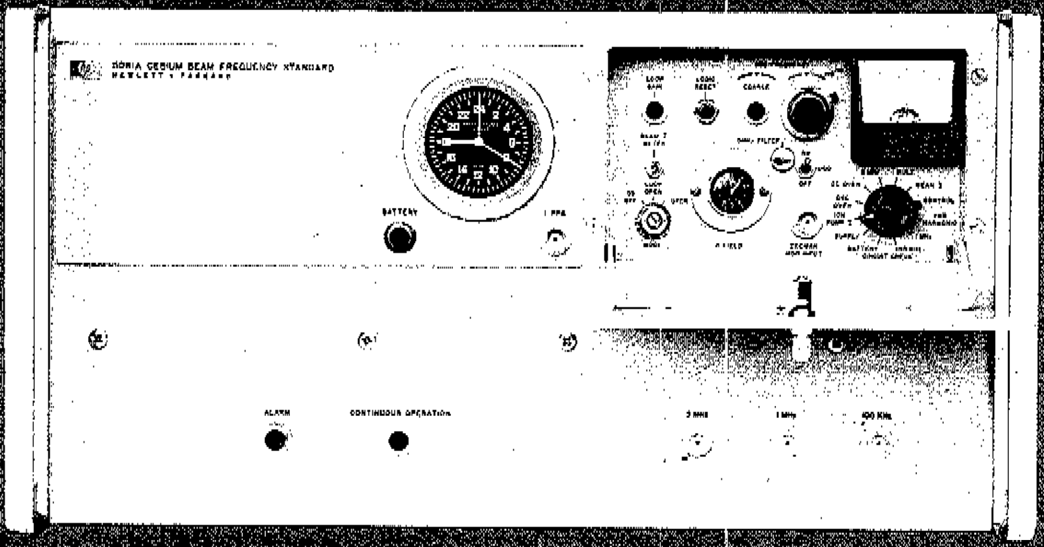
HEWLETT PACKARD

CESIUM BEAM FREQUENCY STANDARD

model 5061A

TECHNICAL DATA 15 JAN 68



PRIMARY FREQUENCY STANDARD

1 x 10^{-11} ACCURACY

UTC OR ATOMIC TIME SCALES SELECTED BY SWITCHES

COMPACT CONSTRUCTION

ALL SOLID STATE

OPTIONAL BUILT-INS:

Clock & Digital Divider

with Automatic Synchronization

Standby Battery Supply

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The Hewlett-Packard Model 5061A is a compact, self-contained primary standard of the atomic beam type, utilizing Cesium 133. It incorporates new features that many years of operating experience with its predecessor, the HP 5060A, indicate would be very useful. A cesium beam tube resonator stabilizes the output of a new, high quality quartz oscillator, which results in an exceptional accuracy of ± 1 part in 10^{11}. The 5061 has provision for an optional internal clock and digital divider and for battery with 1 hour (typical) standby power capacity.

OPERATION

In the atomic resonator a beam of state selected cesium 133 atoms passes through a microwave cavity. When the frequency of the microwave magnetic field is near the hyperfine transition frequency of cesium 133 (see "Time Scales"), it induces transitions from one energy level to another. Those atoms which have undergone such a transition are then detected by a hot wire ionizer and electron multiplier. The microwave field, derived from a precision quartz oscillator by frequency multiplication and synthesis, is phase modulated at a low audio rate. When the microwave frequency deviates from the center of the atomic resonance, the current from the electron multiplier contains a component alternating at the modulation rate and proportional to the frequency deviation. This component is then filtered, amplified, and synchronously detected to provide a DC voltage proportional to the frequency deviation. The integral of this DC voltage is then used to automatically tune the quartz oscillator to zero frequency error.

The control circuit provides continuous monitoring of the output signal. Automatic logic circuitry is arranged to present an indication of correct operation. Figure 1 shows a simplified block diagram of the 5061A operation. The compact cesium beam tubes exhibit frequency perturbations so small that independently constructed tubes compare within a few parts in 10^{12}.

