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Solartron CellTest® System

Solartron CellTest® System

The Solartron CellTest System is a multi-channel test system designed for the complete DC and impedance characterization of a wide range of energy storage devices such as batteries, fuel cells and super-capacitors. The speed, range and resolution of the CellTest system also make it suited to other research applications including the analysis of sensors, coatings, corrosion and general electrochemical applications.

The CellTest system consists of one or more 1470E multi-channel potentiostats and multiple 145x series frequency response analyzers (FRAs) connected to a computer providing simultaneous DC and impedance tests on multiple cells. Each 1470E unit provides eight fully independent potentiostats, allowing up to eight separate cells to be tested simultaneously. Each channel is completely independent allowing the same or quite different experiments to be run on each cell.

The CellTest system provides a wide range of experimental techniques, including charge / discharge, potentiostatic, potentiodynamic, galvanostatic, galvanodynamic, fast cyclic voltammetry, open circuit, fast pulse and step techniques, ohmic-drop analysis and impedance.

Simultaneous impedance tests can be run on multiple cells by connecting Solartron 145x series frequency response analyzer (FRA) modules to the 1470E. These FRAs can operate in single sine correlation or multi-sine / Fast Fourier Transform (FFT) analysis mode, providing the ultimate in speed, precision and accuracy.

The 1455 FRA provides high performance impedance measurements over the frequency range 10µHz to 1MHz, while the 1451 FRA operates from 10µHz to 100kHz.

Temperature controlled ovens and furnaces can be added to the system and automatically controlled from the PC over a serial communications link, providing the facility to test cells at different temperatures (for example for testing solid oxide fuel cells at up to 1000ºC).

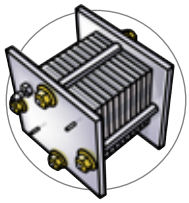
Ethernet control
The 1470E and 145x FRA units are Ethernet controlled providing either local or remote control of the instrumentation from a PC connected anywhere on the same Ethernet network. This allows experiments to be set-up and run from a quiet office environment while the test equipment and cells are located quite separately in another room or building.

The Solartron CellTest system is the most advanced multi-channel battery, fuel cell, supercapacitor test system available, giving the ultimate in DC and impedance test performance.

CellTest System capabilities

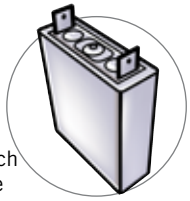
- Simultaneous high-speed impedance measurements on all channels
- Single sine correlation and multi-sine / FFT impedance measurement techniques
- Impedance and DC measurements of cell anodes and cathodes (14702A option)
- High power tests by connecting channels in parallel or by adding power boosters
- Ethernet control to allow equipment to be placed where it is needed
- Each 1470E allows any combination of potentiostatic / galvanostatic tests to be run simultaneously on up to eight test cells.
- High rate data acquisition during DC tests at up to 10,000 samples per second (allows fast cyclic voltammetry or GSM mobile phone pulse tests)
- 4-terminal cell connections, essential for testing very low impedance devices such as batteries and fuel cells.
- Floating measurement capability allows tests on cells connected to ground.
- Instantaneous switching (0.1msec) between experiment steps
- 14703A option provides temperature measurement and on / off control of external devices such as power boosters, stirrers, motors, gas flow valves, etc.

Applications

Fuel cells

The CellTest system may be used to characterize a wide range of fuel cell technologies at a research and development level. Micro fuel cells, such as those used in mobile communications and PC applications, may be tested directly, while channels may be connected in parallel or power boosters added to the system for testing higher power cells. Impedance tests may be run while under DC load conditions to fully characterize the cells over their range of performance. Temperature can also be controlled for testing high temperature fuel cells such as solid oxide fuel cells (SOFC).

Batteries

In addition to standard DC multi-channel experimental techniques such as cyclic voltammetry, charge-discharge testing and ohmic-drop measurements, the CellTest system provides anode / cathode impedance measurements (in addition to the overall cell impedance) for the improvement of secondary (rechargeable) cell cycle life and for non-destructive research on primary cells leading to improved electrode materials and cell performance.

