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RS 1243/80

DEPARTMENT OF ENERGY DECLASSIFICATION REVIEW

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1. CLASSIFICATION RETAINED
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7. OTHER (SPECIFY):

ALERT 747 (U)

Rec'd. 7320 7-8-
Code Initi
7321
7322
7323
7324
1. Action
2. Note & Forward
3. See Me
4. Return to 7320
5. File 3.1.1
6. Destroy

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SATELLITE SENSORS [illegible]

CLASSIFICATION CANCELLED
OR CHANGED TO: Unclas w/deletions
BY AUTHORITY OF E.O. 12958, 5USC §552
BY AFTAC DATE 6 May 98

Sandia Laboratories

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ALERT-747 (U)

May 1, 1980

G. H. Mauth
Division 1243
Sandia National Laboratories

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INTRODUCTION

At 0215Z on September 22, 1979, AFTAC began a routine acquisition of Vela satellite 6911 to verify the state-of-health of the spacecraft and its nuclear event detection payload and to read out the payload event memory. The memory was found to contain an event recorded by both bhangmeters at 0052:43Z -- an event whose amplitude versus time characteristics were consistent with those produced by a low-yield atmospheric nuclear detonation (NUDET). Based on a preliminary analysis of these data records, AFTAC initiated a "pre-alert" at 0300Z and after a more thorough analysis declared Alert 747 at 0730Z.

A search was begun immediately for corroborative data which would confirm the Vela observation. Data from other satellites with NUDET sensor payloads whose area of earth coverage overlapped with that of Vela 6911 at event time was recalled and thoroughly evaluated. These satellites included Defense Support Program spacecraft [(b)(1)] None of the bhangmeters on these satellites showed any response at Vela 6911 event time. AFTAC flew 25 sorties in the South Atlantic/polar region with debris collection aircraft between September 25 and October 17. No debris was found. Ground-based debris collection stations, acoustic sensors, hydro-acoustic sensors, seismic sensors, and ionosonde sensors were all interrogated for possible supporting information. Data records from these sources are still being studied. Some potentially confirmatory evidence has been found, but its significance is still being debated.

Sandia has been involved in Alert 747 activities since September 29, primarily to evaluate the performance of the Vela 6911

FIGURE 1

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bhangmeters. The following review begins with a summary of satellite bhangmeter design principles, followed by a more detailed description of the Vela 6911 bhangmeter system, and concludes with an analysis of the Alert 747 Vela data from a bhangmeter performance point-of-view.

SATELLITE BHANGMETER DESIGN PRINCIPLES

NUDET Optical Signal Characteristics

Atmospheric NUDETs are known to produce a characteristic thermal time history signature, the prominent features of which scale with device yield. [

(b)(1)

] To properly record all of these features [

(b)(1)

]

A typical device detonated in the atmosphere will radiate about 1/4 of its total energy in the visible and near-infrared spectral region. The source power at the second peak of the time history signal for a 1 kiloton explosion is about 10^{13} watts. The fraction of this power which reaches a satellite bhangmeter is dependent upon the satellite-to-event range and atmospheric attenuation.

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FIGURE 2

(b)(1) INFORMATION DELETED

FIGURE 3

(b)(1) INFORMATION DELETED

FIGURE 4

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FIGURE 5

The amount of attenuation suffered by an optical signal passing through the earth's atmosphere is a function of source spectrum and also of the slant path through the atmosphere. Given the earth-satellite geometrical conventions as defined in Figure 6, transmission through a clear atmosphere can be reasonably approximated by $T = e^{-\tau \sec\theta}$, where τ is a spectrally dependent coefficient and θ is look angle. Given clear conditions and a zero degree look angle, and assuming a $6000^{\circ}K$ source temperature (typical for a NUDET at second peak time) and a silicon spectral response for the receiver, the atmospheric transmission will be about 0.85. For a look angle of 75°, the transmission drops to about 0.5, and at 85° it drops to about 0.2. The presence of clouds in the source-receiver line-of-sight path can further attenuate signals and, again, this attenuation increases with look angle.

[(b)(1)]

A bhangmeter records incident irradiance (optical power per unit area) as a function of time. For a bhangmeter at Vela altitude (approximately 10^5 kilometers) with clear weather conditions and a 0° look angle, the irradiance received from the second peak of a [(b)(1)]explosion is about 10^{-8} watts/cm^2. At minimum time, the irradiance is only about 5×10^{-10} watts/cm^2.

Satellite Bhangmeter Design

In order to maximize earth coverage, satellite bhangmeters are normally designed to be mounted on an earth-oriented spacecraft platform. Typically, these platforms are either 2-axis

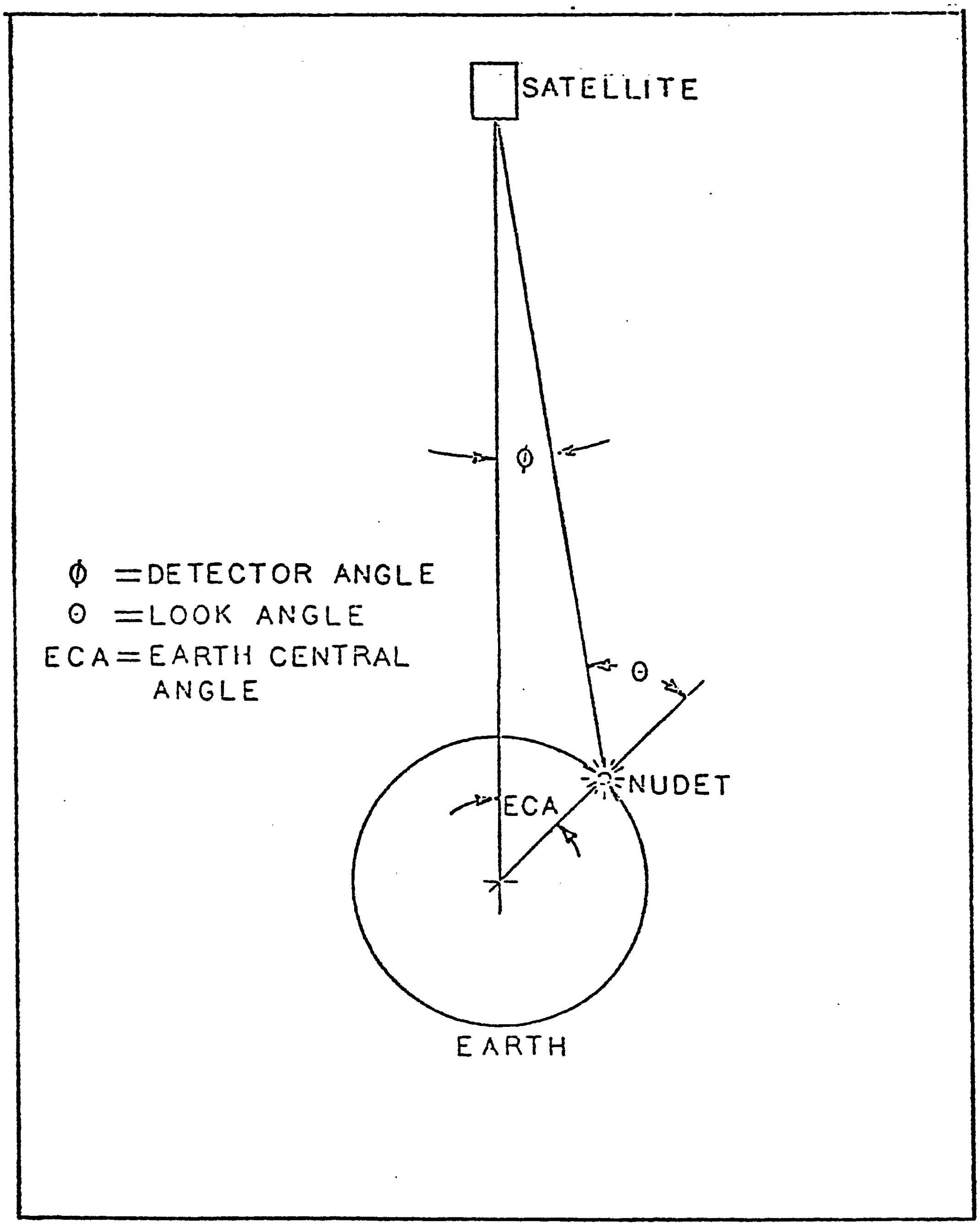

FIGURE 6

EARTH-SATELLITE-EVENT GEOMETRY

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FIGURE 7

or 3-axis stabilized to point continuously at the center of the earth's disc. The bhangmeter optical field-of-view (FOV) is sized to maintain the full earth entirely within the primary FOV for all platform worst-case pointing conditions. Sunshades in front of the light-collecting optics are employed to minimize the length of time that the sun is in the FOV during spacecraft eclipse seasons, but more importantly to block out reflected sunlight from adjacent spacecraft structures.

An optical lens system is employed when it is necessary to increase the light-gathering capability of the bhangmeter beyond the size of available photosensors. Utilizing a non-imaging optical design helps to average out photosensor response variations and also eliminates any possibility for permanent damage to the photosensor which would otherwise occur with an imaging system when the sun is within the primary FOV. A typical bhangmeter optical configuration and the conventions for FOV definition are shown in Figure 8.

Satellite bhangmeters employ silicon photodiodes as electro-optical transducers. There are many advantages to using silicon sensors including 1) rugged, solid-state construction which can withstand launch vibration and on-orbit temperature environments, 2) a spectral response, as shown in Figure 9, which matches well with the NUDET source spectrum, [

(b)(1)

]

Amplification of the signal current from the silicon photodiode sensor is accomplished using a transimpedance (current-to-voltage) preamplifier and a cascaded string of linear post-amplifiers. To keep this amplifier chain balanced, and to compensate for variations in the reflected sunlight from the earth,

(b)(1) INFORMATION DELETED

FIGURE 8

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FIGURE 9

a non-linear feedback system is used. (A more detailed description of the analog electronics as designed for the Vela bhangmeters is provided in the next section of this report.) Preamp gains are selected to optimize the signal-to-noise ratio as a function of light-collection aperture size and electronic bandwidth. The gain and number of post-amplifiers are selected to maximize the dynamic range and amplitude resolution of the system. [

(b)(1)

]

The voltage signals present at the outputs of the analog post-amplifiers are digitized by a logarithmic A/D converter which is designed to sample these analog outputs at discreet, logarithmically-spaced points in time. [

(b)(1)

]

The length of the digitized message, which can either be stored in an on-board memory or telemetered in real-time to a ground receiving terminal, is dependent upon the resolution (quantization step sizes) desired in both time and amplitude. A good fidelity bhangmeter time history recording typically consists of 500-1000 bits of data.

Since the bhangmeter is designed to record only transient optical signals, the digital sampling system must be triggered in some manner. In its simplest form, triggering is accomplished whenever a signal on a selected amplifier output exceeds a specified threshold. In order for the signal to appear on the amplifier output, its rate of rise (volts/second) must exceed the maximum compensation rate of the feedback circuitry. Thus, slowly varying changes in the magnitude of the sunlit earth background will not trigger the system but rapidly rising NUDET signals will. As will be described later in more detail, once triggering occurs, the feedback circuit is interrupted to prevent distortion of the event signature.

All bhangmeters also include logic circuitry in their digital electronics which "test" the quality of the signal which triggered the system. These test mechanisms, which are described more fully in the following paragraphs, effectively eliminate a large number of spurious trigger sources which would otherwise cause difficulties in operating the system; e.g., filling up on-board memories with false events, over-loading the telemetry down-link, reducing the probability of detection of a real NUDET event, etc.

Background Considerations

Reflected sunlight from the earth is the dominant source of background for satellite bhangmeters since it is many orders of magnitude brighter than the minimum yield NUDET signals to be detected. At Vela altitude, the irradiance of a fully illuminated earth approaches 10^{-4} watts/cm^2 which is approximately 4 orders of magnitude more intense than the second peak irradiance of a 1 kiloton device and in excess of 5 orders of magnitude brighter than the irradiance at minimum of 1 kt.

