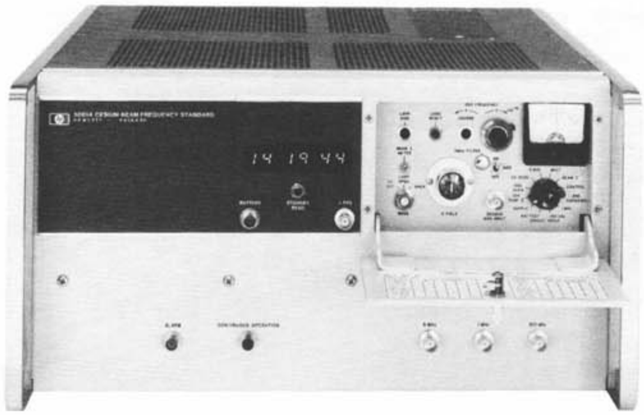
FREQUENCY & TIME STANDARDS

Atomic Frequency Standards

Models 5061A, 5065A

5061A
- Primary standard, $\pm 1 \times 10^{-11}$ accuracy
- Proven reliability
- World-wide usage

5061A, Opt 004
- Accuracy $\pm 7 \times 10^{-12}$
- Settability $\pm 1 \times 10^{-13}$
- Time domain stability 5×10^{-12} (1 s avg)



5061A

Introduction

Hewlett-Packard Atomic Frequency Standards have become the world-wide standards for frequency and time keeping since the introduction of the 5060A Cesium Standards in 1964. The user has a choice of three different frequency standards to satisfy a wide variety of applications:

1) 5061A Cesium Beam Frequency Standard. This standard with an accuracy of $\pm 1 \times 10^{-11}$ was introduced in 1967 to replace the 5060A. The high accuracy and excellent reliability of these units have gained world-wide acceptance of HP frequency standards.

2) 5061A with Option 004 High Performance Cesium Beam Tube. With the unique design features in this improved Cesium Beam Tube, the 5061A accuracy is $\pm 7 \times 10^{-12}$ and short term stability is improved by a factor of 10.

3) 5065A Rubidum Frequency Standard. This instrument features excellent long and short term stability performance at approximately one-half the cost of a cesium standard.

The units are described in detail on the following pages and the specifications are combined in a table to facilitate the comparison and selection of the best unit to suit the user's application.

Principles of Operation

The basic block diagram of both cesium and rubidium standards is the same (see Figure 1). The output of the 5 MHz crystal oscillator

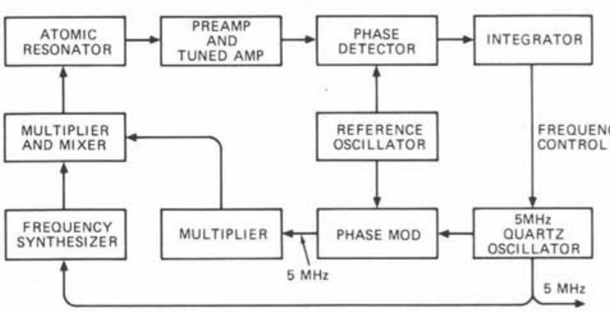


Figure 1. Block diagram of atomic frequency standards.

is multiplied and synthesized to the atomic resonance frequency (6834+ MHz for rubidium and 9192+ MHz for cesium). The signal is frequency modulated to sweep through the atomic resonance frequency causing the beam intensity in the cesium tube or transmitted light through the rubidium cell to vary. The output signal is amplified and through a phase detector controls the frequency of a low noise 5 MHz quartz crystal oscillator. The oscillator provides the 5 MHz output. Dividers produce 1 MHz and 100 kHz outputs.