Supercapacitors

Supercapacitors are often used for instantaneous high power applications together with other energy sources such as batteries. Similar tests are carried out on supercapacitors including cyclic voltammetry, charge / discharge cycling, open circuit tests, ohmic-drop and impedance. The flexibility of the CellTest system for connecting channels in parallel is again of great benefit for testing these devices.

Electrochemical cells

There are many other applications such as the development of sensors, corrosion analysis, coatings and bio-research, where multi-channel DC and impedance analysis is very beneficial in providing high throughput of results.

Multi-channel DC test capability

Each independent potentiostat / galvanostat channel within the 1470E is controlled by its own dedicated high performance digital signal processor, which provides accurate and instantaneous test control, data averaging and safety limit functions. A wide range of potentiostatic (voltage controlled) and galvanostatic (current controlled) techniques may be performed, including:

- open circuit
- cyclic voltammetry
- constant level and scanned voltage / current controlled techniques
- fast voltage / current pulse techniques (e.g. for mobile phone cell tests)
- voltage / current step techniques
- linear polarisation resistance techniques
- ohmic-drop measurements (for accurate equivalent series resistance ESR analysis)

High-speed data acquisition

The 1470E is able to acquire DC data at 10,000 samples per second, which allows the unit to make very accurate measurements of the equivalent series resistance (ESR) of batteries, fuel cells and supercapacitors using DC ohmic-drop techniques. If required, the 10,000 samples per second data acquisition rate can be used in extremely short bursts of 1 millisecond, for example immediately after the cell current is reversed or interrupted in order to measure the ESR. The 1470E can operate at different measurement sample rates at each step in the experiment so high-speed data is only acquired precisely where it is needed and the PC disk is not filled with repetitive data.

The 1470E also provides data reduction and averaging techniques to minimize noise on the data and to reduce PC data storage requirements.

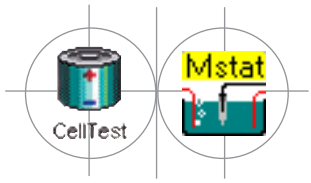
Safety / step termination limit checking

The high-speed digital signal processor on each channel of the 1470E reacts immediately when safety or step termination limits are reached on the cell (the PC is not involved in this process) with the obvious benefit of protecting test cells from being over-tested or damaged.

The user is informed of safety limit trips, allowing appropriate action to be taken where necessary.

Anode / cathode investigations

The 1470E has optional auxiliary voltage inputs that allow monitoring of individual anode / cathode electrodes in a cell, or of individual cells in a battery or fuel cell stack. The auxiliary voltage DC measurements are synchronized with those from the main channels, allowing detailed analysis of fast pulse or cyclic voltammetry tests at multiple points within a stack.



High power DC tests

The 1470E provides 10V, ±4A stimulus to cells, but for tests on higher power devices (larger batteries or fuel cell stacks) it may be necessary to increase this range of operation.

Higher current tests can be performed by connecting a number of 1470E channels together in parallel (since each channel has independently floating electrodes), providing 8A, 12A, and even up to 32A stimulus to the cell.

If increased voltage range is also required, Solartron offer power boosters that are able to boost the voltage and current level that is applied to the cell.

High speed multi-channel impedanc

Why are Solartron FRAs the best?

Solartron Analytical frequency response analyzers (FRAs) have an enviable worldwide reputation for accuracy, resolution, repeatability and frequency bandwidth. Solartron was the first company to introduce FRAs for aerospace applications in the 1950s. That was followed by the world's first digital FRA in the 1970s and various spectral analysis and high frequency FRA products for a wide range of applications in the 1980s and 1990s. The latest addition to this outstanding sequence of products is the new generation of high performance Solartron FRAs, coupled with multi-channel potentiostats, that are again set to raise the standard for high speed / high accuracy impedance measurement.

Solartron's purpose built 1455 (1MHz) and 1451 (100kHz) frequency response analyzers utilize state-of-the-art digital signal processor (DSP) technology together with a wide range of impedance analysis techniques (including single sine correlation, harmonic analysis and multi-sine / FFT) to provide the ultimate in impedance measurement performance.

