SECTION XVIII

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DISCIPLINED HP 5071A CESIUM OSCILLATOR (OPTION)

1-1 INTRODUCTION

1-2 This external oscillator option offers the user a highly accurate frequency source with the ultimate in medium and long term stability as well as holdover performance during periods when GPS satellites are not usable. While GPS satellite data is available, the XL-DC microprocessor controls this oscillator via Steering corrections which are transmitted to the HP 5071A via the XL-DC secondary RS-232 serial I/O port. These are implemented in such a way as to phase lock the Cesium outputs to UTC. Since all time and frequency outputs of the XL-DC are coherent with this oscillator, all display the same enhanced stability and holdover performance.

1-3 In addition to controlling the frequency of the HP 5071A, the XL-DC microprocessor also monitors and reports all of the status information available from the HP 5071A over the RS-232 interface. The standard XL-DC fault reporting and alarm generation functions are augmented to include the HP 5071A fault status information.

1-4 This option consists of an HP 5071A Cesium Beam Frequency Standard, which is essentially a high quality ovenized 10 MHz crystal oscillator that is frequency locked to the resonance of Cesium atoms. Fine frequency adjustments are made possible by the ultra-fine resolution digital synthesizer which is internal to the HP 5071A and allows offsetting its outputs relative to the actual Cesium resonance by precisely controlled amounts. The important performance benefits provided by this Cesium oscillator unit are the ultimate in stability versus environmental effects, no systematic drift and rapid warm-up and restabilization.

1-5 SPECIFICATIONS

1-6 All standard XL-DC accuracy and stability specifications (see Section I) are valid when the XL-DC has been operating continuously for at least 24 hours with an accurate position (error < 10 m in WGS-84) and at least four satellites are visible. The ambient temperature variations may include the full specified operating temperature range of the XL-DC. Refer to the HP 5071A Operating and Programming Manual for detailed specifications concerning its performance. The addition of this option impacts the standard XL-DC specifications in these areas:

1-7 Time Domain Stability (Allan Deviation):

τ	$\sigma_\gamma(\tau)$
1	6×10^{-11}

10	3×10^{-11}
10^2	6×10^{-12}
10^3	3×10^{-12}
10^4	6×10^{-13}
10^5	3×10^{-13}
10^6	6×10^{-14}

1-8 Holdover Characteristics (after 240 hrs operation):

Initial Frequency Error: $< 1 \times 10^{-13}$
Drift Rate: N/A
Temperature Coefficient: $< 2 \times 10^{-15}/\ ^{\circ}C$

1-9 Oscillator Warm-Up:

< 15 minutes to NORMAL Operational Status ($< 2 \times 10^{-12}$)

2-1 INSTALLATION

2-2 This option is factory installed. Field installation is not available for this option. In the case of operation with a customer supplied HP 5071A, two connections between the HP 5071A and the XL-DC must be made:

1) One of the HP 5071A 10 MHz outputs must be cabled to the Ext. Osc. input on the rear panel of the XL-DC using coaxial cable and BNC connectors.
2) A null modem RS-232 cable must be connected between the HP 5071A RS-232 DB9M connector and the XL-DC Aux. RS-232 DB9M connector.

An optional connection may be made which will allow synchronizing the HP 5071A 1PPS output to the XL-DC 1PPS, which will be on-time to UTC when operating normally. This connection consists of a coaxial cable between the XL-DC 1PPS output and the HP 5071A 1PPS Sync input.

3-1 OPERATION

3-2 No special operation procedures are required, however initial acquisition of satellites after a cold start-up may be delayed relative to the standard TCXO oscillator due to the warm-up time of the Cesium oscillator. In addition, due to the narrow tuning range of the Cesium oscillator, longer than normal initial acquisition time to first LOCK will be required. See Section III for general XL-DC operation.