Earth background induces a large but slowly-varying current in the bhangmeter photosensor which, under most circumstances, is nulled out by the analog feedback circuit. This background current also introduces shot noise in the system proportional to $\sqrt{I_{bkgnd}\Delta f}$ (Δf being the amplifier electronic bandwidth). Under essentially all phases of earth illumination, except for full satellite eclipse, this shot noise dominates all other system noise sources and thus determines the ultimate sensitivity achievable for a bhangmeter which views the entire earth disc.

Intense lightning strokes usually associated with severe storm cells constitute a different type of background to be considered in bhangmeter design. Typical lightning flashes seen by satellite bhangmeters have rise times on the order of 100 microseconds and total pulse durations not exceeding several milliseconds. As such, they are easily distinguishable from nuclear event signals in terms of total energy content. However, their rise times are more than sufficient to initiate a bhangmeter trigger. In order to avoid making a complete multi-second time history recording for every lightning-induced trigger, "test" logic in the bhangmeter requires that the triggering signal have a predefined minimum energy content. The simplest implementation of this test discriminant requires that the triggering signal remain above a preset amplitude level for a specified time interval.

Energetic space particles (protons, electrons, etc.) which regularly impact the bhangmeter silicon photodiode sensor produce another type of background response. Energy deposited by these particles in the silicon sensor appears at the amplifier outputs as a pulse with a characteristic decay time. Most triggering particles deposit their energy in the P-N junction depletion region with a resultant very narrow pulse shape which is characteristic of the electronics impulse response function. Much less frequently, a particle will deposit its energy in the undepleted, bulk silicon region of the sensor and when this occurs, the resultant pulse is wider but with a decay time constant proportional to the carrier diffusion time constant for silicon. Particle triggers occur much more frequently than lightning triggers and are discriminated using the energy test concept previously described.

Bhangmeter time history recordings can be measureably distorted, and in extreme cases triggers can even be induced, by motion of the spacecraft platform. Any platform motion converts directly to motion of the bhangmeter optical FOV and correspondingly, in nearly all cases, to an apparent movement of the sunlit earth disc within the FOV. Given the fact that the bhangmeter optical response function is not absolutely uniform over the entire FOV, a modulation of the total earth background signal is produced. Small, unavoidable misalignment of the sensor optical axis with the spacecraft spin axis can also cause a modulation of the earth background. Since the earth can be as much as 10^5 brighter than the minimum recordable signal level, background modulation is essentially unavoidable given any platform motion whatsoever. The analog electronics feedback system is designed to accommodate a considerable amount of background modulation; however, once the recording system is triggered, further background compensation is inhibited and modulation effects appear as an output signal which is summed with the true event signal thus producing distortion. This distortion has been labelled as "tail-up" or "tail-down" depending upon whether the modulation signal is increasing or decreasing during the recording period.

Spacecraft with two-axis stabilized platforms rotate about their earth-oriented spin axis and produce background modulation signals with characteristic frequencies equal to the spin rate. Three-axis stabilized spacecraft do not rotate and thus are intrinsically a better platform for bhangmeter deployment. Experience has shown, however, that even 3-axis stabilization is no guarantee that modulation will not occur, because of effects such as bearing noise, reaction wheel vibration, etc., which cause the platform to vibrate and thus induce higher frequency modulation. Again, feedback systems can be designed to accommodate this modulation and prevent system triggering, but in extreme cases some sacrifice of low yield NUDET detection capability must be accepted.

Diurnal brightening of the earth as viewed from a spacecraft platform represents a source of time history signal distortion which cannot be avoided using conventional bhangmeter feedback techniques. During the nominal 10 second time history recording period, fractional increases (or decreases) in the phase of sun illumination of the earth disc will cause a small change in the total background irradiance which will appear at the amplifier outputs as an increasing (or decreasing) linear ramp modulation signal added to the event signal. Since this effect is generally predictable given the sun-earth-satellite geometry at event time, it is often possible to calculate a first order correction for this type of distortion.

Sunlight reflected from other portions of the spacecraft and/or from objects such as meteoroids passing through the bhangmeter FOV can cause background increases/spurious triggers under certain sun angle conditions. The case for Vela bhangmeter detection of meteoroids is presented later in this report.

VELA BHANGMETER SYSTEM

Vela Program History

The Vela satellite program began in the early 1960's; three pairs of spin-stabilized Vela satellites built by TRW Systems were launched between 1963 and 1965 for detection of exoatmospheric NUDETs. LASL designed the payload sensors and Sandia designed the payload detection logic, data handling and telemetry interface electronics. The fourth pair of Vela satellites launched in 1967 were 2-axis stabilized, earth-oriented spacecraft which carried the first generation of Sandia-designed downward-looking optical sensors (bhangmeters and source locators) for atmospheric NUDET detection. All eight of these satellites have since been retired from the active Vela inventory.

Based on the on-orbit experience gained from the fourth Vela launch, the optical sensor payload for Vela launches V and VI was significantly upgraded to improve surveillance and diagnostic capabilities for atmospheric NUDET monitoring. The Vela V satellites 6909 and 6911 were launched in May 1969 followed in April 1970 by Vela VI satellites 7033 and 7044. These four satellites in 110,000 km altitude circular orbits inclined approximately 50° to the equator were phased to provide near-continuous full earth coverage. Three of these four Velas (6911, 7033, and 7044) continue to provide an atmospheric NUDET detection capability in spite of the fact that they were only designed for a 2-year mean mission duration. Vela 6909 lost its atmospheric detection capability in December 1977 when the last of its attitude control propellant (gaseous N_2) was expended. At this time its optical payload was still functioning properly, but without control gas, earth orientation could no longer be maintained. In order to conserve control gas on the remaining three Velas, phasing maneuvers are no longer performed and significant earth coverage gaps accordingly exist. Even with these time-dependent gaps in geographical coverage, the Vela satellites still constitute the best, and in some areas only, NUDET detection system for extreme southern latitude regions.

Vela Bhangmeter Design

The Vela V and Vela VI spacecraft are identically configured; the optical sensors are mounted on a common platform whose surface is oriented perpendicular to the spacecraft spin axis. The optical sensor complement includes two bhangmeters designated as YCA and YVA, a three-axis event locator system designated as YBA1, YBA2, YBA3, and an x-ray fluorescence exoatmospheric height-of-burst sensor designated as YFA. Figure 10 shows the layout of these sensors (actually their optical apertures) on the earth-oriented Vela platform. A 3-axis x-ray event locator system designated YXL was also mounted on this platform.

The spacecraft is 2-axis stabilized and completes one revolution about its spin axis every 64 seconds. The spacecraft attitude control system points the spin axis vector to the center of the earth's disc within 1.4 degrees. The external spacecraft structure is a 26-sided configuration with an approximate envelope diameter of 4 feet, and its on-orbit weight is approximately 550 lbs.

The YCA and YVA bhangmeters are identical in principle of operation but have different sensitivities. [

(b)(1)

] Both have sunshades which are of sufficient length to block sunlight reflections from all other spacecraft structures. [

(b)(1)

] A quartz protective cover glass is mounted between the photodiode and the base of the light cone assembly. The YVA is identical to the YCA except that it does not utilize a light-gathering cone and is therefore less sensitive. The optical configurations

(b)(1) INFORMATION DELETED

FIGURE 10

for YCA and YVA are as shown in Figures 11 and 12. The optical FOV response functions for these detectors are plotted in Figure 13. On Vela VI, the YCA light cone was replaced with an objective lens/field lens combination which helped to somewhat flatten the near-field optical response but left the optical gain essentially unchanged.

The silicon photodiodes used in YCA and YVA are identical; their spectral response function calibration curve is shown in Figure 14. [

(b)(1)

]

A simplified block diagram of the YCA and YVA analog amplifier system is shown in Figure 15. [

(b)(1)

]

As mentioned earlier, a non-linear feedback system is used to provide the required photodiode background current so that the signal amplifier outputs remain at zero under all normal untriggered conditions. As can be seen from Figure 15, this feedback is essentially an integrator and as such is rate-limited so that signals whose rate of change exceeds the maximum rate of change capability of the feedback appear as outputs

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FIGURE 11

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FIGURE 12

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FIGURE 13

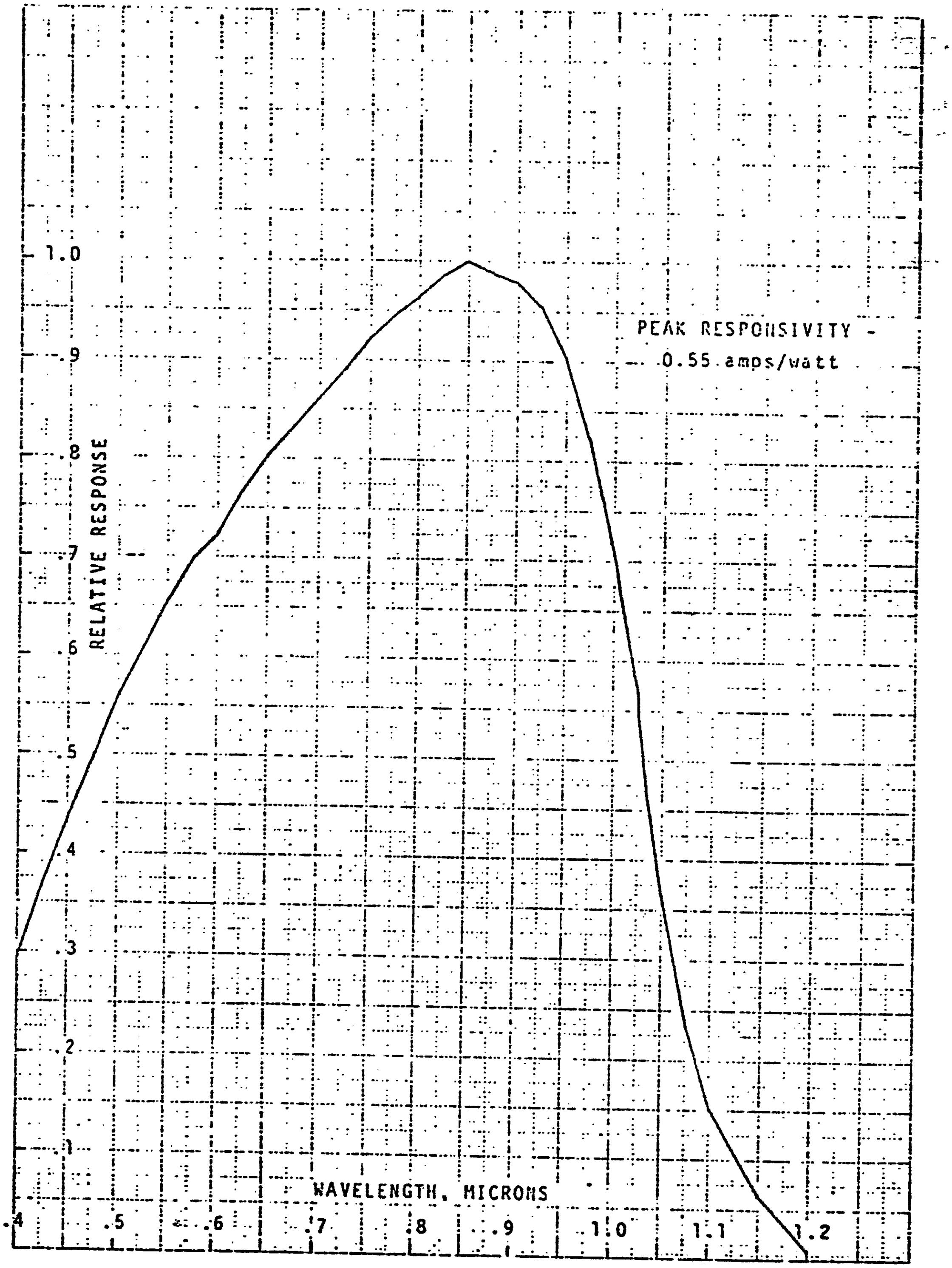

FIGURE 14

VELA PHOTODIODE SPECTRAL RESPONSE CALIBRATION

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FIGURE 15

on the amplifier string. [

(b)(1)

] These rates are several orders of magnitude slower than rise rates for NUDET signals, but fast enough to track earth background modulation and thus prevent it from triggering the system. The field-effect transistor switch shown in the feedback loop is opened by a switching signal at trigger time (labeled "Y-RUN") from the digital sampling logic. By opening this switch, the voltage on the integrating capacitor is prevented from changing further and this in turn causes the background current (labeled i_b) to be held constant. Upon completion of the time history recording, the switch is closed and earth background compensation is reenabled.

