MAINTENANCE OF HP 5071A PRIMARY FREQUENCY STANDARDS AT USNO

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Abstract

The U.S. Naval Observatory (USNO) has been operating Hewlett-Packard model 5071A cesium-beam frequency standards for over five years. During that period, there have been a variety of failures and these devices have shown frequency and phase changes.

The HP 5071A model primary frequency standard offers a very useful troubleshooting tool by outputting the status of 22 different operating parameters. This paper will present an explanation of the parameters and show any correlation of them with the time, frequency, and environmental changes. This paper will also offer some indicators to predict future device problems.

INTRODUCTION

The Hewlett-Packard (HP) model 5071A Primary Frequency Standard is a quantum leap forward compared to the HP model 5061B. Among the improvements is the greater frequency stability through a broader temperature and humidity range. HP also improved the device's operational parameter monitoring capabilities. No longer must people enter the room housing the device (disrupting its environment) and physically make the measurements on the device. The new standards can output their parameters via an RS-232 connection to a computer for permanent filing and analysis.

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The analysis of these permanent files can range from a snapshot picture of the parameters to a time series analysis with plotting. Having the extreme long-term history of the parameters has additional benefits, especially if that history extends throughout the life of the standard. USNO has 45 standards from the 100, 200, 300, 400, 500, 700, and 1000 production series. Each device has its own "personality." Some characteristics have been correlated with production series. This paper will present the general characteristics of the USNO devices and note where they may differ. The parameters will be discussed in the order of their output. The more important parameters will be noted and discussed in greater detail.

THE PARAMETERS

There are 22 parameter values available via the RS-232 connection. These parameters are: frequency offset, oscillator control percentage, rf amplitude 1 percentage, rf amplitude 2 percentage, Zeeman frequency, C field current, electron multiplier voltage, signal gain percentage, tube oven voltage, tube oven temperature error, oscillator oven voltage, ion pump current, hot wire ionizer voltage, mass spectrometer voltage, SAW tuning voltage, DRO tuning voltage, 87 MHz PLL voltage, uP clock PLL voltage, +12 volt supply voltage, -12 volt supply voltage, 5 volt supply voltage, and internal temperature. USNO collects these data once per hour. The information appears as:

MJD 48587 21:03:42
CBT ID: 6-temp
Status summary: Operating normally
Power source: AC
Log status: Empty

Freq Offset:	0e-15	Osc. control:	-1.67 %
RF amplitude 1:	20.2 %	RF amplitude 2:	19.9 %
Zeeman Freq.	39949 Hz	C-field curr:	12.137 mA
E-multiplier:	1870 V	Signal Gain:	28.8 %
CBT Oven:	6.2 V	CBT Oven Err:	0.00 C
Osc. Oven:	-8.8 V	Ion Pump	0.2 uA
HW Ionizer:	1.0 V	Mass spec:	9.1 V
SAW Tuning:	3.5 V	DRO Tuning	6.8 V
87MHz PLL:	-0.8 V	uP clock PLL:	2.9 V
+12V supply:	12.3 V	-12V supply:	-12.4 V
+5V supply:	5.3 V	Thermometer:	35.0 C

USNO permanently files these values as:

> 50717.007569 CBT ID: 3128A00110(H) /Status summary: Operating normally /Power source: AC /Log status: Empty 0e-15 29.94 26.5 25.4 39949 12.166 2553 15.4 8.3 0.00 -8.7 0.0 0.8 12.8 1.8 5.8 1.7 2.6 12.3 -12.3 5.2 41.3

A computer program can sort and display the information in whatever format is needed. One might want several devices listed on one page when looking at snapshot pictures. On the other hand, one might want several consecutive readings for a particular device listed on one page to look for trends. Outputting the values to a plotting program is better for trend observation. Although the snapshot pictures will tell if a device is operating normally, it is the plot of the parameters' history that will help most in detecting the onset of problems and in fixing the device when a failure occurs.

CLOCK PERFORMANCE

The frequency offset can be set by either the manufacturer or the user. Typically, it is set to 0e-15.