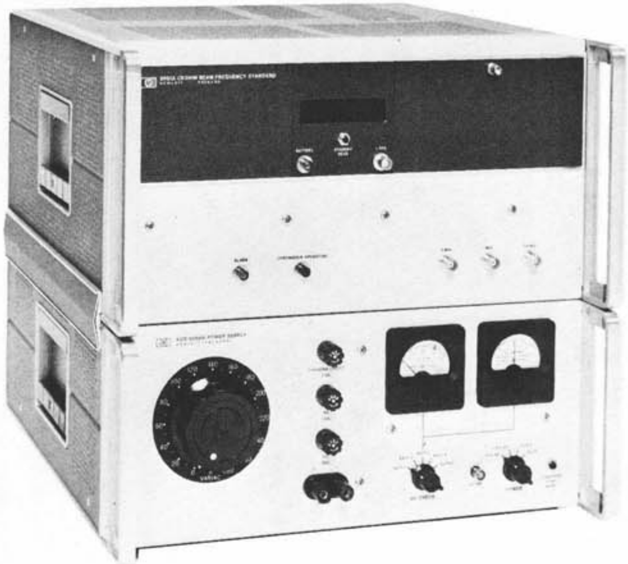
The invariant resonance frequency of the cesium atoms passing through the microwave cavity maintain the output frequency of the cesium standard constant to extremely high accuracy. The accuracy is in part a function of the microwave cavity length and is highest in the 5061A with the long cavity of the high performance beam tube.

In the rubidium standard a buffer gas is required to reduce collisions between the rubidium atoms in the gas cell and the resonant frequency varies slightly with the pressure of the buffer gas. As a result, the rubidium standard has to be calibrated and the frequency drifts slowly with time because of small changes in gas pressure and other effects within the rubidium cell and lamp. Offsetting this disadvantage are: 1) high signal-to-noise ratio of the rubidium cell output which results in excellent short term stability and; 2) a lower cost standard because of the simpler rubidium cell and associated electronics.

Each of the instruments has front panel controls, a circuit check switch and meter for monitoring performance. These and other controls are protected by a panel door. Front panel lights indicate any interruption of continuous operation and that the crystal oscillator is locked to the atomic resonance.

Applications: starting with their initial usage as reference standards in national laboratories the applications of HP atomic standards have expanded to include use in operational systems such as the Loran C and Omega navigation transmitters, satellite tracking and guidance stations, very long base line interferometers, navigation receivers based on direct distance measurement (Loran Rho-Rho), geophysical survey positioning systems and communications systems. Precise timing for frequency control is required for some secure communications systems and to improve efficiency of PCM and spread spectrum systems.

Cesium standard accuracy: the cesium beam standard is a primary frequency standard. A cesium beam tube carefully constructed along with the required supporting electronics will, when independently aligned, put out the correct frequency within very narrow limits. The frequency spread of the output for over 250 independently aligned 5061A standards with the standard beam tube is shown in Figure 2. It can be seen from this data that the frequency perturbations in the standard beam tube are so small that all the units are within $\pm 5 \times 10^{-12}$ of each other and of NBS frequency. The one sigma standard deviation is 1×10^{-12} between units. This performance is intrinsic to the 5061A and is achieved without calibration. The absolute accuracy, intrinsic reproducibility and absence of any perceptible long-term drift or aging are important advantages of cesium standards and assure that the output frequency of a cesium standard is always within the specific accuracy.



E21-5061A

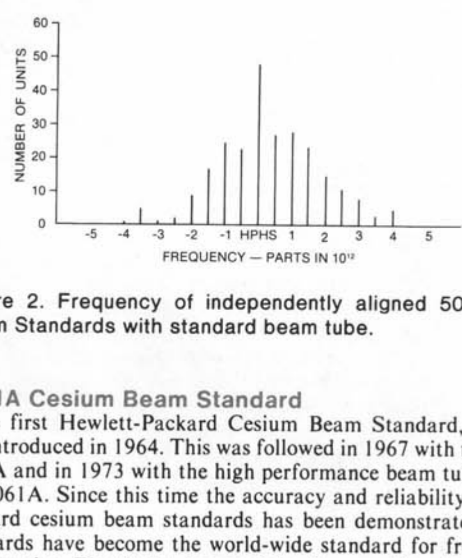


Figure 2. Frequency of independently aligned 5061A Cesium Beam Standards with standard beam tube.

5061A Cesium Beam Standard

The first Hewlett-Packard Cesium Beam Standard, the 5060A, was introduced in 1964. This was followed in 1967 with the improved 5061A and in 1973 with the high performance beam tube option for the 5061A. Since this time the accuracy and reliability of Hewlett-Packard cesium beam standards has been demonstrated and these standards have become the world-wide standard for frequency and time keeping. The 5061A has provision for an optional digital divider and reliable, easy-to-read LED clock (Option 001) and for a battery with ½ hour standby power capacity with automatic charging (Option 002).

Reliability and warranty: over 60 million operation hours have proven the performance and reliability of Hewlett-Packard cesium beam standards in various world-wide applications. The units have provided dependable microsecond accuracy in aircraft, ship and fixed environments.

