(2)

POR-2033(EX)
(WT-2033)(EX)
EXTRACTED VERSION

OPERATION DOMINIC

CHRISTMAS AND FISH BOWL SERIES

PROJECT OFFICERS REPORT — PROJECT 7.1

ELECTROMAGNETIC SIGNAL, UNDERWATER MEASUREMENTS

A.P. Bridges, Project Officer
B.J. Bittner
V.D. Peckham
A.D. Moorhead
E.L. Cole
S.A. Bliss

Kaman Nuclear
Colorado Springs, Colorado

NOTICE:
This is an extract of POR-2033 (WT-2033), Operation DOMINIC, Christmas and Fish Bowl Series, Project Officers Report, Project 7.1.

Extracted version prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, DC 20305-1000

1 April 1985

CHAPTER 3

RESULTS AND DISCUSSION

Data was successfully recorded on 22 of the 26 shots listed in Table 2.1 which produced EM signals. Of the four shots for which no data was obtained, one (Tanana) had such a low yield that the signal could not be detected in the presence of the high noise level* at the test site at the time. A second shot (Star Fish Prime) completely saturated recording equipment so that no definable trace was obtained. Two shots (Aztec, Sunset) were not recorded because of miscoordination in communications about event timing.

The film data on 13 of the 22 recorded shots has been used to calculate field strengths of the EM pulses. Insufficient scope deflection, loss of calibration data, or improper triggering of the scope sweeps caused nine film records to be unreliable with respect to data analysis.

Since the tape recorders used were of low quality in phase and amplitude response in the desired frequency

---

*Loran station within line of site in bay where we sought shelter after experiencing 57°-roll weather!

range, the tapes were not analyzed for EM signal strengths. The tapes, however, produced a considerable quantity of information on spheric levels and other interferences one might encounter in attempting to differentiate an EM signal in the same time intervals.

Table 3.1 is a resume of EM pulse records obtained by Project 7.1 during the tests. The tape and oscilloscope records from each ship are listed separately. The figures listed by each record are of the traces which were photographed directly or transferred from a tape to film.

Figures 3.2 through 3.19 are reproductions of oscilloscope traces of the EM signals of shots listed thereon.

Signal strength is listed on the figure alongside the trace, if scope deflection was sufficient to allow the calibration. The method of calculation of the signal strengths is given below. (Also see Figure 3.1.)

1. NPM was used to calibrate the system at 19.4 kc.
2. NPM "at location" was measured with the URM-6

field strength receiver.

3. The intermediate amplifier was essentially flat from 5 kc to well above 25 kc (**Figures 2.5 and 2.6**).

4. The vertical whip signal as displayed on the scope represents the recorded equivalent level of NPM field strength. The actual input is modified by the whip's effective aperture, cable attenuation, and preamplifier gain. These factors do not enter into the calibration except as they are frequency dependent.

5. The effective height of the antenna

$$H_e = \frac{\lambda}{\pi \sin(\frac{2\pi h}{\lambda})} \sin^2 (\frac{\pi h}{\lambda})$$

$h = 12$ ft, whip $= 3.7$ meters

Case "A" λ_c = NPM = 15.5×10^3 meters

Case "B" λ_{10} kc = 30 km

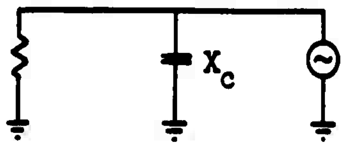
ratio $\frac{He\ (10\ kc)}{He\ (19.4\ kc)} = 1.0$ (within 1% accuracy)

The vertical whip is presumed to have an omni-directional pattern at these frequencies, although some variation was noted as the ships were rotated.

