N91-32636

THE SANDIA TRANSPORTABLE TRIGGERED LIGHTNING INSTRUMENTATION FACILITY

George. H. Schnetzer and Richard J. Fisher
Sandia National Laboratories
Albuquerque, NM 87185

ABSTRACT

Development of the Sandia Transportable Triggered Lightning Instrumentation Facility (SATTLIF) was motivated by a requirement for the *in situ* testing of a munitions storage bunker. Transfer functions relating the incident flash currents to voltages, currents, and electromagnetic field values throughout the structure will be obtained for use in refining and validating a lightning response computer model of this type of structure. A preliminary shakedown trial of the facility under actual operational conditions was performed during the summer of 1990 at the Kennedy Space Center's (KSC) rocket-triggered lightning test site in Florida. A description is given of the SATTLIF, which is readily transportable on a single flatbed truck or by aircraft, and its instrumentation for measuring incident lightning channel currents and the responses of systems under test. Measurements of return-stroke current peaks obtained with the SATLLIF are presented. Agreement with data acquired on the same flashes with existing KSC instrumentation is, on average, to within ~7 percent. Continuing currents were measured with a resolution of ~2.5 A. This field trial demonstrated the practicality of using a transportable triggered lightning facility for specialized test applications.

INTRODUCTION

During 1990, the Sandia Transportable Triggered Lightning Instrumentation Facility (SATTLIF) was designed, built, and fielded at the Kennedy Space Center's (KSC) rocket-triggered lightning test site in Florida. Development of the facility was jointly sponsored by the U.S. Army and Sandia National Laboratories (SNL) to support the testing of a munitions storage bunker located at Ft. McClellan, Alabama. In that test, scheduled for the summer of 1991, lightning will be triggered to various points on the bunker's lightning protection system (Figure 1). Both the incident flash current and response voltages, currents, and electromagnetic fields within the structure and its grounding system will be simultaneously measured. The data will be used to improve and validate a detailed finite difference computer model of the structure developed for the Army by Electro Magnetic Applications, Inc. (EMA) [1].

Selection of the triggered lightning technique over the use of a conventional large-scale capacitive pulser as a test source for this application was based on at least two major technical considerations. First, the inductance inherent in a large test object and its connections to the test source would result in an inadequate rise rate of the test current that could be delivered by any practical pulser. Since rise rate is a dominant controlling factor in the coupling process, this represents a serious shortcoming. Second, of particular importance in the validation of the computerized response model is the proper simulation of the natural distribution of lightning current throughout the test object's structural members, grounding system, and surrounding earth. This distribution simply cannot be reproduced with a conventional test source. Given the present maturity of the triggered lightning technique, which circumvents the above technical issues, it was chosen for the bunker test application.

In preparation for the bunker test, the SATTLIF was fielded during the summer of 1990 at KSC. In this way, the facility and its basic instrumentation designs could be validated under actual field conditions prior to procurement of the multiple data channels that will be required for the 1991 test. A further benefit of the 1990 shakedown test was that added responsibility for rocket operations, range clearance, and other administrative requirements could be left to KSC. Finally, once in the field, the opportunity was taken to acquire direct-strike damage data on aluminum and steel

