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Lightning Strike Tests of Composite Connectors

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Test results are presented on the lightning strike effects on composite and hybrid type multipin aircraft connectors in comparison with the standard all metal connectors. These tests were performed using a unipolar double exponential long duration pulse recommended by the SAE-AE4L committee at peak current levels of 3 kA, 10 kA, 15 kA, and 20 kA. Such peak current levels might be found in all-composite or partially composite aircraft or in exposed areas of all-metal aircraft.

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LIGHTNING STRIKE TEST OF COMPOSITE CONNECTORS

BACKGROUND

Several connector manufacturers have recently introduced light weight multipin wiring connectors that employ composite construction using various combinations of non-metallic resins, metal platings and metal sleeves. The simultaneous development of composite airframes employing partially conductive or non-conductive materials has reduced or eliminated the conventional protection of the all-metal airframe and connectors against the high current surges normally encountered during lightning strikes. This increased vulnerability has become particularly critical with the increasing use of advanced avionics and fly-by-wire control systems. The introduction of these new technologies has thus necessitated an independent evaluation of the electrical performance of these composite-hybrid connectors under the expected operational environment of naval aircraft.

The purpose of these lightning strike tests is threefold:

(1) evaluation of a few typical commercial composite-hybrid connectors in comparison with the conventional aluminum connector,
(2) evaluation of the test procedures and
(3) to provide information on modes of failure and possible improvements

The specific connector types and manufacturers were chosen in an effort to represent presently available options in composite and hybrid connector constructions. The tests were not intended to provide a broad screening of all available composite-hybrid connectors nor are the results of these tests to be construed to be an endorsement or rejection of any particular type, component or manufacturer. As with all such electrical equipment, the appropriate use and specifications are determined by the service conditions.

The lightning strike test procedures described in this report evolved from several sources; The Federal Aviation Administration (FAA Advisory Circular No. 20-136), The society of Automotive Engineers (SAE Subcommittee SAE-AE4L), The Electronics Industries Association (EIA Subcommittee P-5.1) and numerous communications with NAVAIR (V-22 program office AIR-546D1F), the Naval Avionics Center (Code 916) and the Naval Air Test Center (Code SY-84).

The specific type of lightning strike threat that we wish to address is that for the low impedance conduction path through cable shields and connector shells to ground as might be found in an all-composite aircraft or in exposed areas in a partially composite aircraft or all metal aircraft. While the threat

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environment has not been fully characterized, there is at present, a general consensus that a lightning strike to a composite partially conductive aircraft structure causes a diffusing attenuation and lengthening of the initial current pulse to produce the so called long duration test pulse recommended by the SAE-AE4L committee (SAE-AE4L-87-3 Rev. B Waveform 5B). This waveform is for indirect effects testing and is a unipolar double exponential pulse having a rise time to peak value of 50 μs ± 20% and a decay time to 50% peak of 500 μs ± 20%. The SAE-AE4L report also suggests peak current test levels of 3 kA to 20 kA. However, there is considerable controversy in the lightening strike community regarding the appropriate peak current test levels and the maximum level. The ranges suggested go from 100 A min.→ 10,000 A max. up to 3,000 A min. → 30,000 A max. In the interest of safety, we took a conservative approach and conducted the test at peak current levels of 3 kA, 10 kA, 15 kA, and 20 kA.

TEST PROCEDURES

In order to minimize the variables and to facilitate ease of direct comparison, all test were conducted with as nearly identical connector components as possible. The type connectors chosen for these tests is the MIL-C-38999 shell size 9 either flange mount or jam-nut mount. The shell size 9, which is the smallest size for this type circular connector, was chosen because it is the most vulnerable to the effects of high current surges and serves to limit the number of tests required. i.e., survival without damage of this size connector at a given peak current level would presumably indicate survival of all larger size connectors since they will have a correspondingly larger metal cross section area and higher peak current capacity.

The specific MIL-C-38999 connectors, components and associated fittings were provided by the following major suppliers via the Naval Avionics Center:

1. Standard Aluminum Connector	Bendix
2. Composite with metal plating	Deutsch ATD
3. Composite with metal plating	Amphenol-Bendix
4. Hybrid with aluminum sleeve	ITT-Cannon

Because of the different requirements of the V-22 program (AIR-546D1F) and the NAC program (AIR 546D4), the tests include two different test configurations. (I) a systems test assembly and (II) a component test assembly. These two configurations are shown in Figure 1 at top and bottom respectively. As indicated, the system test consists of a complete assembly of a receptacle, plug, backshell, cable shield and termination. The system is assembled according to manufacturer specifications as it would be installed in a typical aircraft application. The component test assembly is designed to test only a coupled receptacle-plug pair. i.e., the backshell and cable shield assembly is replaced with a very low resistance copper adapter cap and insert to match the plug.

In order to limit the size of the test matrix and achieve a reasonable balance between statistical effects and the number of peak current levels, three new connector assemblies (samples A, B and C) of each of the four types were subjected to four progressively increasing peak current levels of 3 kA, 10 kA, 15 kA, and 20 kA for both the system test and the component test. At each peak current level, starting with the 3 kA level, 3 systems tests (for samples A, B, and C) were carried our first for each of the 4 different type connectors. If a system test failure (i.e., extensive damage which prevents the connector assembly from functioning normally mechanically and/or electrically) occurs in one or more of the three samples, then three component tests will also be run at the same peak current level. A component test is not required, however, if there is no system test failure since presumably the components separately would also not fail. All connectors that experience no damage or only slight to moderate damage (i.e., connector assembly can continue to function both mechanically and electrically) will be advanced to the next higher current level.

Figure 1 shows the details of the system test configuration and the component test configuration. Considerable precaution was taken to insure that the method of electrical connection to the pulse generator would not compromise the connector test by premature failure. In the system test, the shield braid (1/2" flat width x 3 1/2" length) was connected both to the backshell and to the copper split clamp with stainless bands (Band-It ™) assembled per manufacturer specifications using a special Glenair Band-It tool. (Glenair recommended that the bands be double-looped through the band-buckle before inserting into the banding tool). The tool has a pre-set tension spring that locks a ratchet before the band is cut so that the quality of all shield terminations are accurately reproduced. The copper split reducing collar was used to achieve a low resistance copper to copper slip fit which was clamped tight to the 1/2" copper conductor tube with a standard hose clamp. At no point during tests did we experience a failure of this joint or the braid or braid attachment to the backshell tube (on one shot #61, the shield was burned but this was caused by arcing flash-back through the shield tube).

In the case of the component test, the entire backshell, shield and terminations are replaced by a low resistance copper cap and insert supplied by Electro Adapter Inc.. The threaded cap and serrated tooth insert are designed to accurately match and simulate the mechanical and electrical contact of the usual backshell. This simulation design is not valid, however, for the ITT- Cannon backshell which uses non-metallic threads and employs metal spring fingers as the primary electrical contact with rear of the plug. Figure 2A and B show photographs of a typical system test assembly (A) and a component test assembly (B).

Figure 3 shows a schematic of the NATC Hercules pulser which is a two stage Marx type generator. The circuit is basically identical to the lightning pulse current generator suggested by the AE4L test set up with the exception that the current to ground through the connector assembly load R_{TL} is measured with a calibrated Pearson 1330 transformer probe shown as P rather than a current viewing resistor to ground. The 500 μf capacitors are charged in parallel through the 200 K Ω and 100 K Ω resistors and then discharged in series through the gas switches S1, S2, and S3. The shape of the pulse waveform (i.e., the peak current, the rise time to peak current T(P) and the decay time to 50% peak T(50%) is controlled by selecting the appropriate values of the inductor coil L_{WS} and the resistor R_{WS}. A typical pulse waveform at ~ 15 kA is shown in Figure 4. The values of R_{WS} (Ω) and L_{WS}(μh) for the series of shots are shown in Table I. Figure 5 shows a photograph of the capacitor and gas-switch section of the Hercules pulser. Resistance measurements (R_{TL}) of the test samples were measured according to the AE4L recommendations 4.7.48. Prior to the application of a test pulse, an end to end resistance measurement R(B) was measured before the test. Following the test pulse, and without disturbing the test sample, a second resistance measurement R(A) was made after the test. The sample components were then uncoupled (where possible) and examined visually and mechanically by three members of the test team*. The combined observations were then recorded in the enclosed test Data Sheets 1 through 16 (p 23 through 38) for all shots. Following this inspection, the components were reassembled and a third end to end resistance measurement R(AR) was made after reassembly. Note that the resistance R(AR) is also the initial R(B) for the next higher current level and was generally measured at that time unless otherwise noted in the Data Sheets. All connector resistance measurements R(B), R(A), and R(AR) were measured by using a Biddle Digital Low Resistance Ohmeter. (See Certification of Calibration, Appendix I). This ohmeter can measure from the low 10^{-6} Ω range up to 60 Ω. The ohmeter uses a 4 terminal probe method which delivers 10 A in the μ Ω range and 1 A in the m Ω range. The four probe points are fitted with spring loaded sharp contact points which rotate as they are compressed to a pre-set minimum pressure in order to penetrate the metal oxide and to insure reproducible stable measurements. Figure 6 shows the hand held probes being used during an end to end resistance measurement prior to a component test.

* C. D. Bond NRL, Dave Smith SFA Inc., and Hubert Hibbler NAC.

TEST RESULTS

Examples of some of the more prominent visual aspects of the test results are shown in Figures 7, 8, and 9. Figure 7 shows an example of a system test result on a composite connector at 3 kA (shot no. 19). The top photo (A) shows assembly before test and the bottom photo (B) shows the same assembly after test. As indicated by the arrow, the rear of the backshell and shield tube area shows melted plating and carbonization. (Details are listed in Data Sheet No. 3). Figure 8 shows an example of a component test of a composite connector at 10 kA (shot no. 48). Again the top photo (A) is prior to the test and the bottom photo (B) is after the test. Here one sees extensive carbonization on the plate with melted plating on the flange and at the rear of the plug locking nut. (Details are listed in Data sheet No. 10).

Figure 9 shows a time sequence during a system test of a composite connector at 10 kA (shot No. 42). The frames were taken from a 16 mm film camera running at a normal framing rate of 24 frames per second or 0.042 sec. per frame. The sequence starts at the top of the first frame approximately 42 ms after pulse initiation. Here one seen a shower of fragments of molten metal plating. the second photograph was selected at 126 ms later and shows areas and points of molten plating on the backshell and flange. The last frame at bottom, selected at 210 ms, continues to show points of molten metal plating on the flange and backshell. Since the peak current of 10 kA decays to approximately zero in about 2.0 ms, all of the thermal phenomena shown in this sequence is taking place long after the test pulse is terminated.

The detailed description of the test results measurements, calculations, and pulse waveforms for each connector type, sample and test shot are listed in the data sheets 1 through 16 (p 23 to p 38), Tables I through VI and Appendix I. In order to present this somewhat extensive tabulation of data and results in a more rapidly understandable format, we have summarized the system test and component test results in Figures 10 and 11 respectively. Of necessity these charts suppress much of the detail and present the results in three broad categories of test results for each connector type and peak current level. The three categories of results as indicated in the data sheets and measurements are as follows:

1. No visible damage. This is represented by an open circle (O) and indicates that the connector assembly can continue to function normally both mechanically and electrically. (i.e., all components can be uncoupled and recoupled smoothly with normal hand torque and the resistances R(A) and R(AR) are within acceptable limits relative to R(B) or $R(A)/R(B) \leq 2$ and $R(AR)/R(B) \leq 2$).

2. Slight to moderate damage. This is represented by a half-filled circle (⊖) and indicates that the connector assembly can continue to function both mechanically and electrically. (i.e., all components can be uncoupled and recoupled with normal hand torque but there may be evidence of local arcing, carbonization, pitting or loss of spring contact fingers but the resistances R(A) and R(AR) remain within acceptable limits relative to R(B). There may be however, a reduced ability to sustain further higher current strikes.

3. Extensive damage. This is represented by a filled circle (●) and indicates that the connector assembly can not continue to function normally mechanically and/or electrically (i.e., one or more of the components can not be uncoupled with normal hand torque because of welding of components and/or the resistances R(A) and R(AR) are clearly outside of acceptable limits relative to R(B). In this case a component test was performed.

Using the above definitions, Figure 10 shows a summary of the systems test results. The chart is essentially self explanatory. In some cases more than one circle symbol may appear for a particular sample (A, B, or C) and current level. This indicates that this particular sample was subjected to more than one shot at the indicated current level for various technical reasons which are detailed in the corresponding data sheets. In some cases the symbol (⊖) may be followed by the symbol (O) which indicates that no "additional" damage has occurred.

Figure 11 shows a summary of the component test results again using the above definitions. In those cases where no component test was required, NA (not applicable) is listed. The asterisk in the 20 kA blocks indicate that the results of these component test can not be considered valid in the case of the ITT-Cannon connector for reasons previously discussed on p. 3.

In both the system test and component test, the charts clearly indicate a wide separation in performance between the metal plated type of composite connectors and the metal sleeve hybrid type of connector. Over the 3 kA to 20 kA test range, the hybrid type connector is comparable to the standard all aluminum connector. i.e., one sample of the hybrid (sample C) and one sample of the standard all metal (sample A) survived all four test levels in sequence without any significant damage. In the system test (Figure 10), the composite connectors (plastic over-plated with metal) sustained extensive damage at the 3 kA level with the exception of one sample (sample A of Amphenol-Bendix) which survived to the 10 kA level. In the component test (Figure 11), however, we see a clear difference between the two different type composite metal plated connectors at the 3 kA level. i.e., the Deutsch ATD connector sustained extensive damage in both the system and component test at the 3 kA level whereas the Amphenol-Bendix connector sustained no damage in the component test at 3 kA. This indicates that, in the latter case, the backshell probably initiated the system test failure. Another factor which may have also contributed to the different results at 3 kA is the fact that the Amphenol-Bendix plug outer locking nut is metal plated whereas this same nut on the Deutsch ATD is not plated which reduces the number of current conduction paths and metal-to-metal contact surfaces. The main mode of failure of the composite type of connectors was melting and vaporization of the metal plating with loss of conduction paths and subsequent increase in resistance from several ohms to complete open circuit.

In the case of the ITT-Cannon system test, the damaged observed at 15 kA (sample B) and 20 kA (samples A and B) was confined primarily to the area of the spring contact fingers of the backshell. (see details in data sheets 12 and 14). The contact area of the spring fingers with the rear of the serrated edge of the plug is minimal and it is somewhat difficult to determine if the backshell is properly seated against the plug.

In most of the shots that did not result in extensive damage, we observed that the undisturbed end-to-end resistance after the test pulse R(A) was generally lower than the resistance R(B) before the test pulse. This was particularly noticeable in the case of the standard all metal connector and the aluminum sleeve hybrid. (See Tables II through V). This effect has been observed by other investigators* and is attributed to "microwelding" at the interface surfaces. This phenomena in not considered a damage mechanism and in no way interferes with the uncoupling of the connector components. Indeed this effect is not detectable either visually or mechanically.

TABLES AND WAVEFORMS

Each data sheet 1 through 16 list results on three samples (A, B, and C) for a specific type of connector and manufacturer at a given current level as following:

1. Type of test (system or component)
2. Type of connectors (Standard, composite, hybrid & mfg.)
3. Peak current level(nominal)
4. Sample A, B, and C
5. Shot number
6. R(B), R(A), and R(AR) as defined
7. Observation and remarks

*"Lightning Strike Hazards For Composite Connectors", Gerald E. Walters and David E. Welch, NAVAIR E^3 Progress Review Meeting, P. 16 and/or D-117, May 7-11 1990, Jacksonville, FL.

At each current level 3 kA, 10 kA, 15 kA, and 20 kA, the system test results are listed first followed by the component test results. The data sheets and shots are numbered sequentially as they were performed. The pulse waveform associate with each shot number is shown in Appendix I.

The test measurements and calculations are summarized in Tables II, III, IV, and V which lists the following parameters for each peak current level, connector type, sample and shot number.

1. R(B) = resistance before test
2. R(A) = resistance after test
3. R(AR) = resistance after reassembly
4. I(P) = peak current measured from waveform
5. T(P) = time to peak current from waveform
6. T(50%) = time to 50% decay point from waveform
7. A = action integral over pulse from 0 to ∞
8. Q = total charge transferred during pulse

It should be noted that in the case of the system tests, all resistance measurements R(B), R(A), and R(AR) include a 1/2" wide x 3 1/2" length of braid shielding as shown in Figure 1 and 2A. The average resistance of this braid as assembled was 0.390 mΩ. Thus the connector backshell to plate resistance can be obtained by subtracting 0.390 mΩ from R(B), R(A), and R(AR). In the case of the component tests, the resistance of the adapter cap is negligible so that the values of R(B), R(A), and R(AR) are also the resistance from the rear of the plug to the mounting plate.