Oscillator control percentage is a very important value to monitor. The value can be positive or negative and like most of the other parameters, the value is very characteristic of the device. One standard may have an oscillator control value of -8.6% and another standard may have a value of -43.1%. Neither of these values alone means that the clock is performing (or will perform) poorly. A variation in the value may suggest a future failure, and that will be covered in the next section. What is important about the oscillator control percentage for performance is its frequency and amount of change. This is an example of when continuous, periodic readings are needed. For example, USNO has had at least two standards that exhibit a phase or rate change that was coincident with a change in its oscillator control percentage. Such an occurrence may be due to the standard experiencing an environmental change (temperature and/or humidity), a Cesium Beam Tube (CBT) change, or a CBT controller board change, or it may be a precursor to a failure.

The rf amps have been found to have relatively constant values between 20.0 and 31.0 for each standard after initial burn-in. (The values may change somewhat during the first 1 1/2 to 2 years of operation.) The values will differ slightly from one device to another. The Zeeman frequency is set at the factory and should be 39949.0. The C field current should be between 12.0 and 12.2 milliamps and remain fairly constant. Again, the exact value will differ between standards.

The electron multiplier voltage is another very important parameter to watch. There is a limit at 2553 volts. USNO does have a standard performing quite well below the 1000 volt specification found in the 5071A owner's manual. (Its startup voltage was about 440 volts.) Typically, our standards have a startup voltage between 1150 and 1500. The voltage will decrease slightly and then begin to rise slowly during the first two years of operation. The total change will usually range from 150 to 200 volts. The voltage should continue to increase slowly after this initial startup period. The absolute value is characteristic of the device. The standard should be performing well if the value is changing slowly and CONSISTENTLY during the entire life time of the CBT.

The signal gain should be constant at 14.4 percent as long as the standard is below its maximum electron multiplier voltage. When the electron multiplier voltage reaches its limit, the signal gain will increase to keep the overall gain constant.

The cesium-beam oven voltage depends on ambient temperature. The USNO standards values are consistent between 7.5 and 8.0 volts. Actual values differ between devices. The cesium-beam tube error must be small (+/- 0.1 volts) for the standard to be operating properly.

The oscillator oven voltage typically has a value of -8.7 to -8.8 volts during normal operation. It should change by no more than 0.1 volts throughout the life of the device.

The ion pump current should have a low startup value (typically near 0.0) and remain constant. Some devices, however, are working quite well with constant values of 10, 20, or higher. (USNO has one device working well with an ion pump current of 36.0 microamps.) This value is another one of those "personality" characteristics of each device. A high current value can indicate a vacuum or electrical leak, that the tube has been off for a long period, or that the tube is contaminated. A current greater than 50 microamps will cause shutdown.

The hot wire ionizer voltage references the voltage across the ionizer ribbon. A value of 1.0 is ideal and it should be between 0.9 and 1.1 volts.

The mass spectrometer value will range from 10.0 to 14.0 volts. It should remain the same value during normal performance due to environmental changes.

The SAW and DRO tuning, 87 MHz PLL, uP clock PLL, +/-12 volt supply, and 5 volt supply values should be relatively constant from initial startup. All may vary by +/- 0.1 volts during normal operation.

The temperature value is the internal temperature of the standard. The value should typically range from 35 to 45 degrees Celsius and should remain constant. It will change as the standard's environment changes.

CLOCK FAILURES

The recording of the parameters once per hour, every hour, and retaining the information in permanent data files has a great benefit for detecting and analyzing failures. It also allows for the prediction of some future failures. Usually, analysis of the historical parameters may only indicate that a failure will occur, but not when. USNO has experienced a few problems with the standards and often looking at the parameters has pointed directly to the needed repair. By taking hourly readings of the parameters, one can watch a standard fail and prevent a related system disaster.

An example of a minor problem that can be seen in the parameters is a significant change in the standard's environmental temperature. A change in the environmental temperature can show up as an unusually large change in the electron multiplier voltage (see Figures 1, 2, and 3).