Unlike copycat "FRAs", Solartron FRAs are true high performance analyzers not to be confused with soft-FRAs, sub-sampling FRAs, lockin amplifiers or frequency detectors all of which are subject to one or more performance limitations (limited frequency bandwidth, limited frequency resolution, no FFT capability or limited frequency range for each measurement technique).

With Solartron FRAs there are no compromises; everything has been carefully designed, from the high-resolution 26-bit frequency synthesizer (providing ultra-fine frequency sweep resolution) to the flexible single sine correlation and multi-sine / FFT impedance analysis modes that provide the fastest and most accurate impedance characterization of a wide range of test cells. The single sine correlation and FFT analysis modes are available over the complete frequency range and unlike other "FRAs", there are no restrictions or limitations.

The 145x series FRAs are modular, allowing additional impedance measurement channels to be added to the system as and when they are required. Each FRA module has its own dedicated Ethernet 100BaseT communications interface allowing flexibility in positioning equipment and ensuring high-speed data transfer to the PC.

Solartron lead the world in the design and manufacture of high performance frequency response analyzers and the latest generation products provide a further leap forward in capability and technology that other systems cannot equal.

Single sine correlation

Single sine correlation is recognized by impedance researchers throughout the world, as being the most accurate and repeatable technique available for the investigation of cell impedance.

Solartron's high performance 145x FRAs provide very high measurement rates, allowing detailed impedance scans from 1MHz to 10Hz to be performed in just a few seconds! The single sine correlation technique is available across the entire bandwidth of the system (from 10µHz to 1MHz).

Multi-sine / FFT analysis

At high frequency, the single sine correlation technique provides very fast impedance analysis. At lower frequency however, for example where cell diffusion characteristics need to be analyzed, the measurement time may become extended since at least one cycle of the waveform must be analyzed at each frequency. This may result in tests that run into several hours. For example, a single frequency measurement at 1mHz takes 1000 seconds (>16 minutes).

The 145x series FRAs however, provide an alternative measurement technique (multi-sine / Fast Fourier Transform FFT analysis), which is available across the entire frequency range of the system but is particularly efficient for low frequency tests.

Multiple sinewave frequencies are simultaneously applied to the cell, providing stimulus throughout the frequency range of interest. The multi-sine waveform looks similar to random noise but actually is a waveform containing only the selected frequencies. The voltage and current waveforms from the cell are simultaneously captured and analyzed using the FFT technique and the ratio of the spectral data provides impedance results at all of the frequencies in the original stimulus waveform.

For example, three frequency decades may be selected with a base frequency of 1mHz providing ***simultaneous*** impedance results from 1Hz to 1mHz with 1mHz resolution in a single measurement timeframe of 1000 seconds (16 minutes). By comparison, a single sine correlation analysis from 1Hz to 1mHz at 10 points per decade would take around 80 minutes (five times as long).

This makes the multi-sine / FFT approach suited to applications where the speed of measurement is critical, for example, measurements of time variant cells where measurements need to be performed quickly before the cell changes.

The technique is fast but may be less accurate than single sine correlation due to issues related to simultaneous measurement of multiple frequencies.

However, the 145x series FRAs provides some very advanced facilities to help the user to minimize these effects by providing:

- user selection of frequencies that are present in the applied multi-sine waveform
- a default frequency list as an aid to appropriate frequency selection
- automatic waveform optimization to minimize any peaks on the multi-sine waveform