A three-year warranty on the 5061A standard cesium beam tube is provided as a result of proven field reliability over an extended period. This warranty includes replacement of the cesium beam tube if it should fail within the warranty period. Typically, beam tube life has been in excess of five years.

5061A with Opt 004, High Performance Cesium Beam Tube

The Hewlett-Packard Model 5061A primary frequency standard with the Option 004 Cesium Beam Tube offers increased stability and accuracy in the instrument which has become the worldwide standard of frequency and time keeping since its introduction in 1967. Improvements in magnetic shielding, ruggedization and environmental performance permit improved performance and expansion of navigation and communication systems that have been made practical by the 5061A.

The design concept of the high performance beam tube includes unique HP designed dual beam optics with higher beam intensity to accomplish better short term stability and greater immunity to effects of shock and vibration. A 50 percent increase in resonance cavity length without change in the overall beam tube size contributes to better accuracy and settability because of the high Q of the narrower resonant line width. This tube retains the unique cesium standard feature of virtually no long term instability or aging.

The intrinsic accuracy is improved to $\pm 7 \times 10^{-12}$ which provides an excellent reference standard without need of calibration. If desired, as in many timekeeping applications, two or more units may be calibrated to determine the difference in rate or may be adjusted to the same frequency. With the improved settability specifications of 1×10^{-13} small changes in frequency are accomplished rapidly and accurately. A provision for degaussing the tube without adversely affecting the instrument operation allows removal of any residual magnetic field in the tube. This is important in achieving the settability performance.

The short term stability specification is improved by a factor of ten with this tube. The 5×10^{-12} (1 s avg.) performance compares very favorably with that of rubidium type standards which are noted for their excellent short term stability. An important advantage from the better short term stability is the capability to make measurements to 1 sigma precision of 1×10^{-12} in about one minute compared to the two hours required previously. The 5061A with the Option 004 High Performance Tube has the same high reliability as the 5061A with the standard tube. The new high performance tube is warranted for one year, but is designed to have the same long life as the standard tube.

10638A Degausser

The Model 10638A Degausser is designed for use with the Option 004 High Performance Beam Tube to achieve settability of $\pm 1 \times 10^{-13}$ and reproducibility of $\pm 3 \times 10^{-12}$. The degausser removes residual magnetic fields in the beam tube which slowly decay and cause a small frequency change. The degausser should be used when initially setting up the 5061A with Option 004 or after the instrument has been moved or adjusted.

K34-59991A Broadband Linear Phase Comparator

The K34-59991A accurately compares the phase relationship of the output signals of two frequency standards having the same nominal frequency between 100kHz and 10MHz. The comparator output signal is suitable for driving a stripchart recorder, thus allowing long-term monitoring of the frequency standards' output differences. By using this comparator, very small frequency differences can be detected and adjustments can be made to the frequency standards to correct for timekeeping errors.

E21-5061A Flying Clock

The E21-5061A consists of a 5061A Cesium Beam Standard with Option 001 LED Clock and K02-5060A Power Supply joined together to make one portable unit. The power supply, which can be operated from 6 or 12 V dc, 24 to 30 V dc, or 115/230 V ±10%, 50 to 400 Hz, will provide approximately 7 hours standby power (from sealed nickel-cadmium batteries) for the 5061A Cesium Beam Standard.

This wide range of operating power capabilities enable the E21-5061A to operate on local power in virtually any country in the world. Operation is approved aboard commercial aircraft. The seven hours standby capability make it possible to travel where there is no power available and, of course, allow the E21-5061A to conveniently be transported between power sources and operated in almost any air or surface vehicle as a "flying clock" (see Hewlett-Packard Journal, August 1966 and December 1967).