A switchable low-pass analog filter is placed midway down the cascaded postamplifier string. The upper cutoff frequency [

(b)(1)

] This technique reduces the system noise level by $\sqrt{10}$ for the latter portion of the NUDET time history record to allow a more accurate measurement of time to minimum.

Signals on the amplifier string output taps labeled S1 through S8 (and referred to as "S-lines") are digitized by a logarithmic analog-to-digital converter. An A/D conversion is accomplished in two steps. The most sensitive S-line output which is not saturated is selected first and encoded as a 3-bit binary word. [

(b)(1)

] The selected S-line output is then gated to a parallel set of 8 level discriminators (referred to as "LDs") whose thresholds are logarithmically spaced a [(b)(1)] apart and the output state of these LD's is encoded as a 3-bit binary word. Taking these three bits as the least significant bits of a 6-bit word and the encoded S-line state as the 3 most significant bits, the signal amplitude is defined [(b)(1)] With [(b)(1)] LD levels, the total recordable signal dynamic range [(b)(1)]

With the system in an untriggered state, log A/D conversions of the amplifier outputs are made continuously at [(b)(1)] and the four most recent samples are held in a 4 word shift register. Trigger occurs when the LD value of the sampled output exceeds a selected level, which for YCA and YVA is [(b)(1)] When trigger occurs, the contents of the 4 word shift register (referred to as pre-samples) are frozen and a pseudo-logarithmic time sampling plan is initiated. Assuming that the sampled signal passes the test criterion described below, a total of 64 time samples are taken at the times specified in Table 1 covering a total period of 8 seconds. These 68 (including pre-samples) log-amplitude, log-time samples constitute the Vela bhangmeter time history record. To minimize the total number of bits in the event message, only the four least significant amplitude bits are stored for pre-samples. Furthermore, alternate post-samples are recorded as only 3-bit (least significant bits) words. For event data plots in this report, the amplitude scale is presented as Octal LD Level which can range [(b)(1)] 6-bit words. Again, [(b)(1)]

TABLE 1

VELA BHANGMETER LOGARITHMIC TIME SAMPLING PLAN

Post Sample Number	Time*
1	.030
2	.061
3	.092
4	.122
5	.183
6	.244
7	.305
8	.366
9	.488
10	.610
11	.732
12	.854
13	1.09
14	1.34
15	1.59
16	1.83
17	2.32
18	2.81
19	3.30
20	3.78
21	4.76
22	5.74
23	6.71
24	7.69
25	9.64
26	11.6
27	13.5
28	15.5
29	19.4
30	23.3
31	27.2
32	31.1
33	38.9
34	46.8
35	54.6
36	62.4
37	78.0
38	93.6
39	109
40	125
41	156
42	187
43	219
44	250
45	312
46	375
47	437
48	500
49	625
50	750
51	875
52	1000
53	1250
54	1500
55	1750
56	2000
57	2500
58	3000
59	3500
60	4000
61	5000
62	6000
63	7000
64	8000

*Timing of post-samples from 4th pre-sample, in milliseconds.

The test criterion for YCA and YVA requires that the signal amplitude be at least LD 3 at the time of the seventh post-sample [(b)(1)] If the test is passed, sampling continues for the full 8 second period. Test failure causes sampling to be terminated and feedback compensation to be reenabled, thus returning the system to its pre-trigger state.

The YCA and YVA systems both derive their basic sampling frequency from the same master clock. Thus, even though the two systems are independently triggered, trigger time differences are constrained to be an integral multiple of the [(b)(1)] sampling interval. A measure of the trigger time coincidence between YCA and YVA is provided in each event data message as a bit whose state is set high if the triggers occur [(b)(1)] of one another.

Pre-Launch Calibration

All Vela bhangmeters were calibrated prior to launch to assure that actual performance parameters were within design limits. The absolute spectral response of each photodiode was measured both with and without quartz cover glass windows in place. The FOV response was mapped for each bhangmeter with and without sunshades in place. Total system electronic gain and LD threshold values were verified as well as response linearity and dynamic range using both electrical and optical input signal sources. Feedback circuit performance was verified using a simulated earth background source. Absolute optical sensitivities were established using pulsed Xenon flashers whose irradiance output was monitored with secondary standard sensors.

Relative sensitivity optical calibrations were performed numerous times during spacecraft-level testing at TRW Systems and just prior to launch at the Air Force Eastern Test Range (AFETR). The entire spacecraft was mounted in a horizontal position on a precision rotary table in front of an optical collimator which utilized both tungsten filament and Xenon flasher sources to stimulate the bhangmeters and locators. This test provided a relative sensitivity check for all detectors as well as a mapping of optical FOVs.

On-Orbit Calibration

The bhangmeter designs include a provision for in-flight calibration using light-emitting diodes mounted immediately adjacent to the photodiode sensors. This LED calibration is initiated by ground command (Cal 1 command) and produces a linearly-increasing ramp optical LED output preceded by a shorter pulse injected electrically at the preamplifier input. The resultant time history signal for a YCA Cal 1 is as shown in Figure 16. The YVA Cal 1 response is essentially identical, as shown in Figure 17. These signals are extremely repeatable over all on-orbit temperature and voltage conditions and provide an excellent means for monitoring end-to-end system performance.

The bhangmeter and locator detectors can also be calibrated on-orbit using a ground-based laser/telescope system. AFTAC has successfully performed this exercise on several occasions from the AFETR Range Measurements Lab (RML) at Malabar, Florida. The 1 millisecond signal received from the .6943 micron wavelength pulsed ruby laser appears as shown in Figures 18 and 19 for YCA and YVA. Although the primary purpose of this type of calibration is to achieve a boresite correction for the locator detectors, it also provides a good check of the