More serious problems are seen when an electronic card inside the standard fails. USNO has had some problems with the A2 and A6 cards failing and has documented the parameters showing the indications of a failure.

A failure in the A2 CBT controller card shows up as a significant change in only one parameter. The electron multiplier voltage will jump more than 10 volts. This greater than 10-volt change will occur over a 12- to 24-hour period (see Figure 4). Although a step in this parameter is not always an indication of an A2 card failure, the change is an indication that it is probable. No parameter changes seem to foretell this problem.

A failure in the A6 servo card causes the clock to lose frequency lock and shows up as a change in most of the parameters. The failure is most notable in the oscillator control, rf amplitudes, and CBT parameters. The oscillator control will jump more than 5 percent when the failure occurs (see Figure 5). The rf amplitudes will jump and remain at a constant value (see Figure 6). The CBT oven voltage will go to 0.0 volts (see Figure 7). The CBT temperature error will step more than 1 degree Celsius and remain constant (see Figure 8). These jumps occur within a few hours and can occur between two consecutive hourly readings. Again, although a step in these parameters is not always an indication of an A6 card failure, the change suggests that it is probable. The occurrence of this failure is sometimes predictable. One cannot, however, foretell when it will occur. The signs are in the CBT parameters. The CBT oven voltage will vary more than +/-0.4 volts, rather than the normal less than +/- 0.1 volts (see Figure 7). The CBT temperature error values will also show an abnormally large variation. They will vary more than +/- 0.15 degree Celsius rather than the normal less than +/- 0.1 degree Celsius (see Figure 8). Another type of failure in the A6 card normally occurs only at startup. A short can cause a fuse to fail on the A6 card. Notice that after repair, the rf amplitudes have returned to their prefailure characteristics (see Figure 6) and the CBT parameters show a "normal" amount of variation (see Figures 7 and 8). It is also worth noting that the oscillator control and electron multiplier have assumed new initial states after repair (see Figures 5 and 9).

The standards at USNO are now getting old enough so that we are starting to see end-of-life CBT failures. This is probably the only failure that every organization will see if they keep the standard for a long time or receive an old standard. The Hewlett-Packard manual says that the standard CBT should last about 5 years. The high performance is warranted for 3 years. USNO's experience is that the high performance CBT lasts on average more than 5 years. Two parameters that say the CBT has failed are the electron multiplier voltage and the signal gain percentage. The electron multiplier voltage will rise quickly during the failure. It will read 2553 (the limit) when the failure has occurred (see Figure 10). The signal gain will very quickly rise to 100% after the electron multiplier voltage has hit its limit (see Figure 11). The alarm light should but will NOT always be lit after the CBT failure has occurred.

The oscillator control percentage will slowly increase its amount of variation during the failure. The size of the variation will increase as time passes after the CBT failure (see Figure 12).

The failure will also be observed in the rf amplitude 1 and 2 parameters. They will both show a large increase in variation either at the time of CBT failure or shortly thereafter.

There seem to be three parameters that suggest a CBT failure will occur. These are the electron multiplier and rf amplitudes 1 and 2. (Although the signal gain does show that the CBT has failed, it does not show any sign of when the failure will occur.) The first and most obvious foretelling event is a rapid increase in the electron multiplier voltage (see Figure 10, MJD 50712 to 50716). USNO found that the clock is sometimes already outside our performance criteria during this period. The step in the electron multiplier voltage (see Figure 10 at MJD 50708) indicates that the failure is about to begin. This step will usually occur between 2 weeks and 2 days before the electron multiplier voltage reaches its limiting value of 2553 volts and indicates that end-of-life is inevitable. This is, however, not much advance warning.