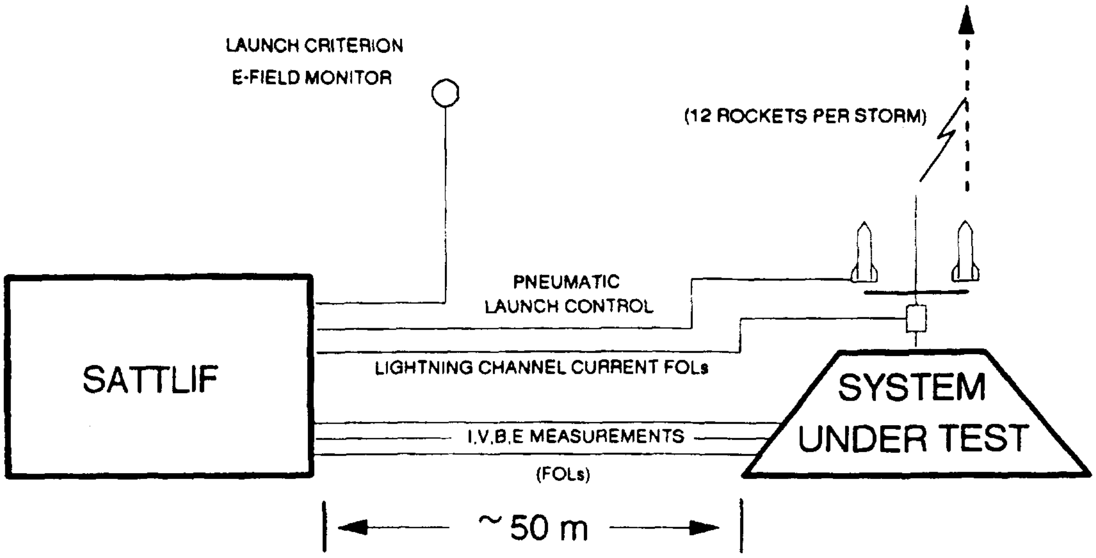


Figure 1. Munitions Storage Bunker Triggered Lightning Test Configuration

specimens produced by fully recorded lightning. These particular experiments are presented in a companion paper in these proceedings [2]. The remainder of this paper describes the SATTLIF and its performance.

GENERAL DESCRIPTION

The SATTLIF is housed in a 20'x8'x8' steel ocean cargo container that has been converted to an instrumentation shelter. This air-conditioned unit provides electromagnetic shielding as well as safety for the test personnel and instrumentation. A single window is provided to permit visual observation of the launch and test area and optical recording of the triggered lightning events. The facility subsystems include an ambient electric field monitor, video and cinematic photographic systems, data acquisition channels for measuring both test item response and the incident lightning (return-stroke and continuing-current components), data processing computer and plotter, pneumatic rocket launch control system, National Lightning Detection Network [3], test range radio communications, and an external power generator. The entire self-contained SATTLIF is readily transportable on a single flatbed truck or by aircraft and can be made operational within one or two days of its arrival at a test site. Figure 2 shows the SATTLIF deployed at KSC 80 feet from the strike tower.

Figure 3 is a diagram of the SATTLIF subsystems. Except for the short lines from the power generator and the antennas of the range communications and lightning detector systems, there are no penetrations into the shelter (dotted enclosure in the figure) by conductive lines. The lightning measurement signals are transmitted from the experiment over fiber optic links (FOLs), and rocket launch control is by pneumatic lines. Figure 4 shows the interior of the shelter.