6. The attenuation in 35 feet of RG-58/U is negligible. The cable capacity of 28.5 pf/ft introduces a reactance of (1000 pf).

$$X_c\ (19.4\ \text{kc}) = \frac{1}{WC} = -j8.2\ K\Omega$$

$$X_c\ (10\ \text{kc}) = \frac{1}{WC} = -j16.2\ K\Omega$$

270 K  Antenna Z

$$K\ell = \frac{2\pi h}{\lambda} \text{ - the electrical length}$$

$$(19.4\ \text{kc})\ k = 15 \times 10^{-4}$$

$$(10\ \text{kc})\ k = 7.74 \times 10^{-4}$$

The antenna impedance is

$$Z_{19.4} = 1/2[(20)(k\ell)^2 - j\ 120\ (k\ell)^{-1}(\log \frac{2\ell}{a} - 1)]$$

$$= 1/2(.000045 - j\ 39.6 \times 10^4)$$

$$= 45\ \mu\text{ohms} - j\ 396\ K\Omega$$

$$Z_{10} = 1/2(.000012 - j\ 76.8 \times 10^4)$$

$$= 12\ \mu\text{ohms} - j\ 768\ K\Omega$$

Thus, the ratio across this voltage divider at 19.4 kc and at 10 kc varies by only 2%.

Figures 3.20 through 3.39 are photographic reproductions of the signals recorded on tape during the test series. Although not of sufficient quality to allow amplitude and phase calculations, these data show characteristics of the signal as regards initial polarities, gross distortions, time duration, etc.

In addition to amplitude calculations, the film records allow an estimate of phase distortion in the underwater signal.

The effective, equivalent depth of the electrical center of the antenna is required before an attempt is made to compare attenuation versus depth.

First. The phase shift between the NPM signal into the loop and into the whip was measured, with the loop at the surface. This delay (whip to loop) was 1.66 μsec corresponding to the cable length and velocity of propagation plus loop phase shift, which was not 90° as is the case for an above-water or smaller antenna.

Second. The NPM phase shift was noted as the loop was lowered. Correlation between the measured spacing from the surface to the top of the loop is poor due primarily to wave motion and also due to the expected difficulty in predicting the electrical center of the underwater loop, since the maximum dimension of the loop is 1.414 fathoms.

Summarizing the data for two examples, Truckee and Swanee:

	Depth to Top of Loop	NPM Effective Depth	Bomb Signal Effective Depth
TRUCKEE	2 fathoms+rigging	7.34 meters	7.834 meters
SWANEE	2 fathoms+rigging ± 3-to 6-ft swells		5.3 meters (11-kc component) 5.36 meters (9.2-kc component)

Using these same examples, the computations were performed as follows:

TRUCKEE Depth/phase measurements

Estimated depth: 2 fathoms to top of loop plus rigging spacers

NPM phase measurements: inverted loop at depth phase lag, 35 μsec. Inherent loop fixed delay: 1.66 μsec. The actual phase delay was, therefore, 33.34 μsec.

Underwater phase velocity = 22×10^4 m/sec

= 0.22 m/μsec

Effective delay depth = 7.34 meters at 19.4 kc to electrical center = 23.4 ft ≈ 3.9 fathoms

Shot Signal phase measurements:

Effective frequency: 5000 cps

Loop at depth phase lag: 80 μsec

Fixed delay: 1.66 μsec

Actual delay = 78.34 μsec

Phase velocity: 0.10 m/μsec

Effective delay depth 7.834 meters at 5 kc

SWANEE Depth/phase measurements

Estimated depth: 2 fathoms ±3- to 6-ft wave motion (14 ft wave maximum). Inverted signal due to direction of loop.

