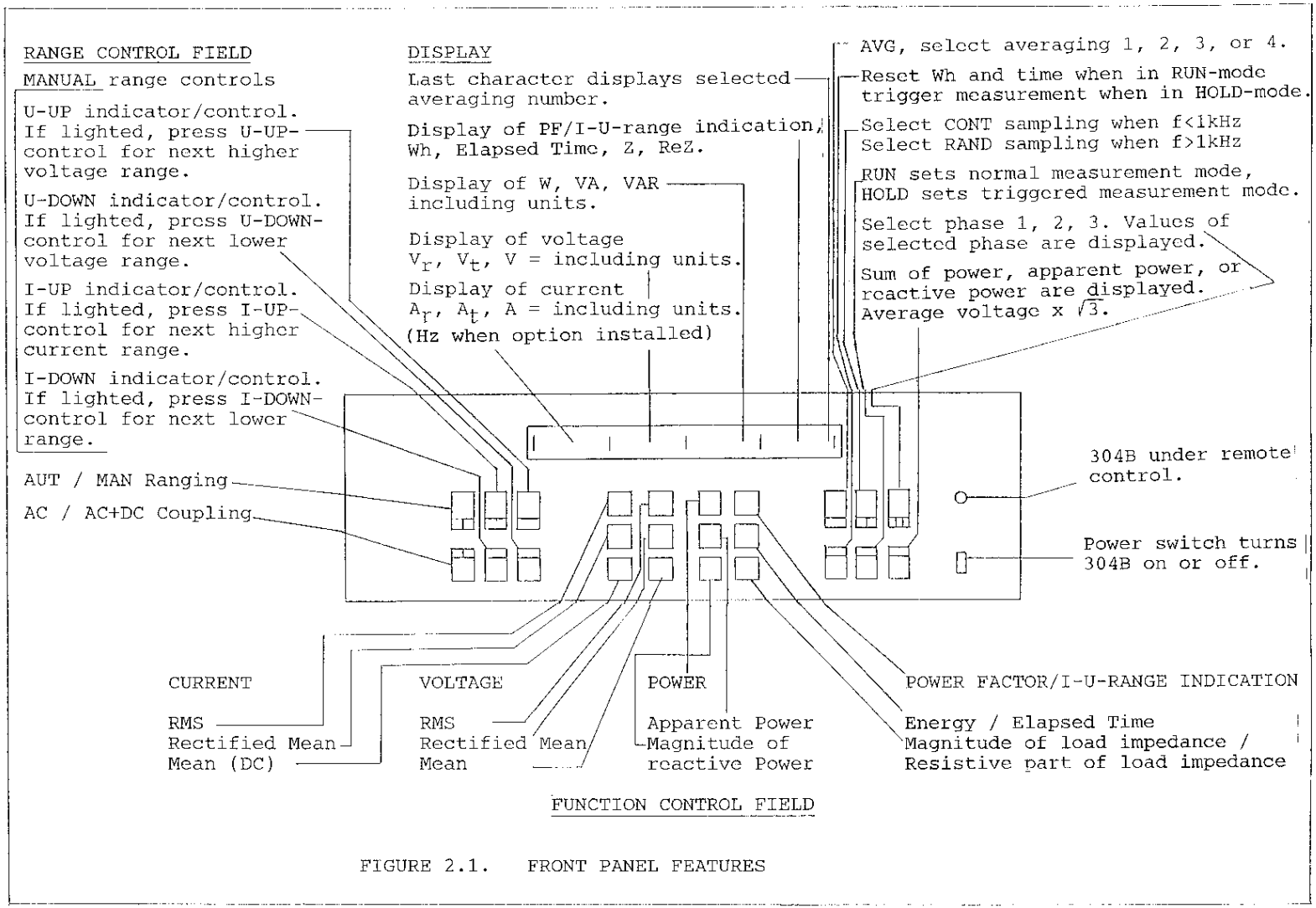


FIGURE 2.1. FRONT PANEL FEATURES

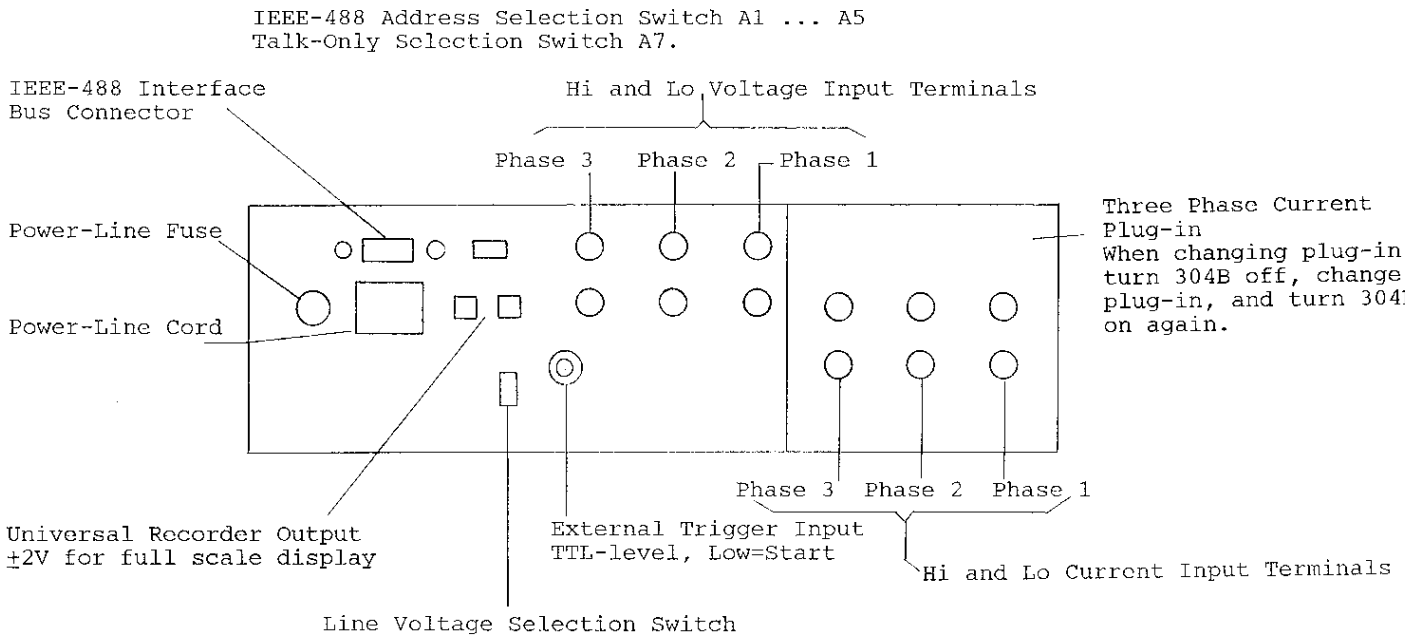


FIGURE 2.2. REAR PANEL FEATURES

2.10. Ranging

Measurement ranges of all three phases can be selected simultaneously using either autorange (Led AUTO is lighted) or manual range (Led MAN is lighted). The 304B displays explicit units in every current and voltage range, so that the displayed quantities may be read directly.

Autorange: In autorange the 304B goes to a higher range when the current or voltage input exceeds 2045, or 6135 counts (ranges are 2/ 6/ 20/ ...), or when the instantaneous peak values exceed the A/D-Converter operating range. The 304B goes to a lower range when the input falls below approx. 30% of full scale (600, resp. 1800 counts). For frequency inverter applications use manual ranging.

Manual-Range: In manual range, the 304B remains fixed in the selected range until you select another range or press AUTO RANGE. The user is guided by the UP- and DOWN range Led indicators. To select the next higher current range press the I-UP control once. To select the next lower range press the I-DOWN control once. The same procedure applies for the voltage ranges.
Always use manual ranging for frequency inverter measurements.

2.11. Sampling

CONT (continuous) or RAND (random) sampling is selected and indicated in the control field to the right of the display. The instrument starts up in the CONT sampling. To select RAND sampling press the sampling control once (Led RAND lights up). To go back to CONT sampling press the sampling control again.

CONT sampling: When the fundamental frequency of current and voltage to be measured is less than 1kHz select CONT sampling. Power is now determined from a minimum of 1800 continuous samples of current and voltage. High harmonic content does not introduce errors. For most power measurements averaging 1 will suffice. CONT sampling should always be selected when the fundamental frequency is less than 1kHz because higher accuracy for power and faster measurement cycles result. Precise power measurements of periodic signals down to 10Hz within one measurement cycle (approx. 0.8 sec.) can be made.