OPTIONS

Three options are available for the 5061A: Option 01, Time Standard; Option 02, Internal Standby Power Supply; Option 03 combines Options 01 and 02.

The Option 01 provides the 5061A with a 1 pulse per second clock output available at both front and rear panel BNC connectors. The clock is driven by 1 MHz, internally connected. The clock pulse is adjustable with respect to a reference by 6 thumbwheel switches in decade steps from 1 μs to 1 s. An internal screwdriver adjustment allows fine continuous adjustment over any 1 μs range. The thumbwheel switches are located under the access door in the top cover (see Fig. 3).

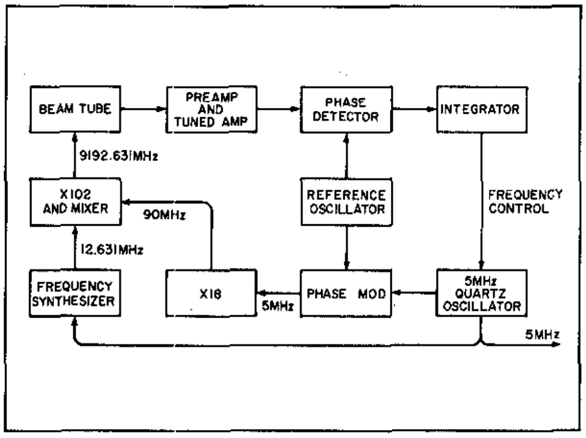


FIGURE 1. Block Diagram

The time standard option includes a Patek Philipe clock movement indicating time in hours, minutes, and seconds. Advance/Stop pushbuttons on clock module allow clock to be set to the nearest second. Pressing an internal sync button automatically synchronizes the 1 pps clock pulse to an external sync pulse.

The temperature coefficient of the clock pulse is typically 3 ns/°C over the 0° to +50°C range. The clock will not be affected by ± 4 V steps on the external 22-30 V dc supply or by up to 200 V external pulses fed into the clock pulse outputs.

The Option 02 provides the 5061A with 30 minutes battery standby power (typically 1 hour at 25°C) if the power line should fail. Recharging of the battery is automatic by means of an internal digital timing system each time standby is used. Maximum recharge takes 14 hours. A front panel warning light indicates float charge, fast charge or battery operation.

The Option 03 combines Options 01 and 02 and should be specified if both Options 01 and 02 are required.

ATOMIC AND UTC TIME SCALES

The 5061A can easily be referred to either of the two time scales in widespread scientific use: UTC or Atomic. The change is accomplished by changing a set of 4 thumbwheel switches and a slide switch, located under the top cover (see Fig. 3).

The time interval of the atomic time scale is the International Second, defined in October 1967 by the Thirteenth General Conference of Weights and Measures: "The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the fundamental state of the atom of cesium 133."

The Universal Time Scale, UT2, is related to the earth's rotation and has been proceeding at a rate slightly slower than that of the atomic scale. Its time interval—second—is slightly longer. A time scale (UTC) which approximates UT2 can be produced by oscillations offset from the atomic frequency in an amount proportional to the difference in the intervals employed.

By international agreement, the amount of this frequency offset is fixed each year by the Bureau International de l'Heure, in Paris. For 1965 the offset was -150×10^{-10}, and for 1966, 1967, and 1968 it is -300×10^{-10}.

U.S. Standard Time, kept by the U.S. Naval Observatory's master clock, differs from nominal UTC by an integral number of hours. The time interval broadcast by NBS stations WWV, WWVH, and WWVL is UTC, which is a smoothed approximation to UT2. WWVB (60 kHz) broadcasts the atomic second, without offset.

