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Westinghouse Astronuclear Laboratory

**HIGH CURRENT PULSE ATTENUATION
OF BELL AEROSYSTEMS
PYROHARNESSES No. 302 And No.308**

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PREFACE

The effort described in this report was supported by the Bell Aerosystem Company under Purchase Order No. 289546-48 (Westinghouse General Order No. XAL-70334A). Project Leader for the effort was Dr. Robert R. Ferber, Advisory Engineer in the Electronics and Instrumentation Department of the Westinghouse Astronuclear Laboratory.

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1.0 INTRODUCTION

The design and optimum materials selection for a shield that can protect electrical cables from induced currents caused by incident high-intensity electromagnetic pulses can be a very complex problem. This is especially true where multiple branches, joints, and connectors must be considered as a part of the shielding system. Joints and connectors can be handled reasonably well by ordinary RF shielding techniques if the connector shells are made thick enough and are well bonded to the conduit. The actual wideband high-level RF attenuation through a thin conduit, however, has been the subject of much controversy -- particularly where magnetic materials are concerned. When this is combined with the complexity of a multiple branch cable or harness, it becomes impossible to calculate or measure accurately the shielding provided to a large current pulse without actually using such a pulse for the tests. The purpose of this program was to test the shielding capabilities of the subject Hipernom[®] shielded harnesses while subjected to current pulses in the 10^3 ampere range.

The shielding provided by non-magnetic electrical conductors is relatively well understood and consists of a reflection at the air-metal interface and an exponential attenuation with distance into the material, with magnitude decreasing by $\frac{1}{e}$ (8.7 dB) for every skin depth penetration into the conductor. Magnetic materials, on the other hand, have additional attenuation factors due to: (1) their ability to store energy in the magnetic field produced in tracing a path along a B-H (magnetic flux vs magnetizing force) curve to saturation for a portion of the material near the surface facing the

[®] Hipernom is the Westinghouse Registered Trademark for a 79 percent nickel, 4.5 percent molybdenum, remainder primarily iron, magnetic alloy.

impinging wave, and (2) their high permeability in the unsaturated region greatly decreasing the characteristic skin depth. Thus, it should be possible to substantially reduce the necessary weight of shielding for a given attenuation by use of magnetic shielding materials.

This document presents the results of a high current pulse test program conducted on two Bell Aerosystems Company Vintage III Pyroharnesses, Serial Nos. 302 and 308, by the Westinghouse Astronuclear Laboratory. The purpose of the tests was to determine the shielding capabilities of the harnesses when subjected to damped RF current pulses of considerably greater amplitude than those anticipated in actual applications.

The test harnesses consisted of 8 multi-conductor shielded legs of varying lengths (P23 - P30), each connected, at one end, to a junction box on which is mounted an additional jack (J31). Each leg had a number of conductors shielded by convoluted braided Hipernom[®] flexible conduit with a nickel wire overbraid for additional mechanical strength. The two harnesses tested differed only in details of fabrication techniques.

The experimental test program consisted of impressing capacitor discharge current pulses onto the harness while observing the induced signals on various wires within the harness. The test procedures used and the measurements taken are quite similar to previously performed tests on a Vintage II Pyroharness (FMH0002) and reported in WANL TME-1929. For further background material on magnetic material shielding, the reader is referred to TME-1929 as well as previous publications^(1,2) by Westinghouse personnel.

2.0 EXPERIMENTAL SETUP

Electromagnetic Pulse Generation

An electromagnetic pulse was induced on the test harness by the use of a capacitor discharge to generate high current pulses. A 0 ± 30 KV power supply was used to charge the energy storage capacitor through a 10 megohm high voltage resistor. A spark gap switch was employed to discharge the energy in the capacitor through the test harness by grounding the high voltage end of the capacitor to the copper enclosure. Thus, if the capacitor was charged using a positive power supply output, a negative pulse would propagate down the test harness when the spark gap switch was triggered.

Figure 1 is a photo of the copper test enclosure and one of the harnesses tested. The copper box (.032 inch Cu) serves the purpose of a ground plane and low impedance ground return for the pulse, as well as a shield to prevent excessive spurious signal radiation from the test fixture.

Figure 2 shows the EMP test fixture with the Pyroharness installed, and Figure 3 is a schematic of the internal wiring connections of the harness.

¹ F. J. Young, "Ferromagnetic Shielding Related to the Physical Properties of Iron," 1968 IEEE Electromagnetic Compatibility Symposium Record, July 1968 (IEEE 68012-EMC), pages 88-95.