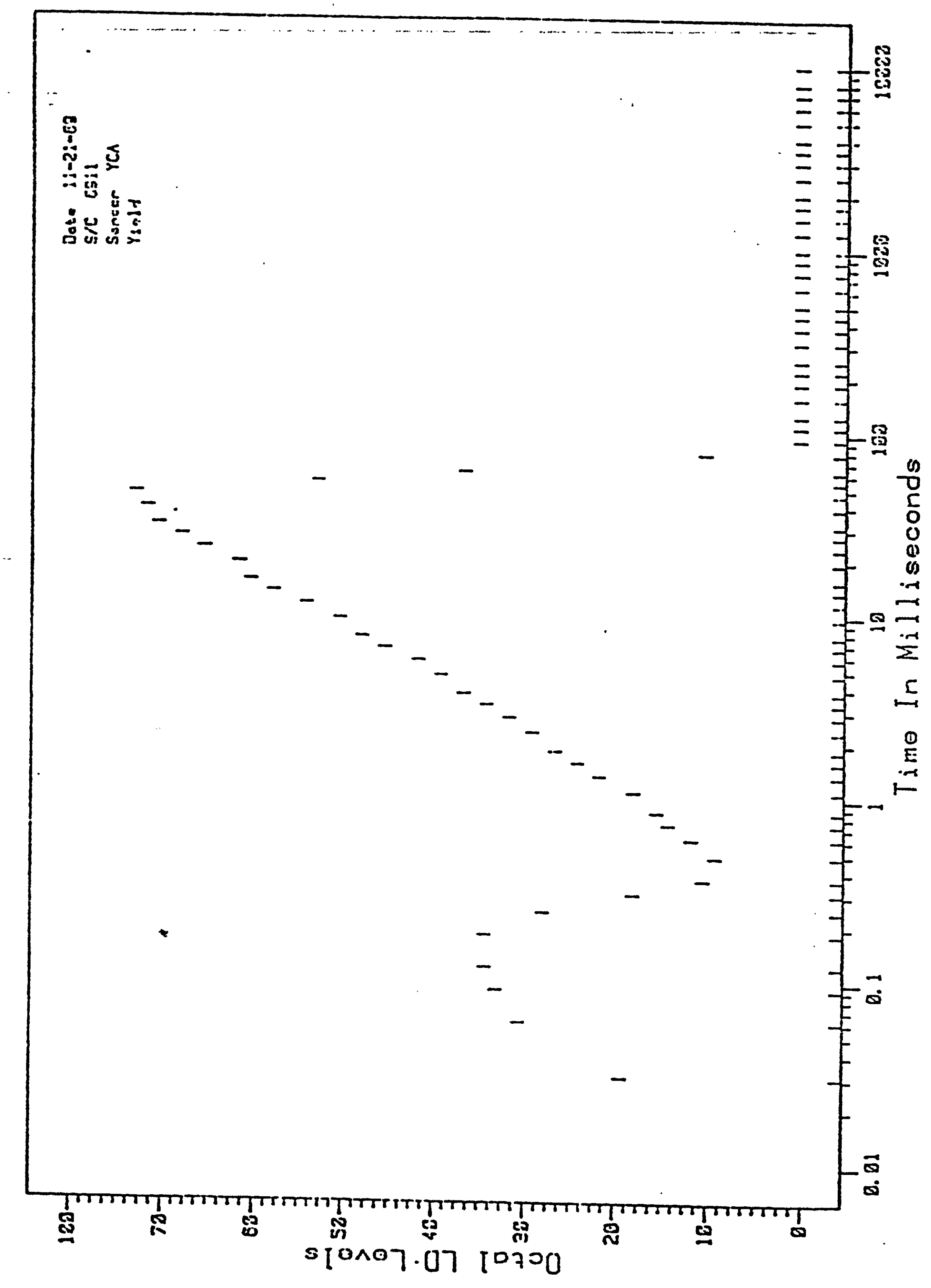

FIGURE 16

VELA YCA CAL 1 RESPONSE

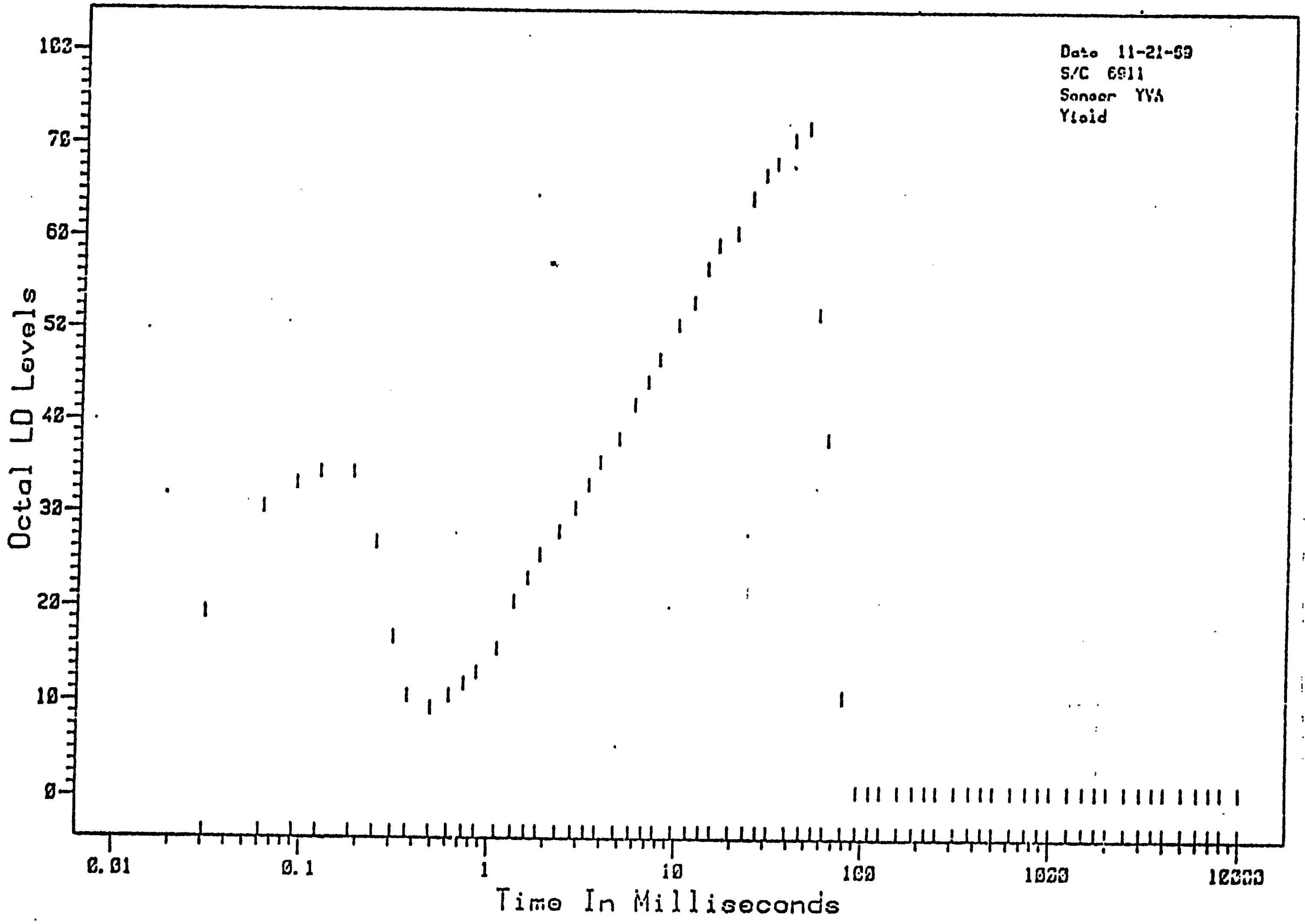

FIGURE 17

VELA YVA CAL 1 RESPONSE

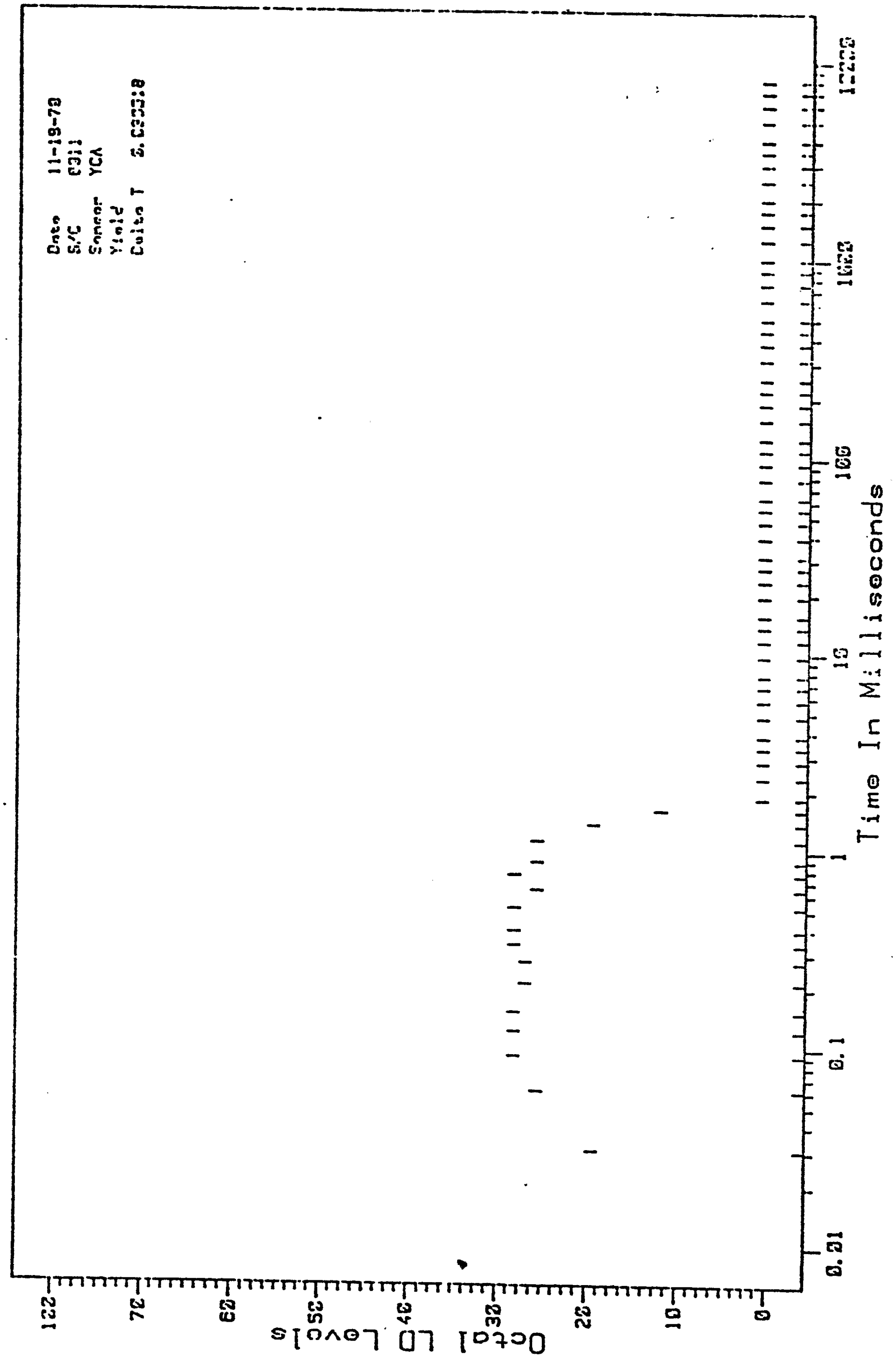

FIGURE 18

VELA YCA LASER CALIBRATION RESPONSE

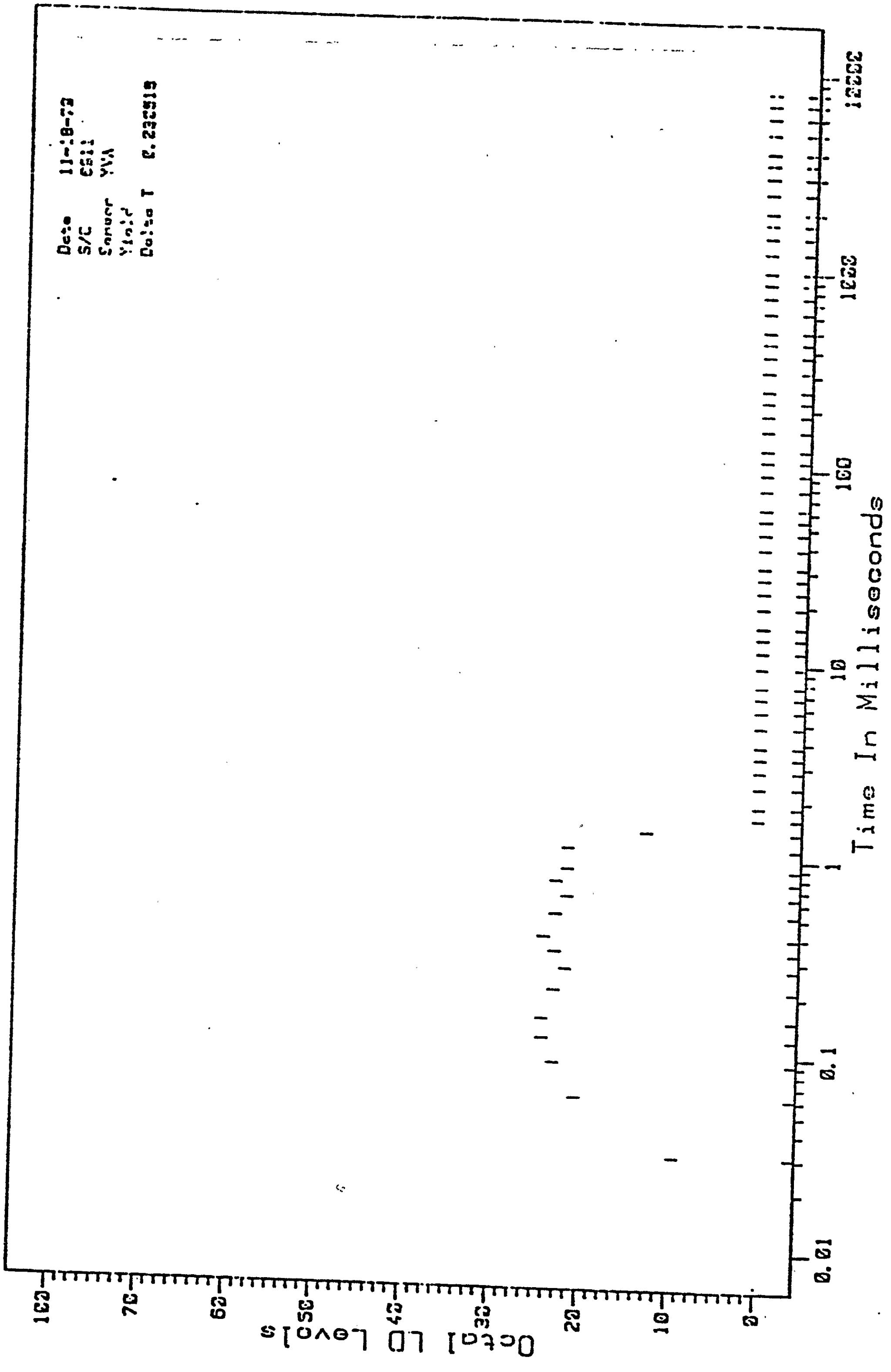

FIGURE 19

VELA YVA LASER CALIBRATION RESPONSE

relative YCA/YVA sensitivities and an approximate check on their absolute sensitivities.

NUDET events themselves have also provided a means of on-orbit calibration for those instances where multiple-satellite bhangmeter observations could be compared. Comparison with data from ground-based (ship and aircraft) bhangmeters has also been particularly valuable in verifying proper system performance.

Vela 6911 Performance History

During its 11 years on-orbit, Vela satellite 6911 had detected a [(b)(1)] atmospheric NUDET events, [(b)(1)] were confirmed by other observations, [(b)(1)] being the event of September 22, 1979 (Alert 747). The yield of these events ranged [(b)(1)] The 6911 bhangmeter(s) have never failed to detect a confirmed event for which the signal strength at the satellite (as influenced by yield, look angle, and weather conditions) exceeded the trigger threshold irradiance. For some of the lower yield events, the YVA failed to trigger, but this was as expected because of its lesser sensitivity.

In July 1972, the 6911 spacecraft memory which stores all payload event data malfunctioned in a manner resulting in the effective loss of approximately the second half of the bhangmeter time history samples. In March 1978, this anomaly cleared itself. During the period in which the memory failure existed, 6911 detected [(b)(1)] NUDET events, but only the initial [(b)(1)] or so of the data from each was decipherable. Thus, later sample time comparisons of signal consistency between the YCA and YVA bhangmeters (which has become an issue in the analysis of Alert 747 data) was not possible. Satellite 6911 has detected [(b)(1)] since the memory failure disappeared, [(b)(1)] but because of the low yield of this device, only the YCA triggered and the opportunity to evaluate the complete time history consistency between YCA and YVA was not available.

The Vela Launch V (6909 and 6911) YVA bhangmeters have a minor design deficiency in their analog electronics which introduces a low-level gain nonlinearity effect. This effect is exemplified in the YCA and YVA time history records for the [(b)(1)] shown in Figures 20 and 21. Given a pair of YCA/YVA recordings for the same event, it is expected that a good agreement should exist when these signatures are overlaid and the YVA is shifted 4-5 LD amplitude units to account for its known lesser sensitivity. This is in fact the case for the example chosen, except that for low signal levels, particularly around principle minimum time, the YVA record drops below YCA. This YVA distortion is seen in nearly all 6909 and 6911 NUDET records and is more obvious for lower yield events where overall signal levels are lower. The nonlinearity is introduced when the system triggers and the "Y-RUN" signal opens the FET switch in the feedback loop (reference Figure 15). The switching transient creates a small change in the voltage on the feedback capacitor and accordingly a small change in the total amount of feedback compensation current. Given that the system was properly compensated prior to trigger, the step change in feedback current at trigger time appears as an offset bias in the amplifier outputs. Since amplitude is recorded logarithmically, a small additive offset is perceptible only at lower LD levels. The Vela Launch VI (7033 and 7044) YVA circuit design was improved to greatly reduce this effect.