TIME SCALE CHANGES

Changing of time scales is accomplished by changing the division ratio in the Preset Divider. Figure 2 shows the block diagram of the frequency

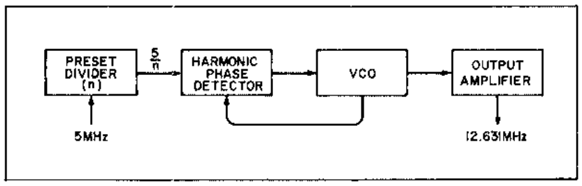


FIGURE 2. Synthesizer Block Diagram

synthesizer. A frequency of 12.631 . . . MHz is produced by first dividing 5 MHz (by an integer n) using a preset divider. Then the 12.631 . . . MHz is phase locked to the 5/n frequency from the preset divider.

The synthesized frequency is mixed with 9180 MHz to produce a frequency very close to the Cs transition frequency. The remaining frequency error is removed by C field adjustment. Since the error is always less than $\pm 5 \times 10^{-11}$, the C field will always lie in the range of 50-70 milligauss.

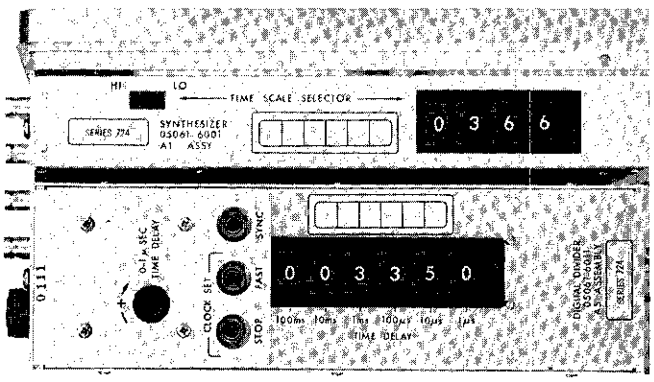


FIGURE 3. Thumbwheel switches for time scale changes (upper). Controls for Option 01 (lower)

The 5061A is an advanced version of the HP 5060A, which has been proven by long term testing in the factory, laboratory, and field. The data gathered on the HP 5060A is shown below to illustrate typical performance of HP Cesium Beam Frequency Standards. The 5061A uses the same cesium beam tube, and basic circuitry as did the 5060A.