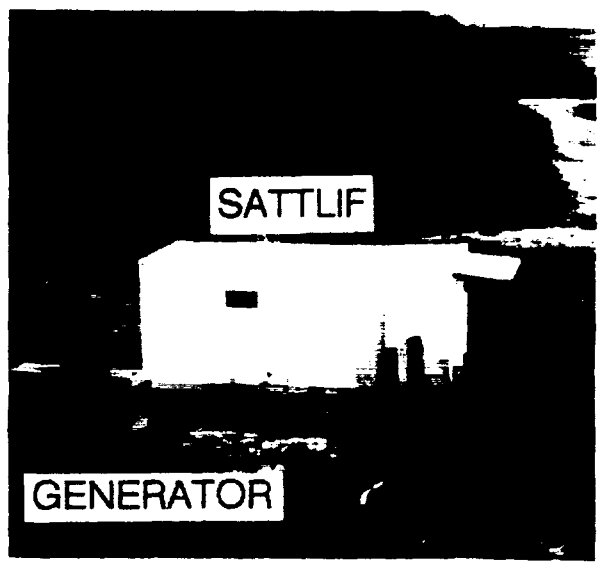


Figure 2. SATTLIF Deployed at KSC . RTL Site

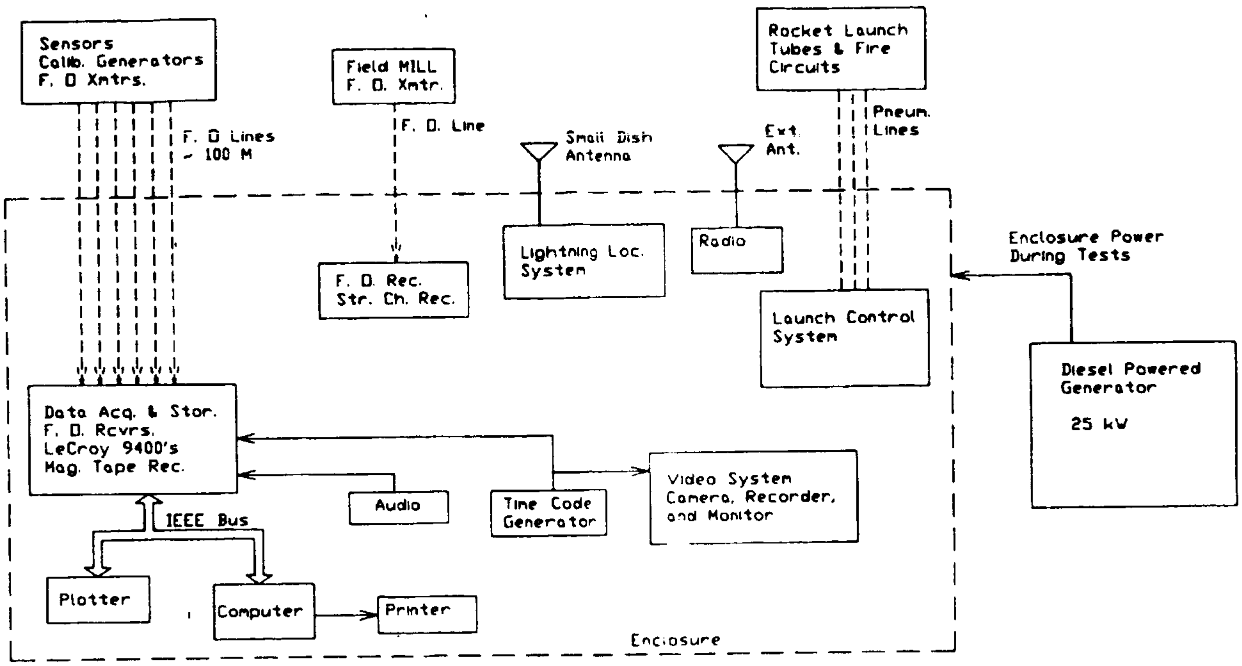


Figure 3. Diagram of SATTLIF Subsystems

Figure 4. Interior Views of the SATTLIF

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

The ambient electric field is monitored by a Mission Instruments Model EFS 100 inverted field mill, which produces an analog output of 0 to ±10 V, corresponding to a ±20 kV/m field. This output is transmitted to the shelter via a dc to 10-kHz Dymec frequency modulated (FM) FOL and is there scaled as desired and displayed on a strip chart recorder. The field mill and its FO transmitter are powered from a rechargeable battery that provides for at least 8 hours of continuous operation per charge.

An IBM AT compatible computer with an IEEE 488 interface is used in the data acquisition system. Traces stored on LeCroy 9400A digitizing oscilloscopes are transferred via the IEEE 488 bus to the computer where they can then be analyzed, processed, and plotted. The data can also be plotted directly on an HP 7440 digital plotter.

The video recording system includes (1) a Pulnix TM 545 high-resolution CCD camera (disabled AGC and γ=1 options) with a Vivitar 70- to 210-mm macro zoom lens, (2) a JVC BR-S600U SVHS video cassette recorder, (3) FOR-A VTG-33 video timer, and (4) a Sony SSM-910 black and white monitor. The video camera lens was operated at f/22 with an additional eight-stop equivalent neutral density filter. An Action Master 500 high-speed 16-mm, cinematic camera with zoom lens was operated at 200 frames per second to provide a 5-ms time resolution.

A six station electro-pneumatic rocket launch controller was housed in a 10.5-in-high rack space adjacent to the observation window. Arming pressure is applied by activating any one of the six key switches. All are operated by a single, common key, thereby ensuring that only one rocket can be armed at a time. Panel lights indicate the status of each rocket: one light for the armed condition and a second, SPENT, light to indicate that the proper launch pressure has been applied to the selected rocket. All activated SPENT lights remain lit until panel power is interrupted, so that a continuous indication is given of which rockets have been fired. The pneumatic pressure source is located inside the shelter and consists of a small compressor with integral reservoir. The operating pressure is 95 psi.