(b)(1) INFORMATION DELETED

FIGURE 20

(b)(1) INFORMATION DELETED

FIGURE 21

Vela satellite bhangmeters have recorded numerous events attributed to lightning. On several occasions, a particularly intense lightning stroke has been observed simultaneously by two Vela satellites and at least one of these events was also located with the YBA optical locator sensors. The location was subsequently found to correlate geographically and temporally with a known area of severe thunderstorm activity. The YCA signature from one of these events is shown in Figure 22. Note that a majority of the lightning triggers of Vela bhangmeters are rejected by the [(b)(1)] and only the most intense, of which there are typically several per day, are recorded.

Vela bhangmeters are triggered many times per day by energetic particles impacting the silicon photodiode sensor. Most of these particles are rejected by the [(b)(1)] but occasionally a particle deposits enough energy in the photodiode to create a signal which passes test. Examples of such particle triggers are shown in Figures 23 and 24 for the two different types of particle responses discussed earlier.

Background modulation effects on Vela bhangmeter time histories are typically expected to appear as shown in Figure 25 where the "tail-up" signal results from the modulation induced by the 64 second period rotation of the satellite about its spin axis. This event was ground-command initiated (Cal 2 command). The system responds to a Cal 2 command by triggering the sampling logic and over-riding test requirements, thereby generating a time history which records only background effects. Bhangmeter responses can either "tail-up" or "tail-down" depending upon the phase of the modulation signal at event trigger time. There is no reason to expect

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FIGURE 22

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FIGURE 23

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FIGURE 24

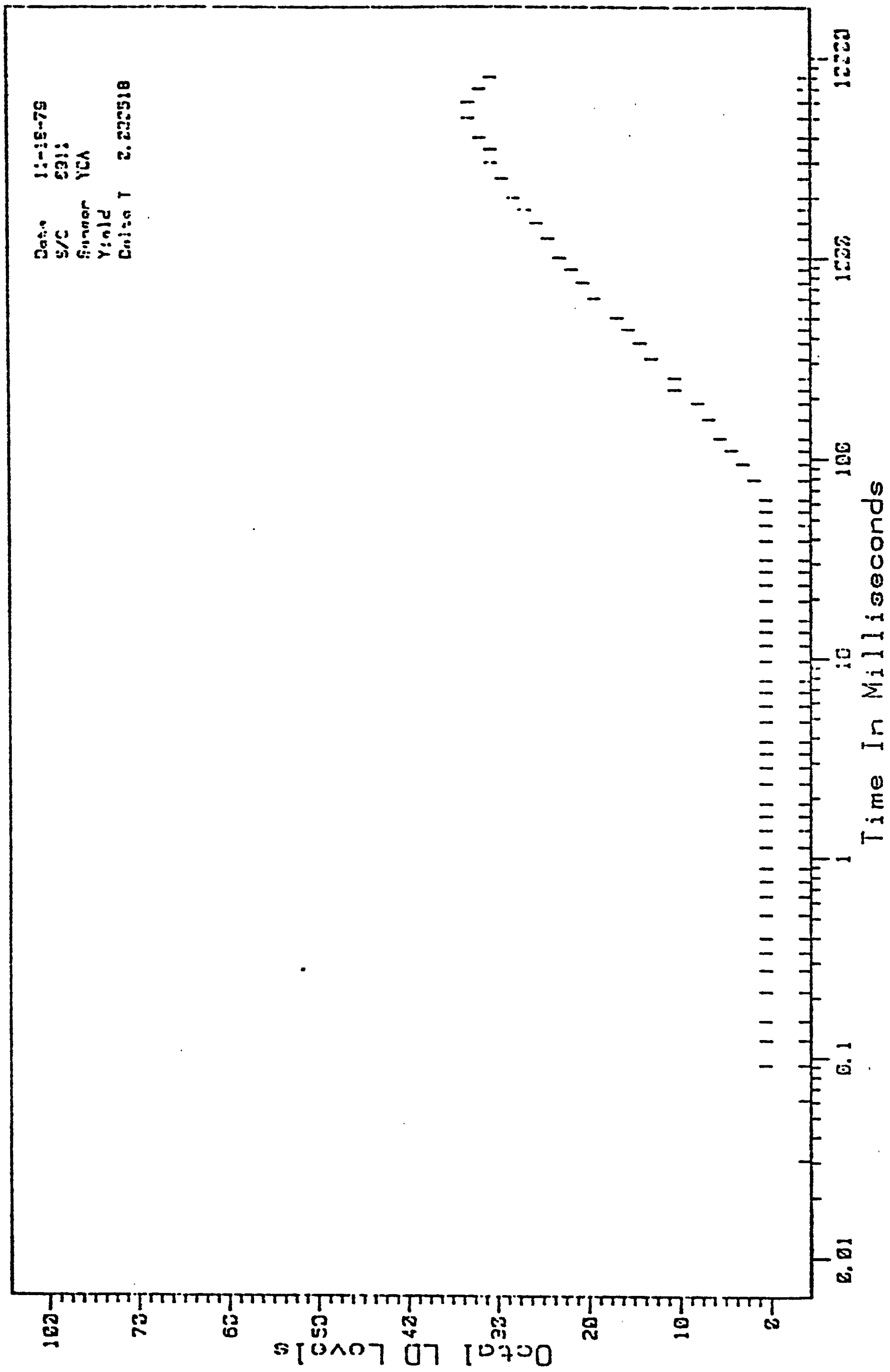

FIGURE 25

VELA YCA TYPICAL BACKGROUND MODULATION RESPONSE that tail-up/tail-down YCA and YVA modulation responses should be in-phase since their FOV response function asymmetries and optical axis misalignments are totally independent. An AFTAC-sponsored statistical study of Vela tail-up data confirmed that there was no background modulation phase correlation between YCA and YVA. This study also showed, as expected, that the magnitude of the YCA tail-up response was typically larger than that seen on YVA.

ALERT 747 ANALYSIS

Vela 6911 Data

At 0052:43Z on September 22, 1979, the Vela 6911 satellite was positioned 65,722 nautical miles above a point on the earth located at 48.6° South latitude, 2.2° East longitude. From this position, the mostly dark earth appeared as shown in Figure 26. The sun was illuminating the optical sensor platform at an angle of 50.2° off the sensor optical axes.

The YCA and YVA event data for Alert 747 is plotted as received in Figures 27 and 28. An irradiance ordinate has been added on the YCA plot to define actual signal levels.

The YBA atmospheric NUDET event locator detectors did not trigger on this event. These detectors are designed to respond to the first maximum of a NUDET signal and have a trigger sensitivity equivalent to [(b)(1)] on the YCA. Since the first maximum peak of the Alert 747 signal reached only [(b)(1)] on YCA, the YBA detectors were not expected to trigger.

Although the YCA and YVA records in Figures 27 and 28 appear qualitatively similar, some disagreement in the two signatures

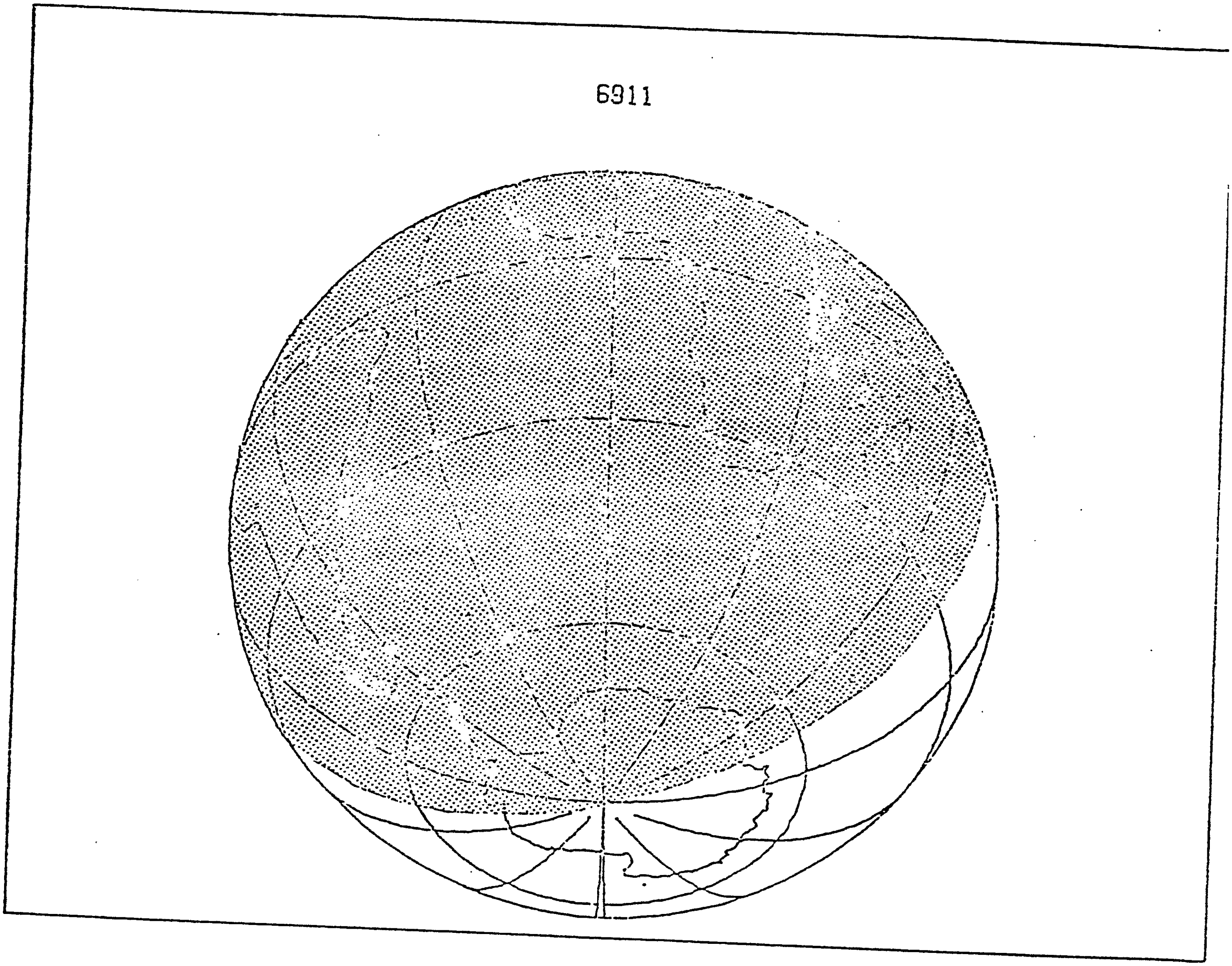

FIGURE 26

EARTH AS SEEN FROM VELA 6911 FOR ALERT 747

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FIGURE 27

(b)(1) INFORMATION DELETED

FIGURE 28

is noted when they are overlaid in the manner previously described. There are two types of corrections which can legitimately be applied to the YVA data to improve the YCA-to-YVA consistency. The first involves delaying the trigger time of YVA with respect to YCA without, of course, exceeding the [(b)(1)] coincidence period. Because the YVA is less sensitive than YCA, it will always trigger somewhat later. For sharply rising NUDET first maximum signals of sufficient amplitude, the YVA trigger time delay is negligible, but for signals with longer risetimes such as the first maximum portion of the Alert 747 event, the YVA trigger delay can be significant. Figure 29 shows the result of applying a trigger time delay correction of [(b)(1)] to the Alert 747 YVA data.