The action integral, which is listed in column A, is related to the total energy E which has been absorbed by a connector of resistance R_c. i.e.,

$$E = R_c \int_0^\infty I^2(t)\, dt \tag{1}$$

$$A = \int_0^\infty I^2(t)\, dt$$

and for the general unipolar double exponential pulse waveforms used here,

$$I(t) = I_o\,[\,e^{-\alpha t} - e^{-\beta t}\,] \tag{2}$$

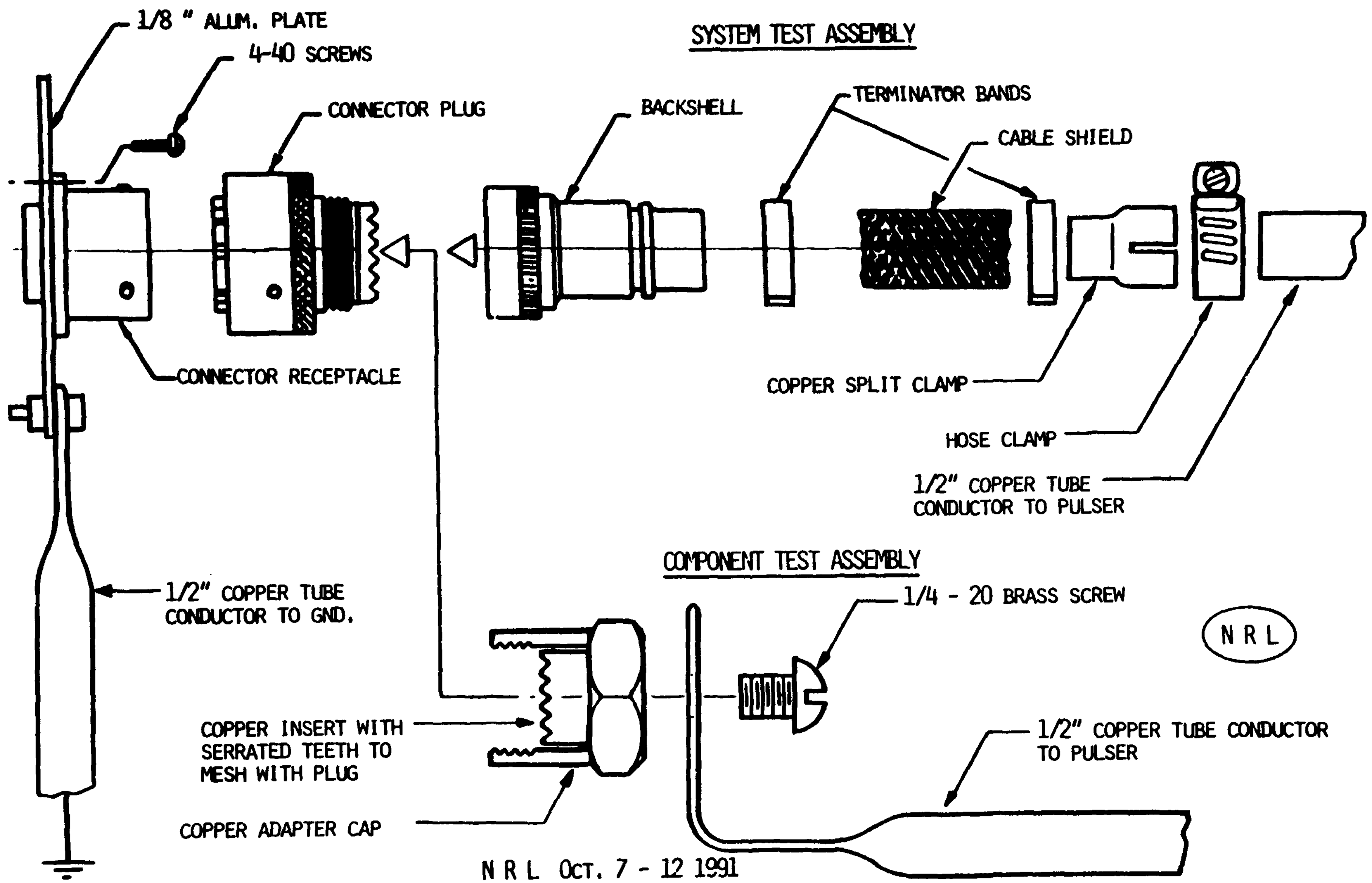
Here E is measured in joules, R_c in ohms, A in amp^2 sec or joules per ohm, I(t) in amps, and t in sec.. The connector resistance R_c will vary for different type of connectors. However, the magnitude of the action integral A is a measure of the ability of a particular current pulse I(t) to deliver energy to R_c. Since the current pulse waveforms used here decay to approximately zero in 1.5 to 2 ms, insufficient time is available for significant transfer of heat away from the connector assembly. Thus essentially all of the energy E results in heating the connector to a temperature T that depends on the metallic mass, cross section, specific heat, resistivity and contact resistance of the metals involved in the connector design.

The action integrals A listed in Tables II, III, IV, and V have been calculated using the Hercules pulse waveforms listed in Appendix I, shots #6 through #67. The value of each action integral, as integrated from zero up to 1,000 μs, was provided by NATC using direct integration of the scope digitation. This scope digitation time scale was chosen so that the peak current, the peak rise time T(P) and the 50% decay time T(50%) could be clearly displayed and measured for each pulse. However, in most cases, as can be seen in Appendix I, the pulse amplitude still shows significant current levels at the 1000 μs point. This is particularly true in the 3 kA shots. In order to extend the integration from 0 to ∞ as indicated in equations (1), a NRL program "EXPULSE 8" was used to fit the theoretical pulse waveform of equation (2) to the actual Hercules pulse waveforms from t = 0 to t = 1000μs. The program then extrapolates the actual pulse and calculates the action integral exactly from 0 to ∞ for each shot. EXPULSE 8 also calculates the total charge transferred (Q) over the duration of the pulse by evaluating the integral $\int I(t)dt$ from 0 to ∞.

Figures 12 and 13 show two computer output examples of the above fitting process. In Figure 12 (shot #57 at 20 kA) the pulse is decaying somewhat too rapidly (T(50%) ~ 380 μs) so that at 1,000 μs the pulse amplitude is relatively low (~2 kA). Thus the difference in the value of A between integration for 0 to ∞ and integration from 0 to 1,000 μs is not large. i.e., 113,000 A^2-sec. and 106,649 A^2-sec. respectively. However, in Figure 13 (shot #14 at 3 kA) the pulse is decaying too slowly (T(50%) ~ 800 μs) so that at 1,000 μs the pulse is still relatively high (~1.2 kA) and the value of A integrating from 0 to ∞ is 4,940 A^2-sec. as compared to a value of A = 2,033 A^2-sec. integrating from 0 to 1,000 μs. In this case there is a large difference. All of the values of (A) listed in the tables have been calculated by integration of the fitted pulses from 0 to ∞ so as to give an accurate value of A for the actual pulse current delivered to the test sample.

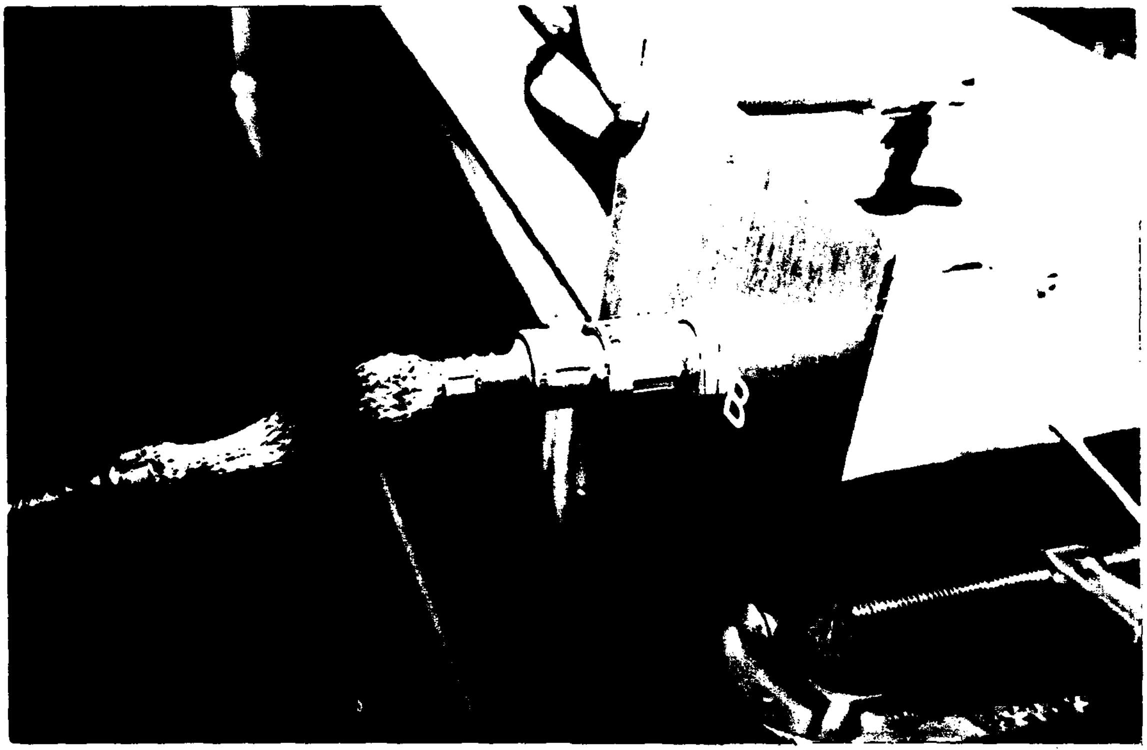
Table VI lists the values of the peak current I(P) and the action integral A for the ideal SAE-AE4L pulse in comparison with the actual average values achieved during the NRL/NATC tests (i.e., the average of the values of I(P) and A in the Tables II, III, IV and V). The error listed is the standard deviation (rms deviation) in each case. As can be seen, the test values of the peak currents $I(P)_{av}$ are quite close to the desired values I(P) whereas the test values of the action integrals A_{av} exhibit a much larger deviation from the desired values A. This results mainly from the fact that A depends on the integral of $I^2(t)$ and is thus quite sensitive to the magnitude of current at the 500 μs point which should be 1/2 I(P) ideally.

TEST ASSEMBLY FOR COMPOSITE CONNECTORS



N R L Oct. 7 - 12 1991

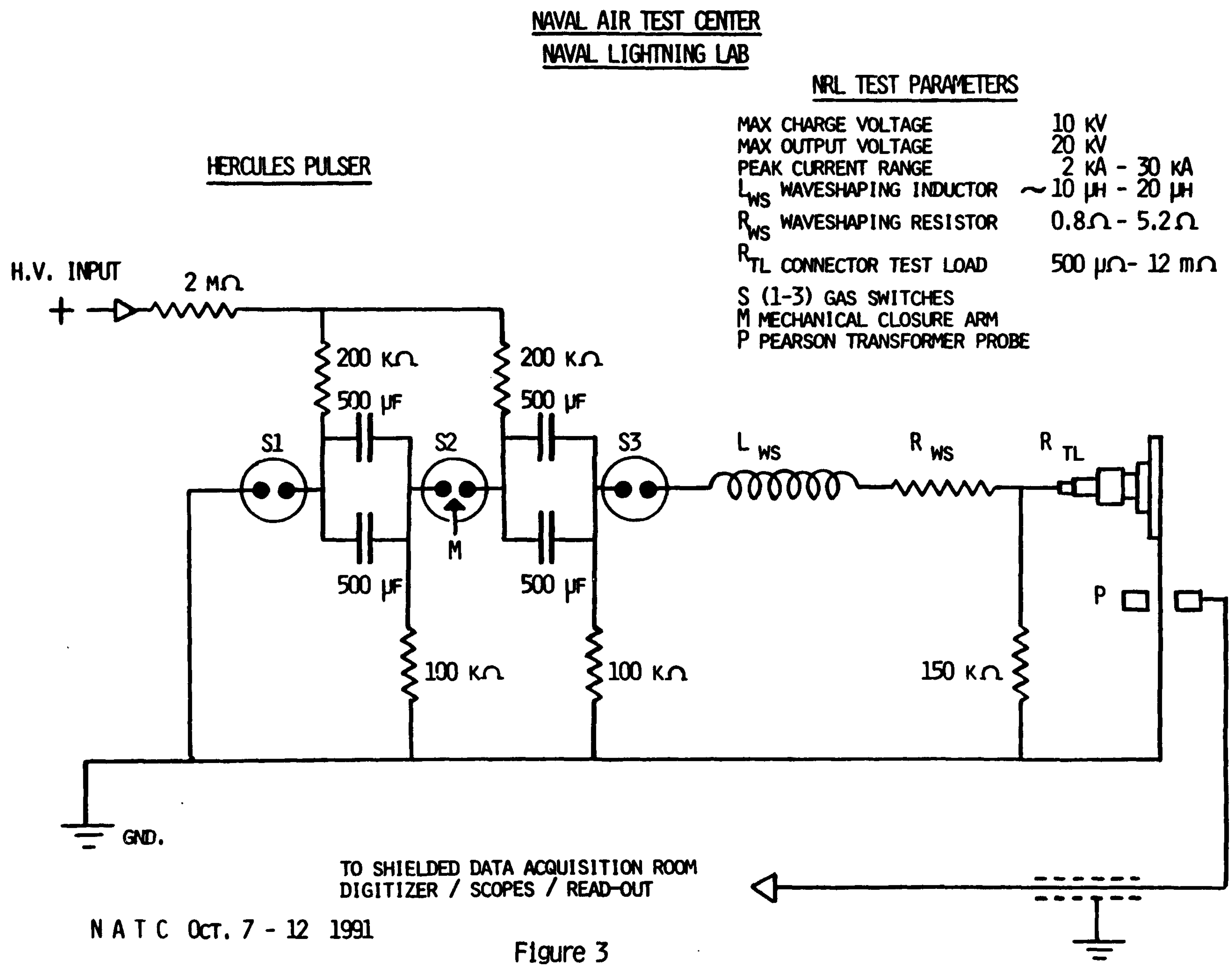
Figure 1



(A)

(B)

Figure 2



NAVAL AIR TEST CENTER
NAVAL LIGHTNING LAB
NRL TEST PARAMETERS
MAX CHARGE VOLTAGE 10 KV
MAX OUTPUT VOLTAGE 20 KV
PEAK CURRENT RANGE 2 KA - 30 KA
LWS WAVESHAPING INDUCTOR ~10 μH - 20 μH
RWS WAVESHAPING RESISTOR 0.8Ω - 5.2Ω
RTL CONNECTOR TEST LOAD 500 μΩ - 12 mΩ
S (1-3) GAS SWITCHES
M MECHANICAL CLOSURE ARM
P PEARSON TRANSFORMER PROBE
HERCULES PULSER
H.V. INPUT
+
2 MΩ
200 KΩ
500 μF
200 KΩ
500 μF
S1
S2
S3
L WS
R WS
R TL
M
500 μF
500 μF
P
100 KΩ
100 KΩ
150 KΩ
GND.
TO SHIELDED DATA ACQUISITION ROOM
DIGITIZER / SCOPES / READ-OUT
N A T C OCT. 7 - 12 1991

Figure 3

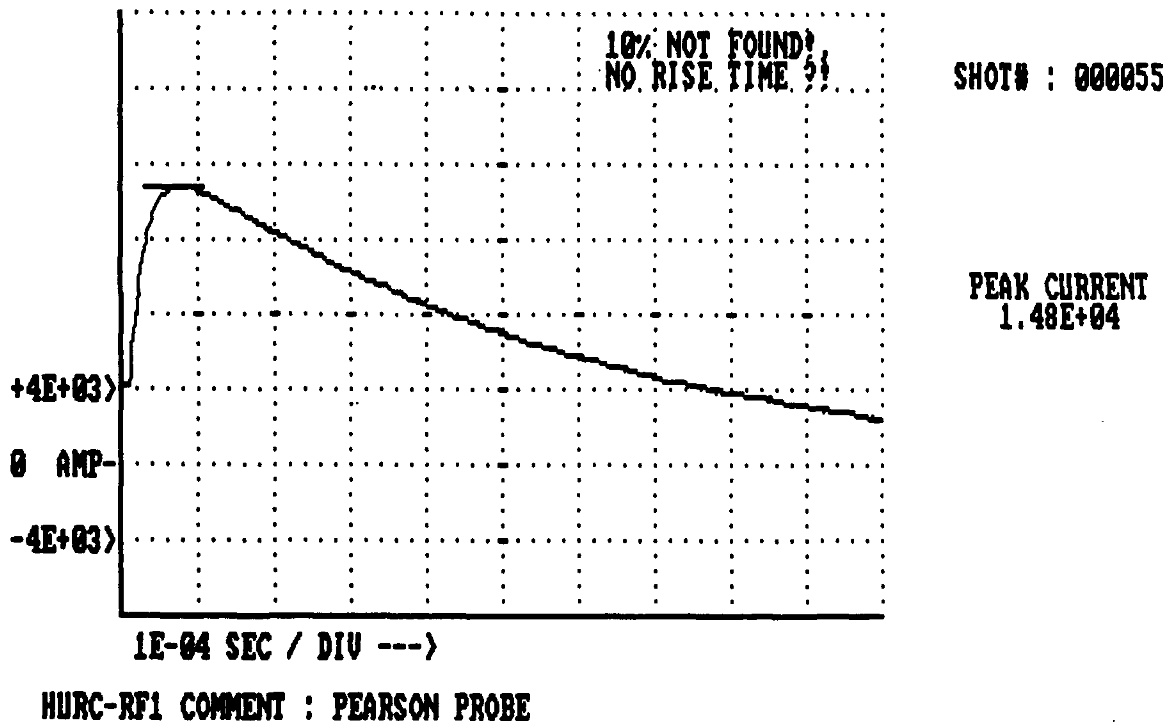

10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000055
PEAK CURRENT
1.48E+04
+4E+03>
0 AMP-
-4E+03>
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE

Figure 4

TABLE I

WAVESHAPING COMPONENT VALUES		
SHOT NO	RESISTANCE R_{ws} (Ω)	INDUCTOR L_{ws} (μh)
3 - 12 *	5.2	20
13 - 28 *	4.5	20
29	1.2	20
30 - 40	1.2	12
41 - 48	1.4	12
49 - 55	1.1	10
55 - 65	0.8	10

* Shots 3 through 28 were conducted with only one capacitor per stage.