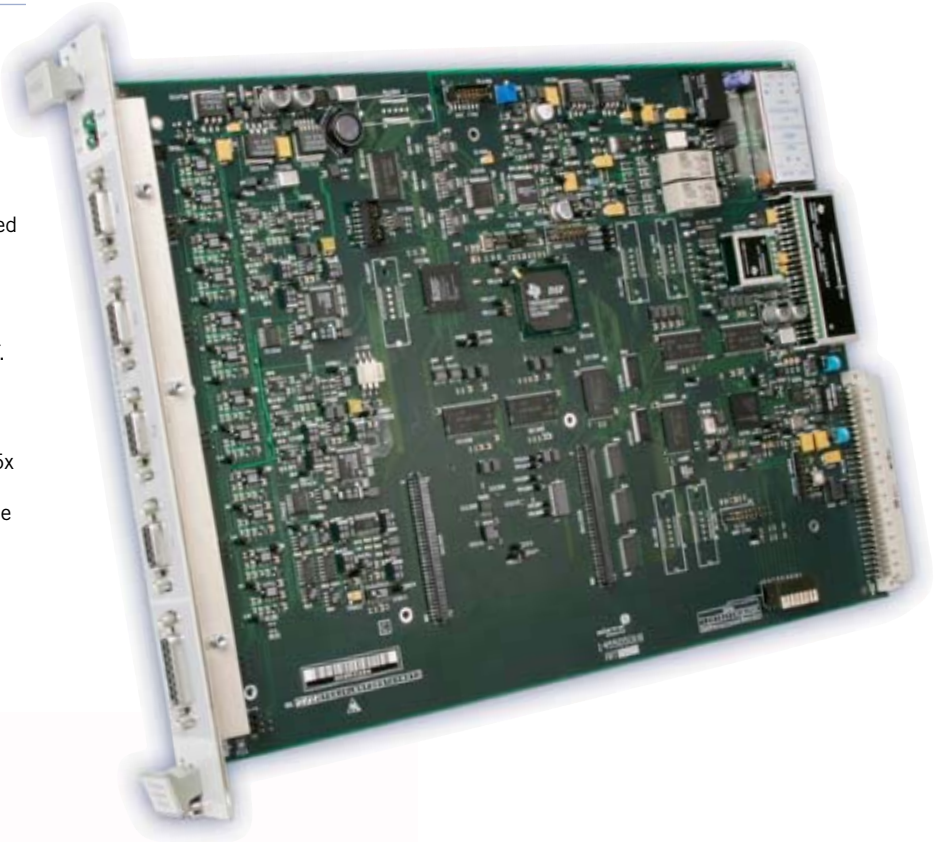
e analysis

The frequency selection facility allows measurement noise to be reduced by utilizing less frequencies in the multi-sine waveform since each frequency will then be higher amplitude while maintaining the same overall stimulus level.

The frequency selection facility can also be used to minimize issues caused by electrochemical cell non-linearity and to obtain virtually logarithmically spaced data; giving very similar results to the swept sine correlation technique while retaining the speed advantage of the FFT.

Impedance accuracy and stability
The measurement performance of Solartron FRAs is unsurpassed with accuracy for the 145x series FRAs of 0.1%, 0.1° across the entire frequency bandwidth from 10µHz to 1MHz. The FRA delivers the ultimate in AC measurement performance and it is fast. Measurements are completely reproducible and stable. The impedance measurement accuracy of the CellTest system is fully specified over its full range of frequency and impedance.

Fast switch experiments
The FRAs are so closely integrated into the CellTest system that it is possible to switch instantaneously from DC tests such as cyclic voltammetry to impedance analysis. There are no delays waiting for FRAs to become available since each channel can have its own FRA.



Auto-integration
Auto-integration facilities are available in single sine and FFT operating modes allowing the FRA to optimize test time while ensuring that noise and interference signals are rejected from the results. The auto-integration facility provides increased integration time just where it is needed (for example, where results are noisy due to interference) and provides high-speed measurement for those frequencies that are free from noise. This gives the best of both worlds: optimal measurement speed with noise-free results.

Anode / cathode impedance
Usually battery / fuel cell test systems provide auxiliary inputs that are only capable of providing DC measurements. The Solartron CellTest system (with auxiliary channel option fitted) provides simultaneous ***impedance*** measurements of the whole cell as well as its component parts such as the anode and cathode. This unique capability allows detailed research into electrode materials or the detection of bad cells in a stack. Either single sine or FFT / multi-sine techniques may be used for this analysis as required.

DC bias rejection
The Solartron 145x series FRAs provide full rejection of DC offsets. This allows all impedance measurements to be performed on the most sensitive measurement ranges, providing accurate, noise-free results.

High power impedance tests
The voltage and current range of 1470E is 10V / 4A per channel. If impedance tests are required on higher power cells, for example when testing fuel cell stacks or batteries under load, multiple 1470E channels may be connected in parallel to provide the high DC load (up to 28Amps). Impedance may then be performed using another channel connected in parallel. In this case, the impedance measurement channel is not carrying the high DC current and may therefore be on a sensitive, wide bandwidth range providing high quality impedance results.