The YVA time history data must also be corrected to account for the low-level non-linearity distortion discussed earlier. Correcting YVA amplitude samples for a constant offset bias [(b)(1)] results in the data plot shown in Figure 30. (This plot also includes the [(b)(1)] time delay correction.) Note that since only the non-zero YVA amplitude points are correctible, the LD 0 samples should not be considered in the YCA/YVA comparison.

Correcting the YVA data as just described results in an excellent YCA/YVA signature consistency through the first maximum pulse portion of the Alert 747 data. However, a disagreement still remains for the second maximum region of the event which can be interpreted as either a less-than-expected YVA response or a greater-than-expected YCA response. The disagreement between YCA and YVA can be expressed as a difference signal which is generated by subtracting corresponding

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FIGURE 29

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FIGURE 30

YVA sample amplitudes (taking into account the known 4 LD's of lesser YVA sensitivity) from YCA samples, converting these differences to LD values, and plotting the resultant LD's in the standard time history format. Figure 31 shows the difference signal time history. This difference signal is discussed again in following sections.

Post-Event Performance Checks

A considerable effort was made by AFTAC and Sandia to determine whether or not the Vela system had operated properly in reporting the Alert 747 data. Shortly after the event, AFTAC performed a second memory readout (MRO) of the Vela 6911 event memory utilizing a different Air Force Satellite Control Facility (AFSCF) Remote Tracking Station (RTS) for satellite acquisition and telemetry readout. The MRO data as received at the AFTAC data terminal using a different RTS was found to agree bit for bit with the original MRO data.

YCA and YVA Cal 1 responses obtained after the Alert 747 event, as shown in Figures 32 and 33, were compared with earlier Cal 1's including those shown previously in Figures 16 and 17. The comparison results were excellent; no measureable change in system performance could be identified.

AFTAC also performed a post-event ground-based laser calibration of Vela 6911 from RML at Malabar, Florida, on November 18, 1979, and again on November 27, 1979. The results obtained, examples of which have already been shown in Figures 18 and 19, were consistent with earlier laser calibration data taken in 1971 and indicated a totally nominal system response.

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FIGURE 31

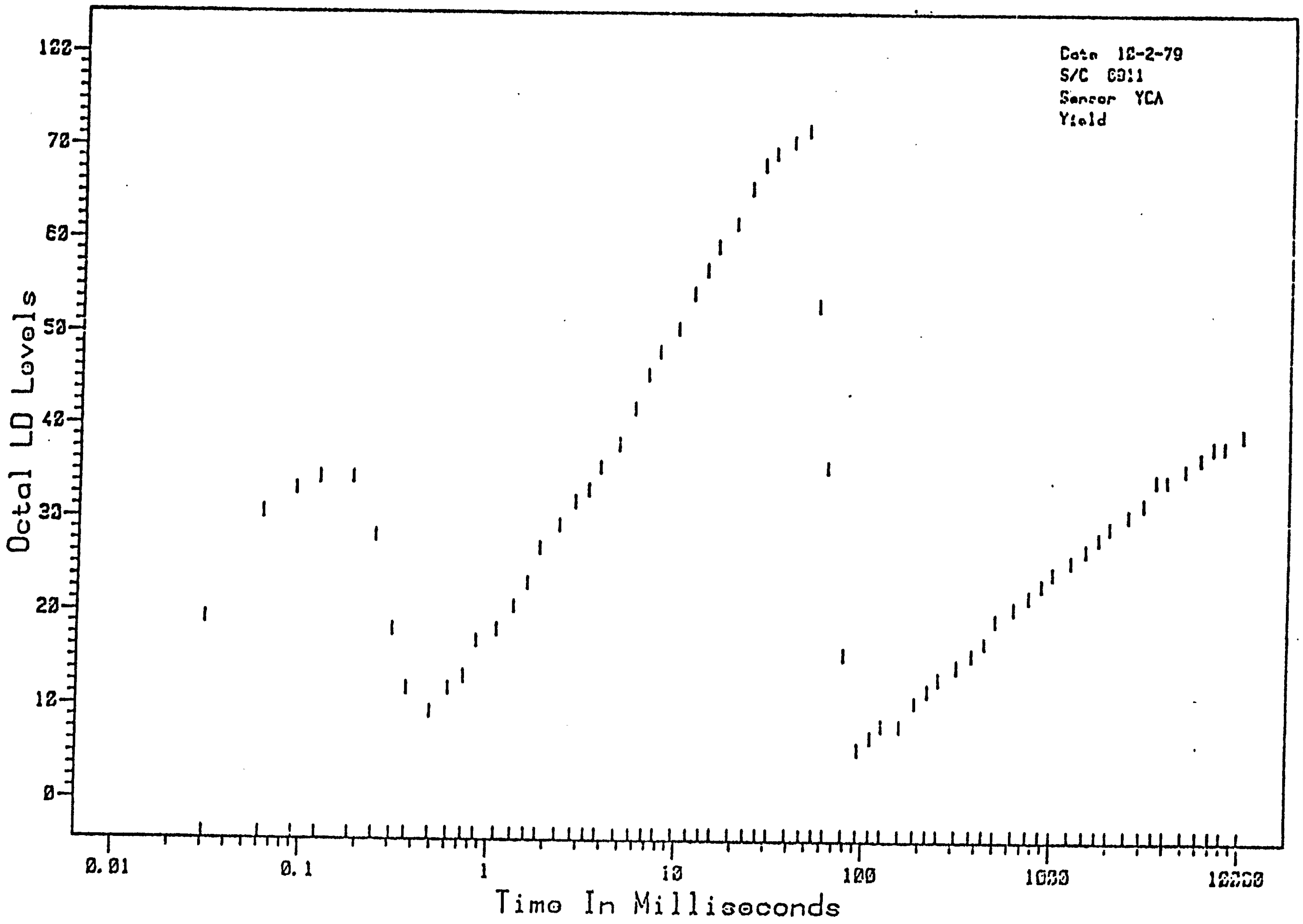

FIGURE 32

ALERT 747 POST-EVENT YCA CAL 1 RESPONSE

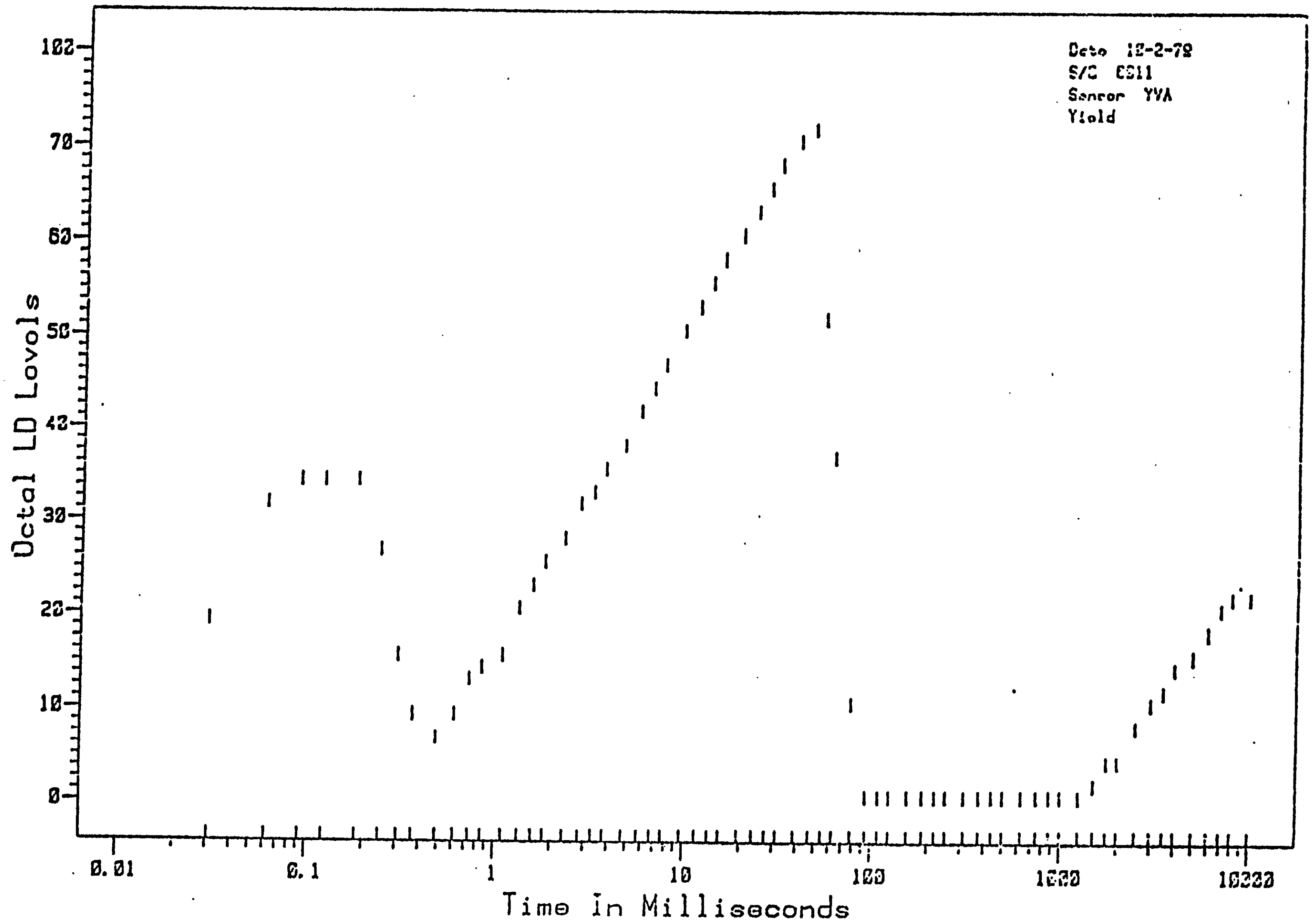

FIGURE 33

ALERT 747 POST-EVENT YVA CAL 1 RESPONSE

Using time-sequenced Cal 2 commands, a "mapping" of the 6911 YCA and YVA background modulation characteristics as a function of platform azimuthal orientation and sun-earth-vehicle angle was performed. The magnitude and frequency content of the background modulation signals recorded in this manner were compared with previous background records to determine if there had been any change in system response. Higher modulation frequency components than the nominal 64 second period component produced by spacecraft rotation were found, as exemplified in Figures 34, 35 and 36. Examples were also found (reference Figures 37 and 38) of background modulation tail-up which began significantly earlier than expected in the time history recording period. (Note that in Figures 37 and 38 the background recording was actually triggered by a laser calibration pulse rather than by a Cal 2 command. However, since the laser pulse duration is only 1 millisecond, it does not at all affect the character of the "tail-up" signal.) The presence of higher frequency, large amplitude modulation signals than experienced in earlier on-orbit years is consistent with an aging spacecraft/detector system. A decrease in spacecraft stability caused by small amounts of spacecraft unbalance, increases in reaction wheel bearing noise, etc., is certainly plausible and would result in increased background modulation. Degradation in bhangmeter sunshade surfaces such as flaking of the black paint is also plausible and would result in the creation of specular surfaces which could glint when illuminated by the sun, thus changing the character of the modulation. An increased background modulation environment is particularly significant in terms of interpreting the Alert 747 signals because it could likely be the cause of the YCA-YVA difference signal shown in Figure 31.