NATC OCT. 7 - 12 1991

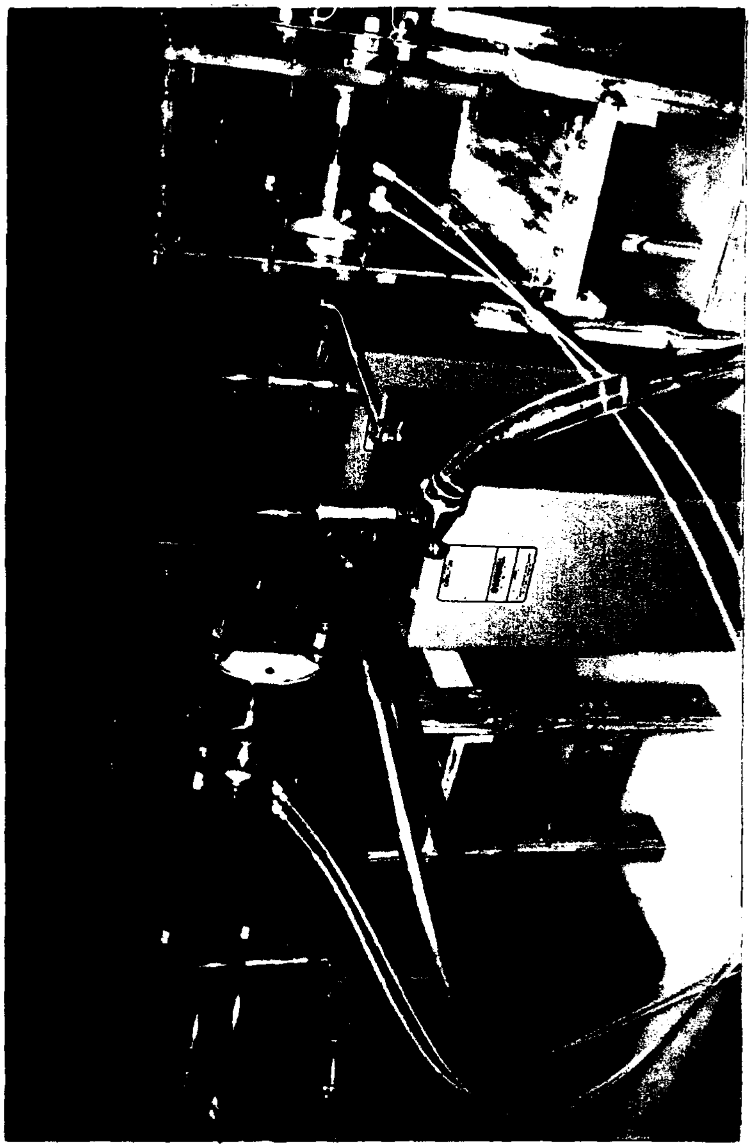


Figure 5

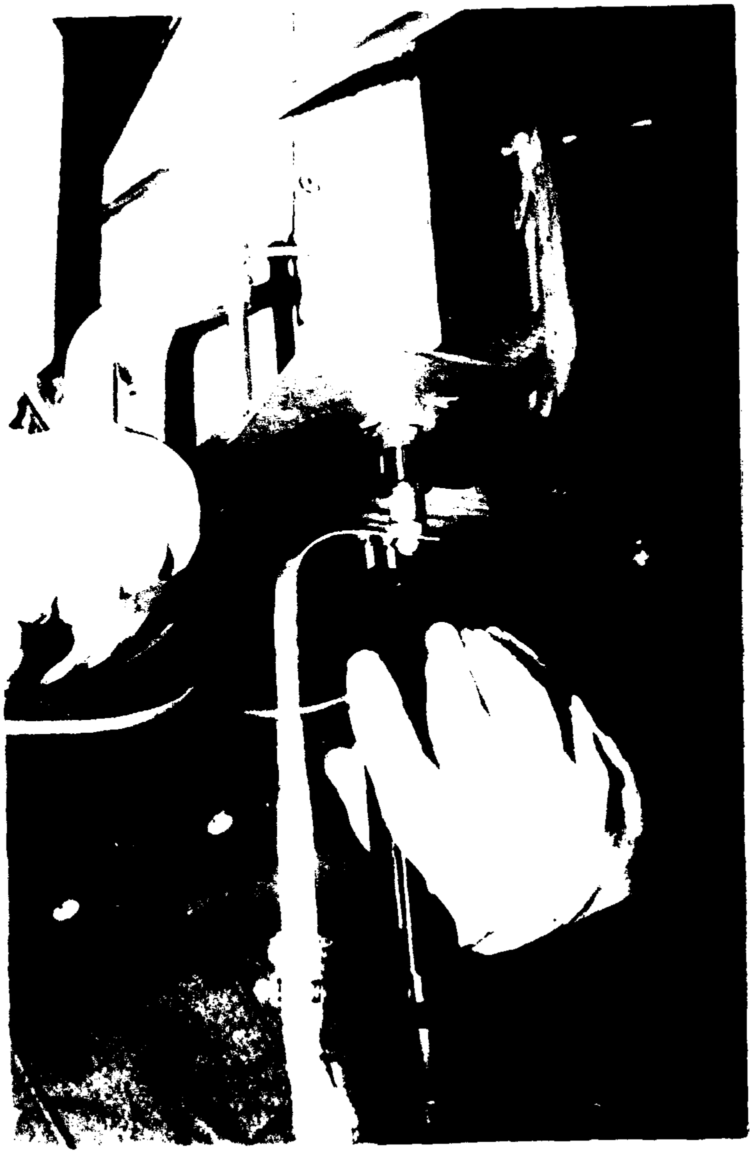
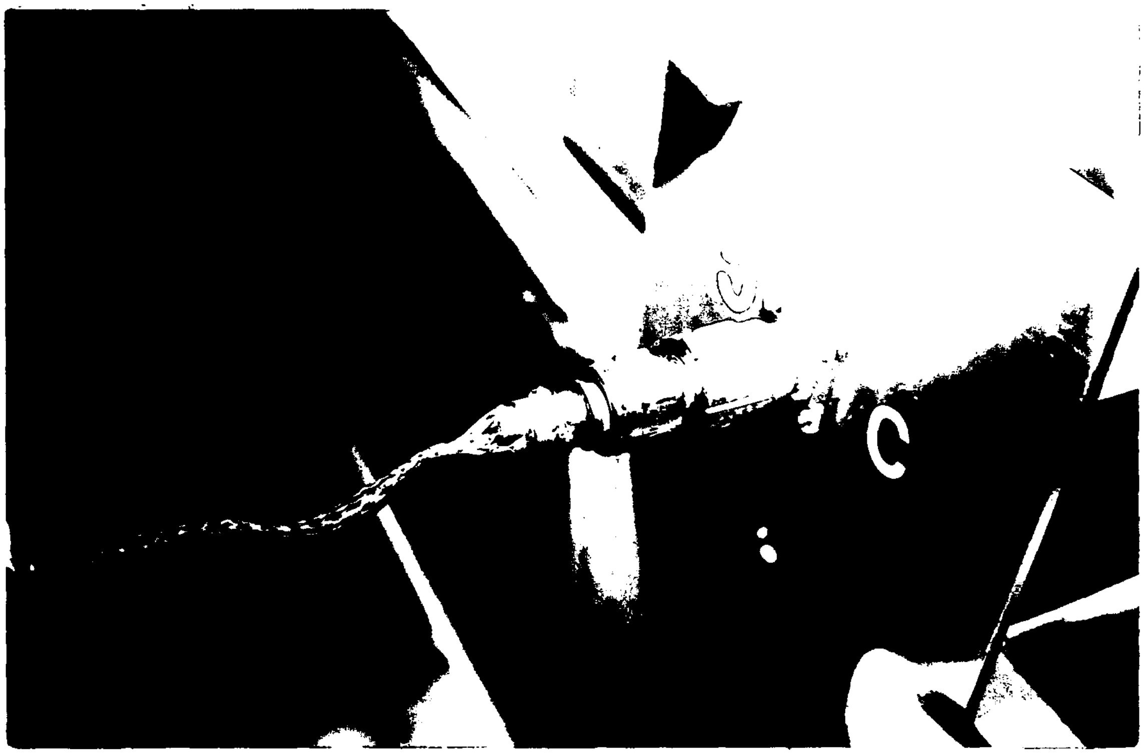
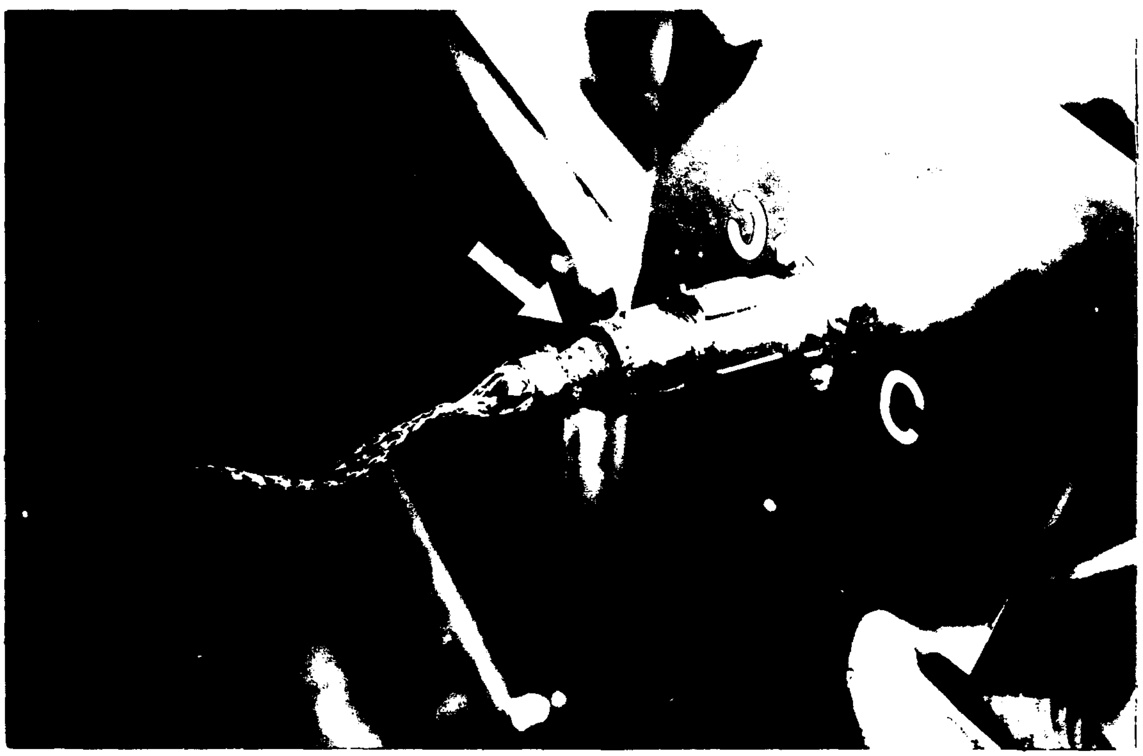


Figure 6



(A)



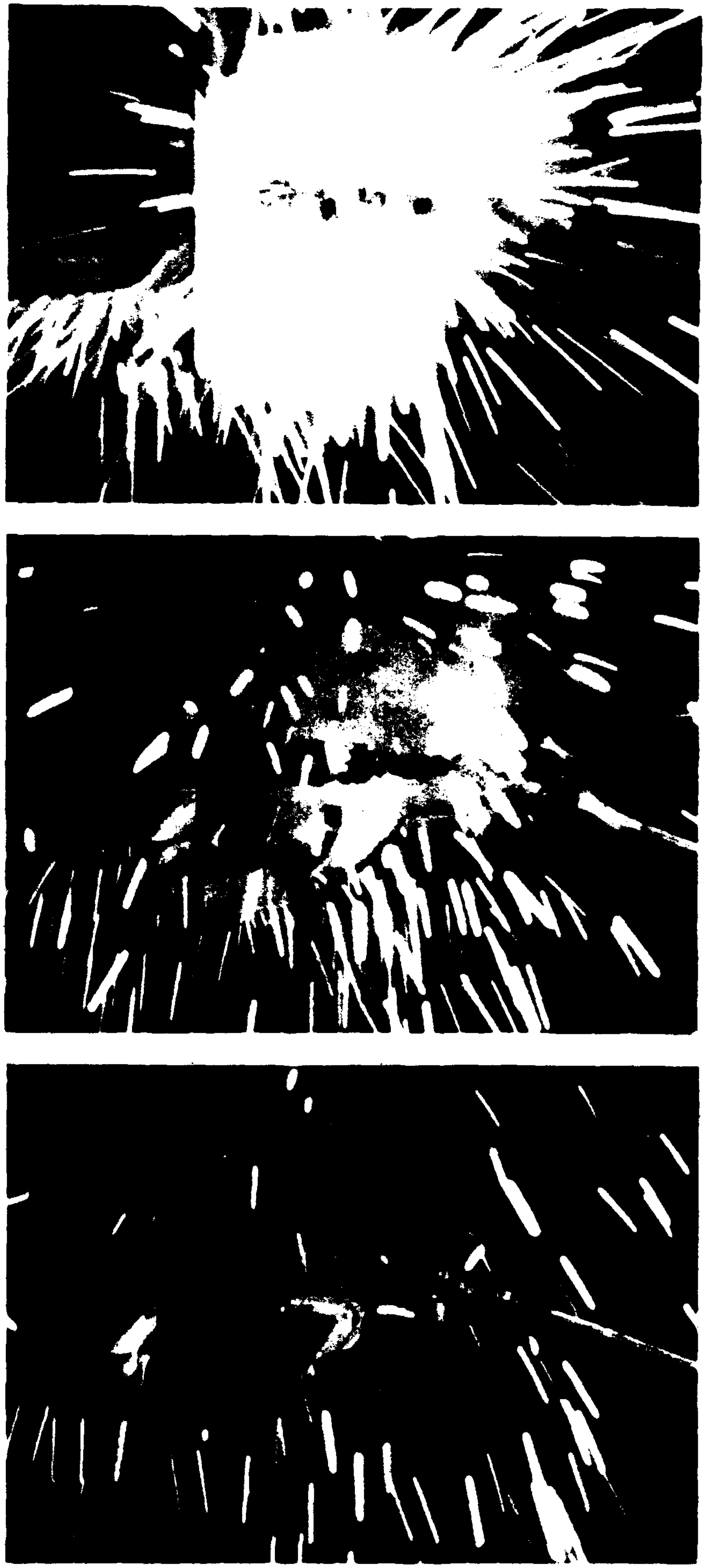
(B)

Figure 7

(A)

(B)

Figure 8



42 mS

126 mS

210 mS

Figure 9

SYSTEM TEST SUMMARY
LIGHTNING STRIKE TESTS OF COMPOSITE CONNECTORS

Pulse form used AE4L, 5b. Rise time = 50 μ s, 50% Decay time 500 μ s

CONNECTOR TYPE	SAMPLE	PEAK PULSE CURRENT AMPLITUDE			
SHELL SIZE 9					
MIL-C-38999		3 kA	10 kA	15 kA	20 kA
BENDIX	A	O	O	O	O
(All aluminum Std.	B	O	O	O	◒
Construction)	C	O O O	O ◒	O	◒
DEUTSCH ATD					
COMPOSITE	A	●			
(Plastic over-plated	B	●			
with metal films)	C	●			
AMPHENOL-BENDIX					
COMPOSITE	A	O	●		
(Plastic over-plated	B	●			
with metal films)	C	●			
ITT - CANNON					
HYBRID	A	O	O	O	◒
(Metal sleeve over-	B	O	O	◒	●
molded with plastic)	C	O	O	O	O O

O = No visible damage. Connector system can continue to function normally both mechanically and electrically.

◒ = Slight to moderate damage. Connector system can continue to function both mechanically and electrically. Possible reduced ability to sustain further strikes.

● = Extensive damage. Connector system can not continue to function normally mechanically and/or electrically.

Figure 10

NRL

COMPONENT TEST SUMMARY
LIGHTNING STRIKE TESTS OF COMPOSITE CONNECTORS

Pulse form used AE4L, 5b. Rise time = 50 μ s, 50% Decay time 500 μ s

CONNECTOR TYPE	SAMPLE	PEAK PULSE CURRENT AMPLITUDE			
SHELL SIZE 9					
MIL-C-38999		3 kA	10 kA	15 kA	20 kA
BENDIX	A	NA ----	----	----	---- ▶
(All aluminum Std.	B	NA ----	----	----	---- ▶
Construction)	C	NA ----	----	----	---- ▶
DEUTSCH ATD					
COMPOSITE	A	●			
(Plastic over-plated	B	●			
with metal films)	C	●			
AMPHENOL-BENDIX					
COMPOSITE	A	O	●		
(Plastic over-plated	B	O	●		
with metal films)	C	O	●		
ITT - CANNON					
HYBRID	A	NA ----	----	---- ▶	* ◒
(Metal sleeve over-	B	NA ----	----	---- ▶	* O
molded with plastic)	C	NA ----	----	---- ▶	* ◒

O = No visible damage. Connector system can continue to function normally both mechanically and electrically.

◒ = Slight to moderate damage. Connector system can continue to function both mechanically and electrically. Possible reduced ability to sustain further strikes.

● = Extensive damage. Connector system can not continue to function normally mechanically and/or electrically.

Figure 11

NRL

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/7/91

TYPE OF TEST: System

DATA SHEET NO.: 1

NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 µs

TYPE OF CONNECTOR: Bendix Aluminum (Std.)

NOMINAL 50% DECAY: 500 µs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	5	0.668	0.575	1.23	Shot fired O.K. No waveform trace obtained. O-Scope failed to trigger. Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible damage.
B	6	0.758	0.615	1.65	Waveform trace obtained. Connector components uncoupled & recoupled O.K.. No visible damage.
C	7	0.638	---	---	Shot #7, Prefired @ ~ 80% (~2.4kA). No waveform trace. Will reshoot as is.
	8	---	0.539	---	Shot #8 Fired O.K. No trace. O-Scope trigger prob. *
	13	0.770	0.569	1.16	Shot #13 Repeat of #8. Trace O.K.; Connector components uncoupled & recoupled O.K. No visible damage.