The receiving end of the pneumatic control system (the Safing, Arming, and Firing box) is housed in an 8"x8"x4" steel box with snap-tight fasteners. The associated circuit is shown in Figure 5. The PREARM and SAFE shorting plugs are provided as additional positive operational safety features.

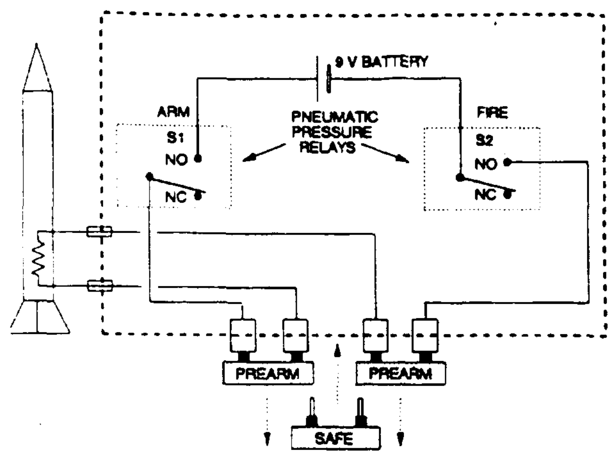


Figure 5. Rocket Launch Safing, Arming, and Firing Circuit

Actual firing of rockets from the SATTLIF was not part of the 1990 program. All rocket operations were provided at KSC by experimenters from the Centre D'Etudes Nucleaires de Grenoble (CENG) using their systems that are described elsewhere [e.g., 4]. However, the SNL launch control system was fully deployed and was successfully tested in all safety modes with both dummy and real initiator squibs.

The facility requires 208 V, 3-phase power. During triggering operations, or whenever a commercial source is not available, this power is provided by a 25-kW diesel generator. The generator is located within 25 feet of the shelter. For safety reasons, the connecting power cable is provided with a shield that is connected to both the generator and the shelter, as well as to a ground rod.

INSTRUMENTAION

A block diagram of the data acquisition instrumentation system is shown in Figure 6. In this configuration, there are two sensor packages: one for the incident flash current, and a second for measuring currents within some test item, which, in this case, was one of the down conductors of the grounding cable grid below the experiment platform.

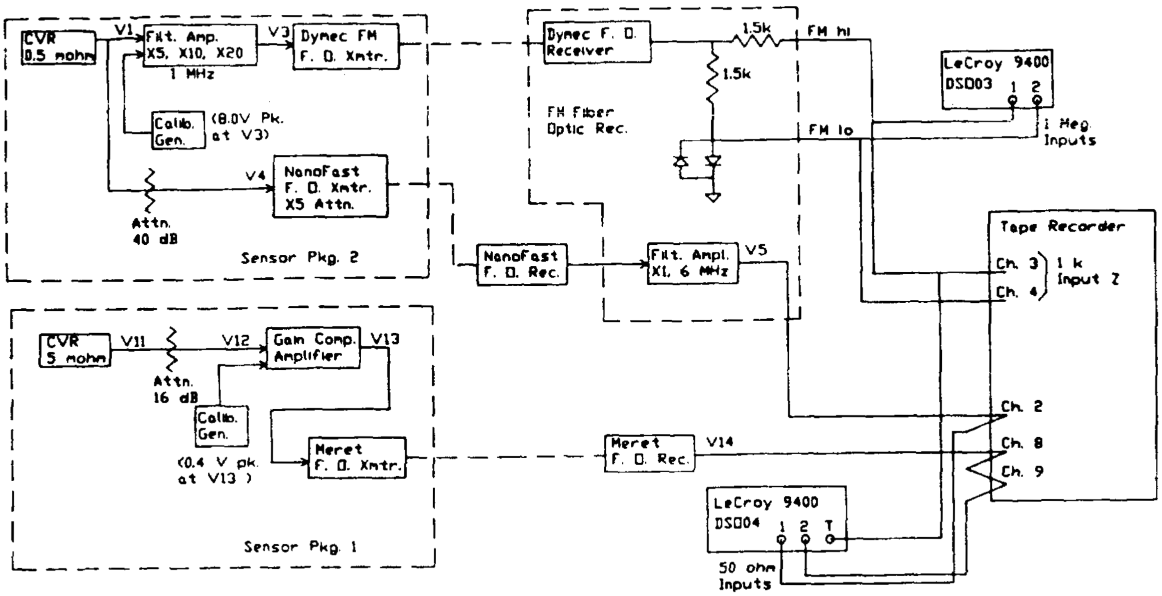


Figure 6. SATTLIF Data Acquisition Instrumentation

Both sensor packages were housed in gasketed, EM-tight steel Hoffman boxes.