3-3 KEYPAD/SERIAL I/O FUNCTION F73 - REQUEST/SET ALARM STATUS/CONTROL

3-4 The standard Keypad and Serial I/O Function 73 is augmented to include both a Major and a Minor Alarm due to HP 5071A faults. The faults indicated in the HP 5071A Operation Condition Register (OCR): CAL, STANDBY, NORMAL, and FATAL are interpreted by the XL-DC as Major Alarm faults. In addition, the ON BATTERY fault from the HP 5071A OCR will become a Major Alarm fault if it persists for more than 30 minutes. An RS-232 communications failure between the XL-DC and the HP 5071A will also cause a Major Alarm. The faults indicated in the HP 5071A Questionable Condition Register (QCR): TIME, FREQ and PHAS are interpreted as Minor Alarm faults. In addition to these faults taken from the HP 5071A QCR, a short failure in RS-232 communication between the XL-DC and the HP 5071A will also cause a Minor Alarm as will short intervals of the ON BATTERY fault from the HP 5071A OCR. Refer to the HP 5071A Operating and Programming Manual for details concerning its fault reporting.

Keypad Function 73 will have new entries at the end of the Major and Minor Alarm lists when this option is installed:

Major Alarm: <en>
 Cs Osc: <Cs status>

Minor Alarm: <en>
 Cs Osc: <Cs status>

<Cs status> may be either "OK", "FAULT" or "OK *" depending upon the status information obtained from the HP 5071A.

Serial I/O Function 73 will have a new entry at character position 7 in both the Major and Minor Alarm fields when this option is installed. When HP 5071A operation is normal, a '-' appears at this position. When a fault exists, a 'C' appears at this position.

Refer to the Keypad and Serial I/O Function 73 topics in Section III of the XL-DC Operation Manual for general use of this function.

3-5 KEYPAD/SERIAL I/O FUNCTION F74 - HP5071A SET-UP AND STATUS ENTRY/REQUEST

3-6 Keypad and Serial I/O Function 74 is available when this option is installed. It provides the ability to force setting the HP 5071A time and Modified Julian Date (MJD) and to clear the HP 5071A event log. In addition, It displays the individual status indicators of the HP 5071A Operation and Questionable Condition Registers.

As part of the normal start-up sequence during its initial lock to the GPS system, the XL-DC will synchronize the HP 5071A 1PPS to UTC and set the MJD which the HP 5071A uses internally to timestamp events in its event log. However, if a synchronization input is not present on the HP 5071A Sync input BNC when this occurs, then the seconds displayed on the HP 5071A clock display will not be synchronized with UTC and can be off by a noticeable amount relative to the on-time XL-DC clock display. To remedy this possibly annoying situation, Keypad and Serial I/O Function 74 provides a way to force a resynchronization once the operator has connected an on-time 1PPS to the HP 5071A Sync input BNC.

Keypad Operation:

Pressing FUNC/ENTR followed by 7 and 4 will cause this screen to be displayed:

Set Cesium Osc
 Time? <resp>

<resp> may be either "No" or "Yes". Pressing the UP or DOWN arrow keys will allow toggling between these. When the desired response is indicated, press FUNC/ENTR to affect the desired operation. A "Yes" response will cause the XL-DC to issue commands to the HP 5071A which will cause it to hardware re-synchronize its 1PPS to the 1PPS applied to its Sync input and to set its time of day and MJD. Now this screen will be displayed:

Clear Cesium Osc
 Log?   <resp>

which operates just like the previous screen. A "Yes" response will cause the XL-DC to issue a command to the HP 5071A which will cause it to clear its event log. Now this screen will be displayed:

Major Cs Status
Not Normal:<status>

Here <status> may be either "OK", "FAULT" or "OK *". "OK" means that the *Not Normal* condition is not present and that it has not been present since the status latch was last cleared. "FAULT" means that the *Not Normal* condition is currently present. "OK *" means that the *Not Normal* condition is not currently present, but that the fault has been latched since the last time that the status latch was cleared. Repeatedly pressing FUNC/ENTR will bring up these status displays:

Major Cs Status
Cal Mode: <status>

Major Cs Status
Fatal: <status>

Major Cs Status
Standby: <status>

Major Cs Status

Bat30Min: <status>

Major Cs Status
Reinit Cfg:<status>

Each of these Major Cs Status displays reflect the state of the HP 5071A OCR with the exception of the *Bat30Min* status and the *Reinit Cfg* status indications. The *Bat30Min* indicator indicates that the unit has been operating without AC power for at least 30 minutes. The *Reinit Cfg* indicator indicates that RS-232 communications between the XL-DC and the HP 5071A have become unreliable or non-existent and that the XL-DC has been repeatedly trying to re-establish communications with the HP 5071A by continually re-sending configuration commands and queries. Continuing to press FUNC/ENTR brings up the Minor Cs Status displays:

Minor Cs Status
Frequency: <status>

Minor Cs Status
Phase: <status>

Minor Cs Status
On Battery:<status>

Minor Cs Status
Reinit Cfg:<status>

Each of these Minor Cs Status displays reflect the state of the HP 5071A QCR with the exception of the *Reinit Cfg* indicator which indicates that a disagreement between what the XL-DC sent to the HP 5071A and what the HP 5071A echoed back has occurred at least once. Should this fault occur repeatedly, then it will be elevated to a Major Cs Status fault.

If any latched faults exist, then when FUNC/ENTR is pressed once more this screen will be displayed:

Clear Cesium Osc
 Latch?<resp>

<resp> may be either "Yes" or "No", which is toggled using the UP or DOWN arrow keys. Press FUNC/ENTR to make the desired selection. Clearing this latch will cause the asterisks to disappear, unless the fault condition is still present.

<u>Serial I/O Port Operation:</u>

Sending F74<SP>CLEAR<SP>CESIUM<SP>LOG<CR><LF> will clear the HP 5071A event log.

Sending F74<SP>SET<SP>CESIUM<SP>TIME<CR><LF> will re-arm the HP 5071A Sync input and set the time of day and MJD of the HP 5071A.

Sending F74<CR> over the RS-232 port will return:

F74<SP>M12345678<SP>m12345678<CR><LF>

where:

F	=	ASCII character F	
7	=	ASCII character 7	
4	=	ASCII character 4	
<SP>	=	ASCII space character	
M	=	'M'	Major Cesium Alarm delimiter
1	=	'-'	NORMAL Operation
		'N'	Not NORMAL Operation
2	=	'-'	Not in CAL Mode
		'C'	CAL Mode
3	=	'-'	Not in STANDBY Mode
		'S'	STANDBY Mode
4	=	'-'	Not in FATAL Mode
		'F'	FATAL Mode
5	=	'-'	Not ON BATTERY for 30 minutes.
		'B'	ON BATTERY for more than 30 minutes.
6	=	'-'	Re-Initialization not attempted for more than 200 seconds.
		'R'	Re-Initialization attempted for more than 200 seconds.
7	=	'-'	Currently not used
8	=	'-'	Currently not used
<SP>	=	ASCII space character	
m	=	'm'	Minor Alarm delimiter
1	=	'-'	No FREQ events
		'F'	FREQ events present
2	=	'-'	No PHASE events
		'P'	PHASE events present
3	=	'-'	Not ON BATTERY
		'B'	ON BATTERY
4	=	'-'	Re-Initialization not being attempted
		'R'	Re-Initialization being attempted
5	=	'-'	Currently not used
6	=	'-'	Currently not used
7	=	'-'	Currently not used

8 = '-' Currently not used
<CR> = ASCII carriage return character
<LF> = ASCII line feed character

Sending F74<SP>LATCH<CR> will return

F74<SP>LATCH<SP>M12345678<SP>m12345678<CR><LF>

where each field has the same meaning as the previous command, except that the presence of a fault character means that an event was detected since the last clearing of the latch. The fault may or may not still be present.

Sending F74<SP>CLEAR<SP>CESIUM<SP>LATCH<CR><LF> will clear the latched faults.

4-1 THEORY OF OPERATION

4-2 The XL-DC provides accurate time and frequency whenever one or more satellites are in view, with optimal performance when four or more satellites are in view. When satellite outages do occur, the XL-DC flywheels on its oscillator, either internal or, when using the External Oscillator Control option, external oscillator. During these periods, the rate that the XL-DC time and frequency outputs diverge from UTC is governed by these parameters:

1) The accuracy of the last DAC control voltage setting prior to the outage.