NOTES: * Shots No's 9, 10, 11, & 12 fired as test shots with no connector. Waveform problem due to premature noise trigger/corrected. Waveform on shots 6 & 13 O.K. Connector sample C subjected to 3 (~3kA) shots without visible damage.
Proceeding to next mfg. No component test required.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/8/91

TYPE OF TEST: System DATA SHEET NO.. 2 NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Deutsch ATD (Composite) NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST R(A) RESISTANCE AFTER TEST R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	* R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	14	10.3	16 K	NA	Melting of plating & carbonization between plug & backshell. Connector plug uncoupled from receptacle. Extensive Carbon inside receptacle on threads & pin area. Backshell cannot be uncoupled, welded. Extensive damage. Large increase in R(A)
B	15	10.0	23 K	NA	Same as sample A with additional carbonization on front of receptacle flange. Extensive carbonization inside receptacle on pin area & threads.
C	16	12.2	2.0 M	NA	Melting of plating & carbonization between plug & backshell & between backshell & shield tube. Receptacle & plug & backshell cannot be uncoupled. Extensive carbonization on front of flange. On rear of plate, carbonization in pin area and plate. Extensive damage. Large R(A) increase.

NOTES: * R(A) out of mΩ range, Resistance as noted. All waveform traces normal. Samples A, B, and C all had extensive damage with large increase of end to end resistance and will not be shot at higher current levels.
A component test will be performed on this type of connector per schedule. Proceeding to next mfg.

CONNECTOR LIGHTNING STRIKE TEST   Date: 10/8/91

TYPE OF TEST: System   DATA SHEET NO.. 3   NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Amphenol - Bendix (Composite)   NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST   R(A) RESISTANCE AFTER TEST   R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	17	7.65	8.07	14.0	Connector, plug & backshell uncoupled & recoupled O.K. No visible damage. On recoupling, resistance apprx. doubled. This sample will be shot at next current level at 10 kA in system test..
B	18	8.66	∞ open	NA	Melted plating between backshell & shield tube. Backshell cannot be uncoupled. Plug uncoupled from receptacle O.K.. No visible damage to plug & receptacle. Resistance open end to end.
C	19	8.16	∞ open	NA	Same as sample B.

NOTES: Sample A will be shot at the next higher current level (10 kA). A component test will be performed on this type connector per schedule. All waveform traces normal.

CONNECTOR LIGHTNING STRIKE TEST Date: 10/9/91

TYPE OF TEST: System DATA SHEET NO.. 4 NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid) NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST R(A) RESISTANCE AFTER TEST R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	*20	21.5 4.6	1.38	0.997	Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible damage.
B	21	9.7	0.75	1.11	Same as above.
C	22	9.8	1.03	1.01	Same as above.

NOTES: *Sample A was observed to have an excessively high resistance (21.5 m Ω). It was found that the receptacle flange contact surface was covered with a thin deposit of plastic or some product of sample fabrication. The film was easily cleaned off with light scraping. Remounting to plate reduce resistance to the expected values as noted in R(B). All waveform traces normal. No component test required.

CONNECTOR LIGHTNING STRIKE TEST Date: 10/9/91

TYPE OF TEST: Component DATA SHEET NO. 5 NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Deutsch ATD (Composite) NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST R(A) RESISTANCE AFTER TEST R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	* R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	23	4.90	36 K	NA	Melting of plating & carbonization between plug & adapter cap. Extensive carbonization between plug & receptacle & on flange. On rear of plate, carbonization in pin area. Cannot uncouple plug from receptacle nor adapter cap from plug. Large increase in R(A).
B	24	4.70	2.5 K	NA	Same as sample A, except on rear side of plate, pin insulation insert missing and shell carbonized. Adapter cap could be uncoupled O.K. Plug will move but cannot be unscrewed from receptacle.
C	25	5.10	3.5 K	NA	Melting of plating & carbonization between plug & adapter cap. Flange carbonization. Plug can be uncoupled from receptacle. Carbonization inside receptacle & pin area & on threads. adapter cap can be uncoupled from plug. Large increase in R(A).

NOTES: * R(A) out of mΩ range, resistance as noted. All waveform traces normal. Since samples A, B, & C sustained extensive damage in component test, no further test of the Deutsch ATD connectors will be conducted.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/9/91

TYPE OF TEST: Component

DATA SHEET NO. 6

NOMINAL PEAK CURRENT: 3 kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Amphenol - Bendix(Composite)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	26	2.86	2.15	2.04	Connector plug & adapter cap can be uncoupled & recoupled O.K. No visible. damage.
B	27	2.23	1.94	2.03	Same as above.
C	28	2.53	2.50	2.08	Same as above.

NOTES: All samples (A,B, & C) will be shot again in a component test at the next 10 kA level. All waveform traces normal. Last of 3 kA tests.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/10/91

TYPE OF TEST: System

DATA SHEET NO. 7

NOMINAL PEAK CURRENT: 10kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Bendix Aluminum (std.)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST   R(A) RESISTANCE AFTER TEST   R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	38	1.23	0.670	0.970	Connector plug & backshell uncoupled & recoupled O.K. Slight carbonization on receptacle threads & around interface between flange & plate. No visible mechanical damage. R(A) & R(AR) O.K.; waveform trace obtained. Shot O.K.
B	39	1.65	0.693	0.785	Same as above. Waveform trace obtained normal.
C	40	1.16			Shot #40: no data. Waveform bad (See shot #40 trace).
	41		1.180	0.893	Shot #41: Considerable carbonization around threads. Plug did not uncouple easily. Two spring fingers had burned off and lodged in threads. Fingers removed & place in sample bag. Minor damage.

NOTES: Shots 29 through 37 test shots. Shots 29 & 32 shorted across output resistor of generator. Resistor had to be replaced.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/10/91

TYPE OF TEST: System

DATA SHEET NO. 8

NOMINAL PEAK CURRENT: 10kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Amphenol - Bendix (Composite)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	42	14.0	∞ open	NA	Plug uncoupled from receptacle O.K. Backshell could not be uncoupled, welded. ~20% of plating melted off of receptacle. ~50% of plating melted off backshell. R(A) open. Little damage inside however.
B					No system test reqd. (Sample B did not survive 3kA level)
C					No system test reqd. (Sample C did not survive 3kA level)

NOTES: No further system test will be performed on this type connector. A component test will be performed at this level however.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/10/91

TYPE OF TEST: System

DATA SHEET NO. 9

NOMINAL PEAK CURRENT: 10kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	43	0.997	0.648	0.765	Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible damage.
B	44	1.11	0.682	0.710	Same as above.
C	45	1.01	0.856	0.825	Same as above.

NOTES: No component test reqd. Proceed to 15 kA level per schedule. Waveform traces normal.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/10/91

TYPE OF TEST: Component

DATA SHEET NO. 10

NOMINAL PEAK CURRENT: 10kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Amphenol - Bendix (Composite)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST — R(A) RESISTANCE AFTER TEST — R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	* R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	46	2.04	9Ω	NA	Connector receptacle, plug & adapter cap cannot be uncoupled, welded. ~50% plating melted off receptacle. ~20% plating melted off plug. Extensive carbonization on flange & plate. Extensive damage.
B	47	2.03	20Ω	NA	Connector receptacle & plug cannot be uncoupled. Adapter cap can be removed. O.K. ~15% plating melted off rear of plug.
C	48	2.08	14Ω	NA	Connector receptacle, plug & adapter cap cannot be uncoupled, welded. > 50% plating melted off receptacle & adjacent plug surface. Melting of plug threads & copper between plug & adapter cap. Extensive carbonization on flange & plate.

NOTES: No further component test will be conducted for this type connector. Last of 10 kA test.

* R(A) out of mΩ range, resistance as noted.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/11/91

TYPE OF TEST: System

DATA SHEET NO. 11

NOMINAL PEAK CURRENT: 15kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: Bendix - Aluminum (std.)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	50	0.970	0.563	0.751	Connector receptacle, plug & backshell coupled & uncoupled O.K. No visible additional damage over previous shot #38.
B	51	0.785	0.569	0.835	Same as above. No visible additional damage over previous shot #39.
C	52	0.893	0.704	0.615	Same as above. No visible additional damage over previous shot #41.

NOTES: Will proceed to next 20 kA level per schedule. All waveform traces normal. Shot #49, test shot for 15 kA set-up.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/11/91

TYPE OF TEST: System

DATA SHEET NO. 12

NOMINAL PEAK CURRENT: 15kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST R(A) RESISTANCE AFTER TEST R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	53	0.765	0.563	0.865	Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible damage.
B	54	0.710	0.725	0.802	Connector receptacle, plug & backshell uncoupled & recoupled O.K. Apprx. 80 - 90% of spring contact fingers inside backshell were burned off. Backshell was slightly loose when removed from test fixture. *. However, R(A) & R(AR) remained within expected limits.
C	55	0.825	0.692	0.828	Same as sample A.

NOTES: * The tightness of the plug, backshell & test fixture connections were all checked thoroughly as standard operating procedure by D.S., CDB & NATC technicians before leaving test stand. No other electrical or mechanical damage was visible on sample B. No component test will be performed at this level. Will proceed to next 20 kA system test per schedule.

CONNECTOR LIGHTNING STRIKE TEST

Date: 10/12/91

TYPE OF TEST: System

DATA SHEET NO. 13

NOMINAL PEAK CURRENT: 20kA

NOMINAL RISE TIME: 50 µs

TYPE OF CONNECTOR: Bendix Aluminum (std.)

NOMINAL 50% DECAY: 500 µs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	57	0.751	0.476	*≤ 1.0	Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible additional damage over previous shot #50.
B	58	0.835	0.595	*≤ 1.0	When plug was uncoupled from receptacle, it felt as if a small weld was broken. Evidence of arcing & pitting inside receptacle where spring fingers contacted surface. Same additional carbon on threads. R(A) still O.K. Backshell uncoupled O.K. , no damage..
C	59	0.615	0.484	*≤ 1.0	When plug was uncoupled from receptacle, it felt as if a number of small weld were breaking. All else same as above in Shot 58. (Sample C has sustained several extra shots i.e., Shots 7, 8, 13, 40, 41, 52, 59)

NOTES: * Normally this column, R(AR) at 20 kA would be recorded as R(B) for the 30 kA level: However, the 30 kA level was not achieved during the time allocated and these values were not measured on site at NATC with the DLRO. Measured at NRL with Keithly 197 with 4 point probe with accuracy of only ± 0.001Ω. R(AR) O.K.

CONNECTOR LIGHTNING STRIKE TEST Date: 10/12/91

TYPE OF TEST: System

DATA SHEET NO. 14

NOMINAL PEAK CURRENT: 20kA

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid)

NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST

R(A) RESISTANCE AFTER TEST

R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	60	0.865	~2.1 erratic	*≤ 3 erratic	Connector receptacle, plug & backshell uncoupled & recoupled O.K. ~ 75% of spring contact fingers inside backshell were burned off. R(A) & R(AR) somewhat high & erratic.
B	61	0.802	200 - 800 erratic	*≤ 5 erratic	Connector receptacle, plug & backshell uncoupled & recoupled O.K. All of spring contact fingers inside backshell were burned off. Serrated edges on both rear of plug & backshell burned off with evidence of melting. Carbonization on pin area at back of plug. Shield at rear of backshell burned due to arc-flash through shield tube. R(A) too high.
C	62	0.828	0.660	0.770	Connector receptacle, plug & backshell uncoupled & recoupled O.K.. No visible damage.

NOTES: * These values were measured at NRL for reasons detailed in the NOTES at bottom of a data sheet No. 13. All waveform traces normal.

CONNECTOR LIGHTNING STRIKE TEST　　Date: 10/12/91

TYPE OF TEST: Component **　　DATA SHEET NO. 15　　NOMINAL PEAK CURRENT: 20kA

NOMINAL RISE TIME: 50 µs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid)　　NOMINAL 50% DECAY: 500 µs

R(B) RESISTANCE BEFORE TEST　　R(A) RESISTANCE AFTER TEST　　R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A	63	0.730	1.1	1 - 4	Connector receptacle, plug & adapter cap can be uncoupled & recoupled with some difficulty. Serrated edges on plug & insert of cap burned away. Carbonization in pin area at rear of plug. At rear of plate, flange circular contact area damaged & carbonized with some melting .*
B	64	2.25	0.202	1 - 2	Plug can be removed from receptacle with difficulty. Adapter cap uncoupled O.K. Some carbonization on receptacle threads. No visible damage elsewhere.
C	65	0.197	0.585	≤ 1	Connector receptacle, plug & adapter cap can be uncoupled O.K. Serrated edges on rear of plug & insert of cap burned away. Carbonization in pin area at rear of plug extensive.

NOTES: * Sample A did not have the circular contact area at flange base of receptacle cleaned as indicated in NOTES of data sheet #4. Samples B & C R(AR) values were measured at NRL for reasons stated in NOTES of data sheet 13. All waveform traces normal.
** Component test not valid for ITT-Cannon type backshell (see text).

CONNECTOR LIGHTNING STRIKE TEST   Date: 10/12/91

TYPE OF TEST: System   DATA SHEET NO. 16   NOMINAL PEAK CURRENT: 30kA *

NOMINAL RISE TIME: 50 μs

TYPE OF CONNECTOR: ITT - Cannon (Hybrid)   NOMINAL 50% DECAY: 500 μs

R(B) RESISTANCE BEFORE TEST   R(A) RESISTANCE AFTER TEST   R(AR) RESISTANCE AFTER REASSEMBLY

SAMPLE	SHOT NO.	R(B) mΩ	R(A) mΩ	R(AR) mΩ	VISUAL OBSERVATIONS & REMARKS FOLLOWING TEST DISASSEMBLY AND REASSEMBLY
A					Sample A backshell spring contacts damaged in shot #60 (no test).
B					Sample B backshell spring contacts & serrated edges damaged in shot #61. (no test)
C	67	0.770	0.656	≤ 1	Connector receptacle, plug & backshell uncoupled & recoupled O.K. No visible damage.

NOTES: * This shot did not fire at 30 kA but at 18.75 kA. Pulse did not trigger; fired when shorting. Shot #66, output resistor shorted. Waveform pulse on shot #67 O.K. at 18.75 kA.

TABLE II

3 kA LIGHTNING STRIKE CONNECTOR - SHOT DATA

Sample	Shot #	R(B) mΩ	R(A) mΩ	R(AR) mΩ	I(P) kA	T(P) µs	T(50%) µs	A A^2-sec	Q Coulomb	Remarks in Data Sheet No
	Bendix Aluminum (std.)							System Test		
A	5	0.668	0.575	1.23	--	--	--	--	--	
B	6	0.758	0.615	1.65	3.00	70	900	5950	3.79	1
C	13	0.770	0.569	1.16	2.83	50	800	4710	3.21	
	Deutsch ATD (Composite)							System Test		
A	14	10.3	16k *	NA	2.90	50	800	4940	3.29	
B	15	10.0	23k *	NA	2.90	50	800	4940	3.29	2
C	16	12.2	2.0M *	NA	2.93	50	700	4430	2.90	
	Amphenol Bendix (Composite)							System Test		
A	17	7.65	8.07	14.0	2.95	50	800	5120	3.34	
B	18	8.66	∞ *	NA	3.00	50	800	5260	3.38	3
C	19	8.16	∞ *	NA	3.03	50	800	5360	3.41	
	ITT - Cannon (Hybrid)							System Test		
A	20	4.60	1.38	0.99	2.98	50	750	4770	3.08	
B	21	9.70	1.11	1.11	2.98	50	750	4770	3.08	4
C	22	9.80	1.01	1.01	3.05	50	750	5000	3.15	

* Out of mΩ range, resistance as indicated.

Cont'd

TABLE II

3 kA LIGHTNING STRIKE CONNECTOR - SHOT DATA

Sample	Shot #	R(B) mΩ	R(A) mΩ	R(AR) mΩ	I(P) kA	T(P) µs	T(50%) µs	A A^2-sec	Q Coulomb	Remarks in Data Sheet No
	Deutsch ATD (Composite)							Component Test		
A	23	4.90	36k *	N A	2.93	50	700	4430	2.90	
B	24	4.70	2.5k *	N A	2.98	50	700	4580	2.95	5
C	25	5.10	3.5k *	N A	2.98	50	700	4580	2.95	
	Amphenol Bendix (Composite)							Component Test		
A	26	2.86	2.15	2.04	2.98	50	700	4580	2.95	
B	27	2.23	2.94	2.03	2.90	50	750	4520	2.99	6
C	28	2.53	2.50	2.08	2.90	50	750	4520	2.99	

* Out of mΩ range, resistance as indicated.

TABLE III

10 kA LIGHTNING STRIKE CONNECTOR - SHOT DATA

Sample	Shot #	R(B) mΩ	R(A) mΩ	R(AR) mΩ	I(P) kA	T(P) µs	T(50%) µs	A A^2-sec	Q Coulomb	Remarks in Data Sheet No
	Bendix Aluminum (std.)							System Test		
A	38	1.23	0.670	0.970	9.50	70	550	36000	7.01	
B	39	1.65	0.693	0.785	9.63	75	550	37400	7.16	7
C	41	1.16	1.180	0.893	9.50	70	550	36000	7.01	
	Amphenol Bendix (Composite)							System Test		
A	42	14.0	∞ *	NA	9.63	70	550	37000	7.10	
B										8
C										
	ITT - Cannon (Hybrid)							System Test		
A	43	0.997	0.648	0.956	10.30	70	550	42300	7.60	
B	44	1.11	0.682	0.710	9.75	70	550	37900	7.19	9
C	45	1.01	0.856	0.825	10.30	70	550	42300	7.60	
	Amphenol Bendix (Composite)							Component Test		
A	46	2.04	9Ω *	NA	10.00	70	575	41300	7.66	
B	47	2.03	20Ω *	NA	11.00	70	600	53900	9.14	10
C	48	2.08	14Ω *	NA	10.40	70	550	43100	7.67	

* Out of mΩ range, resistance as indicated.