If increased voltage range is also required, Solartron offer power boosters that are able to boost the voltage and current level that is applied to the cell.

CellTest DC measurement specification

1470E Specification

General

PC communications	Ethernet 10BaseT or IEEE488 (GPIB) Refer to back page for details
Number of channels	8 independent floating channels per unit

Counter Electrode (CE)

Maximum voltage / current	+10V / -3V, ±4A
Maximum power per channel	40W
Bandwidth selectable	10, 100, 1k, 10k, 100k, 1MHz

Voltage measurement inputs (RE1, RE2)

Connections	Driven shields for wide bandwidth
Maximum voltage	+10V / -3V
Voltage ranges	Auto-range or manually selected 10V, 1V, 100mV
Accuracy	±0.1% of range
Voltage resolution	3µV
ADC	16 bit 10,000 samples / sec
Input impedance	>10Gohm

Current measurement input (WE)

Maximum current per channel	+/-4A
Current ranges	Auto-range or manually selected 5A, 500mA, 50mA, 5mA, 500µA, 50µA
Accuracy	±0.1% of range
Current resolution	1.5nA
ADC	16 bit 10,000 samples / sec

Experiment

Maximum steps / experiment	100
Step types:	
voltage, current	constant, ramp, pulse (includes high speed GSM), cyclic voltammetry
power, resistance	constant level (discharge only)
other	rest (open circuit), loop
impedance	requires one or more frequency response analyzers
Step termination limits	voltage, current, power, resistance and charge. temperature (requires option 14703A)
Time to switch test type	100µsec
Minimum sample rate	1 sample / 100 seconds
Maximum sample rate	10,000 samples / second
Measurement modes	Fixed sample rate or measure on change
Shutdown safety limits	voltage, current temperature (requires option 14703A)
Temperature control	Eurotherm 2000 Series controllers

Temperature Range

Operating	5° to 40°C (41° to 104°F)
Specified accuracy	10° to 30°C
Storage	-25° to 70°C (-13° to 158°F)

General

Dimensions (w x h x d)	450 x 286 x 496mm (17.7 x 11.3 x 19.5in)
Weight	18kg (40lb)
Safety	complies with BS EN 61010
EMC	complies with BS EN 61326
Line Voltage	85V to 264V 47-63Hz
Power	1000VA Maximum

Cell connection cable set for 1470E
8 channel cable set included (1 metre length)

14703A Option Specification

Temperature measurement

Temperature inputs	8 (one per main channel)		
Thermocouple types	E, J, K, T		
Temperature accuracy	±1°C (plus thermocouple errors)		
	Min (°C)	Max (°C)	Resolution (°C)
Type E	-200	1000	0.0625
Type J	-210	1200	0.0625
Type K	-200	1372	0.0625
Type T	-200	400	0.0625

The 14703A option provides:
- Temperature safety limits
- Temperature measurement with plots vs time
- Temperature step termination limits

Thermocouple Interface Unit included - for cold junction compensation (with 1 metre connection cable to 1470).

Thermocouples must be chosen to suit temperature range requirements and are therefore not supplied with this option.

Control Outputs

Control outputs	24 (three per main channel)
Switch type	Opto-isolated solid-state switches (similar to relays)
Connections	2 per switch
Maximum voltage	50V
Maximum current	100mA

Control outputs can be automatically switched on / off at each step in the experiment to control external devices (relays, lamps, heaters, gas valves, power boosters etc.).

Supplied with a D-type connector for customers to make up their own connection leads.