RAND sampling: When the fundamental frequency of current and voltage to be measured is greater than 1kHz we recommend to select RAND sampling.

In RAND sampling mode, power is determined from 1 to 8 measurement cycles. Each measurement cycle consists of 4000 randomly modulated samples of current and voltage. The displayed power value per phase is the average of a number of measurement cycles determined by the selected AVG (averaging) as follows:

AVG	Number of measurement cycles	Number of samples
1	1	4,000
2	2	8,000
3	4	16,000
4	8	32,000

Best accuracy is obtained with AVG=4. With increasing AVG the response time of the instrument to attain the final power value of all three phases is increased, and is for AVG=4 approx. 20 seconds.

2.12. Averaging AVG

The averaging is selected by the control AVG and is always displayed as a number from 1 to 4 in the right most character of the vacuum fluorescent display. Each time AVG is pressed, the AVG number is increased until it reaches 4. Pressing AVG again will reset the AVG number to 1, etc. The AVG-number only affects the power averaging, that is, the number of samples taken for power measurement is controlled by the AVG-number. It does not affect the voltage- or current measurement. The table below shows the dependance of the number of samples and instrument response time to reach final value (P, S, Q, PF, Z) to a step input.

	Number of samples		Power response time, step input	
AVG	CONT	RAND	CONT	RAND
1	> 1,700	4,000	~0.8 sec	~ 2.5 sec
2	> 3,400	8,000	~1.6 sec	~ 5.0 sec
3	> 6,800	16,000	~3.2 sec	~10.0 sec
4	>13,600	32,000	~6.4 sec	~20.0 sec

NOTE: In CONT sampling we recommend to use AVG=1. Only for noisy signals it may be required to increase the averaging.
In RAND sampling the display fluctuates more when a lower averaging number is selected.

2.13. RUN/HOLD, Triggered Measurement

RUN is the normal operating mode of the 304B. When the RUN/HOLD control is pressed the 304B completes the measurement cycle being in an goes then to the HOLD mode. All 48 quantities from the last measurement cycle are stored and can be displayed by depressing the corresponding front panel control. In the HOLD mode the 304B panel, or from the rear panel external trigger input, or from the IEEE-interface. When the 304B is being triggered, one complete measurement cycle is performed with AVG=1. From this measurement cycle 46 quantities are determined and can be displayed after measurement completion. Energy is no longer valied since the required time base in the HOLD mode gets lost.

2.14. External Trigger Input

The rear panel external trigger input is a normally high TTL-level input which can be used to trigger a new measurement cycle when the 304B is in the HOLD mode. A measurement is started on a low level of minimum 2ms duration.

2.15. Measurement Cycle

The 304B determines 48 quantities of a 3-phase system in a single measurement cycle. In continuous sampling this is basically done as follows: During the first 180ms-time interval power of phase 1 is determined. Similarly, during the second and third 180ms-time interval power of phase 2 and phase 3 is determine. Now, the outputs of all voltage- and current converters (18 total) are read into memory. From the measured quantities the remaining quantities are computed. Finally, the 304B performs various control- and display functions. This concludes a complete measurement cycle.
In the random sampling mode the sequence of measurements is the same as in continuous sampling except that the 180ms-time intervals for determining power are increased to 480ms each.

2.16. Display Features of the 304B

Figure 2.1. describes the basic display capabilities of the 304B. They can be summarized as follows: When phase 1 is selected, values from phase 1 are displayed. When phase 2 is selected, values from phase 2 are displayed. When phase 3 is selected, values from phase 3 are displayed. For the description to follow this display configuration is called "display mode 1".
In addition to the display capabilities described above the 304B allows the simultaneous display of 4 currents, 4 voltages, or 4 power values. This display configuration is called "display mode 2".

From left to right, the phase-1-value, the phase-2-value, the phase-3-value are displayed. The fourth display value is the average current of all three phases, the average voltage of all three phases, or the sum of power of all three phases.

The 304B starts-up in display mode 1, phase 1, as shown below:

Ar1	Vr1	W1	PF1	1

Ar1 = RMS current phase 1
Vr1 = RMS voltage phase 1
W1 = power phase 1
PF1 = power factor phase 1

To obtain a simultaneous display of the RMS currents of all three phases, enter display mode 2 by pressing the "Ar"-key. The following display results:

Ar1	Ar2	Ar3	Ar	X

Ar1, Ar2, Ar3 = RMS current of phase 1, 2, and 3.
Ar = average RMS current
X = AVG

To display the 3 rectified mean currents press the "At"-key.

At1	At2	At3	At	X

At1, At2, At3 = rectified mean current, phase 1, 2, and 3.
At = average current

To display the mean currents press the "A="-control.

A=1	A=2	A=3	A=	X

Display mode 2 can be left by pressing the "Ar"-control twice. When RMS currents are displayed, press the "Ar"-key only once to leave mode 2.
To obtain a simultaneous display of the RMS voltages of all three phases, display mode 2 must be entered again. First, bring the RMS voltage of any phase to the display and press the "Vr"-control one more time. This will start mode 2, the following display results:

Vr1	Vr2	Vr3	Vr	X

X = AVG
Vr1, Vr2, Vr3 = RMS voltage phase 1, 2, 3.
Vr = average RMS voltage

Press $\sum$ control to display the average line-to-line voltage Vr · $\sqrt{3}$. Press the "Vt"-control to display the rectified mean voltages of all 3 phases. Similarly, press the "V="-control to display the 3 mean voltages.
Again, display mode 2 is left by pressing the "Vr"-control twice. (When RMS voltages are displayed, mode 2 is left by pressing the "Vr"-control only once).
To display the power values of phase 1 through phase 3, display mode 2 must be entered as follows: Bring the power value of any phase to the display. Press the "W"-control again. This starts display mode 2, the following display results:

W1	W2	W3	W	X

X = AVG
W1, W2, W3 = power values phase 1, 2, 3.
W = W1 + W2 + W3

To display the 4 apparent power values press the "VA"-control.
To display the 4 reactive power values press the "VAR"-control.
To change to display mode 1, the "W"-control must be pressed twice.
The skilled operator will find short cuts to operate the display. For example, the display of 3 RMS currents can directly be switched to the display of 3 RMS voltages by simply pressing the "Vr"-control. A similar change from current to power, and voltage to power is possible.

2.17. Current- and Voltage Scaling

Although the 304B offers a broad input current range (20mA-150A) and a broad input voltage range (2V-1000V), the scaling of current and voltage becomes necessary, when current- and voltage transformers, or external high current shunts are used. All 48 quantities are scaled and their correct values displayed.
The following maximum display values are possible:

Current:	99999kAr	(kAt)	(kA=)
Voltage:	99999kVr	(kVt)	(kV=)
Power:	999999 MW	(MVA)	(MVAR)

The 304B stores the scaling factors in non-volatile memory. On power-up the 304B reads the scaling factors from this memory. The voltage- and the current scaling factors can be set anywhere in the range from 0.0001 to 999999. In practice although, the scaling factors for currents should not differ from each other by more than a factor of 10. Also the voltage scaling factors should not differ from each other by more than a factor of 10. Should the difference be larger than 10, a display overflow may occur without warning. As a rule, choose phase 1 (voltage and current) as the phase with the largest scaling factor.
The scaling factors are changed by means of the front panel controls as described below:

⟶ Select "HOLD" mode

⟶ Press "SCALE"

⟶ Press "SCALE A" for current scaling factor change.
The scaling factors for phase 1, 2, and 3 are now displayed.
Enter scaling factor for phase 1 as follows: e.g. 10; format 10/10./10.0 ⟶ Press "ENTER". (The scaling factor 10.000 is now displayed).
Enter scaling factor for phase 2 as follows: e.g. 9.875; format 9.875/9.8750 ⟶ Press "ENTER".
Enter scaling factor for phase 3 as follows: e.g. 5.04; format 5.04/5.040 ⟶ Press "ENTER".
Press "SCALE V" for voltage scaling factor change. The voltage scaling factors for phase 1, 2, 3 are now displayed. Enter the voltage scaling factors following the same procedure as described above.

In the following example the scaling factors for all three phases be equal 100.
Format 100/100./100.0 ⟶ Press "ENTER" (sets scaling factor phase 1=100) ⟶ Press "ENTER" (sets scaling factor phase 2) ⟶ Press "ENTER" (sets scaling factor phase 3).
Press "RUN". This concludes the procedure.

NOTE 1: The decimal point is set by the "AC/AC+DC"-key.
NOTE 2: When any of the 6 scaling factors differs from 1.0, a display indication results. The 40. display character will alternatly display AVG/F.