TABLE IV

15 kA LIGHTNING STRIKE CONNECTOR - SHOT DATA

Sample	Shot #	R(B) mΩ	R(A) mΩ	R(AR) mΩ	I(P) kA	T(P) µs	T(50%) µs	A A^2-sec	Q Coulomb	Remarks in Data Sheet No
	Bendix Aluminum (std.)							System Test		
A	50	0.970	0.563	0.751	13.8	75	500	68700	9.07	
B	51	0.785	0.569	0.835	14.1	75	475	68900	8.86	11
C	52	0.893	0.704	0.615	14.8	75	500	79000	9.73	
	ITT - Cannon (Hybrid)							System Test		
A	53	0.765	0.563	0.865	14.6	75	475	73900	9.18	
B	54	0.710	0.725	0.802	14.8	75	475	75900	9.30	12
C	55	0.825	0.692	0.828	14.8	75	475	75900	9.30	

* Out of mΩ range, resistance as indicated.

TABLE V

20 kA LIGHTNING STRIKE CONNECTOR - SHOT DATA

Sample	Shot #	R(B) mΩ	R(A) mΩ	R(AR) mΩ	I(P) kA	T(P) µs	T(50%) µs	A A^2-sec	Q Coulomb	Remarks in Data Sheet No
	Bendix Aluminum (std.)							System Test		
A	57	0.751	0.476	< 1.0	20.0	90	380	113,000	9.68	
B	58	0.835	0.595	< 1.0	20.1	90	380	114,000	9.72	13
C	59	0.615	0.484	< 1.0	20.4	90	380	117,000	9.87	
	ITT - Cannon (Hybrid)							System Test		
A	60	0.865	~ 2,1	≤ 3	20.1	90	380	114,000	9.72	
B	61	0.802	~ 500	≤ 5	20.1	90	375	111,000	9.44	14
C	62	0.823	0.660	0.770	20.8	90	350	114,000	9.34	
	ITT - Cannon (Hybrid)							Component Test		
A	63	0.730	1.1	1 - 4	20.0	90	380	113,000	9.68	
B	64	2.250	0.202	1 - 2	20.6	90	375	117,000	9.68	15
C	65	0.197	0.585	≤ 1	20.3	90	380	116,000	9.82	
	ITT - Cannon (Hybrid)							System Test		
A										
B										16
C	67	0.770	0.656	≤ 1	18.8	95	350	95,600	8.56	

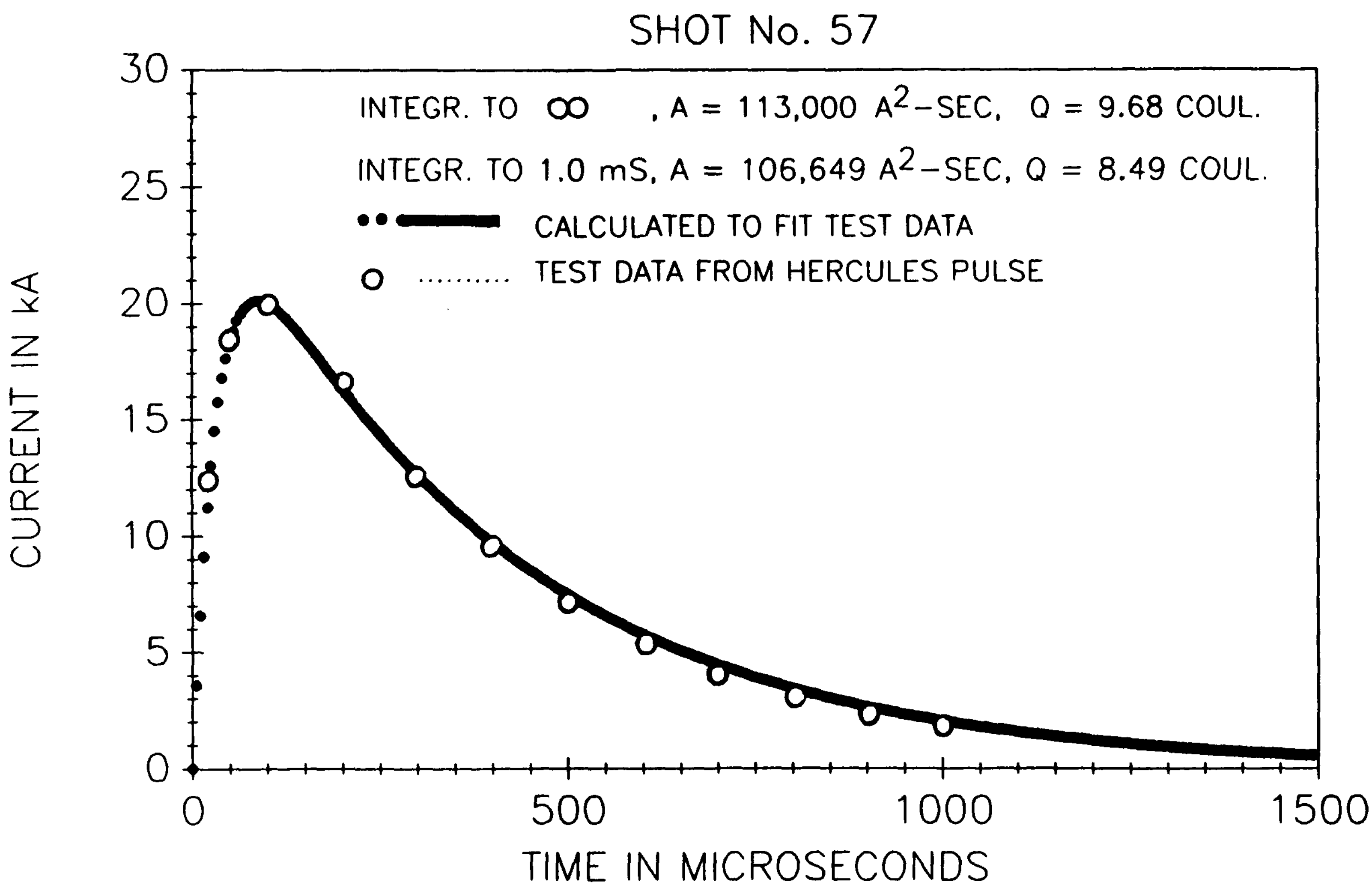

SHOT No. 57
INTEGR. TO ∞ , A = 113,000 A2–SEC, Q = 9.68 COUL.
INTEGR. TO 1.0 mS, A = 106,649 A2–SEC, Q = 8.49 COUL.
CALCULATED TO FIT TEST DATA
TEST DATA FROM HERCULES PULSE
CURRENT IN kA
TIME IN MICROSECONDS
0
5
10
15
20
25
30
0
500
1000
1500

Figure 12

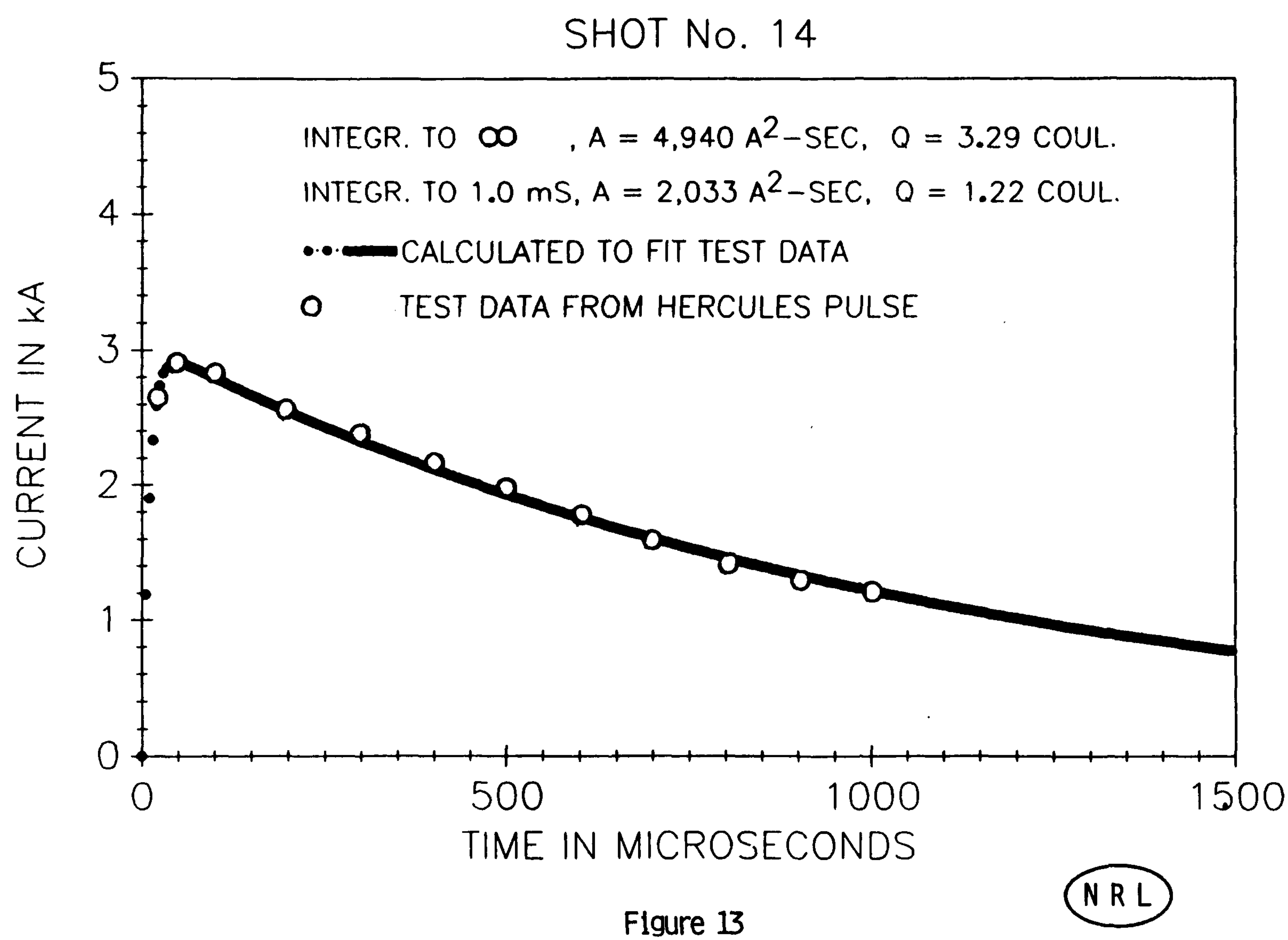

SHOT No. 14
INTEGR. TO ∞ , A = 4,940 A2–SEC, Q = 3.29 COUL.
INTEGR. TO 1.0 mS, A = 2,033 A2–SEC, Q = 1.22 COUL.
CALCULATED TO FIT TEST DATA
TEST DATA FROM HERCULES PULSE
CURRENT IN kA
0
1
2
3
4
5
0
500
1000
1500
TIME IN MICROSECONDS
NRL

Figure 13

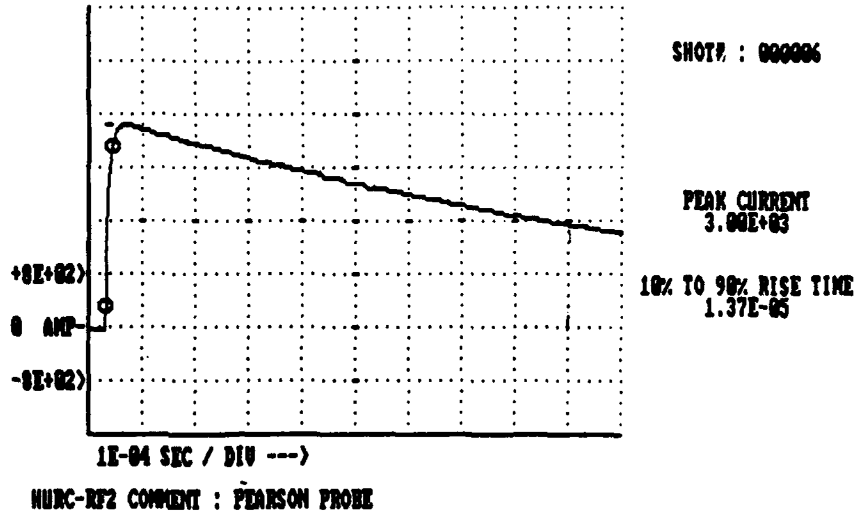
TABLE VI

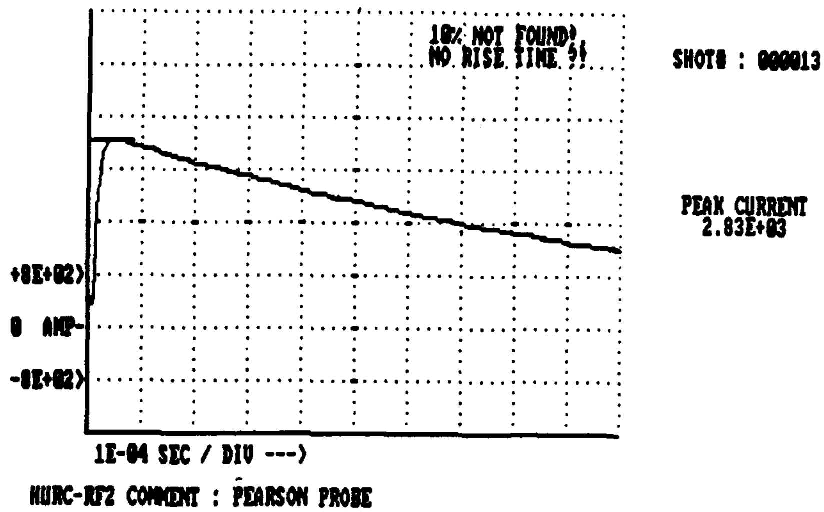
NOMINAL OR SAE AE4L PULSES $T(P) = 50\mu s$, $T(50\%) \approx 500\mu s$		ACTUAL NATC TEST PULSES Test Values of T(P) & T(50%) *	
PEAK CURRENT I(P)kA	ACTION INTEGRAL $A(A^2 - sec)$	PEAK CURRENT $I(P)_{av}$ kA	ACTION INTEGRAL $A_{av}(A^2 - sec)$
3.00	3,300	2.95 ± 0.06	4,850 ± 389
10.00	36,600	10.00 ± 0.47	40,720 ± 5,115
15.00	82,400	14.48 ± 0.39	73,717 ± 3,776
20.00	146,000	20.12 ± 0.30	112,460 ± 2,657

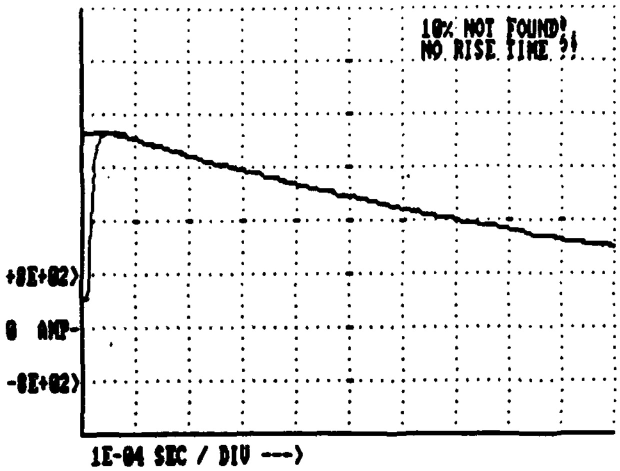
* Test values listed in tables II, III, IV & V.