14702A Option Specification*

Auxiliary Voltage Channels (similar to RE1, RE2)

Connections	Driven shields for wide bandwidth
Maximum voltage	+10V / -3V
Voltage ranges	Auto-range 10V, 1V, 100mV
Accuracy	±0.1% of range
Voltage resolution	3µV
ADC	16 bit 10,000 samples / sec
Input impedance	>10Gohm
DC measurements	synchronized to assigned main channel

Cell connection cable set for 14702A
8 channel cable set included (1 metre length)

**** IMPORTANT NOTE: Option 14702A requires 14703A to be fitted.***

CellTest impedance analysis specification

145x Frequency Response Analyzer Specification

General

Chassis	1400A - 8 slot chassis
PC communications	Ethernet 10 / 100BaseT
Number of FRAs per chassis	Up to 8 independent floating FRAs
Measurement connections	differential voltage generator and analyzer connections to 1470E via supplied cable
Measurement speed	>30 impedance results / second or 1 measurement per waveform cycle, whichever is slower

Generator

Maximum DAC sample rate	40MHz (40x over-sampled)
Frequency range	
1455	10µHz to 1MHz
1451	10µHz to 100kHz
Frequency resolution	1 in 65,000,000
Frequency error	±100ppm
Generator amplitude	50µV to 3Vrms
Output	Short circuit protected
Output impedance	50 ohms
Output waveforms	Single sine, multi-sine
Single sine (PC frequency selection)	Linear / logarithmic sweep
Multi-sine	
No. of frequencies	up to 3 decades per measurement, >3 decades by sequential measurements
Frequency selection	up to 50 (user selectable), or all

Analyzers

Maximum ADC sample rate	40MHz (40x over-sampled)
Frequency range	
1455	10µHz to 1MHz
1451	10µHz to 100kHz
Accuracy	±0.1%, ±0.1° (input X / Y)
Analyzer modes	Single-sine or FFT / harmonic analysis (all modes available throughout the entire frequency range)
Voltage ranges	Auto-range or manually selected 3V, 300mV, 30mV (rms levels)
Maximum voltage resolution	1µV
Phase resolution	0.01°
Integration time	10msec to 10^5 seconds 1 cycle to 10^6 cycles
Auto-integration	long, short or off
DC bias rejection	Automatic
Anti-alias filters (all channels)	cut-off >1MHz
Digital filtering	automatic

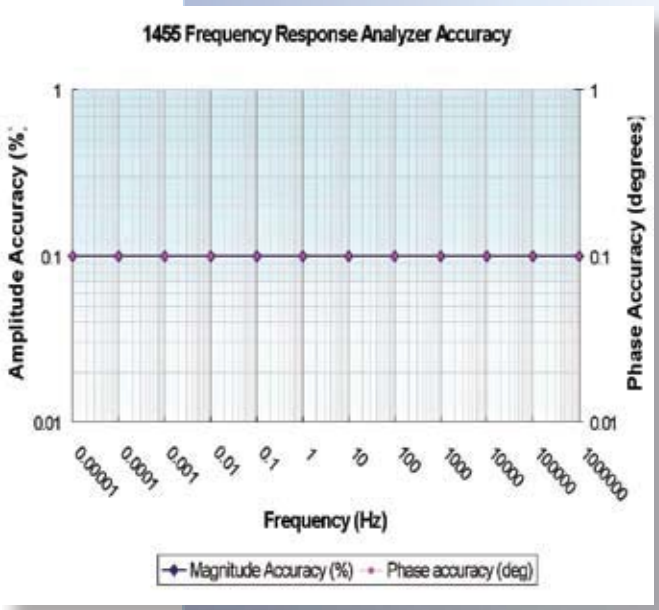
Auxiliary Voltage Analyzers
- for the impedance analysis of cell anode / cathode

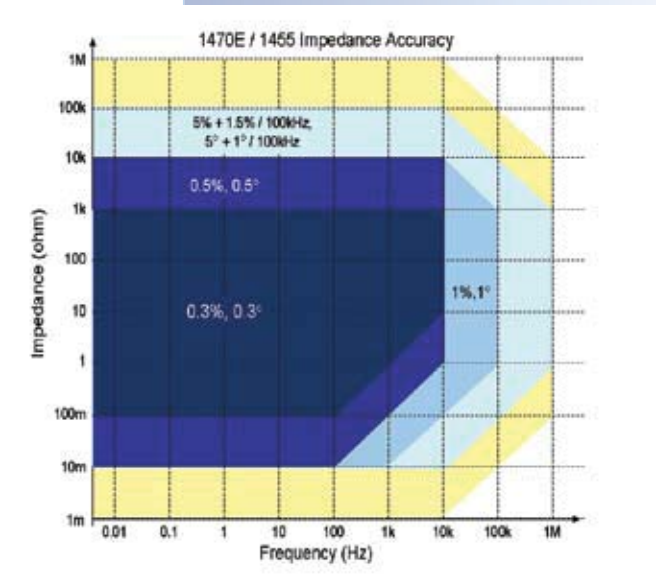
(Requires 14702A/14703A options fitted to 1470E)