Advance warning is provided by the rf amplitude 1 and 2 parameters. The variation of the rf amplitude values is very large (see Figures 13 and 14 after MJD 50716). However, notice how the percentage values decrease just before the failure. This allows for some lead time before the failure. More lead time is provided by the rf amplitudes starting to show a tendency to change. For rf amplitude 1, this can occur about a week before the failure (see Figure 13 at MJD 50708). RF amplitude 2 can show this tendency as much as 25 days before the failure (see Figure 14 at MJD 50689). Both rf amplitudes can be either a more positive or negative variation. Either way, they will show an average decrease just before the CBT failure occurs. A word of caution, though: just because the rf amplitudes are showing these early signs does not mean that the CBT will fail in less then 30 days. It should be taken as a warning that the device needs to be watched more closely. More concern should be used when the tendency becomes more pronounced (see Figure 14 after MJD 50706). Although this is not a great amount of notice before the inevitable failure, some notice is better than none. The notice will hopefully be enough to avoid a system crash or other operational failures.

CONCLUSIONS

The Hewlett-Packard model 5071A primary frequency standard is a great operational improvement over the model 5061B. This operational improvement is enhanced further by the device's ability to output its operating parameters to a computer for analysis. The analysis can help in the diagnosis of problems (e.g., cards gone bad).

Close analysis of the parameters and their historical values will in some cases allow the foretelling of failures. These clues can be as simple as seeing extreme environmental effects on the device and/or a change in a card's operation. If the parameters are watched closely enough, the inevitable CBT failure can be anticipated and corrective measures taken.

Most of the time, the important parameters to be watched are: electron multiplier voltage, ion pump current, oscillator control percentage, signal gain percentage, internal temperature, and readings of rf amplitude 1 and 2 percentages. These seven should enable a person to predict the performance and life of a frequency standard.

ACKNOWLEDGMENTS

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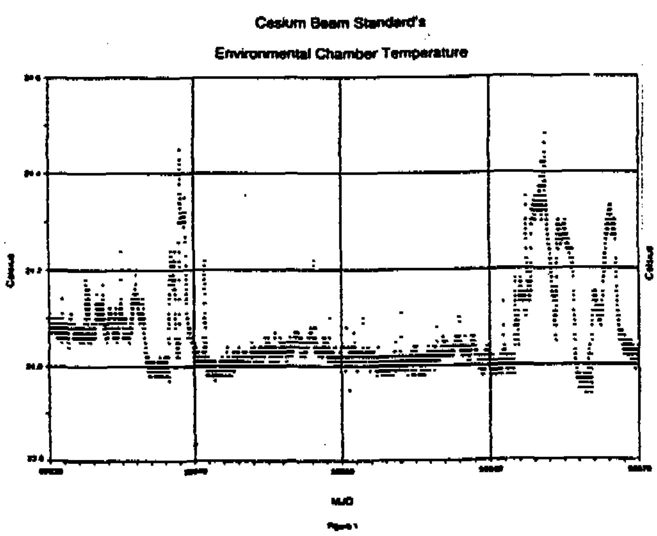
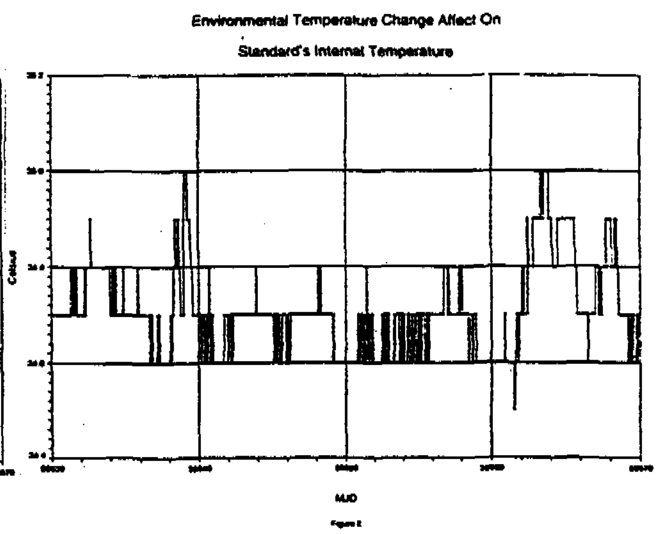
REFERENCE

Hewlett-Packard Company, HP 5071A Primary Frequency Standard Operating and Programming Manual, 1992.