First signal t_1 (peak(pos)loop) - f_1 (peak(neg)whip)=

33.6 minus 1.66 μsec = 32.0 μsec

Third signal t_3 - f_3 = 38.5 minus 1.66 μsec =

36.84 μsec

Effective frequency cross-over time

1 to 2-46.8 μsec = 11 kc

2 to 3-53.7 μsec = 9.2 kc

Phase velocity = 0.166 m/μsec at 11 kc

= 0.150 m/μsec at 9.2 kc

v x t = effective depth

(at 11 kc): 0.166 x 32 = 5.3 meters (17 feet)

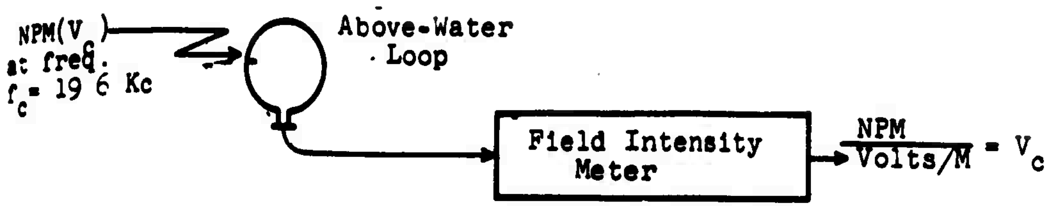
(at 9.2 kc): 0.150 x 36.8 = 5.52 meters

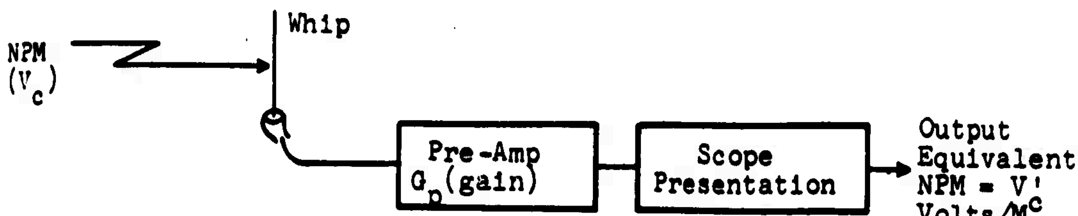
TABLE 3.1 SUMMARY OF RECORDED EM PULSE DATA

On the tape records, the upper and lower traces are misalined due to the tape recorder. If data was recorded, the figure number of the reproduced signal is listed. If data was not recorded, NR is listed.

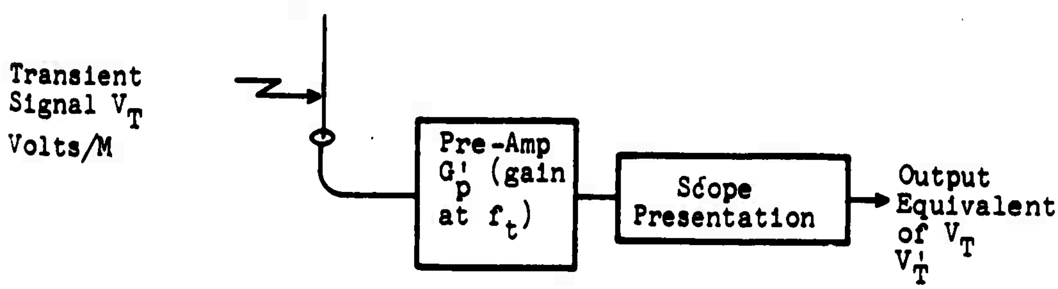
Due to the triggering level differences between the two ship records, a direct corresponding time comparison is not evident from these records by a casual visual inspection. Also, the apparent high-frequency peaking due to the 1,000-foot wire is evident in some USS INFLICT records.