In order to record both return-stroke and continuing-current components faithfully, two separate transmission and recording channels were used. For the return stroke, the output of a 0.5-mΩ T&M R-14000-20N coaxial current viewing resistor (CVR) was transmitted to the shelter over a NanoFast 300-2A FOL. There the signal was recorded on a LeCroy 9400A digitizing oscilloscope channel and on a direct-record (1 MHz) channel of the Ampex 2300 tape recorder. Overall signal bandwidth was set by the 164-ns rise time of the CVR, which, in this case, was selected on the basis of its energy handling capacity rather than rise time. A 6-MHz filter was inserted as indicated in Figure 6 to improve signal-to-noise ratio. The LeCroy was operated in the segmented memory mode at an 80-ns sampling rate, thereby permitting the capture of the first 200 μs of up to eight individual return strokes per flash. A trigger level equivalent to 1000 A was selected.

Due to the long duration and relatively low amplitude of lightning continuing currents, a separate data channel was used to record these components of the flash. In this channel, the output from the CVR is amplified and clipped to pass only the signal equivalent of 1000 A or less. Diodes from the op amp input to ground clamp at ±0.5 V to limit saturation caused by the return-stroke portions of the signal. The output from this amplifier is transmitted via a Dymec Model 5717 FM FOL that has a bandwidth of dc to 1 MHz. During the 1990 trials, the signal was scaled and recorded on two LeCroy channels and on two 500-kHz FM Ampex tape channels. Use of two channels with sensitivities differing by a factor of ten increased the dynamic range of the measurement by 20 dB. As operated during the 1990 field trials, the selected attenuations yielded an overall measurement dynamic range from an approximate 2.5-A floor to the 1000-A saturation level.

Both channel types (return-stroke and continuing-current) are provided with end-to-end calibration features. The NanoFast system has a built-in calibration function that is activated via fiber optic link. A pneumatically activated calibration system was implemented in the Dymec channel (Figure 6) to inject a fixed-peak signal (clipped square wave) at the input of the FOL transmitter.

Table 1 summarizes the set of common data measured simultaneously by KSC and SNL. The comparison includes only return strokes, since the available KSC instrumentation does not record continuing current. The KSC peak currents in the table were read from a set of hard copy plotted on a 4-μs-per-division scale, which limited the accuracy with which those peaks could be established. The resulting differences between the two measurement sets has a mean of 7.4% and a standard deviation of 5.9%. For example comparison, Figure 7 shows the stroke currents of Flash 90-07 as measured by KSC and SNL. All the other data are similar. Figure 8 is a plot of the early portion of the first stroke of Flash 90-07 with the actual sampled data points indicated.

Table I. Comparison of Stroke Current Measurements

Shot No.	Stroke No.	Sandia Ip (kA)	KSC Ip (kA)
90-07	1	24.5	22.6
	2	18.0	17.2
	3	23.5	22.3
90-08	1	13.8	14.4
90-09	1	16.5	16.0
	2	4.1	4.2
90-12	1	3.9	3.9
	2	15.8	13.4
	3	27.5	22.4
90-14	1	17.0	15.0

An example of recorded continuing current is shown in Figure 9. Figure 10 is a similar example of Flash 90-03, a two-stroke flash with a single interstroke continuing current. Other examples are given in these proceedings (Ref. 2) and in Reference 5.

Except for the type of sensor employed, measurements of lightning responses of a system under test can generally be made with the same basic type of instrumentation channel. One issue always of particular concern, however, is achieving sufficient overall dynamic range for such measurements, which sometimes need to be performed on a one-shot basis and for which reliable predictions are often unavailable. In such cases, the penalty is the assignment of multiple recording channels of varying sensitivities to the same measurement point.