APPENDIX I

	Page
PULSE WAVEFORMS FOR SHOTS #6 THROUGH #67	48
CERTIFICATION OF CALIBRATION FROM NATC & NRL	64
CONNECTOR COMPONENTS AND FITTINGS WITH MANUFACTURERS AND PART NUMBERS	66


SHOT# : 000006
PEAK CURRENT
3.00E+03
10% TO 90% RISE TIME
1.37E-05
+8E+02>
0 AMP-
-8E+02>
1E-04 SEC / DIV --->
NURC-RF2 COMMENT : PEARSON PROBE

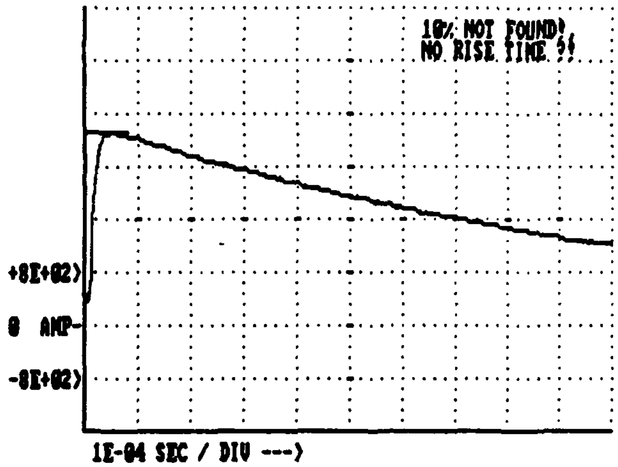

10% NOT FOUND!
NO RISE TIME ?!
SHOT# : 000013
PEAK CURRENT
2.83E+03
+8E+02>
0 AMP-
-8E+02>
1E-04 SEC / DIV --->
NURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000014

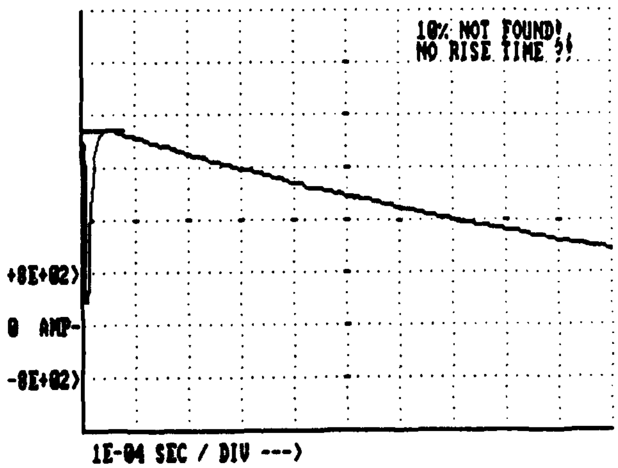
PEAK CURRENT
2.90E+03

HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000015

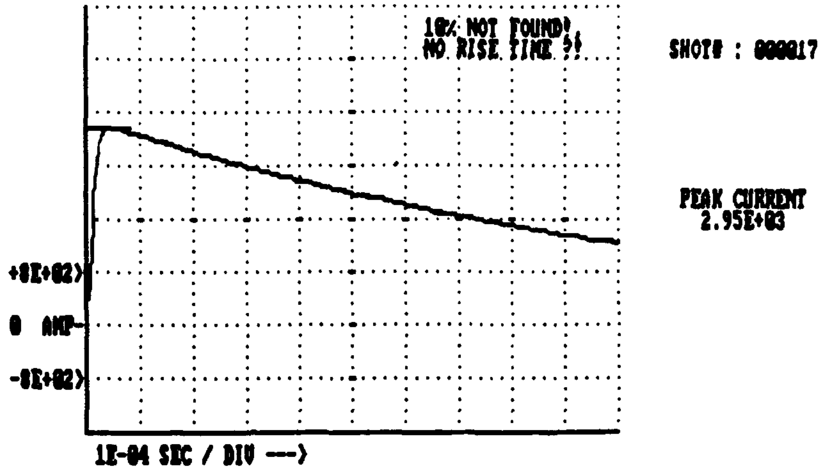
PEAK CURRENT
2.90E+03



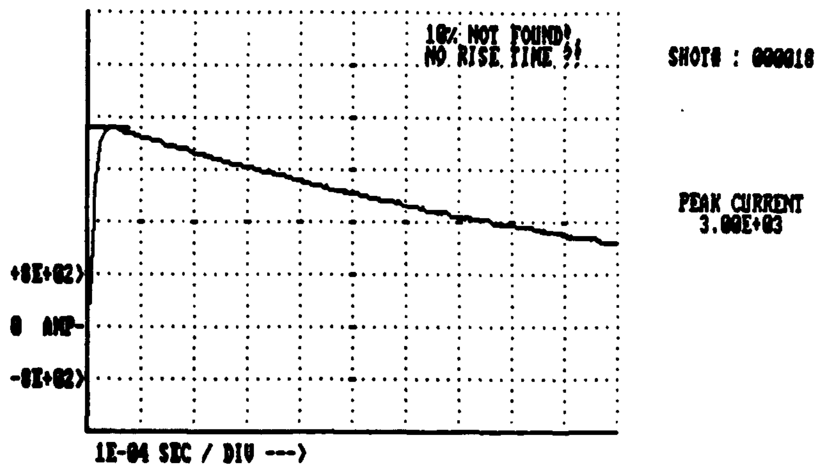
SHOT# : 000016

PEAK CURRENT
2.93E+03

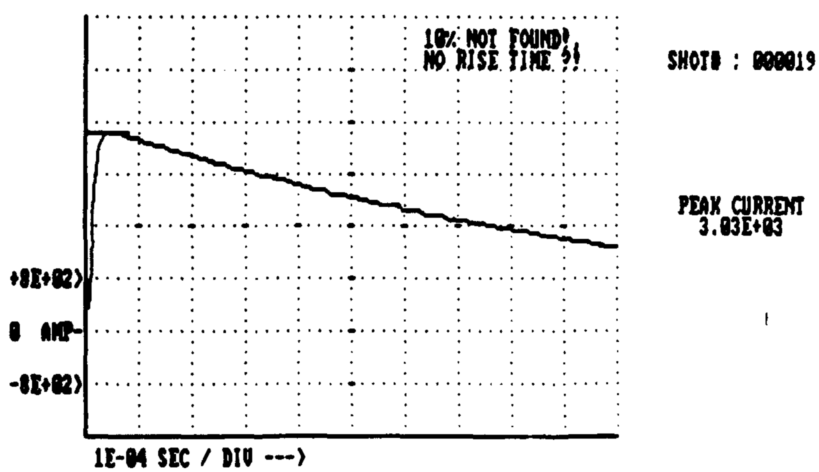
HURC-RF2 COMMENT : PEARSON PROBE

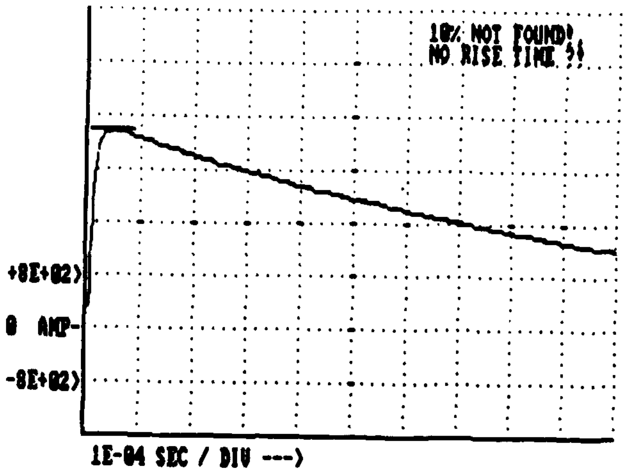


HURC-RF2 COMMENT : PEARSON PROBE



HURC-RF2 COMMENT : PEARSON PROBE

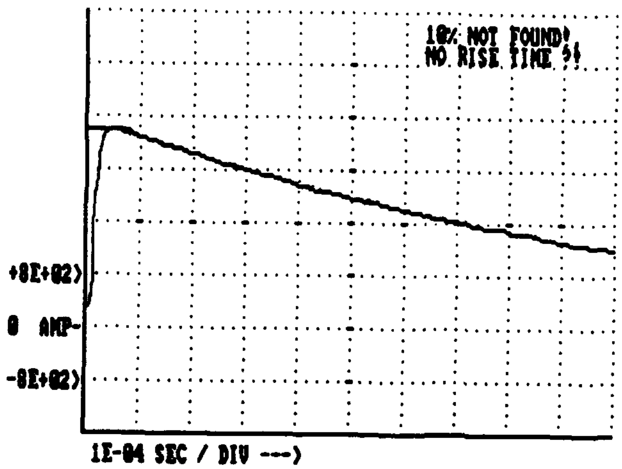




SHOT# : 000020

PEAK CURRENT
2.98E+03

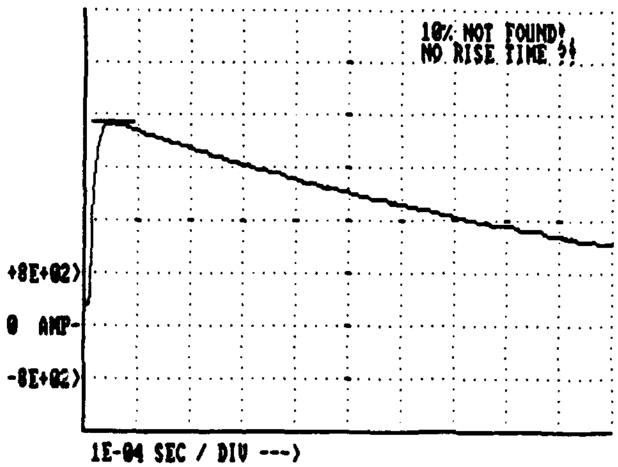
HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000021

PEAK CURRENT
2.98E+03

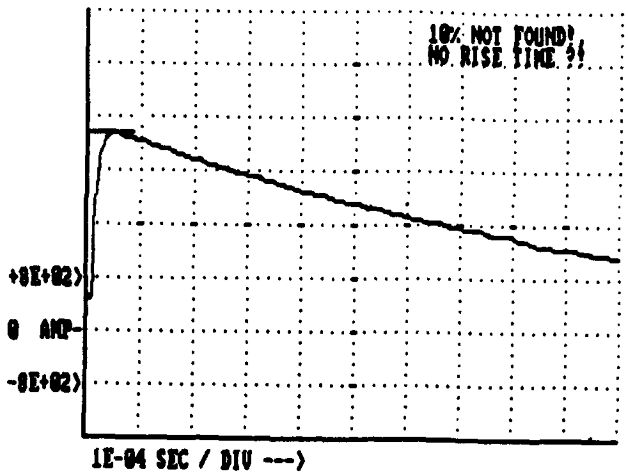
HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000022

PEAK CURRENT
3.05E+03

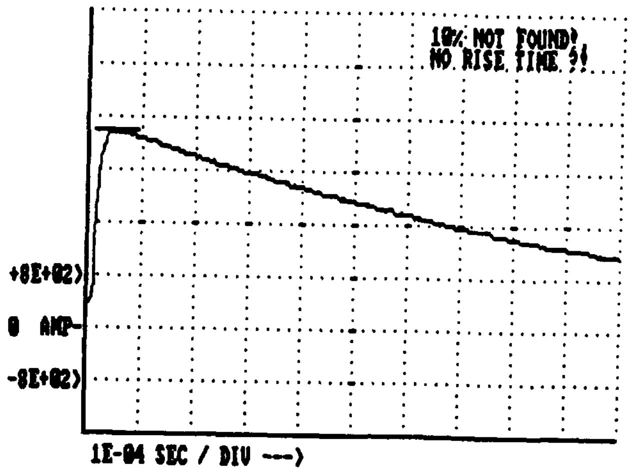
HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000023

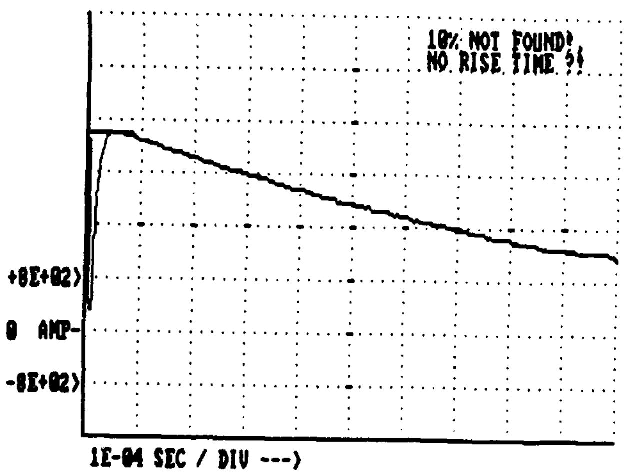
PEAK CURRENT
2.93E+03

HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000024

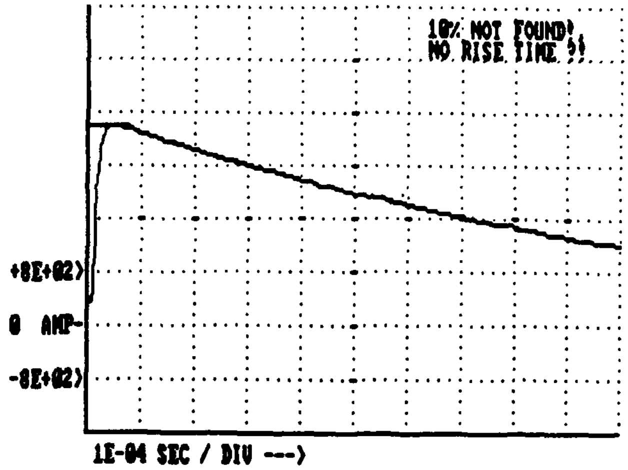
PEAK CURRENT
2.98E+03



SHOT# : 000025

PEAK CURRENT
2.98E+03

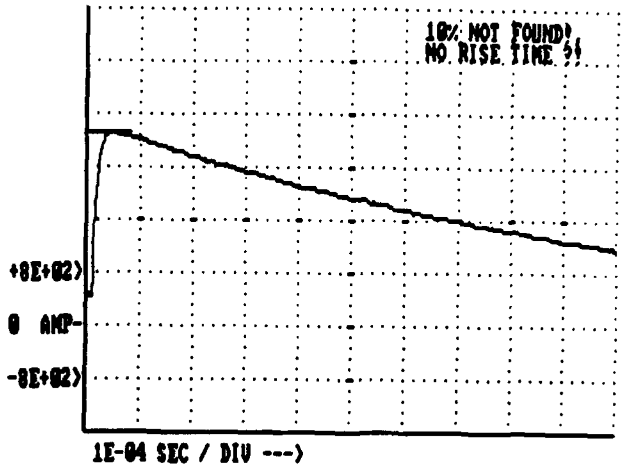
HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000026