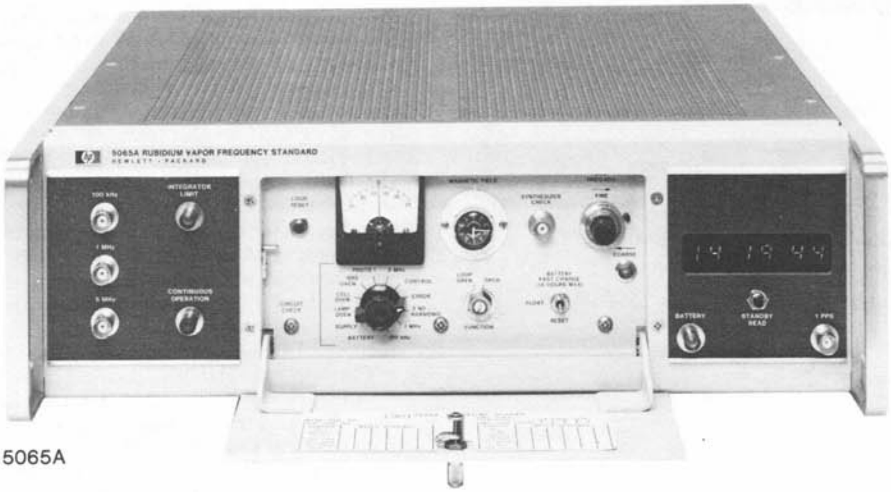
The Option 004 tube, because of the improved shielding, offers a significant increase in accuracy under the varying earth's magnetic field conditions experienced by flying clocks and is a desirable addition to the E21-5061A. In addition, the better short term stability permits more accurate and rapid comparison of standards. The Option 002 Battery may also be added to increase standby capability.

FREQUENCY & TIME STANDARDS

Atomic Frequency Standards

Models 5061A, 5065A (Cont.)

- Compact, high reliability, proven performance
- Long term drift rate $<1 \times 10^{-11}$/mo
- Time domain stability $<5 \times 10^{-13}$ (100 s avg)



5065A

5065A Rubidium Frequency Standard

The HP Model 5065A is an atomic-type secondary frequency standard which uses a rubidium vapor resonance cell as the stabilizing element. As a result, it has long-term stability of better than 1×10^{-11} per month which exceeds that of high quality quartz oscillator frequency standards by 50 to 100 times. Furthermore, it has excellent short-term stability. These features contribute to its desirability as a coherent signal source, as a master oscillator for radio and radar systems where special requirements for stability and/or narrow bandwidth must be met, as a precision time keeper where the better performance of a cesium beam primary standard is not required, and as a house frequency standard for improved accuracy with fewer NBS calibrations compared to that required with quartz standards.

Front panel controls and circuit check meter of the 5065A are protected by a panel door. The magnetic field control provides fine frequency adjustment with which the frequency can be set to a precision of better than 2×10^{-12} without reference to a chart. The 5 MHz low noise quartz oscillator is phase-locked to the atomic frequency and provides the standard 5 MHz, 1 MHz, and 100 kHz outputs. The circuit check meter with selector switch monitors key voltages and currents for routine maintenance readings, calibration procedures, and fault finding.

The 5065A is designed for assured operation—to give the user confidence that the standard output signals are correct and locked to the atomic frequency. Logic within the unit maintains power to a "continuous" operation light on the front panel. If operation is interrupted, even momentarily, for any reason the light goes out and stays out until manually reset. An integrator limit light warns when the frequency correcting servo loop is approaching the limit of its dynamic range.

The HP Model 5065A is contained in a small-size package and is lightweight in comparison to a cesium beam standard. Additionally the rubidium resonance cell is much more frequency stable than quartz oscillators while subjected to shock and vibration, EMC, humidity, and magnetic field effects.

Reliability and warranty: the most significant module in the HP 5065A in terms of performance is the Rubidium Vapor Frequency Reference (RVFR). This temperature controlled, magnetically shielded unit includes the Rb gas cell and a photo sensitive detector designed for maximum possible reliability. Field experience, including several million hours of operation, have demonstrated this reliability and the module is now warranted for a period of three years. This increased warranty protects the owner in the event of random failure.

The Option 001 Digital Clock has an easy to read LED time-of-day display. The olive black upper panel provides a dark background around the readout for excellent contrast and readability. Initial clock setting is accomplished by means of pushbuttons easily accessible by removing the top cover. The LED display offers high reliability, freedom from errors due to mechanical shock, and performance over the full environmental range of the 5065A. A sync button on the digital divider permits automatic synchronization of this 1 PPS pulse to an external pulse. The clock 1 PPS is adjustable in decade steps from 1 μs to 1 s, with respect to the synchronized reference, with 6 thumbwheel switches. A screwdriver adjustment allows fine continuous adjustment over a range of 1 μs.