During the 1990 tests, a baseline channel was tested that incorporated an experimental feature that was hoped would improve achievable dynamic range. This feature was the insertion of a "gain compression" amplifier with an output function as indicated in Figure 11 (in effect, a crude approximation of a logarithmic function). In principle, improvement in dynamic range results from this response function because the lower and higher amplitude portions of the input are amplified by different factors. In practice, the design functioned basically properly but two problems were encountered. First, baseline drift of the amplifier corrupted the data in a complicated way, since the various portions of the input signal were affected by differing amounts. Recovery of the true waveform then required a generally unacceptable trial-and-error iteration in which the baseline of the raw digitized data was adjusted prior to the application of the unfolding algorithm. Second, digitization noise riding on the different portions of the waveform was artificially distorted in the unfolded data. Figure 12 is an example of one (unfolded) measurement of ground cable current obtained with this arrangement. No further pursuit of this technique is planned for the present. Nevertheless, with further development of a compensated amplifier with improved stability, the basic idea might still prove worthwhile for these types of tests.

CONCLUSIONS

The 1990 field trial of the SATTLIF demonstrated the general practicality of using a transportable triggered lightning facility for specialized test applications. These applications include, but are not limited to, cases in which test objects are either too large to be transported to a conventional test facility or cannot be driven adequately by such a facility. A further case involves the situation in which objectives require features in the test current that cannot be obtained from a conventional simulation source.

Lightning return-stroke and continuing-current components were recorded with high resolution by the SATTLIF, which was deployed 80 feet from the strike tower. The Dymec FM FO system used for the latter functioned well and reliably. Its stability proved so good that frequent calibration was found to be superfluous. The combination of