Connections	Differential voltage (via 1470E)
Number of auxiliary inputs	Four differential channels per FRA
Specification	Same as the main analyzer specification

General

Chassis Dimensions (w x h x d)	450 x 286 x 496mm (17.7 x 11.3 x 19.5in)
Weight	18kg (40lb)
Safety	complies with BS EN 61010
EMC	complies with BS EN 61326
Temperature specification	same as 1470E
Line Voltage	85V to 264V 47-63Hz
Power	450VA Maximum





The above typical impedance accuracy specification is achieved under the following conditions:
- 10mV AC stimulus, (higher impedance can be measured at higher AC level)
- 1 second or 2 cycles integration whichever is longer

PC Configuration:

PC *	Pentium IV 1GHz 512Mb RAM 10Mb disk space for program plus >1Gbyte for data 17" or larger SVGA monitor
Operating system	Preferred - Windows XP Professional Or - Microsoft 98, NT4 or 2000

PC Communications Interface:

for DC only tests ** (impedance not required)	Ethernet 10 / 100BaseT or National Instruments IEEE488-GPIB communications interface
for DC and high speed multi-channel impedance **	Ethernet 10 / 100BaseT communications interface
compatible with:	1455 (1MHz) or 1451 (100kHz) (up to 8 FRAs per 1470E)
for DC and multiplexed impedance ***	National Instruments IEEE488-GPIB communications interface
compatible with:	1260 / 1255A / 1255B (1MHz) 1252 (300kHz) 1250 (65kHz) 1253 (20kHz) (one FRA per 1470E)

* A higher performance PC will give improved data throughput, especially for high-speed GSM/CDMA pulse applications.

** Ethernet 100BaseT is recommended for high speed DC data acquisition.

*** If high acquisition rate DC tests and impedance are to be run, a second IEEE488 interface card should be fitted to the PC to control the FRA.

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CellTest Software

CellTest software provides capabilities that are typically required for battery and fuel cell testing including cyclic voltammetry, constant voltage / current charge and discharge, GSM pulse tests, ohmic-drop analysis and impedance. CellTest is included free of charge with the system hardware. Data can be viewed in graphical and tabular form and can be exported to other applications for more detailed analysis.

Multistat Software

Multistat software is targeted at multi-channel electrochemical applications including corrosion or general electrochemistry. Multistat software provides a range of test facilities including potentiostatic, galvanostatic, cyclic voltammetry, linear polarisation resistance analysis and impedance analysis. Data can be viewed in graphical and in tabular form and can be analyzed in detail using a wide range of data fitting algorithms including Tafel and equivalent circuit fitting.

Options for ordering are:

USB147010ES	Multistat for one 1470E (8 channels)
USB147020ES	Multistat for two 1470E units (16 channels)
USB147010EF	Multistat for one 1470E and up to eight 1455 / 1451 FRAs
USB147020EF	Multistat for two 1470E units and up to sixteen 1455/1451 FRAs

Solartron Analytical is a world leader in instrumentation and software for the characterization of materials and electrochemical systems using precision electrical measurement techniques.

These techniques find particular use in the fields of corrosion, battery and fuel cell research, dielectric analysis and electrochemistry. The product portfolio includes industry standard frequency response analyzers, potentiostats, electrochemical software (ZPlot and CorrWare) and battery test equipment.

solartron analytical
AMETEK

Unit B1 Armstrong Mall
Southwood Business Park
Farnborough GU14 0NR
United Kingdom
Tel: +44 (0) 1252 556 800
Fax: +44 (0) 1252 556 899

801 South Illinois Avenue
Oak Ridge
TN 37831
USA
Tel: (1) 865-425-1360
Fax: (1) 865-425-2410

solartron.info@ametek.com
www.solartronanalytical.com