Servo Card Failure Affect On

CBT Oven Voltage

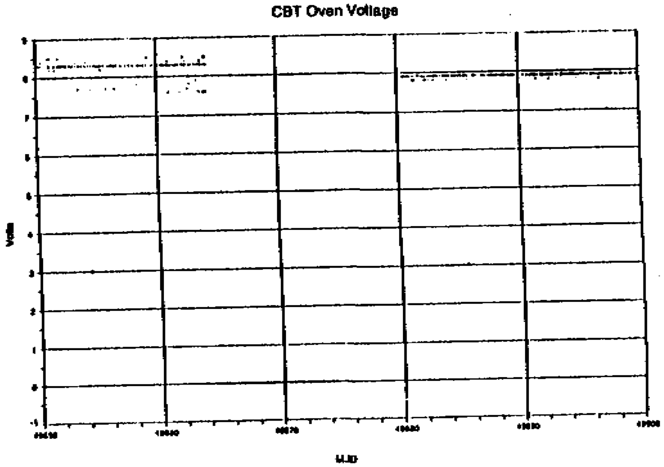


Figure 7

Servo Card Failure Affect on

CBT Temperature Error

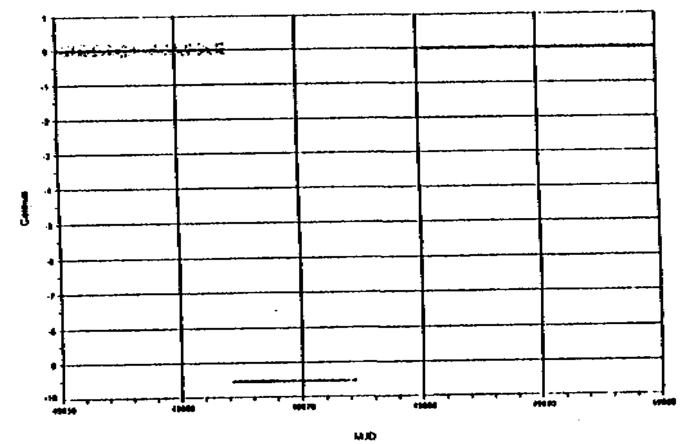


Figure 8

Servo Card Change Affect On

Election Multiplier Voltage

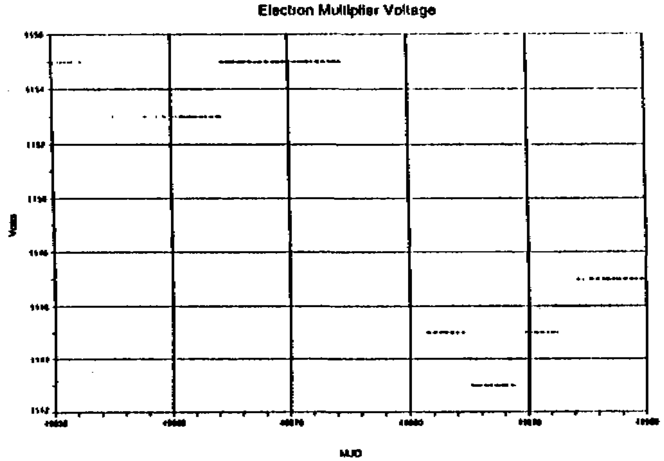


Figure 9

Cesium Beam Tube End Of Life

Electron Multiplier Voltage

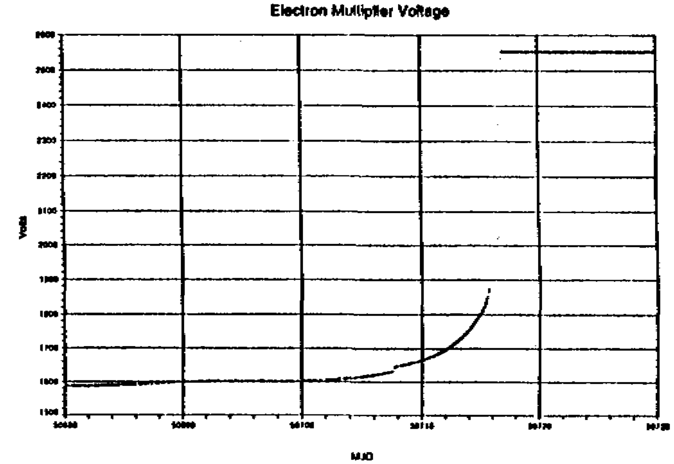