2) The ambient temperature change during the outage period and the temperature coefficient of the oscillator's output frequency.

3) The inherent drift or ageing rate of the oscillator's output frequency as a function of time. All quartz and Rubidium oscillators exhibit this drift.

Items 2) and 3) are functions of the Cesium oscillator and the temperature characteristics of the environment in which the XL-DC is operated. Item 1) is determined by the stability of the GPS system and the control parameters chosen in the digital phase lock loop implemented in the microprocessor of the XL-DC.

4-3 The oscillator control algorithm employed in the XL-DC implements a Type III servo on the phase relationship of the XL-DC clock to UTC as measured via GPS clock bias solutions performed in the core GPS module. Proprietary algorithms are employed to affect multi-satellite averaging and to detect and remove data outliers so that optimally stable steering data is applied to the oscillator. The output of the control algorithm is a floating point number between $+2.0748035 \times 10^{-10}$ and $-2.0748668 \times 10^{-10}$ which is transmitted over a dedicated RS-232 port to the HP 5071A via its Steering command.

The control philosophy is to implement sufficient averaging to reduce the short term effects on stability caused by Selective Availability while maintaining the long term stability available from the GPS system. This philosophy requires that trade-offs be made between having better short and medium term stability versus having better insensitivity to environmentally induced instability, e.g. temperature induced oscillator frequency shifts which cannot be eliminated when heavy control loop averaging is in effect.

The environmental stability of the HP 5071A Cesium Beam Frequency Standard is such that operation over the full 0° C to + 50° C ambient temperature range results in virtually no degradation in the stability characteristics of the unit. This being the case, the time constants in the control algorithm have been chosen based solely on the relative frequency stability characteristics of the GPS system and the HP 5071A. The Allan Deviation stability of the GPS system crosses through 5×10^{-14} at a of $\approx$5 days. Since the Allan Deviation floor of the HP 5071A is also $\approx 5 \times 10^{-14}$, the control loop parameters are set to ultimately reach an equivalent averaging time of 5 days.

For users whose operating environment differs significantly from the assumed environment, the available XL-DC External Oscillator Control option offers the ability to tailor the oscillator control parameters to the user environment. This option is described fully in Section III in Keypad or Serial I/O functions 07 and 14 and is primarily intended for users who wish to supply their own oscillators for control by the XL-DC. However operation with an optional internal ovenized quartz or Rubidium oscillator or this HP 5071A Cesium oscillator is identical in function. Keypad or Serial I/O Function 14 allows user oscillator parameter set-up and Function 07 allows enabling of oscillator control using these user defined parameters in exactly the same way as they would be used for a *user provided external* oscillator. The one disadvantage of this method of defining oscillator control parameters is that they are not stored in firmware. Failure of the battery backed NVRAM would cause the XL-DC to revert to the default firmware resident parameters, requiring user intervention to re-program the "forgotten" parameters and re-enable them. Should operation via the External Oscillator Control option be desired, these function 14 parameters would yield operation comparable to the firmware resident parameters:

Freq: 10
Tuning Slope: 4.15e-11
DAC Nominal: 0.50
Temp Stab: 5.00e-14

5-1 MAINTENANCE

5-2 Due to the non-existent drift rate of the Cesium oscillator, under normal operation no periodic maintenance should be required to re-center the C-Field Tuning. To verify normal operation the user may observe the DAC value returned from either Keypad or Serial I/O function 71 while the XL-DC is properly locked to the GPS system.

Since the DAC value returned by Function 71 is a signed 16 bit integer representation of the DAC output voltage, the positive and negative limits are at 32767 and -32768 respectively. The DAC value is in units of HP 5071A fractional frequency offset steering resolution: 6.331991×10^{-15}. Whenever the XL-DC with HP 5071A Cesium option is operating properly with locked status indications and the steady state DAC value is less than +31000 and greater than -31000, operation should be interpreted as normal. If the DAC is outside of this range, the unit should be returned to the factory for service.

Refer to the HP 5071A Operating and Programming Manual for detailed information concerning the maintenance and service of the HP 5071A Cesium Beam Frequency Standard.