² R. R. Ferber and F. J. Young, "The Shielding of Electromagnetic Pulses by Use Of Magnetic Materials" 1969 IEEE Electromagnetic Compatibility Symposium Record, June 1969 (IEEE 69C3-EMC), pages 73-79.

Figure 1. Pyroharness and Test Enclosure

Figure 2. Pulse Test Apparatus

Figure 3. Test Harness

All branches of the harness were terminated through mating connectors to termination boxes. In each termination box, a $1/4\Omega$ resistor simulated load was connected between each pair of conductors. The harness conductors were shorted to the drive point connector body inside the copper shielding box. The driving pulse was always fed through the connector interface to simulate the worst case installed conditions.

The induced output signals were monitored by passing a leg of the harness through the end of the copper box and into the shielded room. The induced signal was then read out from conductor to sheath with either a $1/4\Omega$ or 50Ω termination. For the differential case, the output was taken between conductors in a given pair and fed to the readout electronics through a pulse transformer. The readout electronics consisted of a 585 Tektronix oscilloscope and C-27 camera.

The input pulse current was measured with a modified Stoddart wide-band RF current transformer, type 93686-4 (0.075Ω transfer impedance).

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3.0 TEST PROCEDURE

Harness Serial No. 302

The tests on harness 302 began using leg P23 as the input leg and P29 as the output. Capacitance values of 0.005 μ f and 0.05 μ f were utilized for these tests. The charging voltage was initially set at 5 KV and was increased in increments of 5 KV up to 20 KV.

With the 0.005 μ f capacitance installed, the input current wave form recorded displayed a ringing frequency of 1 MHz. The 0.05 μ f capacitor produced a ringing frequency of 0.6 to 0.7 MHz. Charging voltages of 10 KV, 15 KV, and 20 KV were employed and input and output signals were monitored for each case.

The harness was re-installed in the test fixture so it was possible to feed P25 and read the induced output signals at P29. Once again the 0.05 μ f and 0.005 μ f capacitors were charged to various voltage levels and the pulse current attenuation ratios were calculated for each case.

The attenuation properties of the junction box and the J31 connector mounted on the box were observed by feeding directly to J31 and reading the output signal at P28.

Harness Serial No. 308

Harness 308 was tested under similar circumstances to 302 with the exception that a lower inductance 0.005 μ f capacitor was utilized to obtain a faster discharge rise time and higher peak currents. The ringing frequency with the new capacitance installed was near 2.0 MHz.

Some additional tests were performed on 308 by replacing the P24 leg with a new leg in which the Hipernom shielding was slit. Figure 4 shows a photograph of one of three cuts made in the P24 leg. This particular cut shown was the largest of the three.

Next, the P29 leg was removed and the connector threads were coated with an insulating spray and tested at various pulse levels. Then, not only the threads but all mating surfaces were sprayed and the tests run again.

Figure 4. Leg P24 Slit Hipernom

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4.0 EXPERIMENTAL DATA

The data obtained in the experimental portion of the program was a series of oscilloscope photos showing the magnitudes of the input current and induced current waveforms. The induced output signals were read out between one pin and the sheath to obtain the attenuation by the normal conducted current method. In this method, the particular signal output wire is always shorted to the interior of the copper shield box at the cable driving point. A typical input current waveform is shown in Figure 5. This particular photo was taken while using P23 as the input. Figure 6 illustrates a typical induced current waveform taken from P29 with a 50Ω load. With this information obtainable directly from the photographs, attenuation calculations can be made by considering the ratio of the peak pulse current to the peak wire current through an external impedance to the sheath, as in equation (1).

$$\text{Attenuation in dB} = 20 \log_{10} \frac{I_{\text{out}}}{I_{\text{in}}} \quad (1)$$

From the theoretical discussion contained in WANL TME-1929, one could expect solid Hipernam shielding to produce attenuation figures of 300 dB or more. However, in harnesses 302 and 308 stray leakages at joints and connectors as well as leakage through the brazed convolutions limits the measurable shielding attainable to much less than theoretically calculated. For example, if a certain connector can provide 150 dB attenuation at a given frequency, it makes little

20 KV

2 μ S/DIV

10V/DIV

20 KV

IV/DIV

2 μ S/DIV

Figure 6. Typical Induced Current Waveform

difference whether the Hipernom gives 160 or 4000 dB attenuation. The measured attenuation is strongly related to the joint characteristics and will be limited to the maximum attenuation of the most leaky part of the system.