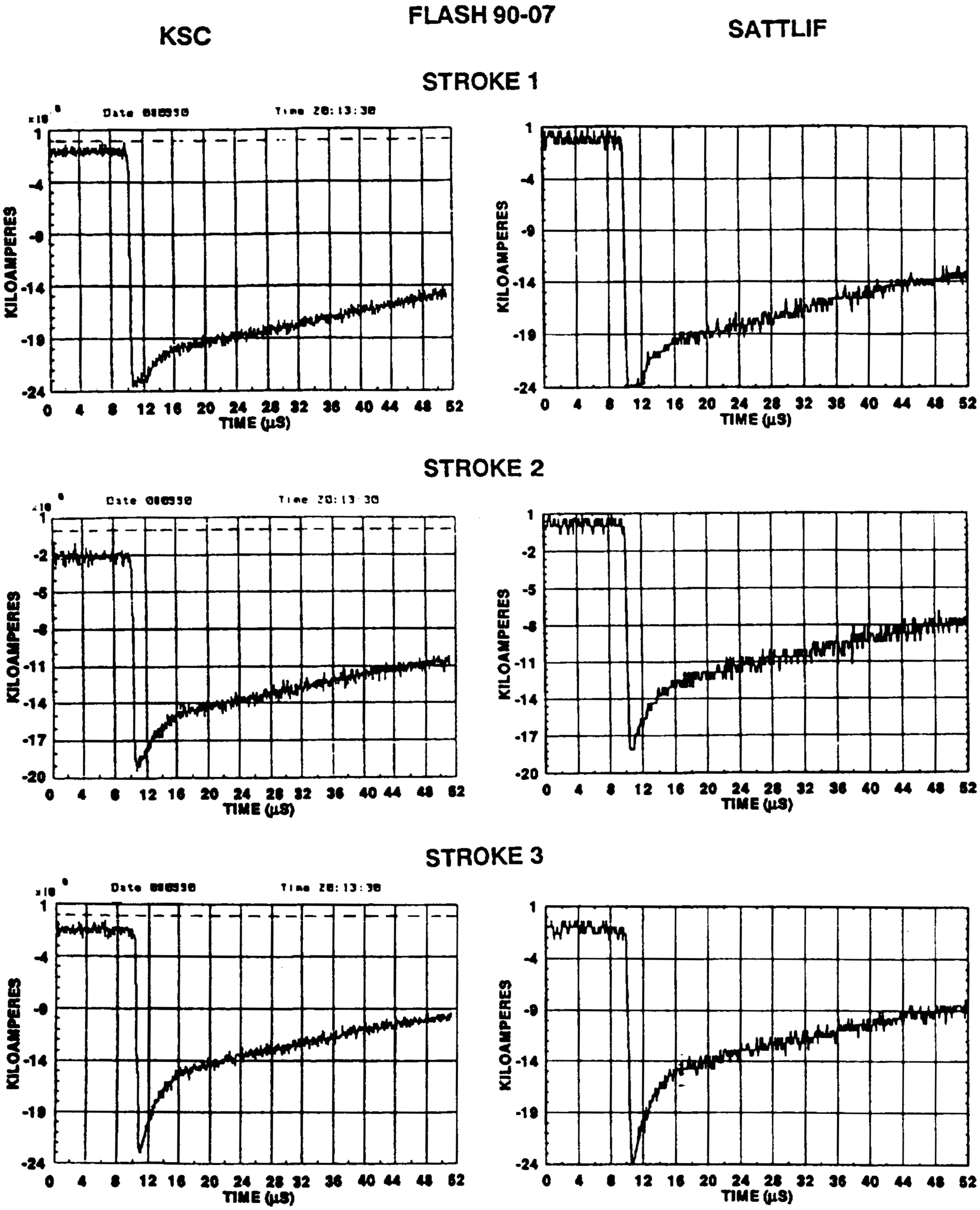


Figure 7. Stroke Currents of Flash 90-07 as Measured by KSC and SNL

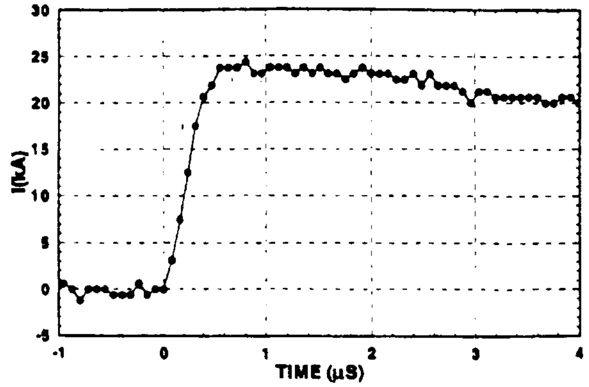


Figure 8. Early Portion of Stroke 1 Current, Flash 90-07. Dots Indicate Data Sample Points.

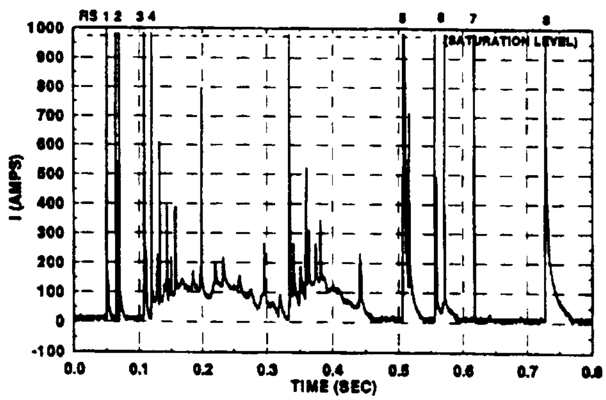


Figure 9. Flash 90-04 as Recorded by the SATTLIF Continuing-Current Instrumentation

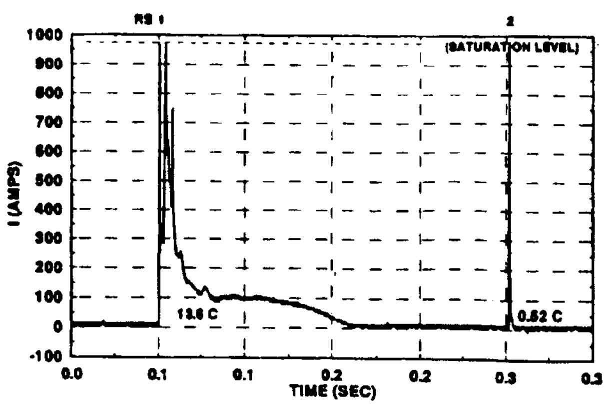


Figure 10. Flash 90-03 as Recorded by the SATTLIF Continuing-Current Instrumentation