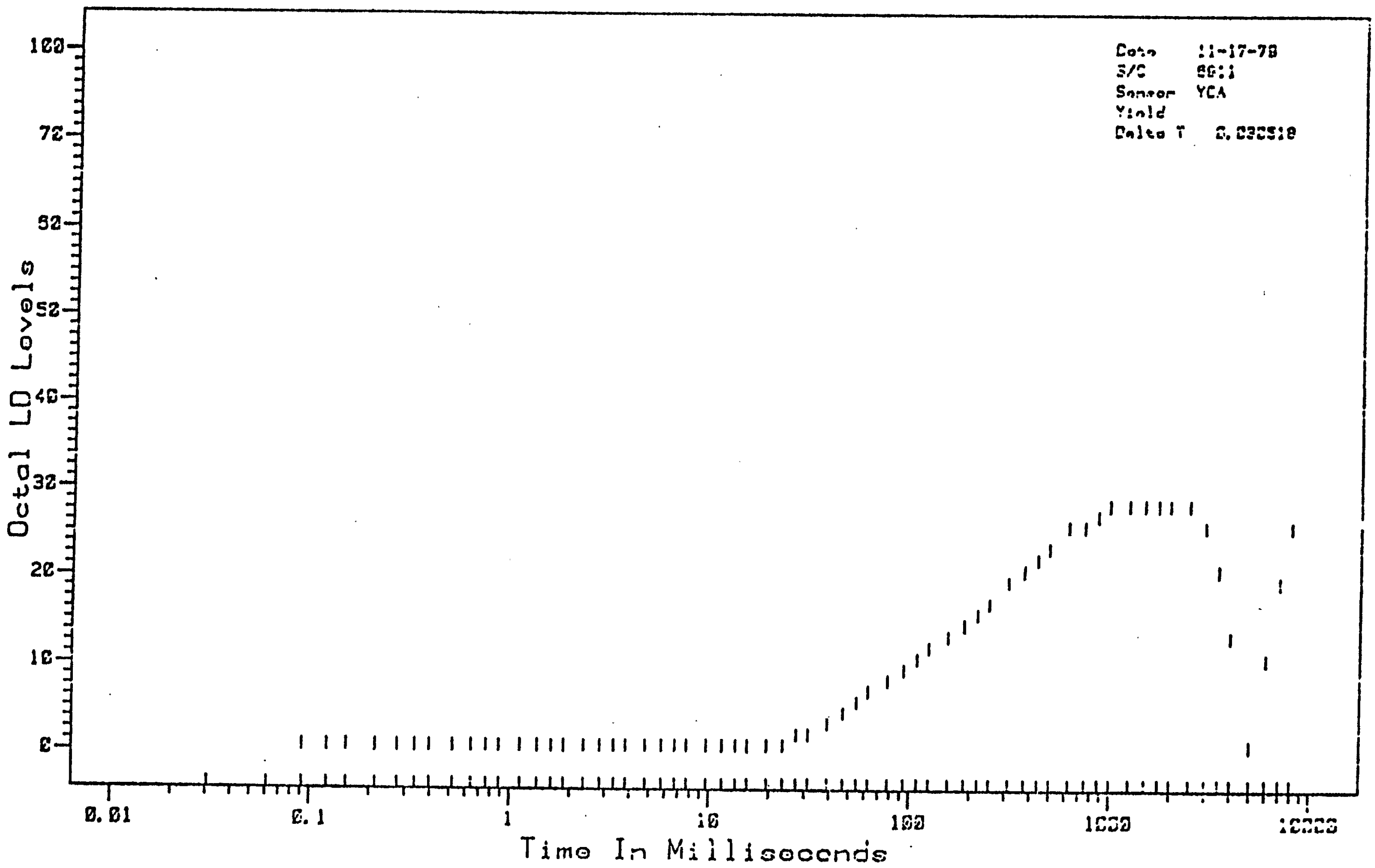

FIGURE 34

VELA 6911 YCA ATYPICAL BACKGROUND MODULATION RESPONSE

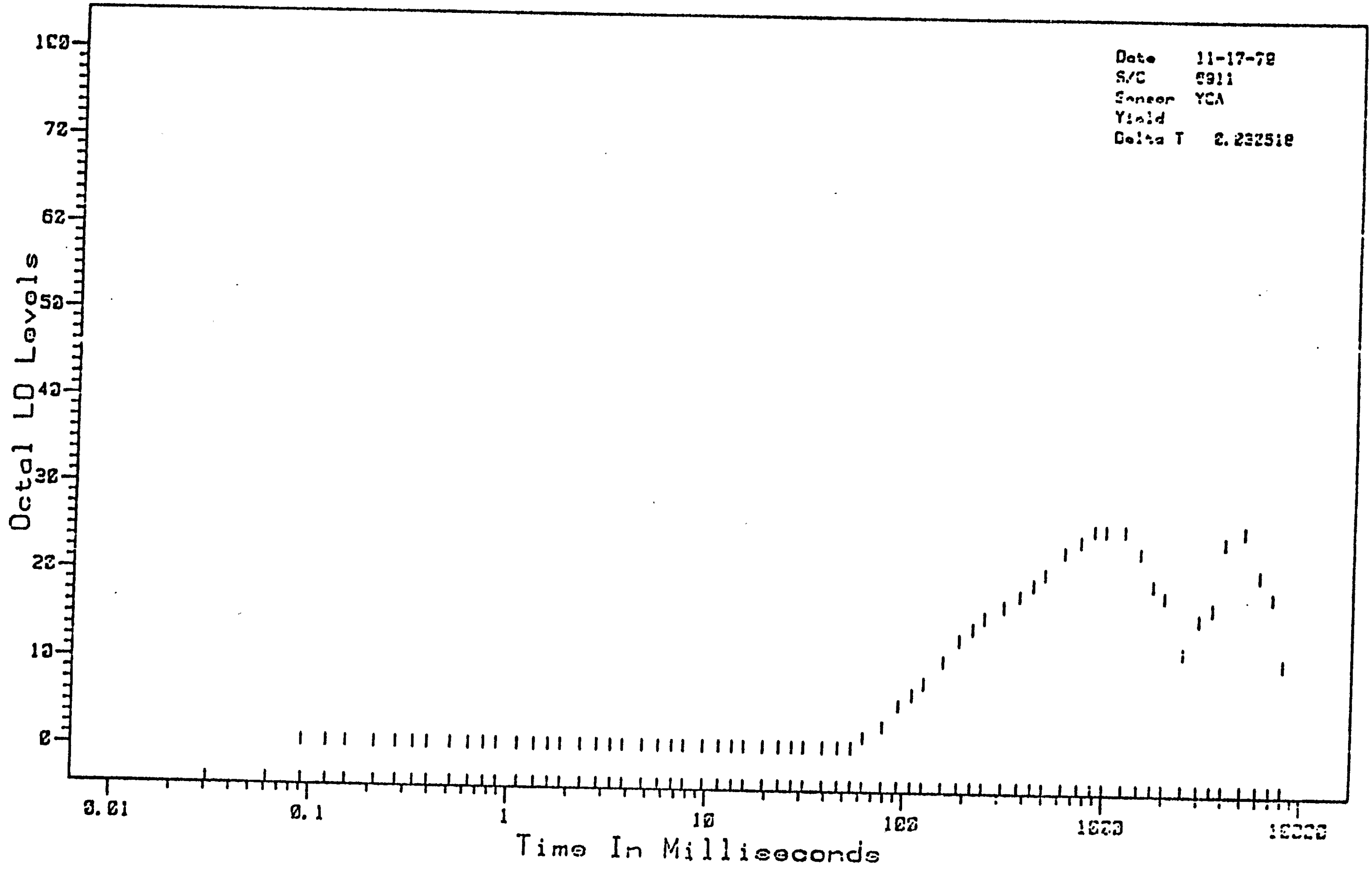

FIGURE 35

VELA 6911 YCA ATYPICAL BACKGROUND MODULATION RESPONSE

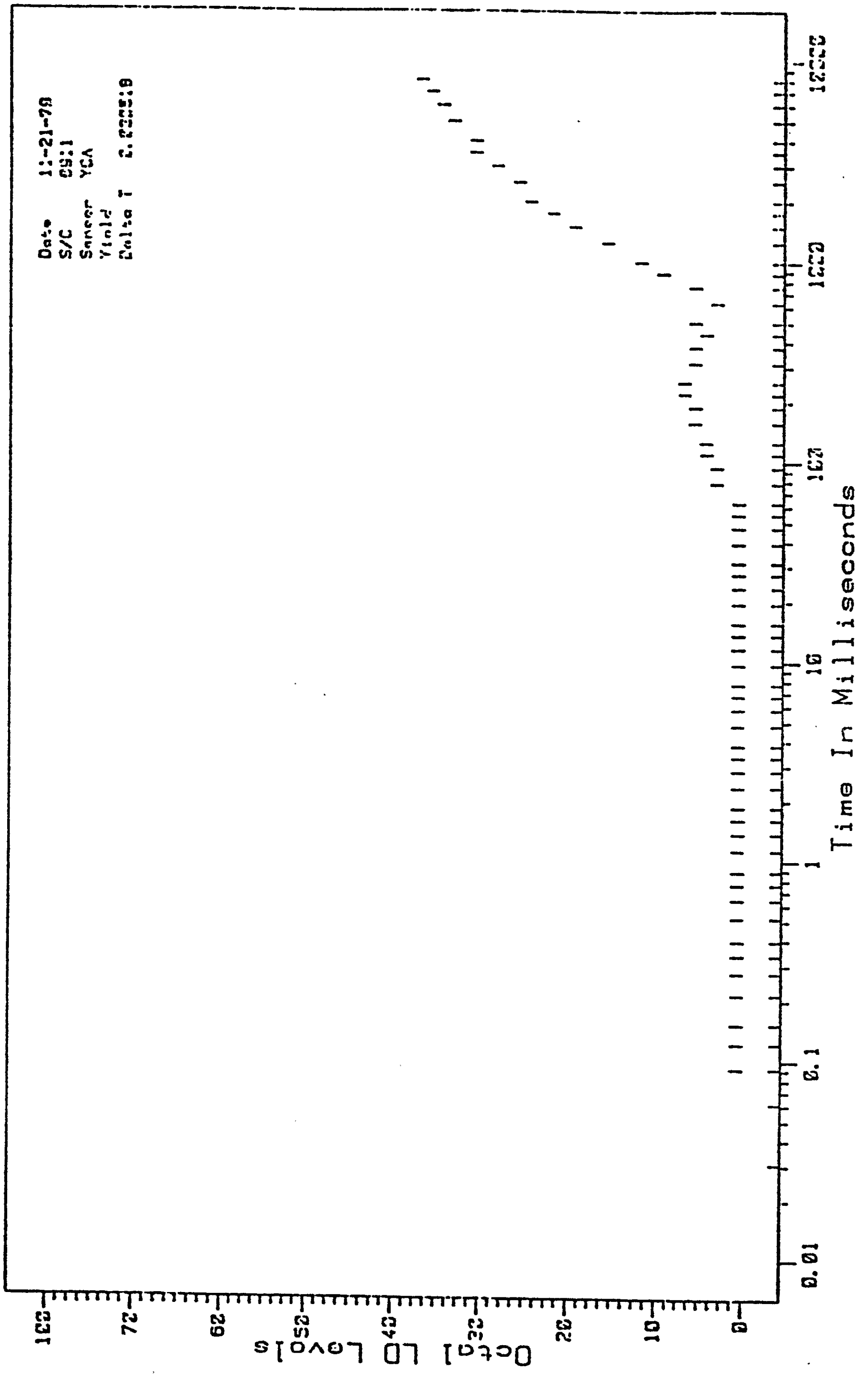

FIGURE 36

VELA 6911 YCA ATYPICAL BACKGROUND MODULATION RESPONSE

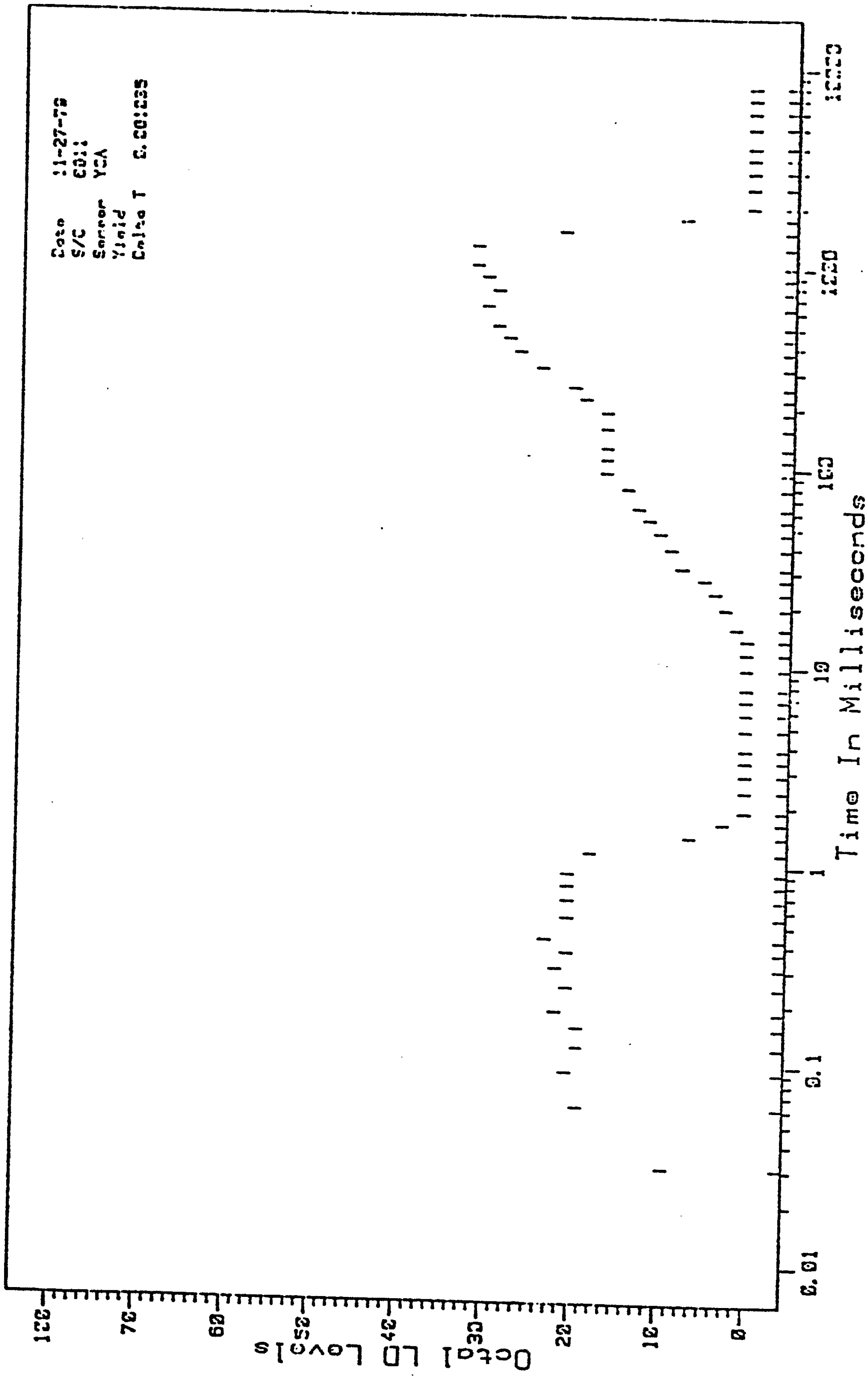

FIGURE 37

VELA 6911 YCA ATYPICAL BACKGROUND MODULATION RESPONSE

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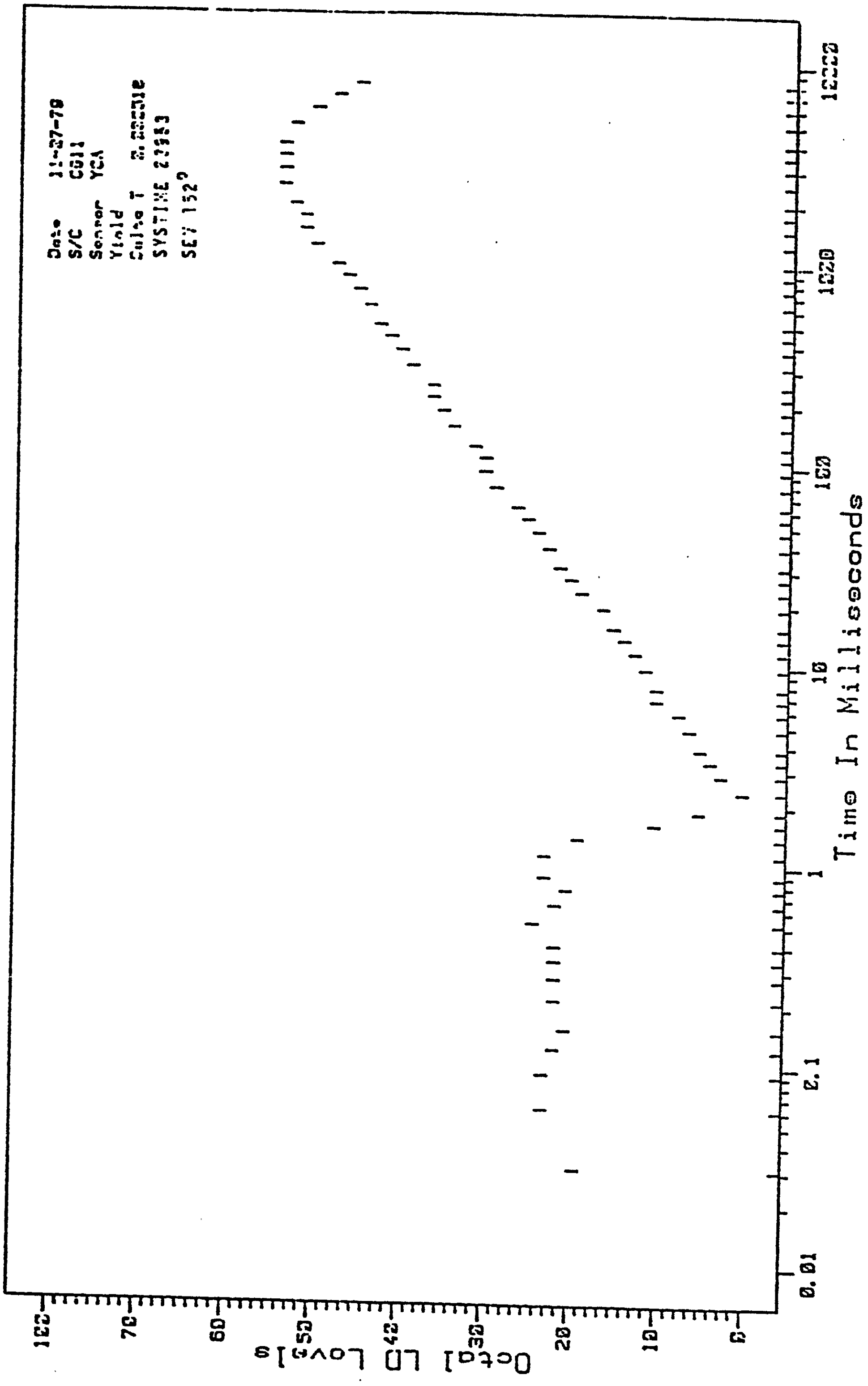

FIGURE 38

VELA 6911 YCA ATYPICAL BACKGROUND MODULATION RESPONSE

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The Vela bhangmeters were designed to operate as nearly independently of, and isolated from, one another as possible and do so except that both derive timing signals from the same master clock, both draw power from the same spacecraft power bus, and event data from both is stored in the same spacecraft data storage unit (a 131 kilobit magnetic core stack). A careful circuit analysis was performed by Sandia and again by F. W. Sarles of MIT-Lincoln Labs to search for any possible mechanism by which the detector/spacecraft electronics systems could have produced the Alert 747 YCA/YVA signal pair in response to some type of spacecraft transient. None was found.

Using flight spare YCA and YVA detector units, extensive bench testing was performed at Sandia to reverify critical system performance parameters. Photodiodes were recalibrated to determine whether an 11 year shelf life had caused a change in absolute sensitivity and/or spectral response. Sunshades, aluminum light-collecting cones and cover glasses were examined for possible degradation effects. Amplifier gains, linearities, bandwidths, noise levels, etc., were checked for evidence of possible component degradation. Feedback rates were reverified. The effects of the YVA low-level non-linearity were re-analyzed. In all cases, test results showed that these flight spare units performed as advertised. Although these results clearly do not constitute proof that on-orbit equipment failures/degradations have not occurred, they do reaffirm the integrity of the original design.

NUDET Data Survey

Several different independent analyses have been performed on [(b)(1)] pairs of Vela bhangmeter records from known NUDET events to determine the extent to which they agree and/or disagree with the Alert 747 YCA/YVA records. The analysis techniques used for signature comparison have been presented on numerous occasions and need not be detailed again in this report. Sandia performed a similar analysis, the results of which agreed with those obtained by others. All analyses conclude that the YCA and YVA time histories for Alert 747 show a larger inconsistency, as exemplified by the difference signal of Figure 31, than ever observed previously for a confirmed NUDET event.

Zoo Analysis

The Vela V and VI satellites have accumulated nearly forty "satellite-years" of on-orbit operation and during this period many hundreds of thousands of bhangmeter events have been recorded from non-nuclear sources. AFTAC recently completed a total search of all Vela bhangmeter event records using a set of discriminants designed to extract events which did not fit the well-known time history characteristics attributable to Cal 1, Cal 2, energetic particle, and lightning events. This set of a hundred or so events, which has come to be known as the "Vela Zoo," has been the subject of considerable discussion in terms of how it affects interpretation of the Alert 747 data.