The harnesses tested in this program have many connectors and joints which are sources of high frequency leakage and in addition the shielding conduit is not solid Hipernom. It is a Hipernom strip which was formed and brazed at each convolution to form a conduit. Thus, there are many leakage paths around the Hipernom conduit through the brazed areas. These brazed points also provide a high reluctance magnetic path, thereby considerably degrading the effective magnetic properties of the fabricated convolute. A cross section of a typical brazed joint between convolutions is shown in Figure 7. The magnetic path across the joint is discontinuous due to the thickness of the brazed material between the two layers of Hipernom. Therefore, any shielding measurements will reflect the effects of this gap.

Tables 1 through 8 have columns labeled "transfer impedance" which is probably the best of all methods for expressing relative shielding. It is particularly appropriate here because the leakage signal induction behaves as a voltage source and once the transfer impedance value is known, the effective attenuation can be calculated for a given shielding system for any load impedance. The transfer impedance relationship is given by

$$Z_T = \frac{V_{out}}{I_{in}} \quad (2)$$

where V_{out} is the open circuit induced voltage on the cable wire.

Figure 7. Cross Section of Convolute Joint Showing Brazed Area
and Resultant High Reluctance Magnetic Path

TABLE 1

HARNESS ATTENUATION SUMMARY WITH INPUT AT P23 AND OUTPUTS TAKEN AT P29

Ring Frequency 1 MHz with .005 μ f capacitor
 Ring Frequency 0.6 - .7 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 302

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Attenuation (differential) 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
5	35	.005	.0625	82	64	>100	3.9×10^{-3}
10	80	.005	.25	82	64	>100	3.8×10^{-3}
15	133	.005	.5625	83	64	>100	3.6×10^{-3}
20	187	.005	1.0	80	65	>100	5.3×10^{-3}
5	600	.05	.625	83	68	>120	3.2×10^{-3}
10	1333	.05	2.5	86	76	>120	2.4×10^{-3}
15	2000	.05	5.6	90	76	>120	1.5×10^{-3}
20	2666	.05	10.0	89	79	>120	1.6×10^{-3}

TABLE 2

HARNESS ATTENUATION SUMMARY WITH INPUT AT P25 AND OUTPUT TAKEN AT P29

Ringing Frequency 1 MHz with .005 μ f capacitor

Ringing Frequency 0.6 to .7 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 302

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Attenuation (differential) 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
10	80	.005	.25	95	86	> 100	7.8×10^{-4}
20	187	.005	1.0	100	90	> 100	8.0×10^{-4}
5	800	.05	.625	98	> 120	> 100	5.0×10^{-4}
10	1600	.05	2.5	102	94	> 100	4.4×10^{-4}
20	3500	.05	10.0	104	106	> 100	2.8×10^{-4}

TABLE 3

HARNESS ATTENUATION SUMMARY WITH INPUT AT J31 AND OUTPUT TAKEN AT P28

Ringing Frequency 0.6 - .7 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 302

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Attenuation (differential) 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
5	655	.05	.625	81	60	> 120	4.0×10^{-3}
10	1330	.05	2.5	85	62	> 120	5.0×10^{-3}
15	2000	.05	5.6	86	66	> 120	2.5×10^{-3}
20	3333	.05	10.0	89	68	> 100	1.8×10^{-3}

TABLE 4

HARNESS ATTENUATION SUMMARY WITH INPUT AT P24 THRU P27 AND OUTPUT TAKEN AT P29

Test Conditions
10 KV .05 μ f capacitor
2.5 Joules

Ringing Frequency 0.6 - .7 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 302

Input Connector	Peak Pulse Current (Amps)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Attenuation Differential 50 Ω Load I_o/I_{in} (DB)	Attenuation Differential 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω $Z_T = V_o/I_{in}$ (ohms)
P23	1333	86	76	96	96	7.6×10^{-4}
P24	1540	94	79	>120	>120	1.0×10^{-3}
P25	1600	102	94	>120	>120	4.4×10^{-4}
P26	1600	91	76	105	112	1.1×10^{-3}
P27	1333	90	81	>120	>120	1.5×10^{-3}
J31 Output P28	1330	85	62	>120	>120	3.0×10^{-3}

TABLE 5

HARNESS ATTENUATION SUMMARY WITH INPUT AT P25 AND OUTPUTS TAKEN AT P29

Ringing Frequency 2 MHz with .005 μ f capacitorRinging Frequency 0.6 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 308