Scaling when using External Current Shunts

Use Option 012. This plug-in will accept shunt voltages in the range 0-2V sensitivity 1mV=1A. Below 3 examples for scaling factor determination are given:

Shunt resistance	Shunt sensitivity	Scaling factor
1.071mΩ	1.071mV = 1A	1mV/1.071mV = 0.9337
20.0 mΩ	20.0 mV = 1A	1mV/20.0 mV = 0.05
0.180mΩ	0.18mV = 1A	1mV/0.18 mV = 5.555

Scaling Current and Voltage to avoid high Common Mode

In switched 3-phase systems extreme common mode signals occur. Switching transients of 2000V/us in the current- and voltage paths are observed. Such transients upset the wattmeter. The feed-through is so high, that the microprocessor looses information.
The 304B must be turned off and on again to start an initialization. This measuring problem can be solved, when external current- and voltage transformers are used.
The least to do is to follow the recommendations of section 2.20.3.

2.18. 2-Wattmeter-/ 3-Wattmeter-Programming

In conventional 50/60Hz 3-phase networks power can be measured using the 2-Wattmeter connection (Aron circuit). In this configuration only 2 current inputs and 2 voltage inputs of the 304B are used. Apparent power Irms x Vrms must be reduced by the factor 0.866. By programming the 304B to the 2-Wattmeter configuration this reduction is automatically done. We recommend to short the unused voltage input of the 304B.

The programming is performed as follows:

——→ Select "HOLD"

——→ Press "SCALE"

——→ Press "AVG"
The scaling factors (for voltage or current) and the selected "2-W" or "3-W" configuration are now displayed. Pressing the "AVG"-key toggels the wattmeter configuration back and forth.

——→ Select the desired configuration

——→ Press "RUN" to continue measurement.

NOTE: The programmed Wattmeter configuration remains stored in non-volatile memory. Turning the 304B off and then on again does not reset this function.

2.19. Energy Timer Programming

A programmable timer for energy summation is a standard feature of the 304B. The timer can be set between 0 and 32760 seconds (9.1 hours). When pressing the "WhRes"-key energy and time are reset to zero. From now on energy is summed until the elapsed time has reached the preset time of the timer.
Energy summation is stopped until reset or until the timer value is increased.
The energy can be displayed by pressing the "Wh" control. By pressing "Wh" a second time the total elapsed time is displayed. Both quantities are in exponential form (leaving out the "E"). The maximum display is 9.999+9 (9.999E+9).

The following two steps are required:

1. Activate the timer function as follows:

   ——→ Select "HOLD"

   ——→ Press "SCALE"

   ——→ Press "WhRES"
   The display shows now scaling factors, 2/3-W configuration, and /T/ (Timer active) or /-/ (Timer not active).
   When pressing "WhRES" the timer function toggels.

2. Set the desired time as follows:

   ——→ Select "HOLD"

   ——→ Press "SCALE"

   ——→ Press " Σ "
   The Talk-only programming and time are now displayed.

   ——→ Press "ENTER"

   ——→ Select the desired time in seconds (max. 32760 s) and press "ENTER" again. The selected time is displayed.

   ——→ Press "RUN" to get back to the Run-mode.

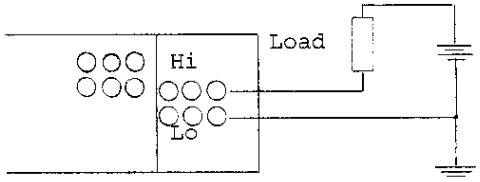
2.20. Taking Some Basic Measurements Using the 304B

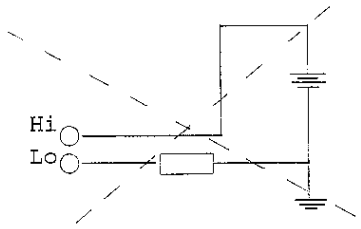
WARNING: To avoid shock hazard and/or instrument damage, do not apply input potentials that exceed the input overload limits specified in section 1.5.

The specified maximum inputs may be applied to the 304B on any voltage and current range without damage.

2.20.1. Measurements in 1-Phase Systems

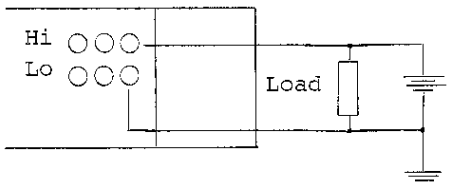
Measuring current

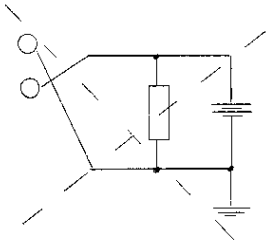




Measure current preferably on the ground side to minimize common mode voltage. Although the 304B has excellent common mode rejection, high common mode voltages at frequencies above 50kHz may result in incorrect measurements. This behaviour is caused by parasitic capacitances resulting from the heat sinking of the high current input.

Measuring voltage



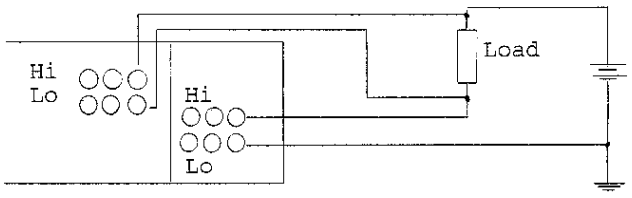


Measure voltage preferably by connecting the Lo-side on the load to the Lo-voltage input and the Hi-side of the load to the Hi-voltage input.

Measuring 1-phase power

Measuring power is a difficult task. A high degree of amplitude- and phase-accuracy is required to obtain reliable measurements. There are many wrong ways to hook up a 1-phase system and only one right way.

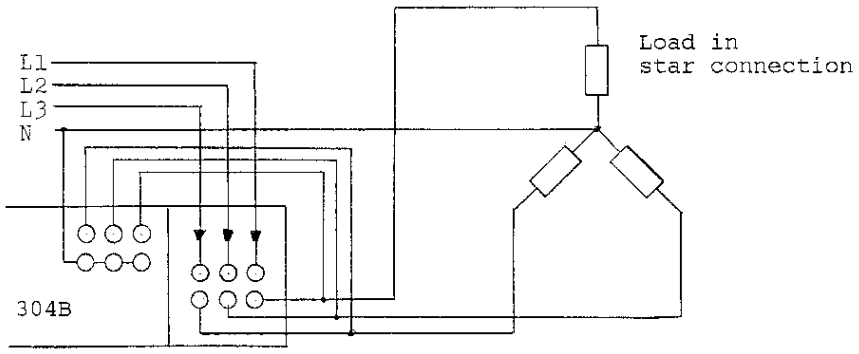
RULE: Measure current always at the point which is closest to ground potential.
Connect the Hi-side of the load to the Hi-voltage input and the Lo-side to the Lo-voltage input.



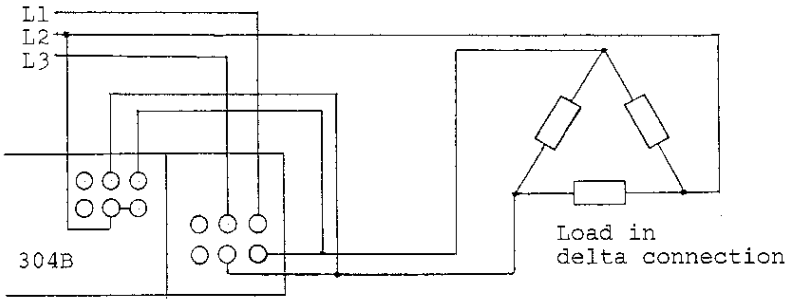
Observing this rule, minimizes the common mode effects; precise power measurements up to 100kHz can be made.
Measuring current on the high side of the load will expose the current input to large common mode voltages. Particularly at high frequencies the common mode error signals increase and introduce amplitude- and phase errors, which in turn yield ambiguous power measurements.