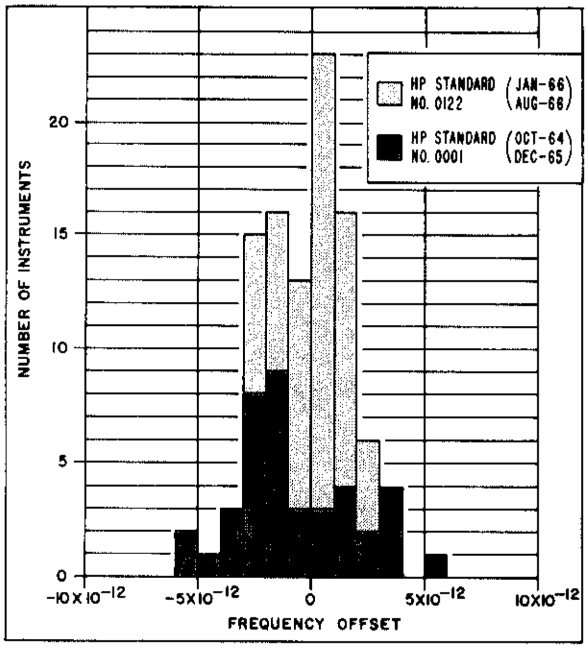


FIGURE 4. 5060A Frequency Comparisons

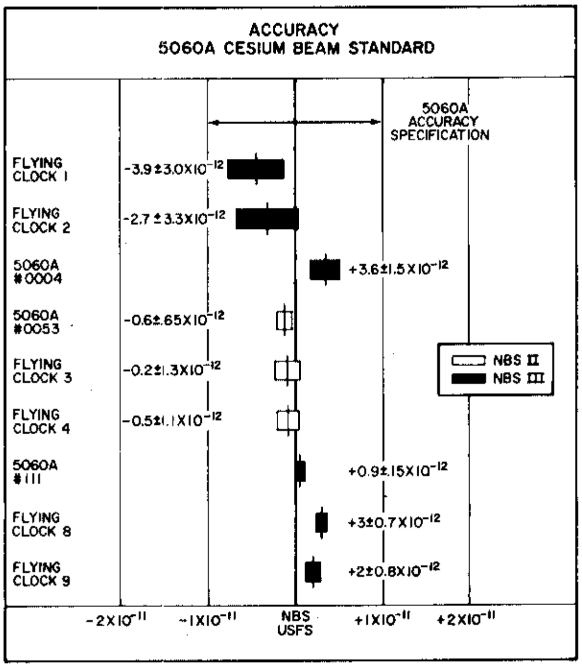


FIGURE 5. 5060A Accuracy*

INTRINSIC REPRODUCIBILITY

Figure 4 shows an intercomparison of 5060A standards with the Hewlett-Packard house standard of the same design. The 100 cesium beam standards were independently aligned. The comparison method used was that of continuous phase difference recordings, each continued for an average of 70 hours. The total spread for these comparisons is $\pm 6 \times 10^{-12}$, well within the 5060A's accuracy specification, $\pm 1 \times 10^{-11}$.

ACCURACY

Figure 5 shows the results of 5060A comparisons against the U.S. Frequency Standard (USFS, NBS-II and NBS-III) over a two-year span. The placement of each bar indicates the mean frequency and its width indicates measurement precision. USFS is regarded as ideal. NBS has reduced its estimated inaccuracy over the years covered, but in every case it can be stated that the accuracy of the standards being compared lies well within the specified limits.

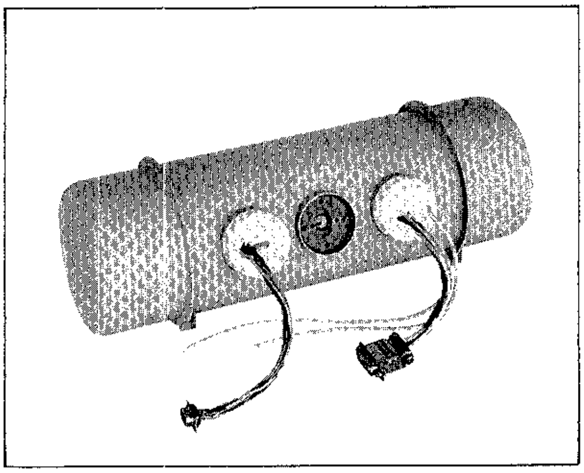


FIGURE 6. Cesium Beam Tube

* *For "Flying Clock" experiments and accuracy details see Hewlett-Packard Journal: L. N. Bodily and R. C. Hyatt, "Flying Clock Comparisons . . .", Vol. 19, Dec. 1967. L. N. Bodily, ". . . Characteristics of Cesium Beam Standards . . . ," Vol. 18, No. 2, October 1966. For earlier data see: Vol. 17, No. 12, August 1966; Vol. 16, No. 8, April 1965; and Vol. 15, No. 11, July 1964.*

SPECIFICATIONS

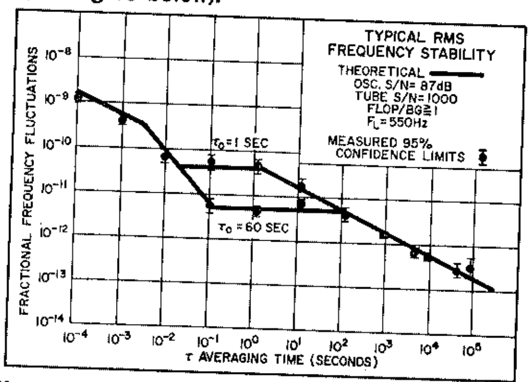
5061A CESIUM BEAM STANDARD

Accuracy:*† $\pm 1 \times 10^{-11}$.