Figure 10

Environmental Temperature Affect On

Electron Multiplier Voltage

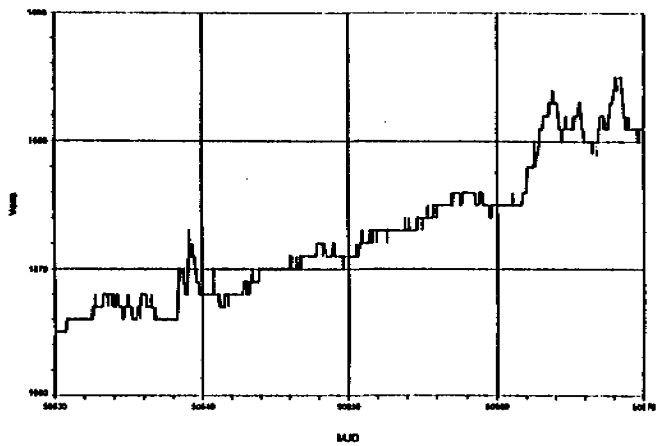


Figure 3

CBT Controller Card Failure Affect On

Electron Multiplier Voltage

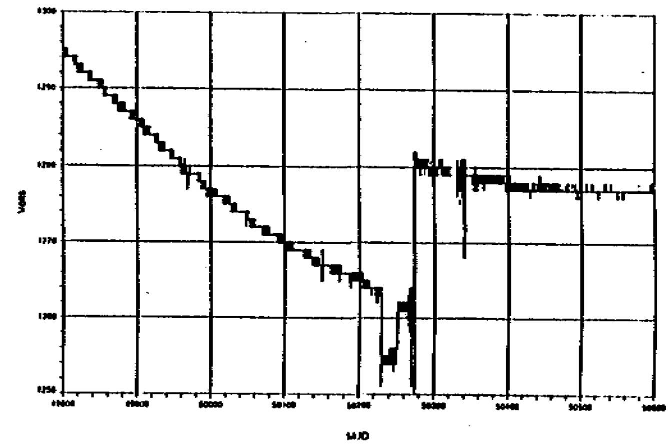


Figure 4

Servo Card Failue Affect On

RF Amplitude Voltages

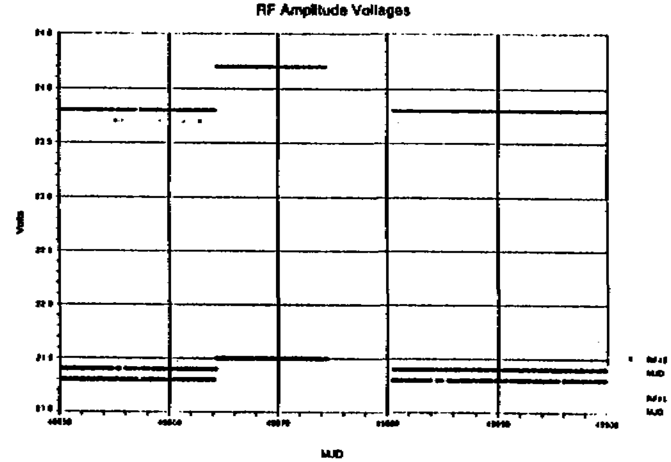


Figure 6

Servo Card Failure Affect On