AFTAC recently provided Sandia with a set of the Zoo data. Although our analysis of these events is still continuing, several preliminary comments are in order. We find that a significant number of the Zoo events, particularly events among those for which only one bhangmeter was triggered, are explainable as energetic particle triggers of the type previously shown in Figure 24. A smaller number of events have signatures which could quite plausibly be created by small objects such as meteoroids passing in front of the spacecraft reflecting sunlight into the bhangmeter FOV. (This subject is addressed in greater detail below.) In analyzing the remaining uncategorized events, we find none whose characteristic features are consistent with observed and/or predicted NUDET event signatures.

Meteoroid Analysis

A popular theory for a time during the analysis of Alert 747 postulated that YCA and YVA records were created by a sunlit meteoroid passing through the Vela bhangmeter FOVs. Sandia modeled the bhangmeter responses for such an occurrence. The model used and the results obtained were presented in an earlier report. Our model only treated objects with uniform, regular surfaces and accordingly required that two objects transit the bhangmeter FOVs nearly simultaneously to produce a double-peaked response. Using two meteoroids we were able to reproduce the YCA signature from Alert 747, but the predicted YVA response was a poor match to the actual YVA data. Mission Research Corporation also developed a meteoroid model, the "fractured ball bearing," which would reproduce both YCA and YVA curves from Alert 747. However, their model, in addition to requiring a very unique object surface configuration, constrained the object velocity to a very small value, much smaller than realistic meteoroid velocities.

SRI International analyzed the probability of occurrence of the Sandia and MRC meteoroid encounters and found that the probability of either occurring was very small. As a part of their study, SRI evaluated the data from the Pioneer 10 Asteroid-Meteoroid Detector (AMD) Experiment, particularly in terms of how it might help to define Vela meteoroid encounter statistics. Based on the similarities in the Pioneer 10 AMD and Vela bhangmeter design characteristics, they concluded that it was quite probable that the Vela bhangmeters should have experienced some small number of meteoroid encounters during their aggregate on-orbit lifetime, but again, that none of these were likely to produce a response similar to Alert 747.

CONCLUSIONS

All investigations conducted to date indicate that the Vela 6911 YCA and YVA bhangmeter systems operated correctly in recording the Alert 747 event data and that the discrepancy between the YCA and YVA signals did not result from an instrument malfunction. The last opportunity to compare YCA/YVA signal consistency over a total NUDET time history was in June 1972, and the 8 intervening years allow consideration of the possibility that some type of component degradation may be responsible for the difference signal. However, all post-event performance checks and analyses performed to date indicate that such is not the case.

There is evidence, as shown in Figures 34 through 38, that background modulation effects have increased for Vela 6911 in recent years. We find it reasonable to conclude that the Alert 747 YCA-to-YVA discrepancy (i.e., the error signal of Figure 31) could have been created by "tail-up" modulation enhancement of the second maximum portion of the YCA time history and therefore that the Vela 6911 corrected YCA and YVA records for the September 22, 1979, event are fully consistent with those expected from a low yield atmospheric NUDET.

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