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
5	160	.005	.0625	86	66	2.5×10^{-3}
10	330	.005	.25	84	68	2.8×10^{-3}
15	530	.005	.5625	88	68	2.2×10^{-3}
20	800	.005	1.0	86	72	2.5×10^{-3}
5	530	.05	.625	88.7	74	1.9×10^{-3}
10	1000	.05	2.5	88	74	2.0×10^{-3}
15	1600	.05	5.6	91	76.5	1.5×10^{-3}
20	2000	.05	10.0	90	73.5	1.6×10^{-3}

TABLE 6

HARNESS ATTENUATION SUMMARY WITH INPUT AT P23 AND OUTPUT TAKEN AT P29

Ringing Frequency 0.6 MHz
 Pyrotechnic Control Cable Code No. 80070 Serial No. 308

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
5	530	.05	.625	82.5	68	4.0×10^{-3}
10	1000	.05	2.5	88.8	74	1.8×10^{-3}
20	2000	.05	10.0	88	74	2.0×10^{-3}

TABLE 7

HARNESS ATTENUATION SUMMARY WITH INPUT AT J31 AND OUTPUT TAKEN AT P28

Ringing Frequency 0.7 MHz with .05 μ f capacitor

Pyrotechnic Control Cable Code No. 80070 Serial No. 308

Charging Voltage (KV)	Peak Pulse Current (Amps)	Capacitor Value (μ f)	Pulse Energy (Joules)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω Load $Z_T = V_o/I_{in}$ (ohms)
5	660	.05	.625	81	58	4.6×10^{-3}
10	1330	.05	2.5	82	56	4.0×10^{-3}
15	1900	.05	5.6	83.5	60	3.1×10^{-3}
20	2400	.05	10.0	84	54	3.4×10^{-3}

TABLE 8

HARNES ATTENUATION SUMMARY WITH INPUT AT P24 THRU P27 AND OUTPUT TAKEN AT P29

Ringing Frequency 0.6 - .7 MHz with .05 μ f capacitor

Test Conditions 10 KV .05 μ f capacitor 2.5 Joules

Pyrotechnic Control Cable Code No. 80070 Serial No. 308

Input Connector	Peak Pulse Current (Amps)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 1/4 Ω Load I_o/I_{in} (DB)	Attenuation Line to Sheath 50 Ω Load I_o/I_{in} (DB)	Single Ended Transfer Impedance 50 Ω $Z_T = V_o/I_{in}$ (ohms)
P23	1000	88.7	74	102	2.0×10^{-3}
P24	1000	90	71	>120	2.0×10^{-3}
P25	1000	88.8	74	>120	1.8×10^{-3}
P26	1066	91	76	111	1.7×10^{-3}
P27	1000	88	70	>120	2.0×10^{-3}
J31 Output P28	1330	82	56	>120	4.0×10^{-3}

5.0 EXPERIMENTAL RESULTS

Harness No. 302

The readout data and calculated results of the tests performed on harness No. 302 are summarized in Tables 1 through 4.

The differential attenuation (line to line) data presented reveals >100 dB attenuation for all cases. Thus, the harness has been fabricated well enough to provide a relatively uniform attenuation characteristic to each wire in each pair.

The attenuation data for the $1/4 \Omega$ load (P23 input, P29 output) reveals a minimum attenuation of 64 dB as shown in Table 1. This value was obtained from low peak pulse currents (35A to ~150A) which correspond to low threat levels. As the peak pulse current increased, the H field differential across the saturated region increased, and the attenuation also increased. This trend continued on the P23 leg and was also observed in the other legs tested. This phenomenon is indicated by Figure 8 which is a sketch of attenuation vs threat level. For low threat levels the attenuation ratio is very nearly the unsaturated bulk material attenuation. However, as the threat level increases, the magnetic shielding material begins to store energy in the magnetic field produced by tracing a path along the B vs H curve of the material to saturation. If the threat level had continued to increase to the point where the saturated region is driven far into the magnetic material, the total attenuation would begin to drop. Thus, the observation that attenuation increased with threat level, to a certain point, is consistent with theory.

Figure 8. Typical Attenuation vs. Threat Level

The 50Ω load tests revealed attenuation ratios larger by a factor of 10 – 20 dB than those produced by the $1/4 \Omega$ load. This occurred because the leakage signal induction behaves like a voltage source with an internal impedance and a load in series and follows the relationship:

$$V_g = I_o (Z + R_L) \quad (3)$$

where V_g is the induced voltage in the conductors, I_o the induced current, R_L the load impedance, and Z the effective cable source impedance. The following is a sample calculation of Z for a given configuration:

From Table 1, 0.05 μ f, 10 KV, P23 Input - P29 Output

$$Z_T \approx 2.4 \times 10^{-3} = \frac{V_{out}}{I_{in}}$$

$$V_o = 3.12V \text{ as read from data photo}$$

$$\text{Attenuation} = 76 \text{ dB} = 20 \log_{10} \frac{I_{out}}{I_{in}} \text{ (for } 1/4 \Omega \text{ load)}$$

$$I_{out} = V_{out} (1/4 \Omega) / R (1/4 \Omega)$$

$$I_{out} = .208A$$

$$I_{out} = \frac{V_o \text{ (open circuit)}}{Z_{Line} + Z_{Load}}, \text{ but}$$

the $1/4 \Omega$ load resistor is small compared to the conductor source impedance.