To conserve battery power, the display is not illuminated when ac power is not available. A STANDBY READ pushbutton below the display is used for readout when operating on the internal battery or external dc.

The Option 002 Standby Battery provides the 5065A with a minimum of 10 minutes standby power at 25°C. Switchover from line to battery is automatic so there is no interruption of operation if ac line power should fail. A front panel ac interruption light warns when ac power has failed or has been disconnected. Fast or float charging rates may be selected when ac power is available.

The Option 003 combines the Option 001 Clock and Option 002 Battery and should be specified if both Options 001 and 002 are required.

E21-5065A Portable Time Standard

E21-5065A Portable Time Standard is a complete system for precision timekeeping and for transporting time from one location to another. It consists of the 5065A Rubidium Standard with digital clock and divider (Option 001) and the K02-5060A Power Supply with 6 or more hours standby capability. The component units are held together by side bars, and the interconnecting cables are protected by a back cover.

Specifications

Instrument:	5061A Option 004	5061A	5065A
Type of Standard:	Cesium	Cesium	Rubidium
Accuracy: maintained in magnetic field to 2 gauss and over temperature range of:	$\pm 7 \times 10^{-12}$ 0 to 50°C	$\pm 1 \times 10^{-11}$ 0 to 50°C	
Stability: **Long Term:** **Short Term 5 MHz**(2): Averaging time: 0.01 1 10 100	 $\pm 3 \times 10^{-12}$(1) 1.5×10^{-10} 5×10^{-12} 2.7×10^{-12} 8.5×10^{-13}	 $\pm 5 \times 10^{-12}$(1) 1.5×10^{-10} 5.6×10^{-11} 2.5×10^{-11} 8×10^{-12}	 $\pm 1 \times 10^{-11}$/month 1.5×10^{-10} 5×10^{-12} 1.6×10^{-12} 5×10^{-13}
SSB Phase Noise **Signal (1 Hz BW)** **Offset from signal:** **Hz:** 10^{-3} 10^{-2} 10^{-1} 0 10^{1} 10^{2} 10^{3}	 −28 dB −48 dB −68 dB −96 dB −120 dB −125 dB −140 dB	 −8 dB −28 dB −48 dB −82 dB −120 dB −125 dB −140 dB	 −25 dB −52 dB −72 dB −93 dB −120 dB −126 dB −140 dB
Reproducibility(4)	$\pm 3 \times 10^{-12}$(3)	$\pm 5 \times 10^{-12}$	
Settability (frequency)(5):	$\pm 1 \times 10^{-13}$(3)	$\pm 7 \times 10^{-13}$	$\pm 2 \times 10^{-12}$
Warm-up:	At 25°C 30 Min.	At 25°C 45 Min.	At 25°C 1×10^{-10} 1 hr. 5×10^{-11} 4 hrs.
Sinusoidal Outputs: **Output Voltage**	5 MHz, 1 MHz, 100 kHz, Front & Rear BNC 1 V into 50 ohms		
Harmonic Distortion: (below rated output) **Non-Harmonic related output:** (below rated output) **Under vibration or AC Mag Field:** **Signal-to-Phase Noise Ratio in 30 kHz noise BW (1 and 5 MHz):**	>40 dB >80 dB >60 dB >87 dB	>40 dB >80 dB >60 dB >87 dB	>40 dB >80 dB >60 dB >87 dB
Environmental **DC Magnetic Field Stability:** **AC Magnetic Field:** 50, 60 and 400 Hz ±10% **Temperature, operating with Option 001 or 002** **Freq. change from 25°C:**	$< \pm 2 \times 10^{-13}$ 2 Gauss Field $<2 \times 10^{-12}$ for 2 Gauss peak 0 to 50°C $<5 \times 10^{-12}$	$< \pm 2 \times 10^{-12}$ 2 Gauss Field $<2 \times 10^{-12}$ for 2 Gauss peak 0 to 50°C $<5 \times 10^{-12}$	$< \pm 5 \times 10^{-12}$ 1 Gauss Field $<5 \times 10^{-12}$ for 1 Gauss peak 0 to 50°C $<4 \times 10^{-11}$
Temperature, non-operating without options: **with Option 001:** **with Option 002**	−40°C to 75°C −40°C to 75°C −40°C to 50°C	−40°C to 75°C −40°C to 75°C −40°C to 50°C	−40°C to 75°C −40°C to 75°C −40°C to 50°C
Humidity, operating: 95% up to	40°C	40°C	40°C
Altitude, operating: **Max. frequency change:**	12.2 km (40,000 ft.) 2×10^{-12}	12.2 km (40,000 ft.) 2×10^{-12}	12.2 km (40,000 ft.) 2×10^{-11}