2.20.2. Measurements in Polyphase Networks

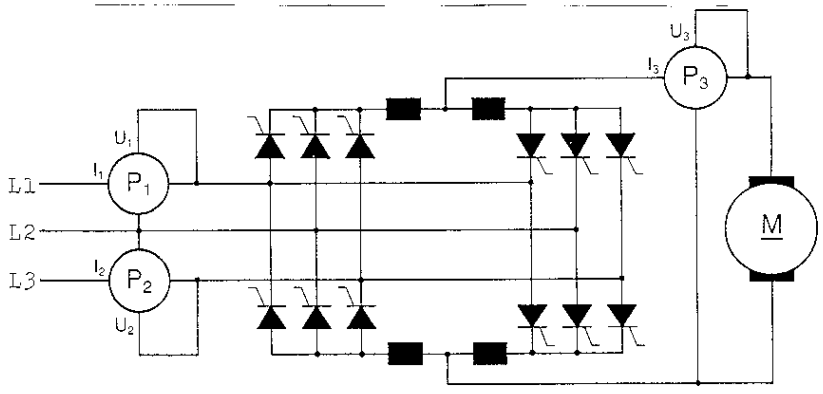
The rules given for measurements in 1-phase systems must partly be violated when making measurements in polyphase systems. Most of the time currents are measured on the Hi-side of the load exposing the current inputs to large common mode voltages. Similarly, when measuring the phase to phase voltages of a three wire 3-phase system the voltage inputs are also exposed to large common mode voltages. Fortunately, the common mode rejection of the 304B is excellent for typical polyphase-network-frequencies (50Hz, 400Hz) and requires no special care. At all times the user must be aware that the common mode rejection of the 304B decreases with increasing operating frequency of a polyphase system. Performing measurements on a polyphase system operating below 10kHz should pose no major problem unless the operating voltage is large (>100V). At frequencies above 10kHz we recommend to use filters to get the highest frequencies out of the system.



304B measures phase voltages, phase currents, and phase power of a 3-phase 4-wire circuit.



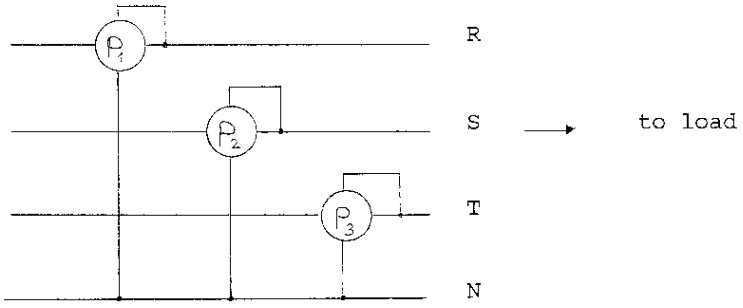
304B in an Aron Connection measures total power P1 + P2 consumed by a load in delta connection. Voltages U1 and U2 are phase to phase voltages. I1 an I2 are phase currents. Switch 304B to 2-Wattmeter configuration. S=S1 + S2, Q=Q1 +Q2, and PF are connected by appropriate factor (for 50/60Hz applications).



304B measures power loss (P1 + P2 - P3) of a 3-phase thyristor controlled rectifier. P1 + P2 represents total AC-power at input and P3 represents total (DC-) power consumed by the motor.

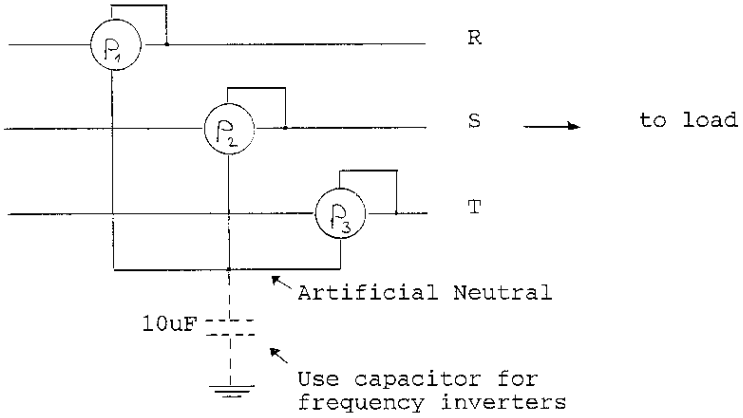
2.20.3. 304B Measurements in Frequency Inverter Systems

To avoid high common mode voltages at current inputs use Option 13 (Broad band transformer input).



Three Wattmeter Method in 3-Wire Circuit

Use artifical neutral to avoid high common mode voltages at Lo-voltage input terminals.



$P = P_R + P_S + P_T$

$S = S_1 + S_2 + S_3$

$Q = Q_1 + Q_2 + Q_3$

$PF_K = P_K/S_K$ ..... ; $\Sigma PF = (P_1 + P_2 + P_3) / (S_1 + S_2 + S_3)$

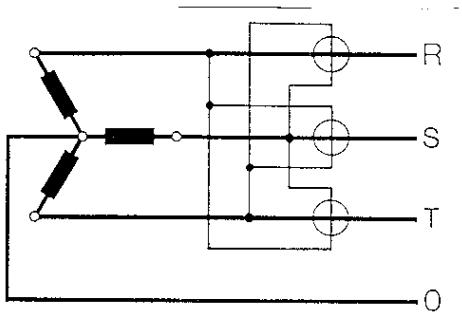
U = Line-voltages
I = Line-currents

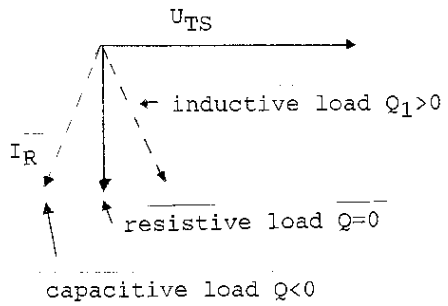
2.20.4. Positive and Negative Reactive Power Measurement

Reactive Power Measurement for 50/60Hz

1. 3-phase 4-wire circuit

$P_1 = U_{TS} \cdot I_R \cdot \cos\varphi_R = Q_1$



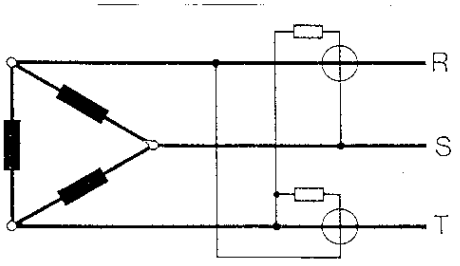


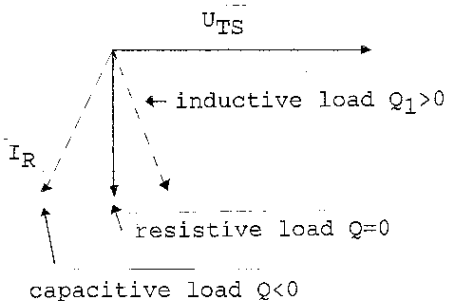
Switch wattmeter to display watt. The displayed values are (positive or negative) reactive power values in VAR.

NOTE: Devide by 1.732 to obtain reactive power per phase.
VAR = VAR1 + VAR2 + VAR3) /1.732.

2. 3-phase 3-wire circuit

$P_1 = U_{TS} \cdot I_R \cdot \cos\varphi_R = Q_1$





Switch wattmeter to display watt.
Total reactive power (positive or negative)
VAR = VAR1 + VAR2

2.21. Programmable Recorder Output (Option 05)

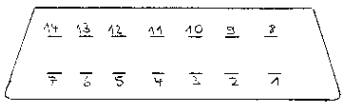
The recorder output option gives the 304B the ability to output a positive or a negative analog signal proportional to power. RMS voltage, or RMS current of phase 1, phase 2, or phase 3. Full scale display of power, voltage, or current corresponds to ±2Vdc on the recorder output. On 304B power-up the recorder output is initialized to output power of phase 1. On every display-update the recorder is also updated.
If another quantity than P1 wants to be output the following procedure (starting in the "RUN" mode) is required: Select AVG (1, 2, or 3) ⟶ Select Phase (1, 2, or 3) ⟶ Press "Hold" ⟶ Press AVG twice ⟶ Press "RUN". AVG and Phase in the above procedure determine the recorder output quantity.

The table below summarizes the recorder output capabilities.

Recorder Output	AVG=1	AVG=2	AVG=3
Phase 1 Phase 2 Phase 3	Irms 1 Irms 2 Irms 3	Urms 1 Urms 2 Urms 3	P1 P2 P3
Output at full scale display	+2Vdc (200.0mA/ 600.0mA ...)	+2Vdc (2V/6V ...)	±2Vdc (400mW/ 1200mW ...)
Control sequence for recorder output selection: Select "AVG" ⟶ Select Phase ⟶ Press "HOLD" ⟶ Press "AVG" twice ⟶ Press "RUN".			