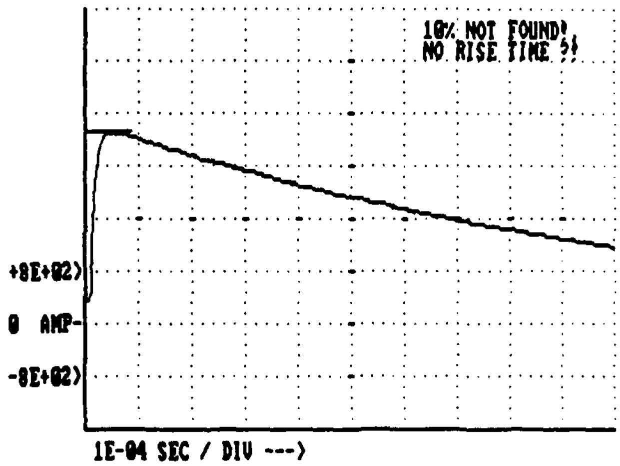
PEAK CURRENT
2.98E+03

HURC-RF2 COMMENT : PEARSON PROBE



SHOT# : 000027

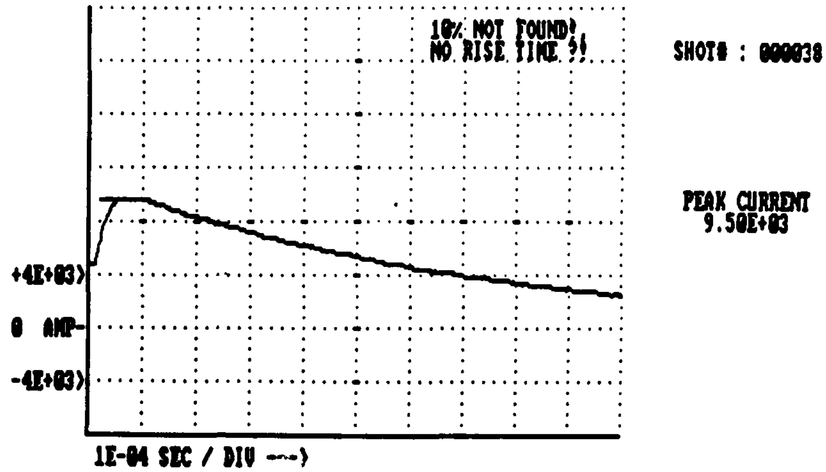
PEAK CURRENT
2.90E+03



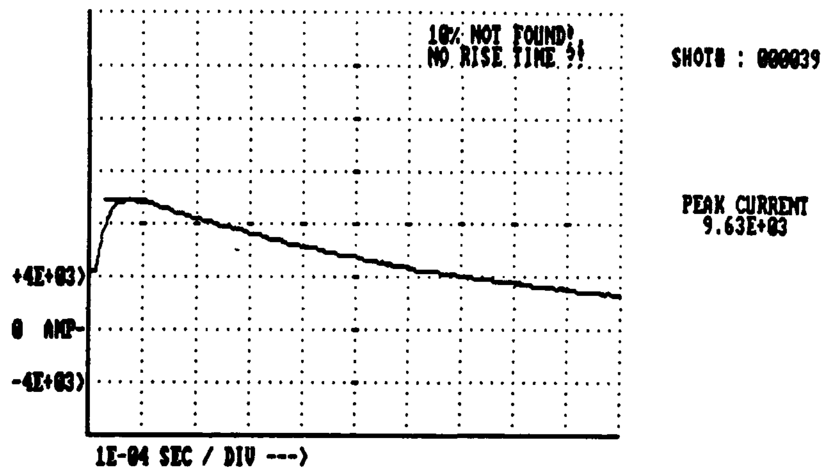
SHOT# : 000028

PEAK CURRENT
2.90E+03

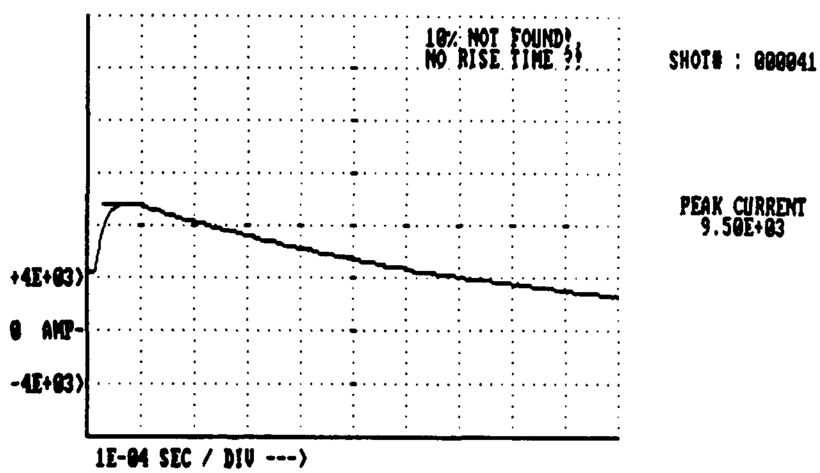
HURC-RF2 COMMENT : PEARSON PROBE



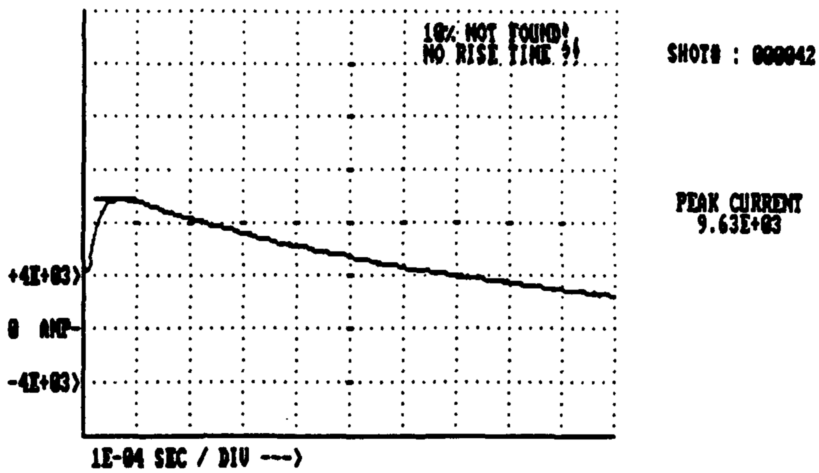
HURC-RF1 COMMENT : PEARSON PROBE



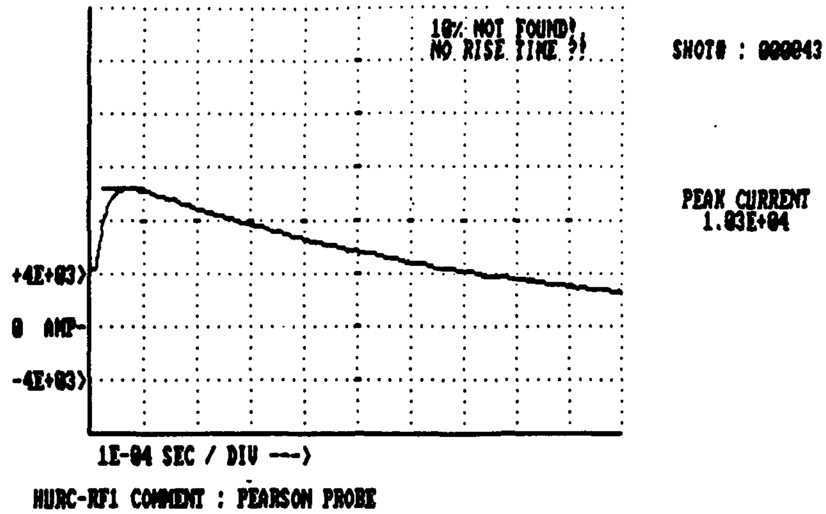
HURC-RF1 COMMENT : PEARSON PROBE

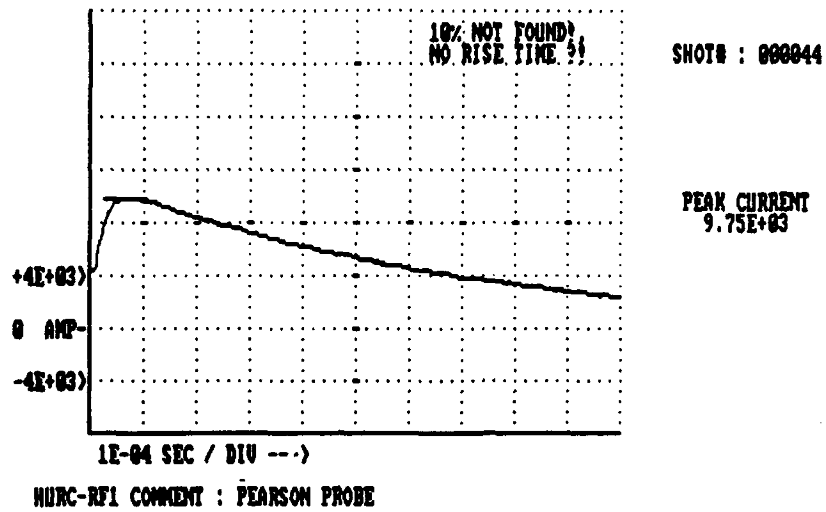


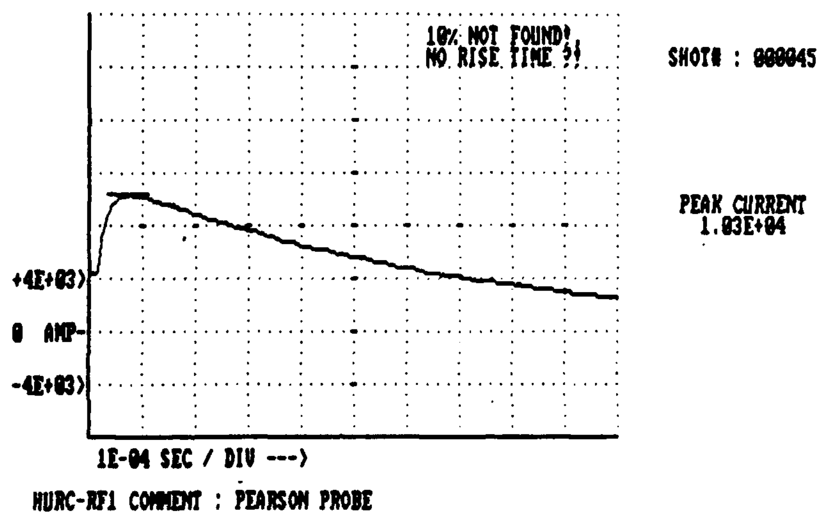
HURC-RF1 COMMENT : PEARSON PROBE

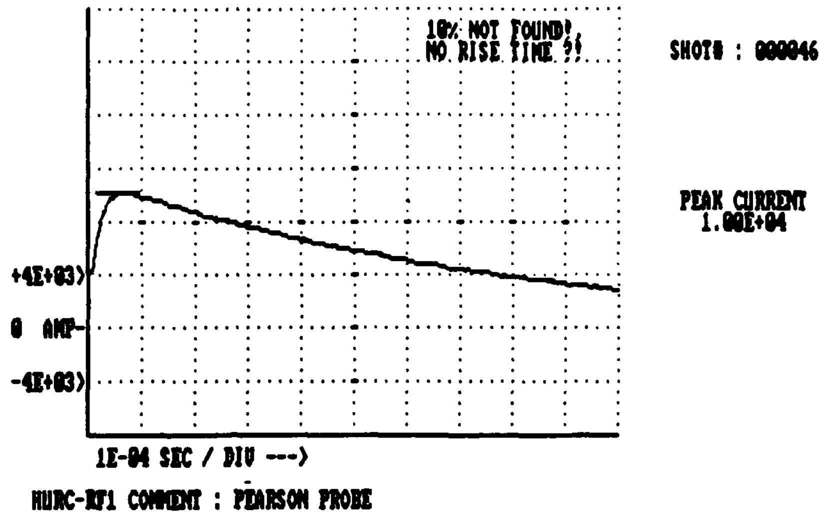


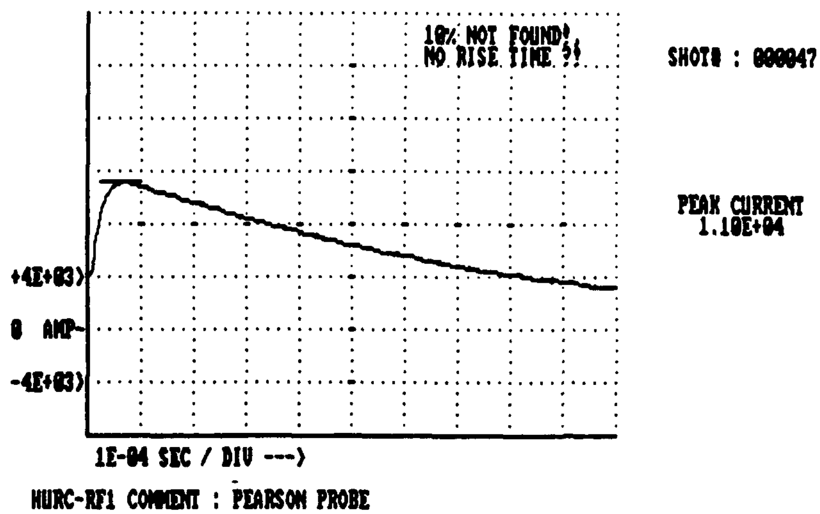
HUBC-RF1 COMMENT : PEARSON PROBE

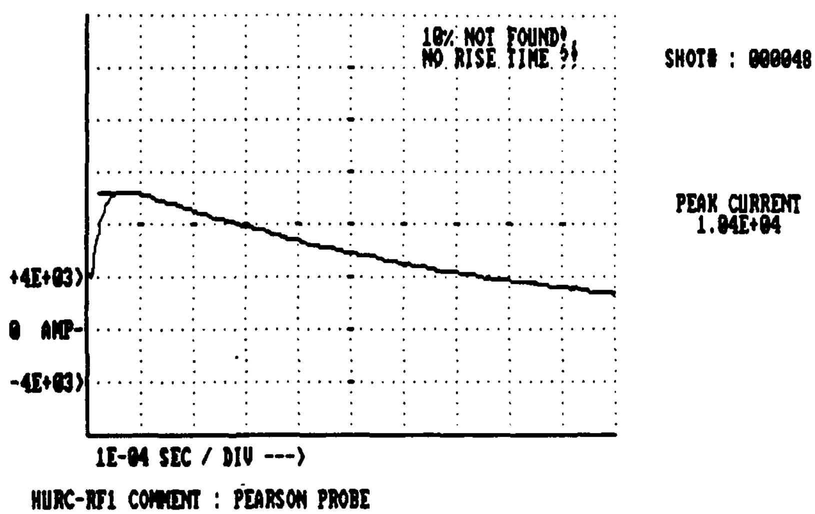

10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000043
PEAK CURRENT
1.03E+04
+4E+03>
0 AMP-
-4E+03>
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE

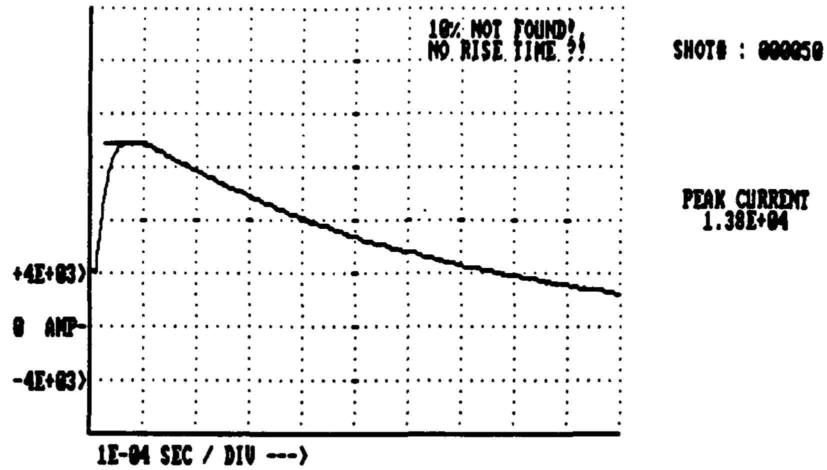

10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000044
PEAK CURRENT
9.75E+03
+4E+03>
0 AMP-
-4E+03>
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE


10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000045
PEAK CURRENT
1.03E+04
+4E+03>
0 AMP-
-4E+03>
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE

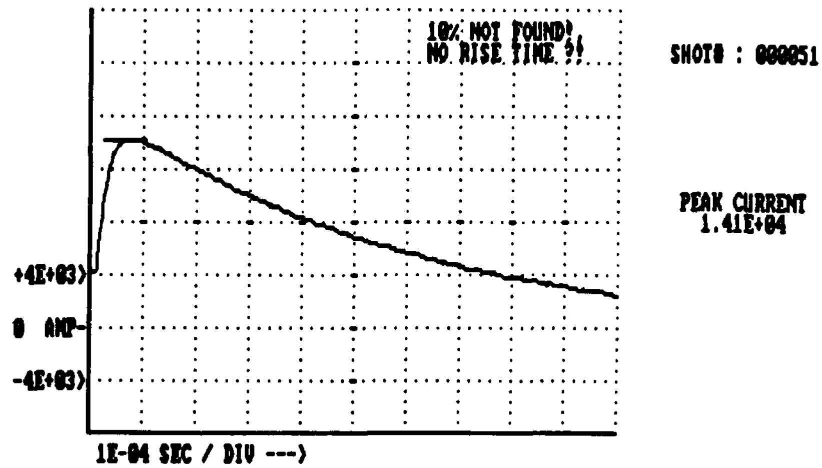

10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000046
PEAK CURRENT
1.00E+04
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE

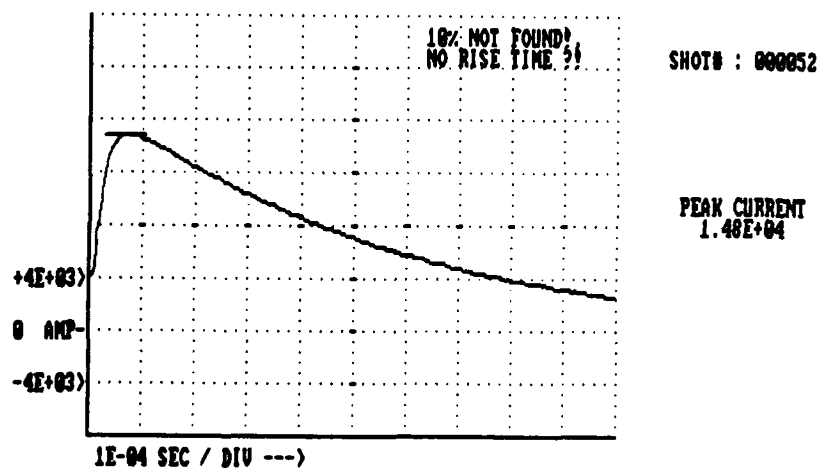

10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000047
PEAK CURRENT
1.10E+04
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE


10% NOT FOUND!,
NO RISE TIME ?!
SHOT# : 000048
PEAK CURRENT
1.04E+04
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV --->
HURC-RF1 COMMENT : PEARSON PROBE