Reproducibility:* $\pm 5 \times 10^{-12}$.

Long Term Stability:* $\pm 1 \times 10^{-11}$ (for life of tube).

►**Short Term Stability:** Front panel switch (behind door) selects 1 sec or 60 sec loop time constant (see figure below).



Warm-up Time: ¾ hour to fully operational from 25°C ambient temperature.

Harmonic Distortion: (5 MHz, 1 MHz, and 100 kHz) Down more than 40 dB from rated output.

Non-harmonically Related Output: (5 MHz, 1 MHz, and 100 kHz) Down more than 80 dB from rated output.

Output Frequencies: 5 MHz, 1 MHz, 100 kHz sinusoidal, 100 kHz clock drive (1 MHz clock drive optional).

Output Voltages: 1 V rms into 50 Ω; clock drive suitable for Hewlett-Packard Frequency Divider and Clocks.

Output Terminals: 5 MHz, 1 MHz, 100 kHz, front and rear BNC connectors, 100 kHz clock drive, rear BNC connector.

Time Scale: Adjustable with 4 thumbwheel switches and a slide switch from 0 to -700×10^{-10}. 12.63 . . . MHz test frequency available on rear panel.

CESIUM BEAM TUBE

Tube Life: 10,000 hours guaranteed (operating) within 2 years of receipt of tube.

Length: 16 ± 1/16 in.

Diameter: Approximately 5⅝ in.

Weight: 16 lbs.

Line Width: 550 Hz (± 20%).

S/N Ratio (Voltage): Typical, 1000 (¼ Hz noise bandwidth).

RF Power (9192 + MHz): 30 μW.

Power Input, 25°C, Typical: 6.5 W.

QUARTZ OSCILLATOR

Aging Rate: $<|5|$ parts in 10^{10} per 24 hours.

Signal-to-Noise Ratio: For 1 and 5 MHz, > 87 dB at rated output (in a 30 kHz noise bandwidth, 5 MHz output filter bandwidth is approx. 100 Hz). For 100 kHz, > 60 dB in 30 kHz noise bandwidth.

Frequency Adjustments:

Fine Adjustment: 5 parts in 10^8 range, with dial reading parts in 10^{10}.

Coarse Adjustment. 1 part in 10^6, screwdriver adjustment at front panel.

Stability:

►As a Function of Ambient Temperature: < 2.5 $\times 10^{-9}$ total from 0° to + 50°C.

As a Function of Load: $< \pm 2 \times 10^{-11}$ for open circuit to short, and 50 Ω R, L, C load change.

As a Function of Supply Voltage: $< \pm 5 \times 10^{-11}$ for 22 to 30 V dc, or for 115/230 V ac, ± 10%.

* *DEFINITION OF TERMS*

Accuracy: The degree to which oscillator frequency is the same as that of an accepted primary standard (for example, the U.S. Frequency Standard), or the degree to which oscillator frequency corresponds to the accepted definition, presently that of the 12th General Conference of Weights and Measures (see "Time Scales").

Reproducibility: The degree to which an oscillator will produce the same frequency from unit to unit and from one occasion of operation to another. Included within this definition is the degree to which the frequency of an oscillator can be set by a calibration procedure.

Intrinsic Reproducibility: The degree to which an oscillator will reproduce a given frequency without the need for calibrating adjustments either during manufacture or afterward. This quality is a characteristic of an apparatus design, not of a resonance.

Long Term Stability: Total fractional frequency drift for the life of the cesium beam tube.

† *See Figure 5.*

SPECIFICATIONS

GENERAL

►**Environmental**

Temperature: Operating, 0-50°C. Typical stability better than $\pm 5 \times 10^{-12}$ over temperature range. Non-operating, -40 to $+75$°C.

Production units have passed type testing as follows:

Humidity: 0 to 95% operating.

Altitude: 40,000 ft. operating.