2.22. Multifunction Recorder Output (Option 08)

This Option outputs 10 signals proportional to 3 x Arms, 3 x Vrms, 3 x W, and W. Full scale display (2V/2A/4W) corresponds to 0-2V at the recorder outputs. The outputs are updated with the display update. Only positive displays can be output. When a single W-display is negative its recorder output goes to zero and the total sum (W) is no longer valid.
Recorder output connector:



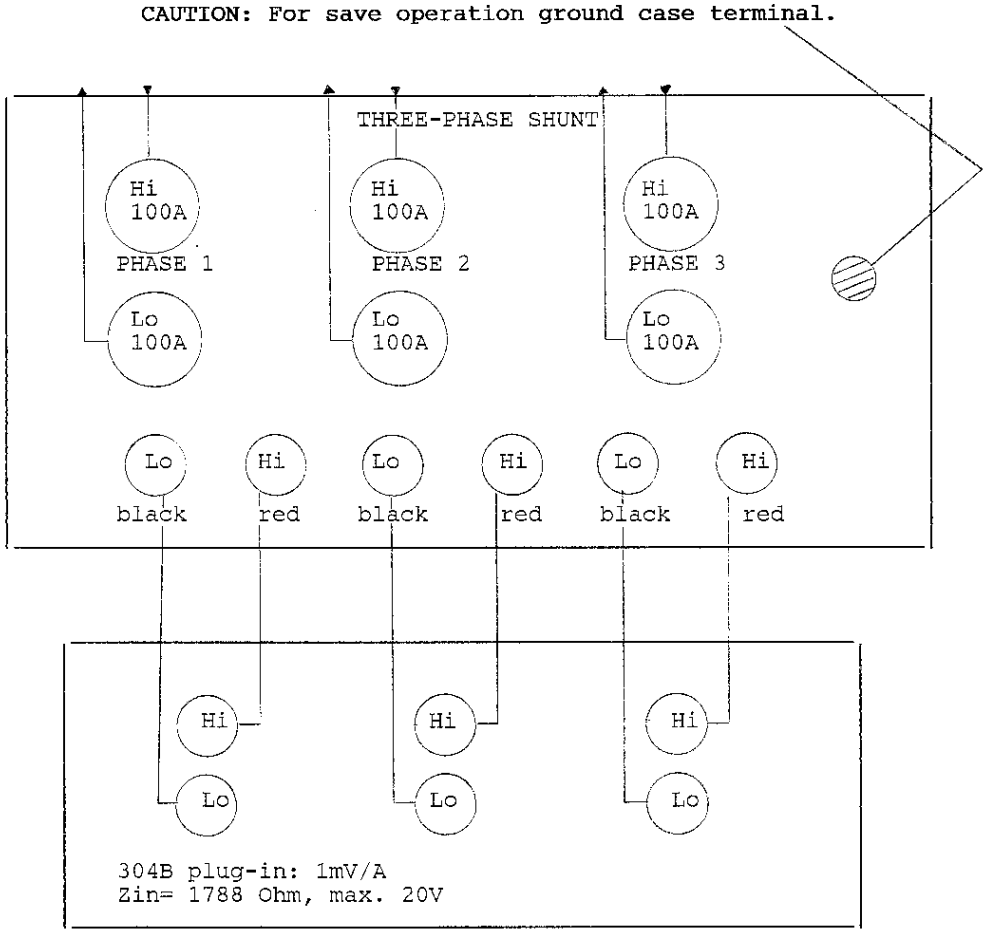
pin 1	W phase Σ1+2+3	pin 8	Ground
2	W phase 3	9	
3	W phase 1	10	W phase 2
4	Vrms phase 3	11	
5	Vrms phase 1	12	Vrms phase 2
6	Arms phase 3	13	
7	Arms phase 1	14	Arms phase 2

Recorder Output

2.23. 100Ampere 3-Phase Shunt (Option 04)

MAX. 100A PER PHASE

CAUTION: For save operation ground case terminal.



Accuracy: Multiply accuracy percentage figures given for current and power by a factor of 2.

Caution: Do not use 100A shunt at frequencies above 1kHz. Faulty measurements may result.

2.24. Broad Band Plug-in for 0-150A

Option 13 is a wide current range broad band plug-in particularly useful for high current measurements in frequency inverter systems with DC-components.
The plug-in has a low current direct input like the standard 0-10A plug-in, and a high current input via broad band transformers. The scaling to be used for the broad band transformers is as follows: 1 winding; scaling=10.0, 2 windings; scaling=5.0, 3 windings; scaling=3.333, etc. The hole diameter for the windings is 10mm. The plug-in requires 3 internal ±12V supplies for the broad band transformers. Therefore, it is of advantage to have this option factory installed.

Specifications

Inputs:

Direct input:	0-200mA, 0-600mA, 0-2A, 0-6A, 0-8A Max. 8A continuous.
Transformer input:	0-2A, 0-6A, 0-20A, 0-60A, 0-150A Scaling factor = 10/number of windings Max. 150A continuous
Accuracy:	(current and power)
Direct input:	As specified on data sheet for 10A plug-in. DC: additional DC-error max. ±20mA.

Transformer input: (current x windings >30A)

± (0.2 % of display + 0.2 % of range) 10Hz-400Hz
± (0.4 % of display + 0.4 % of range) 400Hz-1kHz
± (2 % of display + 0.4 % of range)* DC, 1kHz-20kHz
± (3 % of display + 0.5 % of range) typ.* 20kHz-50kHz
DC: DC Offset error max. ±0.2A
*Power factor >0.7

WARNING: When removing plug-in disconnect cabels carefully. To avoid shock hazards close opening of the three connectors with isolating tape.
Insert new plug-in carefully without squeezing cabels.

IMPORTANT: When reinstalling 0-150A current plug-in (Option 15) make sure to connect cable phase -1 to phase -1- input of current plug-in, cable phase -2 to phase -2- input of current plug-in, and cable phase -3 to phase -3- input of current plug-in.
Interchanging cables may cause shock hazard.

2.25. Frequency Measurement (Option 14)

Option 14 measures the frequency of the current wave form of current amplifier phase 1. It is particularly suitable for speed measurements on inverter driven motors. Basically, the zero crossings of the current wave form are counted.
Consequently, a more or less sinusoidal current wave form is required.
The frequency is displayed in Hz by pressing the "At" control and selecting phase 1, or by entering display mode 2 and pressing the "At" key. The following display results:

Hz	At2	At3	0	X

The average value of At is set to zero.

The frequency can be read over the IEEE-488 interface with the "F2" command. The first number in the 4-number string is the frequency in Hz.

Specifications

Frequency range:	10Hz-8000Hz
Accuracy:	0.2 % ±4Hz
Measuring input:	current input phase 1
Sensitivity:	Selectable by current range

2.26. Other 304B Programming Functions

The programming functions described below are factory installations.
When one of the recorder outputs or the frequency measurement option is installed the 304B must be programmed accordingly.
The following steps are required:

1. Option Initialisation

——→ Select "PHASE 2"
——→ Select "HOLD"
——→ Press "SCALE"
——→ Press "U UP" (All Option programming is removed)
——→ Press "RUN"

2. Multifunction Recorder Installation (Option 08)

No further programming action is required. Make wire connection from connector J10, pin/2 to U505, pin 12 on Encoder PCA Figure 7.13.

3. Programmable Recorder Installation (Option 05)

——→Select "PHASE 3"
——→Select "HOLD"
——→Press "SCALE"
——→Press "I UP" (Sets internal status)
——→Press "RUN"

4. Frequency Measurement Installation (Option 14)

——→ Select "PHASE 2"
——→ Select "HOLD"
——→ Press "SCALE"
——→ Press "I UP"
——→Press "RUN"

Display must show "/Hz". Pressing "I UP" toggels between /Hz (Frequency measurement active) and /-- (Frequency measurement not active).

2.27. 304BT Precision Wattmeter for Transformer Testing

2.27.1 Introduction

The special version wattmeter 304BT is designed for use in transformer test applications. It shows improved accuracy at power factors of 0.1 or less. Additional quantities required for transformer testing are computed. A programmable Talk-Only-Mode is provided to print data in selected time intervals. The scaling factors and the selected parameters for the Talk-Only operation are stored in non-volatile memory. For improved accuracy the input currents for the standard 0-10A plug-in is limited to 0-375mA, 0-750mA, 0-1.5A, 0-3A, and 0-6A ranges (5A maximum, continuous).
In addition, version 304BT measures the line-to-line rms- and rectified mean (Option) voltages (V1-2, V2-3, and V3-1) for a fixed 0-480V range. Infratek advises not to use the 304BT wattmeter in frequency inverter systems unless the line-to-line voltage measurement is omitted.