Shot Name	Station			
	USS INFLICT		USS LOYALTY	
	Film	Tape	Film	Tape
Aztec	No data recorded			
Adobe	3.2	3.20	NR	3.20
Arkansas	NR	3.21	NR	NR
Questa	NR	3.22	NR	NR
Frigate Bird	3.3	3.23	NR	3.23
Yukon	3.4	3.24	NR	3.24
Mesilla	3.5	3.25	3.5	NR
Muskegon	3.6	NR	3.6	NR
Sword Fish	Underwater shot, no signal			
Encino	NR	NR	NR	3.25
Swanee	3.7	3.26	3.7	3.26
Chetco	3.8	3.27	3.8	3.27
Tanana	High level noise interference, no signal			
Nambe	3.9	NR	3.9	3.28
Blue Gill	Shot failed			
Alma	3.10	3.29	3.10	3.29
Truckee	NR	3.30	NR	3.30
Yeso	3.11	3.31	3.11	3.31
Harlem	3.12	3.32	3.12	3.32
Rinconada	3.13	3.33	3.13	3.33
Dulce	3.14	3.34	3.14	3.34
Star Fish	Shot failed			
Petit	3.15	3.35	3.15	3.35
Otowi	3.16	3.36	3.16	3.36
Bighorn	3.17	3.37	3.17	3.37
Bluestone	3.18	3.38	3.18	3.38
Star Fish Prime	Signal saturated equipment			
Sunset	NR	NR	NR	NR
Pamlico	3.19	3.39	3.19	3.39





$$\frac{\text{Scope Volts x cm}}{\text{cm}} = V'_c$$



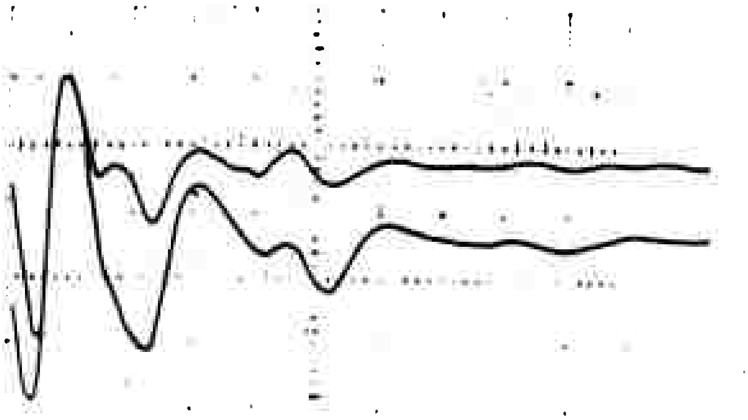
$$\text{Freq. Gain Correction*} \left(\frac{G'_p}{G_p}\right) \times \frac{\text{Scope Volts}}{\text{cm}} \times \text{cm} = V''_T$$

then $\frac{V''_T}{V'_c} \times V_c = V_T$ Volts/Meter of the Transient Signal

---

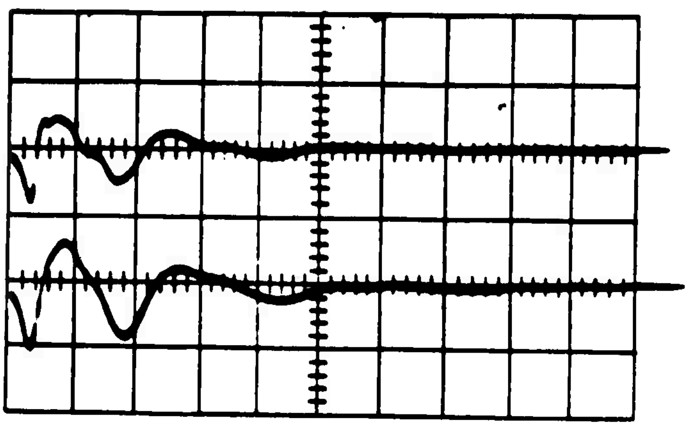
*See Figure 2.5. This illustrates that the preamplifier was sufficiently flat so that $G'_p/G_p \approx 1.2$.

Figure 3.1 Schematic representation of calibration consideration (above water).



ADOBE – INFLICT
UPPER (WIRE) 2.1 V/M
LOWER (WHIP) 3.93 V/M
SWEEP SPEED 50 μsec/cm

Figure 3.2 Experimental signal, film, Shot Adobe.



FRIGATE BIRD – INFLICT
UPPER (WIRE) 1.4 V/M
LOWER (WHIP) 1.6 V/M
SWEEP SPEED 50 μsec/cm

Figure 3.3 Experimental signal, film, Shot Frigate Bird.