Oscillator Control Percentage

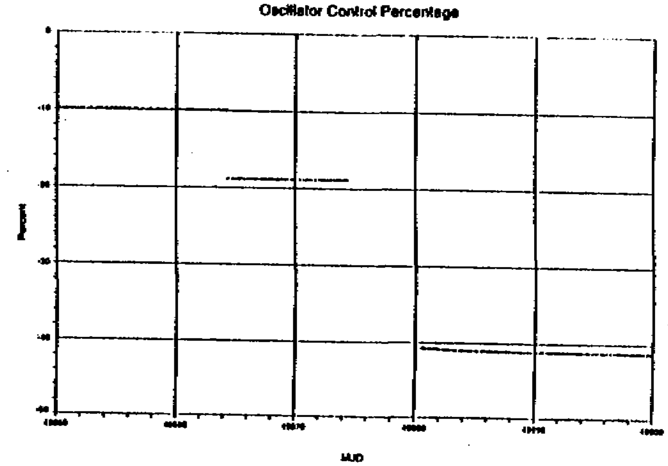
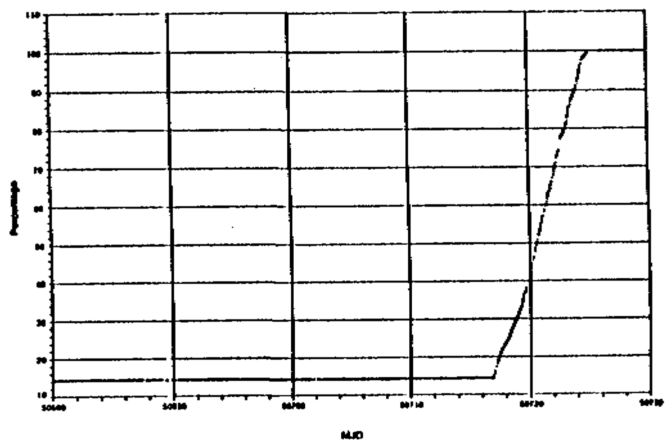


Figure 5

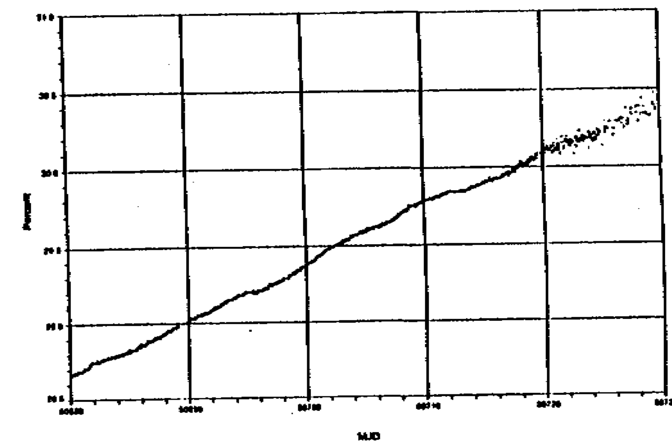
Cesium Beam Tube End Of Life

Signal Gain Percentage



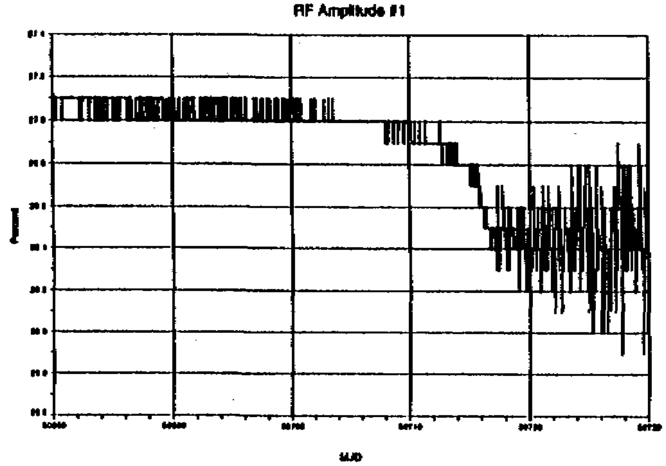
Cesium Beam Tube End Of Life

Oscillator Control Percentage



Cesium Beam Tube End Of Life

RF Amplitude #1



Cesium Beam Tube End Of Life

RF Amplitude #2