2.27.2. Computed Quantities

All values as defined on page 1.3 for the standard 304B wattmeter are valid. In addition, the transformer test wattmeters compute the following quantities:

Average Voltage:

RMS voltage	=	1/3 (Vr1+Vr2+Vr3)	= Vr
Corrected rect. mean voltage	=	1.1107 Vti(i=1,2,3)	= Vti
Corrected rect. mean voltage	=	1.1107/3 (Vt1+Vt2+Vt3)	= Vt
RMS line-to-line voltage	=	V_{RS}, V_{ST}, V_{TR} = V12, V23, V31	
Rect. mean line-to-line voltage	=	V_{RSt},V_{STt},V_{TRt}, x1.1107	

Average Current:

RMS current	=	1/3 (Ar1+Ar2+Ar3)	= Ar
Corrected rect. mean current	=	1.1107 Ati(i=1,2,3)	= Ati
Corrected rect. mean current	=	1.1107/3 (At1+At2+At3)	= At

Power:

$$\text{Corrected power per phase} = \frac{P_m}{0.5 + 0.5\,[(Vr/Vt)\,]^2} = P_{Ci}$$

$$\text{Sum of corrected power} = P_{C1} + P_{C2} + P_{C3} = P_C$$

NOTE: The line-to-line rms voltages are displayed by pressing the "V= control". The line-to-line rect. mean voltages are displayed by pressing the "A= control".

2.27.3. Specifications

Unless stated differently, the specifications of the standard 304B are applicable.

Average current and voltage:

Same accuracy percentage figures as given for standard 304B are applicable.

Line-to-line voltage: (rms and rectified mean)

50/60Hz, (0.15 % of input +0.15 % of range)

Current ranges: (enter appropriate scaling factor)

0-10A plug-in:	375mA, 750mA, 1.5A, 3A, 6A max. 5A, scaling =1
0-2A plug-in:	37.5mA, 75mA, 150mA, 300mA, 600mA max. 2A, scaling = 0.1
0-30A plug-in:	3.75A, 7.5A, 15A, 30A, (60A) max. 20A, scaling = 10
Voltage plug-in:	max. 2V, scaling depends on shunt
Voltage ranges:	15V, 30V, 60V, 120V, 240V, 480V, 960V
Line-to-line voltages:	0-480V, can not be scaled

Power:

(Use AC+DC-Coupling, continuous sampling, AVG=3)
16Hz-400Hz: (0.05 % of input + 0.03 % of range), PF = 0 to 0.1

Corrected Power:

Accuracy percentage figures depend on accuracy percentage figures of power, rms voltage, and rectified mean voltage.

Automatic Decimal Point Selection:

At all times power is displayed as a 5 digit number independant of power factor. The decimal point is automatically shifted to the left. (Example: Power range = 400.00W; display at power factor 0.01 is 4.0000W)

Current Scaling and Voltage Scaling:

Current- and voltage inputs can be scaled individually with the S1 through S6 commands.

Talk-Only Operation:

The quantities to be printed can be programmed. The time intervals for print-out can be set from 1 to 32760 seconds.

Measurement Cycle:

Approximately 1 display update per second. 51 quantities are determined simultaneously.

2.27.4. Display Features for the 304BT

The display features of the transformer test wattmeter and the standard 304B wattmeter are basically the same. In this section differencies to the standard 304B are explained.

In display mode 1 average currents (Ar, At, A=), average voltages (Vr, Vt, V1), and sum of power (W, VA, VAR) are displayed when the " Σ - control" is activated. In display mode 2, always 4 current values, 4 voltage values, or 4 power values are displayed. The right most current values or voltage values are average values as defined in section 2.23.
When displaying power, the right most values is the sum of power (W, Wc, VA, Var). Corrected power is displayed when first the "W-control" and then the "Σ - control" is pressed (display mode 2).
The line-to-line voltages are displayed by pressing the "V= control", and the "A= control", respectively. From left to right the voltages are: V12, V23, and V31. The right most value is the average value of the three voltages.

2.27.5. Remote Programming

The interface programming corresponds to the standard 304B wattmeter. Deviations are listed here.
There are always 4 current values, or 4 voltage values, or 4 power values output to the interface bus - just as displayed on the display. F3 and F6 are the output function commands for the line-to-line voltages, and H5 is the output function command for the corrected power values (Pc1, Pc2, Pc3, and Pc).
When currents, voltages, or power values are output to the controller, the data format is the same as the one used on the display (phase-1-value, phase-2-value, phase-3-value, and average or sum value).

Set Commands S1 through S6

S1	Set current scaling factor phase 1:	Format S1 2.556
S2	Set current scaling factor phase 2:	Format S2 1
S3	Set current scaling factor phase 3:	Format S3 5.801
S4	Set voltage scaling factor phase 1:	Format S4 105.2
S5	Set voltage scaling factor phase 2:	Format S5 98
S6	Set voltage scaling factor phase 3:	Format S6 150.5

Only one command Si must be sent at a time.

2.27.6. Talk-Only Programming

The Talk-Only start-up procedure is described in section 3.20 of this manual. The printer used must have IEEE-488 handshake capabilities, otherwise data will not be transferred in an orderly manner.

The programming of the desired printer output is done as follow:

1. Press "HOLD"

2. Press "SCALE"

3. Press "Σ"
   The present programming status is now displayed. "F 1 2 3 ..." and "H 1 2 3 ..." correspond to the output function commands on page 3.6 of this manual.
   "Time xxx s" is the time interval for printer outputs (1 x to max. 32760 s).

4. Press now all those controls in the function control field (in center below the display) which gives you the desired printer output (Ar, At, A=, Vr, Vt, V=, W, Va, VAR, PF, Wh, Z).

NOTE: When selecting "W" the output functions F7 (power) and G5 (corrected power) are activated. There is no means to select G5 (corrected power) only.
To terminate the output function selection press "ENTER". In case you do not want to change the output functions shown on the display, you must still press "ENTER" to proceed to step 5.

5. In this step the time interval is selected by pressing the appropriate number (0 1 2 ...) in the function control field below the display.

The maximum number to be entered is 32760s, larger numbers are truncated.
To terminate the time interval selection press "ENTER". If no time interval change is required, press "RUN" to leave the Talk-Only programming mode.

6. Press "RUN" to terminated the programming cycle.

Press "Σ" to repeat the Talk-Only programming if desired. This brings you back to step 3. Furthermore, the described programming can be interrupted at any step by pressing "RUN".
To start the Talk-Only-Operation follow the procedure described in section 3.19.
In Talk-Only operation data are printed in the programmed time intervals. Furthermore, data are printed everytime the "HOLD" mode is entered. By setting a long time interval, this way a manual printer activation is achieved whenever the "HOLD" control is pressed.

2.27.7. Activating the Rectified Mean Voltage Measurement

When the electronics for the rectified mean voltage measurement is installed, the wattmeter software has to be activated as described below. This normally has to be done only once in the factory, or, if by false manipulation, the rectified mean voltage measurement was disactivated.

→ Select "HOLD"
→ Press "SCALE"
→ Press "I UP"
→ Select "RUN"

} Activation of rectified mean voltage measurement

Below is described how this measurement can be switched off:

→ Select "HOLD"
→ Press "SCALE"
→ Press "U UP"
→ Select "RUN"

} Deactivation of rectified mean voltage measurement

2.28.1. 304BM Precision Wattmeter for Motor Testing

2.28.1. Introduction

The Precision Wattmeter 304BM is a special purpose instrument for AC and DC motor-testing. The 304BM features a wide frequency range (DC-100kHz, in most ranges DC to 200kHz) and is capable of measuring power of frequency inverter driven motors. Three additional DC inputs from external transducers can be used to measure torque, speed, frequency, and mechanical power of a motor under test.

2.28.2. Computation

The 304BM measures and computes the same quantities as the standard instrument 304B with the exception of the rectified mean voltage V_t which is no longer available.
The following additional quantities are determined:

Average line-to-line voltage: $\sqrt{3}/3\ (V_1 + V_2 + V_3)$

Mechanical quantities:

From the 3 DC inputs DC1, DC2, and DC3 the following quantities are computed and can be displayed by pressing the "Vt" control.

Torque [Nm]	=	DC1 · C1
Speed [R/m=/min]	=	DC2 · C2
Frequency [Hz]	=	DC3 · C3
Mechanical Power [Wm]	=	$(2\pi/60)$ · DC1 · C1 · DC2 · C2

C1 = Scaling factor for DC1 - input (0-99999)
C2 = Scaling factor for DC2 - input (0-99999)
C3 = Scaling factor for DC3 - input (0-99999)

NOTE: The mechanical quantities are displayed by pressing the "Vt"-control (display mode 1 or 2).

2.28.3. Specifications

Unless written otherwise the specification of the standard 304B are valid.