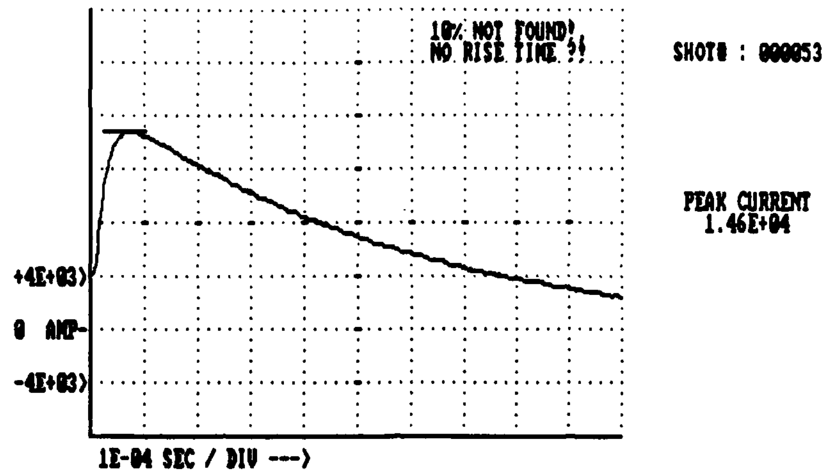


HURC-RF1 COMMENT : PEARSON PROBE

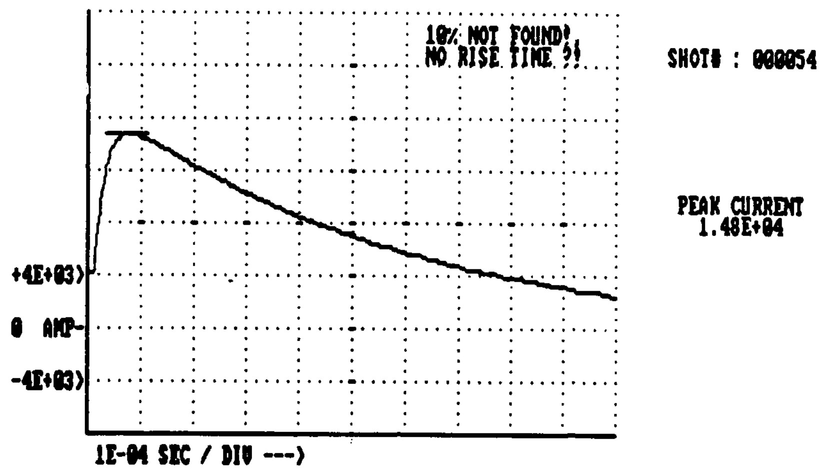




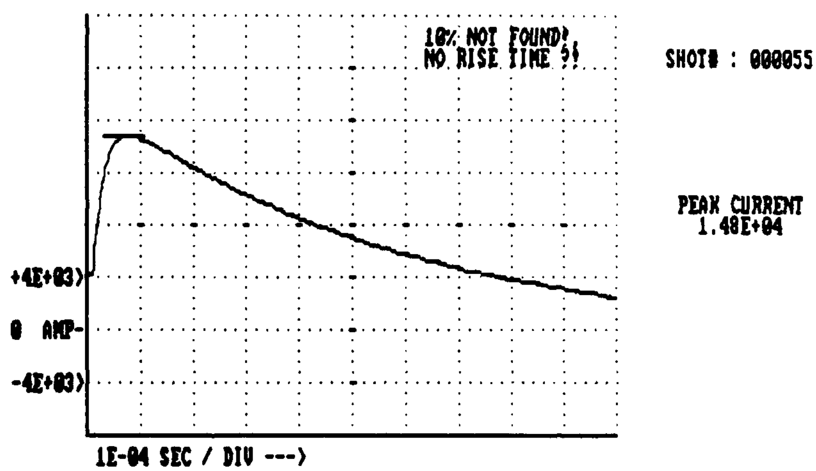
HURC-RF1 COMMENT : PEARSON PROBE



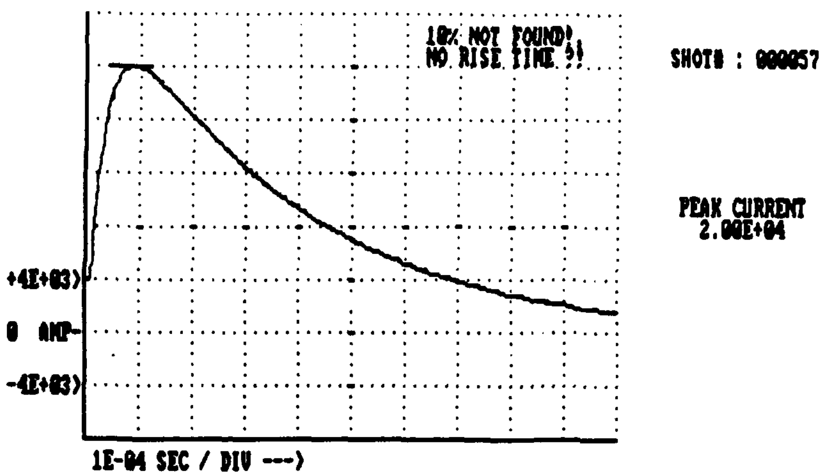
HURC-RF1 COMMENT : PEARSON PROBE



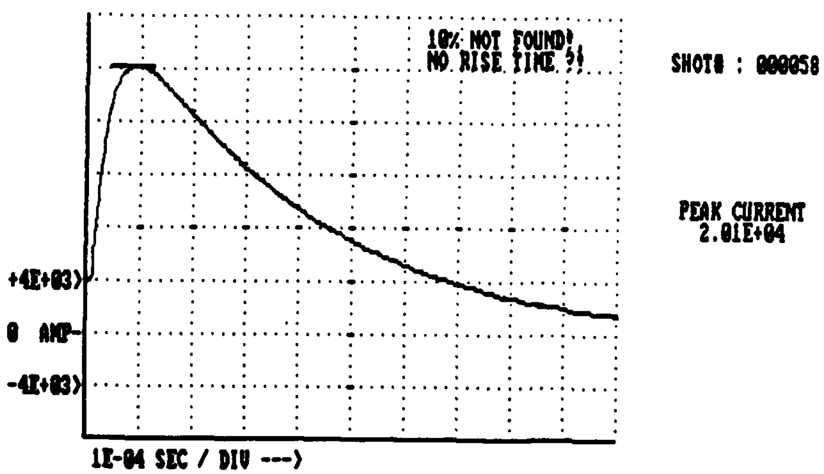
HURC-RF1 COMMENT : PEARSON PROBE



HURC-RF1 COMMENT : PEARSON PROBE



HURC-RF1 COMMENT : PEARSON PROBE



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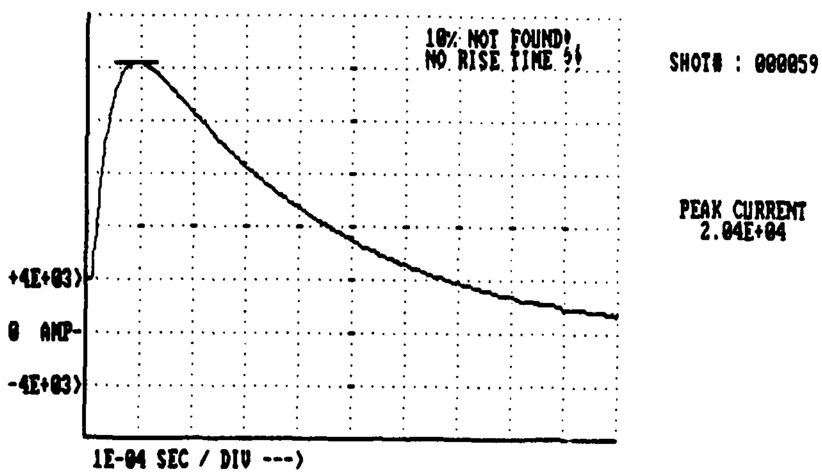
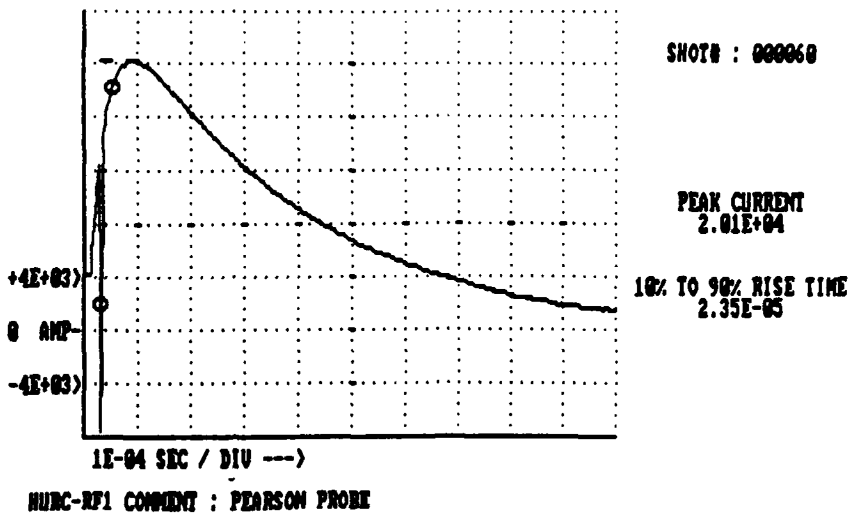
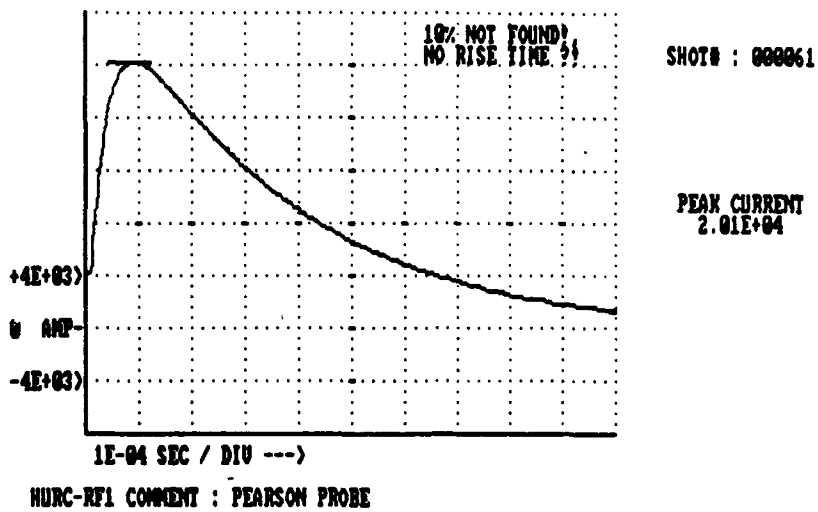
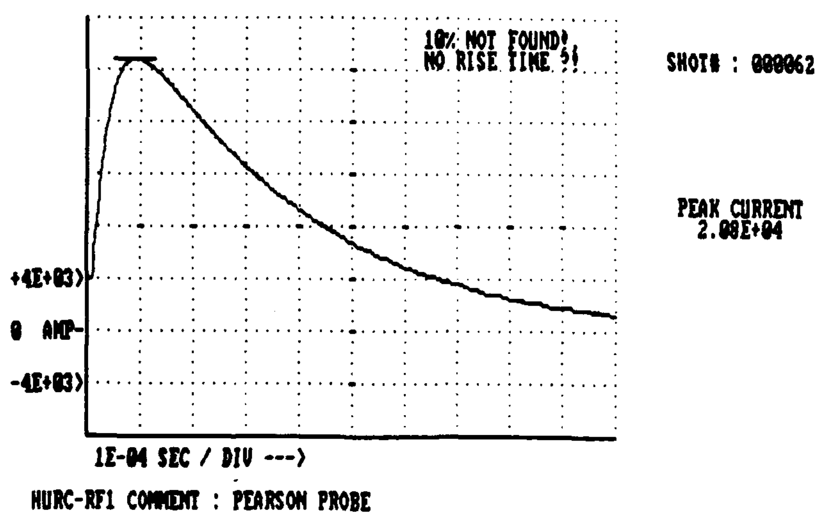
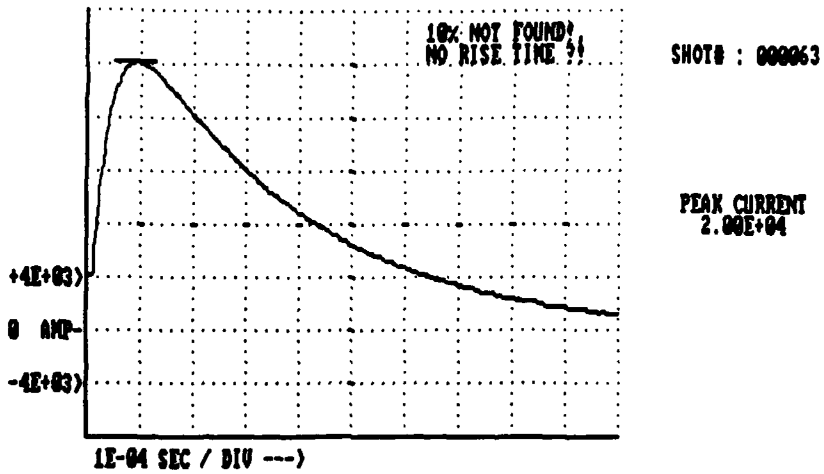


HURC-RF1 COMMENT : PEARSON PROBE

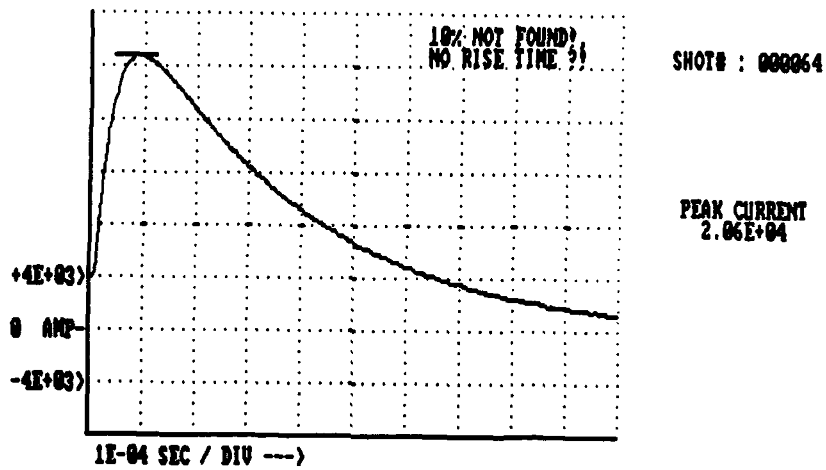

SHOT# : 000060
PEAK CURRENT
2.01E+04
10% TO 90% RISE TIME
2.35E-05
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV ---)
HURC-RF1 COMMENT : PEARSON PROBE


10% NOT FOUND!
NO RISE TIME ?!
SHOT# : 000061
PEAK CURRENT
2.01E+04
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV ---)
HURC-RF1 COMMENT : PEARSON PROBE

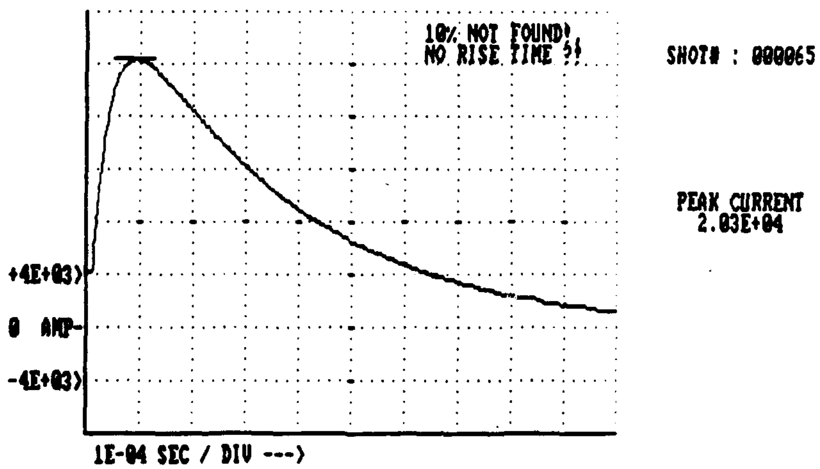

10% NOT FOUND!
NO RISE TIME ?!
SHOT# : 000062
PEAK CURRENT
2.00E+04
+4E+03)
0 AMP-
-4E+03)
1E-04 SEC / DIV ---)
HURC-RF1 COMMENT : PEARSON PROBE



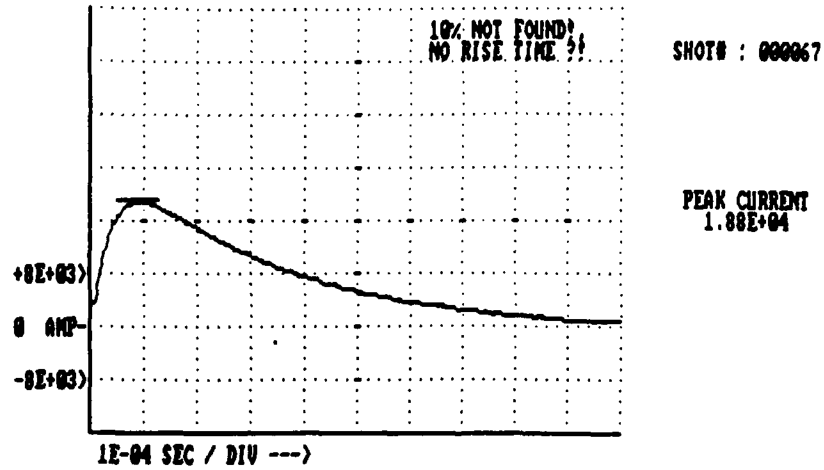
HURC-RF1 COMMENT : PEARSON PROBE



HURC-RF1 COMMENT : PEARSON PROBE



HURC-RF1 COMMENT : PEARSON PROBE



HURC-RF1 COMMENT : (PEARSON PROBE)

CERTIFICATE OF CALIBRATION

A Lightning Test was performed at the Naval Air Test Center during ˉ to 12 October 1991. Test was performed for the Naval Research Lab. The following equipment was used during test for measurements.

a. Pearson Model 1330 Current Probe, Calibration date: 16 Sep 1991, Accuracy ±1%, 3db points at .9Hz and 1.5MHz.

b. Biddle Digital Low Resistance Ohmmeter, Calibration date: 7 Jan 1991, Accuracy of ranges 0.000 to 5.999 milliohm and 00.00 to 59.99 milliohm is ±.25% plus 1 LSD (Least Significant Digit).

c. IWATSU Digitizing Oscilloscope, Model TS-8123, Calibration Date: 3 May 1991, Vertical Accuracy ±2%, Horizontal Accuracy ±2%.

Mike Whitaker — 31 Oct 1991

Test Director — Date

CERTIFICATION OF CALIBRATION

Lightning strike tests were performed at the Naval Air Test Center during the period 7 through 12 October 1991. These tests were performed for the Naval Research Laboratory in connection with the V-22/NAC composite connector tests.

An independent check on the Biddle Digital Low Resistance Ohmmeter used by NATC was conducted by NRL by using a calibrated 1.00 milliohm (0.001 ohm) resistor (i.e., 200 x 10^{-3} volts @ 200 amps.) The resistance measured by the Biddle instrument in the milliohm range was 0.991 to 1.001 milliohms.

Clarence D. Bond

NRL Test Director

Nov. 9 1991

Date

LIST OF CONNECTOR COMPONENTS AND ASSOCIATED FITTINGS

The specific MIL-C-38999 shell size 9 connectors and components were provide by the Naval Avionics Center form the following suppliers:

Part	Mfg.	Part No.
Aluminum Connector / All aluminum		
Receptacle	Bendix	TVP00RW935P
Plug	Bendix	TV06RW935S
Backshell	Sunbank	SPL3202BF6400-12A-1
Composite Connector / Plastic resin with metal overplating		
Receptacle	Bendix	CTVPS00RF935S
Plug	Bendix	CTVS06RF935P
Backshell	Glenair	440HS035XM0903-31931
Receptacle	Deutsch ATD	ATD060RA35PN
Plug	Deutsch ATD	ATD066RA35SN
Backshell	Glenair	440HSO35XM0903-31931
Hybrid Connector / Metal sleeve overmolded with plastic		
Receptacle	ITT-Cannon	KJAH7T9W35SN
Plug	ITT-Cannon	KJAH6T9W35PN
Backshell	ITT-Cannon	KJAM-9 Test Sample 9121
Associated fittings		
Adapter	Electro Adapter In.	N A
Stainless Bands	Band It ™	AL0089
Banding Tool	Glenair	S/N 3081
Std. Braid 0.5" wide		N A