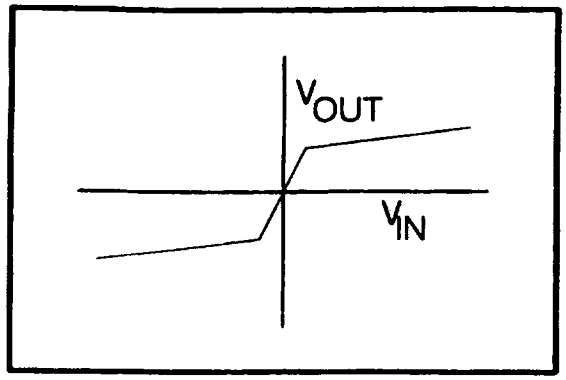
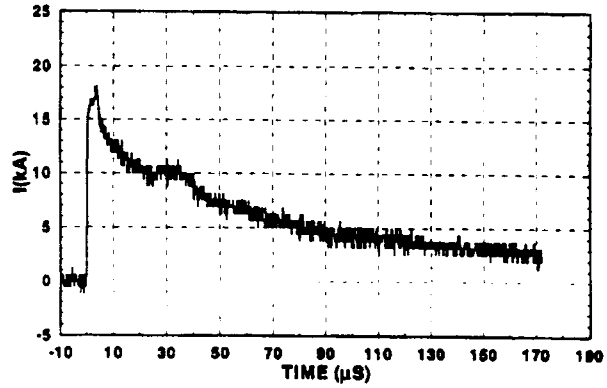
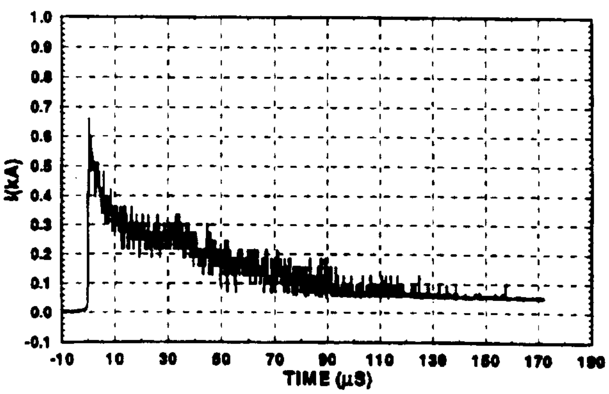


Figure 11. "Gain Compression" Amplifier Response Function



(a)



(b)

Figure 12. a) Incident Flash Current and b) Corresponding Cable Current Obtained Using Experimental "Gain Compression" Amplifier

FM FOL and FM tape recording was so successful that, in future testing, digitizer channels will be reserved solely for the recording of faster phenomena.

Additional examples of data obtained with the SATTLIF during these trials are available in Reference 2, which appears in these proceedings. A fuller description of the facility and all the data acquired during 1990 is available in Reference 5.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the Kennedy Space Center and Mr. William Jafferis for the opportunity to participate in their 1990 rocket-triggered lightning program. The considerable technical input of Dr. Larry D. Scott (SNL) and his contribution in setting up the LeCroy digitizer system software are acknowledged. The detailed design of the SATTLIF's rocket launch system and supervision of its fabrication was largely carried out by C. S. Chocas (SNL). Development of the SATTLIF was jointly funded by U.S. Department of Energy, the Project Managers' Office of the Department of the Army, and the U.S. Army Armament Research, Development, and Engineering Center (ARDEC).

REFERENCES

1. Collier, R. S., P. M. McKenna, and R. S. Perala, "Evaluating Lightning Hazards to Building Environments Using Explicit Numerical Solutions of Maxwell's Equations," *Proc. 1991 Int. Conf. on Lightning and Static Electricity*, April 1991.
2. Fisher, R. J., and G. H. Schnetzer, "Damage to Metallic Samples Produced by Measured Lightning Currents," *Proc. 1991 Int. Conf. on Lightning and Static Electricity*, April 1991.
3. Orville, R. E., R. B. Pyle, and R. W. Henderson, "The East Coast Lightning Detection Network," *IEEE Trans. on Power Systems*, PWRS-1, No. 4, November 1986.
4. Larouche, P., A. Eybert-Berard, and L. Barret, "Triggered Lightning Flash Characteristics," *Proc. 1985 Int. Conf. on Lightning and Static Electricity*, June 1985.
5. Fisher, R. J., and G. H. Schnetzer, *1990 Sandia Rocket-Triggered Lightning Field Tests at Kennedy Space Center, Florida*, SAND90-2926, February 1991.