Current Ranges: (enter scaling factor)

0-2A Plug-in:	37.5/75/150/300/600mA, scaling = 0.1
0-10A Plug-in:	375/750mA, 1.5/3/6A, scaling = 1
0-30A Plug-in:	3.75, 7.5, 15, 30, (60)A, scaling = 10
0-150A Plug-in:	direct 375/750mA, 1.5/3/6A, scaling = 1 LEM 7.5/15/30/60/120A; scaling = 20

Voltage Plug-in: 1.875=1A, 2V=Full scale

Voltage Ranges: 15V, 30V, 60V, 120V, 240V, 480V, 960V

DC-Inputs, DC1, DC2, DC3:

Voltage Range: 0-2V, use external devider for 0-10V range and scale accordingly

Accuracy: 0.2 % of range

Input Resistance: 100kOhm

Input Isolation: All inputs are galvanically isolated from each other and from main electronics.

Input Connector: 14-pol Amphenol on rear panel
DC1: +/- pins 8/1
DC2: +/- pins 9/2
DC3: +/- pins 10/3

Scaling: Individual scaling from 0-99999

Automatic Decimal Point Selection:

Power is at all times displayed by a 5 digit number. The decimal point is shifted depending on the power factor (e.g. Full scale display 400.00W, display at 0.01 power factor is 4.0000W).

Scaling:

The voltage- and current scaling factors as well as the DC-input scaling factors can be programmed either manually on the front panel or bus controlled over the IEEE-488 interface bus. To programm the scaling factors C1, C2, and C3 for the 3 DC-inputs proceed as follows: Select Σ-control (Led on), select HOLD and then follow the same steps as required for programming the voltage scaling factors.

Measurement Cycle:

The display is updated every second. 48 quantities are measured, computed, and stored.

2.28.4 Display Features of the 304BM

Basically the display features correspond to the display features of the standard instrument 304B. The deviations are described below.

$\sqrt{3}$ x average voltage is displayed when the Σ control is active. The four mechanical quantities are displayed by pressing the "Vt" control. In display mode 2 the left most display value is the torque [Nm], the speed [R/min], the frequency [Hz], and the fourth display value is mechanical power in mWm, Wm, kWm, or GWm.
In display mode 1 a single mechanical quantity is displayed and is selected by Phase 1, 2, 3, and Σ.

2.28.5. Interface Programming

The programming is identical to the programming of the standard 304B. With the command F5 all 4 mechanical quantities can be read from the 304BM.
With the set command S1 through S9 the scaling factors for current, voltage, and DC-inputs are programmed. Only one constant can be set at a time.

S1	Current scaling factor phase 1	e.g. S1 2.556
S2	Current scaling factor phase 2	
S3	Current scaling factor phase 3	
S4	Voltage scaling factor phase 1	
S5	Voltage scaling factor phase 2	
S6	Voltage scaling factor phase 3	
S7	Scaling factor DC1-input	
S8	Scaling factor DC2-input	
S9	Scaling factor DC3-input	e.g. S9 285.1

3. REMOTE PROGRAMMING

3.1. Introduction

The IEEE-488 Interface turns the 304B into a fully programmable instrument for use with the IEEE-488 Interface bus. With the interface, the 304B can become part of an automated measurement system. The 304B can be under complete, interactive control from a remote bus controller: or it can be set to the talk-only-mode, connected to one or more listeners.

3.2. Capabilities

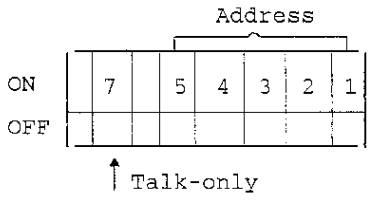
The IEEE-488 Interface provides remote control of all front panel controls except for Power. Other features include:

- Full talk/listen capability, including talk-only operation
- Comprehensive command set
- Fast measurement throughput
- Full remote / local capability
- Full serial poll capability, with bit-maskable SRQ
- External trigger
- Interface trigger
- Selectable output terminators
- Programmable Talk-only mode, timer

The 304B supports the following interface function subsets: SH1, AH1, T5, L4, SR1, RL1, DC1, DT1, PP0, and C0.

3.3. Bus Set-Up Procedure and Address Selection

a. Turn the 304B 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 304B
The Address of the 304B is factory set to Address 05 and talk-only mode off.

3.4. Device-Dependent Command Set

Device-dependent commands are the heart of the 304B remote control. They tell the 304B 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 304B to receive them, they must be sent over the IEEE bus when the 304B is in remote and has been addressed as a listener.

3.5. Output Function Command Fn, Hn

The output function command tells the 304B which quantity to load in the output buffer. When the 304B is addressed to talk, it will put the contents of the output buffer on the bus. The output buffer always contains the values for phase 1, phase 2, and phase 3, and, where applicable also the sum values of phase 1 through phase 3 or the average value of phase 1 through phase 3.

Example	Explanation
"F4"	The output buffer will be loaded with the value of Urms1, Urms2, Urms3, and average value e.g. +221.3 +223.7 +219.8 +221.5Vr.
"F8H4"	F8 will be ignored. The output buffer will be loaded with the value of Wh (H4) and elapsed time in seconds e.g. 5.783 +4 +1.753 +5Wh/s.

3.6. Range Commands In, Un

The range commands tell the 304B which current and voltage range to select. The range commands are accepted when autorange C2 is off. For example, "I3U5" selects the 2A (20A plug-in), and 200V range. The range setting can be read using the G1 command.

3.7. Display Commands Dn, En

The display commands duplicate the function controls below the display. The display commands allow the user to select 4 quantities to be displayed. One out of the following groups can be selected: (D1, D2, D3), (D4, D5, D6), (D7, D8, D9), and (E1, E2, E3, E4). It is also possible to switch from display mode 1 to display mode 2 by duplicating the manual key board operation.

Example	Explanation
"D3,D4,D8,E2"	Imean, Urms, apparent power S, and energy Wh, will be displayed.
"D1"	Irms will be selected. The remaining three displayed quantities will not change. Sending "D1" a second time will switch the 304B to display mode 2. In this case rms currents phase 1, 2, 3 and average current will be displayed.

3.8. Mode Commands

The mode commands C1, ..., C9, and K1, ..., K5 duplicate the front panel controls to the left and right of the display.

Example	Explanation
"C2 C3C8K4C9"	Selects autorange off (interface ranging), continuous sampling, averaging 4, AC-Coupling, RUN.
"K1"	Puts 304B into hold mode. Displayed values are held, 304B can now be triggered with "K2".
"K2"	Starts one measurement cycle when 304B is in "HOLD".
"C9 K3"	RUN mode, sets Wh to zero.

3.9. SRQ Mask Command Pn

The SRQ mask commands P0 through P8 are used to program the 304B to make service requests on user-specified conditions.

Example	Explanation
"P4"	SRQ on triggered measurement finished.

3.10. Terminator Commands Wn

The terminator commands select what terminators the 304B 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 304B sets to W1 on power-up.

3.11. Get Command G1

The G1 command copies the 304B current range, voltage range, SRQ mask, and terminator selected into the output buffer in the format shown below.

Command	Output String	Meaning
G1	frst	f = 1-5 as in I-range commands r = 1-7 as in U-range commands s = 1-8 as in SRQ mask commands t = 1-4 as in Terminator commands

3.12. Set Commands Sn

The set commands Sn set the scaling factors for current and voltage. The scaling factors are stored in non-volatile memory.

Set Commands S1 through S6

```
S1   Set current scaling factor phase 1: Format  "S1 2.556"
S2   Set current scaling factor phase 2: Format  "S2 1"
S3   Set current scaling factor phase 3: Format  "S3 5.801"
S4   Set power scaling factor phase 1:   Format  "S4 105.2"
S5   Set power scaling factor phase 2:   Format  "S5 98"
S6   Set power scaling factor phase 3:   Format  "S6 150.5"
```

Only one command Si must be sent at a time.

3.13. Input Processing

An input string can contain as many commands as required. Commands are executed in the sequence they are received. Commands which can not be recognized by the 304B 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 CR LF pair. If a controller does not have this feature, the programmer must transmit a terminator explicitly.
The 304B accepts alphabetic characters in upper case. Spaces are ignored.