Magnetic: Typical stability in 2 gauss field, any orientation, better than 5×10^{-12}.

Vibration: Passed MIL-STD-167.

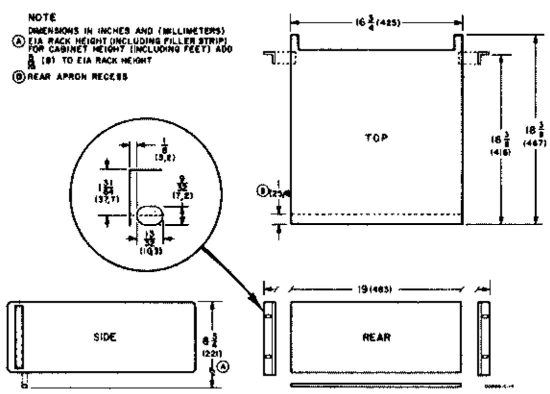
Shock: Passed MIL-T-21200, Class 1.

EMC: MIL-I-6181D. Also known as RFI.

►**Power:** 115 or 230 V ac ± 10%, 50 to 1000 Hz; or 22 to 30 V dc. Approx. power required:

	DC	AC
Without Options:	27 W	43 W
Option 01	Add 7.5 W	10 W
Option 02	Add 4.5 W	22 W
Option 03	Add 12 W	32 W

Dimensions:



Weight: Net, 60 lbs., no options. Option 01 add 2 lbs. Option 02 add 5 lbs.

Accessories Furnished: Power Cord, 6 ft. (180 cm), detachable. Rack Mounting Kit, HP 5060-0777. Accessory Kit, HP 05061-6070, includes two extender boards, test cables, maintenance tools, and a mating connector 1251-0126 for EXT DC input.

Accessories Available: EXT DC Cable: connects 5061A to 5085A standby supply, 103A-16A, $21.50.

Mating Connectors:

EXT DC Input: 1251-0126 (5-contact), Cannon MS 3106E-14S-5S (Series ME) furnished.

Clock Output: 1251-0127 (4-contact), Cannon MS 3106E-14S-2P (Series ME).

AC Line: 1251-0038, Cannon MS 3106A-10SL-35 (C).

Price: HP Model 5061A, $14,800.00.

OPTION 01 TIME STANDARD

Clock Pulse:

Rate: 1 pulse per second.
Amplitude: + 10 V peak.
Width: 20 μs ± 10%.
Rise Time: < 50 ns.
Fall Time: < 1 μs.
Jitter: < 20 ns.
All specs are with 50 Ω load.

Synchronization: 10 μs (± 1 μs) delayed from reference input pulse. Reference pulse must be > + 5 V, with a rise time < 50 ns.

►**Clock Movement:** 24 hrs., Patek Philippe.

Price: Option 01, add $1,500.00.

OPTION 02 STANDBY POWER SUPPLY

Capacity: 30 minutes minimum (1 hour typical at 25°C) at full charge.

Charge Control: Automatic when ac power is connected.

Indicator: A front panel light flashes when ac power is interrupted and battery is being used.

Price: Option 02, add $600.00.

►OPTION 03

Combines Options 01 and 02

Price: Option 03, add $2,100.00.

► Indicates change from prior specifications

RELATED EQUIPMENT

Hewlett-Packard Model 5085A 24 V, 2 A, 18 A-Hr. Power Supply enables operation of primary frequency or time standards when ac line power is interrupted. This power supply is specifically designed to deliver standby power to the Hewlett-Packard Cesium Beam Frequency Standards and peripheral equipment. Price, with batteries: $1,250.00. For "Flying Clock" use, consult HP.

Hewlett-Packard Model 117A VLF Comparator is designed to make accurate phase comparisons in the continental United States between local frequency standards and the U.S. Frequency Standard as transmitted by the National Bureau of Standards from Fort Collins, Colorado, on 60 kHz with the call letters WWVB. Price: $1,300.00.