Similarly, the 50Ω load output voltage is not much less than the open circuit output voltage. Therefore, to the accuracy of the other measurements, the line impedance may be calculated:

$$\begin{aligned} Z_{Line} &\approx \frac{V_o (50 \Omega)}{I_o (1/4 \Omega)} \\ &= \frac{3.12}{.2} = 15.5 \Omega \end{aligned}$$

Harness No. 308

Harness 308 was tested under the same test conditions as 302. The same charging voltage levels were employed and with the exception of a new 0.005 μf capacitor, the test fixture was the same. Tables 5 through 10 show the attenuation ratios, transfer impedances, etc., for all the tests conducted on harness 308.

The differential attenuation column is not shown for the 308 harness because it was always greater than 100 dB.

The attenuation data reveals the same pattern as was noted in harness 302, increasing attenuation with increasing threat levels. Most of the comments made in the preceding section concerning harness 302 apply here also.

Additional testing was performed on No. 308 in an attempt to develop more information on the attenuation properties of holes of known size or leakage points. One such test was conducted on a special P24 leg in which the Hipernom shield had been slit in 3 places as was shown by Figure 4. Table 9 shows the attenuation results at various charging voltages. A comparison of these figures with those of the intact P24 leg shows a substantial decrease in attenuation. This was primarily due to high frequency leakage through the slits as illustrated in Figure 9. Its distorted wave form, if Fourier analyzed, would reveal a large amount of high frequency leakage components in its spectrum.

An additional test was performed on a P24 leg which utilized an alternate construction technique. The leg was installed into the Pyroharness after completion of tests on the above discussed unit with slits cut into it. With a 10 KV charging

TABLE 9
HARNESS ATTENUATION SUMMARY WITH INPUT AT P24 AND OUTPUT TAKEN AT P29
(P24 With Hipernam Slits)

<u>Charging Voltage</u>	<u>Attenuation 50 Ω</u>	<u>Attenuation 1/4 Ω</u>
5	74	58
10	80	62
15	79	60
20	78	61

TABLE 10

HARNESS ATTENUATION SUMMARY WITH INPUT AT P25 AND OUTPUT TAKEN AT P29

(With P25 Junction Box Connection Coated with Insulating Spray)

<u>Sprayed Surface</u>	<u>Charging Voltage (KV)</u>	<u>Attenuation 50 Ω (dB)</u>	<u>Attenuation 1/4 Ω (dB)</u>
Threads	15	97	68
All Surfaces	10	76	56
	15	78	56

Figure 9. Output Current Waveform of
Leg P24 with Hipernom Slits

voltage applied, it showed a line to sheath attenuation of 107 dB with a $50\ \Omega$ load and 80 dB with a $1/4\ \Omega$ load.

Table 10 shows the results of a test in which various mating surfaces of the connector between P29 and J31 were sprayed with an insulating coating to simulate a partial discontinuity. With only the threads on the nut sprayed, the attenuation remained approximately the same as previously measured due to continuing good contact between the cable ferrule and the box flange. However, when all mating surfaces were covered, the connector junction presented a relatively high impedance path for the current pulse and, as a result, an appreciable decrease in attenuation was seen.

6.0 CONCLUSIONS

The EMP attenuation tests performed on Bell Pyroharnesses No. 302 and 308 illustrated that both should perform satisfactorily from a shielding viewpoint in the intended application. When feeding various legs of the harness and driving a 50Ω load, the attenuations observed fell between 80 and 100 dB, and while driving a $1/4\Omega$ load the attenuation fell as low as 54 dB in the J31 input configuration on harness 308, but the remainder of the tests averaged in the mid-70 dB range.

The majority of induced feedthrough can be attributed to leakage through the connectors and the brazed area of the Hipernom convolute. However, in the case of J31 input, the poor attenuation was a result of leakage through a gasket that interfaced the main body of the junction box with the cover and/or leakage due to a poor male-female connector interface. It was not possible to separate the two potential leakage points in the tests that were made.