Output Function Commands

F0	Irms, Vrms, W, VA, PF		
F1	Irms	H1	Power factor
F2	I rectified mean /Hz	H2	|Z|
F3	I mean	H3	ReZ
F4	Urms	H4	Wh / Time
F5	U rectified mean		
F6	U mean		
F7	Power P		
F8	Apparent power S		
F9	Reactive power Q		

Range Commands

Plug-in	0-2A	0-10A	0-30A	0-100A
I1	20mA	200mA	2A	20A
I2	60mA	600mA	6A	60A
I3	200mA	2A	20A	200A
I4	600mA	6A	60A	600A
I5	2A	20A	200A	2000A

U1	2V
U2	6V
U3	20V
U4	60V
U5	200V
U6	600V
U7	1000V

Display Commands

D1	display Irms	E1	display PF (default)
D2	display I rectified mean	E2	display Wh
D3	display I mean	E3	display |Z|
		E4	display ReZ
D4	display Urms	E5	display Phase 1
D5	display U rectified mean		(default)
D6	display U mean	E6	display Phase 2
D7	display P	E7	display Phase 3
D8	display S	E8	display Σ P, Q, S
D9	display Q		(on/off)

D1, D4, and D7 toggle between display mode 1 and display mode 2.

Set Commands

S1	Set current scaling factor phase 1:	Format "S1 2.556"
S2	Set current scaling factor phase 2:	Format "S2 1"
S3	Set current scaling factor phase 3:	Format "S3 5.801"
S4	Set power scaling factor phase 1:	Format "S4 105.2"
S5	Set power scaling factor phase 2:	Format "S5 98"
S6	Set power scaling factor phase 3:	Format "S6 150.5"

Figure 3.1. Device- Dependent Commands

Mode Commands

C1	Autorange on	(default)
C2	Autorange off	
C3	Continuous sampling	(default)
C4	Random sampling	
C5	Averaging AVG=1	(default)
C6	Averaging AVG=2	
C7	Averaging AVG=3	
C8	Averaging AVG=4	
C9	RUN	(default)

K1	HOLD (triggered mode ready)	
K2	Trigger start	
K3	Wh reset / Time reset	
K4	AC-Coupling	(default)
K5	DC+AC-Coupling	

SRQ Mask Commands

P0	SRQ disabled	(default)
P1	SRQ on I-overrange	
P2	SRQ on U-overrange	
P3	SRQ on I-, or U-overrange	
P4	SRQ on triggered measurement finished	
P5	SRQ on I-over, or triggerd measurement finished	
P6	SRQ on U-over, or triggered measurement finished	
P7	SRQ on I-, or U-over, or triggered measurement finished	

Terminator Commands

W1	CR/LF/EOI	(default)
W2	CR/LF	
W3	EOI only	
W4	disable all terminators	

Get Command

G1	Get range I/U; SRQ mask; terminator

Figure 3.2. Device- Dependent Commands (cont.)

Typical command string as it might be sent to the 304B.

HP-85 Controller

```
REMOTE 705
OUTPUT 705; "C2K4I3U5"
OUTPUT 705; "D1D8F7"
ENTER 705; A$
CLEAR 705
OUTPUT 705; "K5F4"
TRIGGER 705
B=SPOLL (705)
```

Fluke 1720A Controller

```
REMOTE @ 5
PRINT @5, "C2K4I3U5"
PRINT @5, "D1D8F7"
INPUT @5, A$
CLEAR @5
PRINT @5, "K5F4"
TRIG @705
B%=SPL (5)
```

3.14. Syntax Rules

Three 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 304B will not respond to the second attempt to read the output buffer. However, if the 304B is in T0, 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.

RULE 3: Read the output data generated by one input command string before sending the next input command string. Output data remains available in the output buffer until it is read, or until the next input command string is received.

3.15. Output Data

The following describes the data that can be loaded into the 304B 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 304B can also send data to the IEEE-488 bus from the serial poll register.

3.16. Loading Output Data

The 304B is preprogrammed to send output data when it receives an output command, e.g. "F7". The data are not actually loaded onto the interface bus until the controller addresses the 304B as a talker. This is done by sending the interface message MTA (My Talk Address). The types of output data are shown in Figure 3.2. Numeric data including units are sent to the IEEE-488 bus in the same format as displayed on the display.

The output data string contains phase 1-, phase 2-, and phase 3 values and, where applicable (P, S, Q), also the sum values. The only exception to this is the output string of the total energy consisting of just one energy value and elapsed time. When data are overrange the suffix "OVER" is appended to the data.
Status data is the output in response to G1 command. The data is formatted as shown in Figure 3.2. and is interpreted in section 3.11.
The terminators appended to numeric data and status data are user-selected by the terminator commands W1 ... W4.

Output Data Type	Format Examples			
	Phase 1	Phase 2	Phase 3	Sum
Numeric Data	+4.221	+4.001	+4.158	+12.38mW Measured Value
	+8.445	+8.787	+7.916	+8.383Ar Measured Value
	Over +20.47	+20.47	+20.47	+20.47Vr Overrange
	1.385 + 4 + 1.789 + 5 Wh/s			Measured Value
	+220.5	+218.0	+214.3	+217.6Vr Measured Value
Instrument Configuration Date:			G1: 3431 - Terminator W1,SRQ P3 U-range 4 I-range 3	
Output from SRQ			decimal 72	SRQ on triggered Measurement finished

Figure 3.2. Output Data Types

3.17. 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 304B 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 304B 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 (SRQ mask).

3.18. The Serial Poll Register

The serial poll register is a binary-encoded register which contains eight bits, as illustrated in Figure 3.3. The controller can read the 304B serial poll register by taking a serial poll. Because serial poll data is loaded directly onto 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 SRQ 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 P1 ... P7, as follows:

Selected SRQ mask	Decimal value bit 1 through 4
P1	1 I-overrange
P2	2 U-overrange
P7	7 Triggered measurement finished

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

Figure 3.3. 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.

3.19. Interface Messages

The interface messages understood by the 304B 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 304B 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 304B to remote. In remote the 304B front-panel controlls are deactivated.

DCL: Device Clear -- A multiline message which is loaded into the input buffer. DCL sets the 304B to the following operating conditions:

- AUTORANGE on
- Display Irms, Urms, P, PF, Phase 1
- AC-Coupling
- Continuous sampling
- Averaging = 1
- Triggered measurement off

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 304B to switch to local (front panel) control.

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

3.20. Talk-Only-Mode

The Talk-Only-Mode lets the user take advantage of the remote capability of the 304B without having to use an instrument controller. The data receiving device must have IEEE-488 handshake capabilities.
If programming of the Talk-only output functions prior to Talk-only operation is required proceed to section 3.20. for programming instructions.
To put the 304B in the talk-only-mode:

1. Turn the 304B power switch off.
2. Set the rear panel Talk Only switch (bit 7 of address switch) to the up position (on).
3. Connect the 304B via the IEEE-488 bus to your data receiving device (listener hand-shake capabilities are required).
4. Turn the 304B power switch on.
5. Configure the 304B with the front-panel controlls.
   (The 304B can also be operated in the Talk-Only Mode when in remote).

The 304B reads the Talk-only bit switch on power-up and sends the programmed (desired) data in the programmed time intervals to your data receiving device. Data are also output, when the "HOLD" state is entered.

3.21. Talk-Only Programming

The Talk-Only start-up procedure is described in section 3.19. The printer used must have IEEE-488 hand shake capabilities, otherwise data will not be transferred in an orderly manner.

The programming of the desired printer output is done as follows:

Step 1: Press "HOLD"

Step 2: Press "SCALE"

Step 3: Press " Σ"
The present programming status is now displayed. "F 1 2 3..." and "H 1 2 3 ..." correspond to the output function commands on page 24 of this manual.
"Time xxx s" is the time interval for printer outputs (1 s to max 32670 s).

Step 4: Press now all those controls in the function control field (in center below the display) which give you the desired printer output (Ar, At, A =, Vr, Vt, V=, W, Va, VAR, PF, Wh, Z).
To terminate the output function selection press "ENTER".
In case you do not want to change the output functions shown on the display, you must still press "ENTER" to proceed to step 5.

Step 5: In this step the time interval is selected by pressing the appropriate number (0 1 2 ...) in the function control field below the display. The maximum number to be entered is 32760 s, larger numbers are truncated. To terminate the time interval selection press "ENTER". If no time interval change is required, press "RUN" to leave the Talk-Only programming mode.

Step 6: Press "RUN" to terminate the programming cycle.

Press " Σ " to repeat the Talk-Only programming if desired. This brings you back to step 3. Furthermore, the described programming can be interrupted at any step by pressing "RUN".
To start the Talk-Only-Operation follow the procedure described in section 3.19.
In Talk-Only operation data are printed in the programmed time intervals. Furthermore, data are printed everytime the "HOLD" mode is entered.
By setting a long time interval, this way a manual printer activation is achieved whenever the "HOLD" control is pressed.