NOTES:
(1) For life of beam tube.
(2) Short-term stability for the 5061A with both standard and high performance tubes is given for the normal loop time constant. For improved short-term stability in controlled environments the long time constant may be used.
(3) With 10638 Degausser.
(4) Degree to which an oscillator will produce the same frequency from one occasion to another without recalibration.
(5) Degree to which frequency can be set to agree with a reference frequency.

Instrument	5061A Opt 004	5061A	5065A
Vibration: **with isolators:**	MIL-STD-167-1 MIL-T-21200	MIL-STD-167-1 MIL-T-21200	MIL-STD-167-1
Shock:	MIL-E-5400, Class 1 (30G)		
	1-MIL-T-21200, C.1		MIL-T-21200, C.1
EMC:	MIL-STD-461, Notice 3, Class A		
General			
Power: AC:	50, 60 or 400 Hz ±10%, 115/230 V ±10%		
	43 W	43 W	49 W
DC:	22 to 30 V 27 W	22 to 30 V 27 W	23 to 30 V 35 W
Option 001: add (AC/DC) **002:** add (AC/DC) **010:** add (AC/DC)	10/7.5 W 22/4.5 W	10/7.5 W 22/4.5 W	10/7.5 W 6/0 W
Dimensions (H x W x D): mm: inches:	221 x 425 x 416 8.7 x 16.7 x 16.4	221 x 425 x 416 8.7 x 16.7 x 16.4	133 x 425 x 416 5.2 x 16.7 x 16.4
Weight: (lb/kg) **Option 001:** add (lb/kg) **002:** add (lb/kg)	70/31.8 2/0.9 5/2.3	67/30.5 2/0.9 5/2.3	34/15.4 2/0.9 3.5/1.6
Option 001, Clock			
1 PPS Outputs: Master: **Clock:**	Front & Rear BNC	Front & Rear BNC	Front & Rear BNC
Amplitude:	10 V peak into 50Ω load		
Width: **Rise Time:** **Fall Time:**	20 μs min <50 ns <2 μs	20 μs min <50 ns <2 μs	20 μs min <50 ns <2 μs
Jitter, pulse-to-pulse:	<5 ns, rms	<5 ns, rms	<5 ns, rms
Synchronization:	Automatic, 10 ±1 μs delay	Automatic, 10 ±1 μs delay	Auto., 10 ±1 μs delay
Clock pulse adjustment range:	1 μs to 1 s	1 μs to 1 s	1 μs to 1 s
Clock display:	Solid State Digital		
Option 002, Standby Power Supply **Capacity at 25°C with Option 001 Clock:**	30 Minutes	30 Minutes	10 Minutes
Recharge, Fast/Float:	Automatic, fast charge		Switch

Ordering Information

	Price
5061A Cesium Beam Frequency Standard	$29,300
Opt 001: Clock	add $2,950
Opt 002: Standby Power Supply	add $1,400
Opt 003: Clock and Standby Power Supply	add $4,350
Opt 004: High Performance Beam Tube	add $5,100
Opt 908: Rack Flange Kit	add $27
E21-5061A Flying Clock	Add $5,525

Consists of: 5061A with Opt 001 (not included in E21 price) and K02-5060A Standby Power Supply.
Weight: 64 kg (141 lb).
Size: 425 H x 405 W x546 mm D (16.7" x 15.9" x 21.5") (includes handles).

10638A Degausser	$1,250

Weight: 1.2 kg (3 lb).
Size: 130 H x 77 W x 279 mm D (5.1" x 3" x 11").

5065A Rubidium Frequency Standard	$16,900
Opt 001: Clock	add $2,950
Opt 002: Standby Power Supply	add $700
Opt 003: Clock and Standby Power Supply	add $3,650
Opt 908: Rack Flange Kit	add $22
E21-5065A Portable Time Standard	add $5,125

Consists of: 5065A with Opt 001 (not included in E21 price) and K02-5060A Standby Power Supply.
Weight: 50 kg (110 lb).
Size: 425 H x 405 W x 546 mm D (16.7" x 15.9" x 21.5") (includes handles).