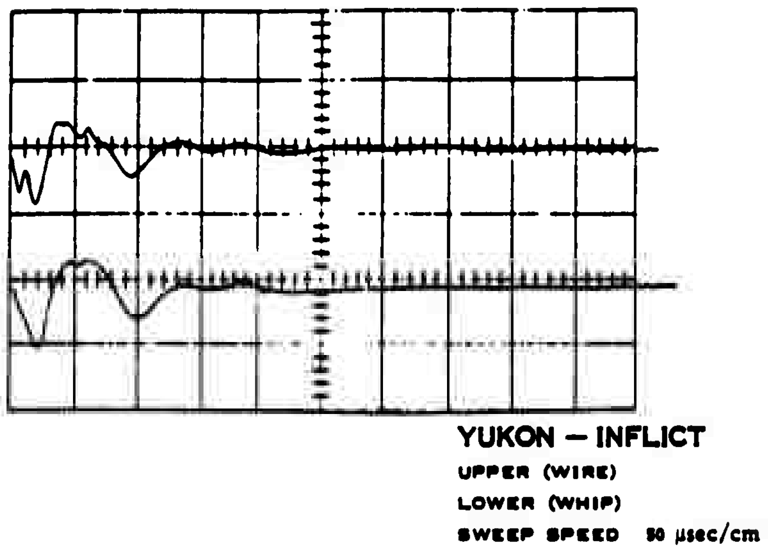
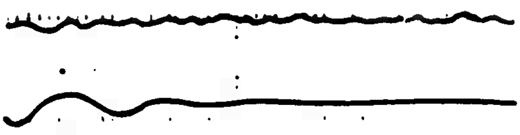
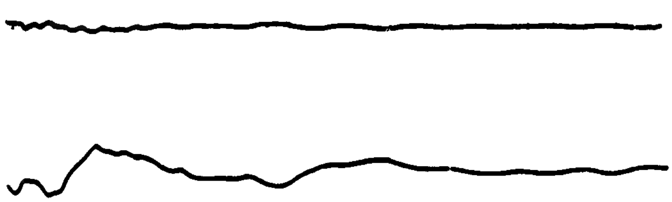


Figure 3.4 Experimental signal, film, Shot Yukon.

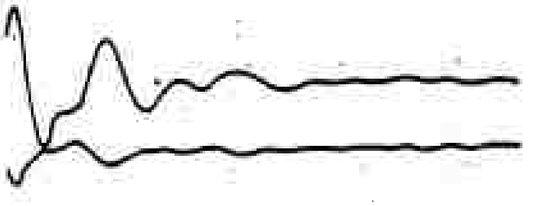


MESILLA — LOYALTY
UPPER (LOOP)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm

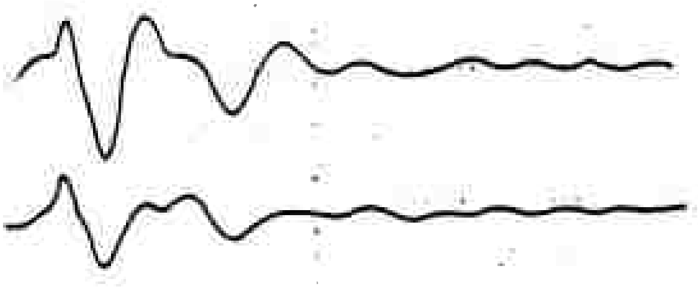


MESILLA — INFLICT
UPPER (WIRE)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm

Figure 3.5 Experimental signal, film, Shot Mesilla.



MUSKEGON — LOYALTY
UPPER (LOOP)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm



MUSKEGON — INFLICT
UPPER 2.87 V/M (SMALL LOOP 8–10 FEET DEEP)
LOWER 1.26 V/M (WHIP)
SWEEP SPEED 50 μsec/cm

Figure 3.6 Experimental signal, film, Shot Muskegon.

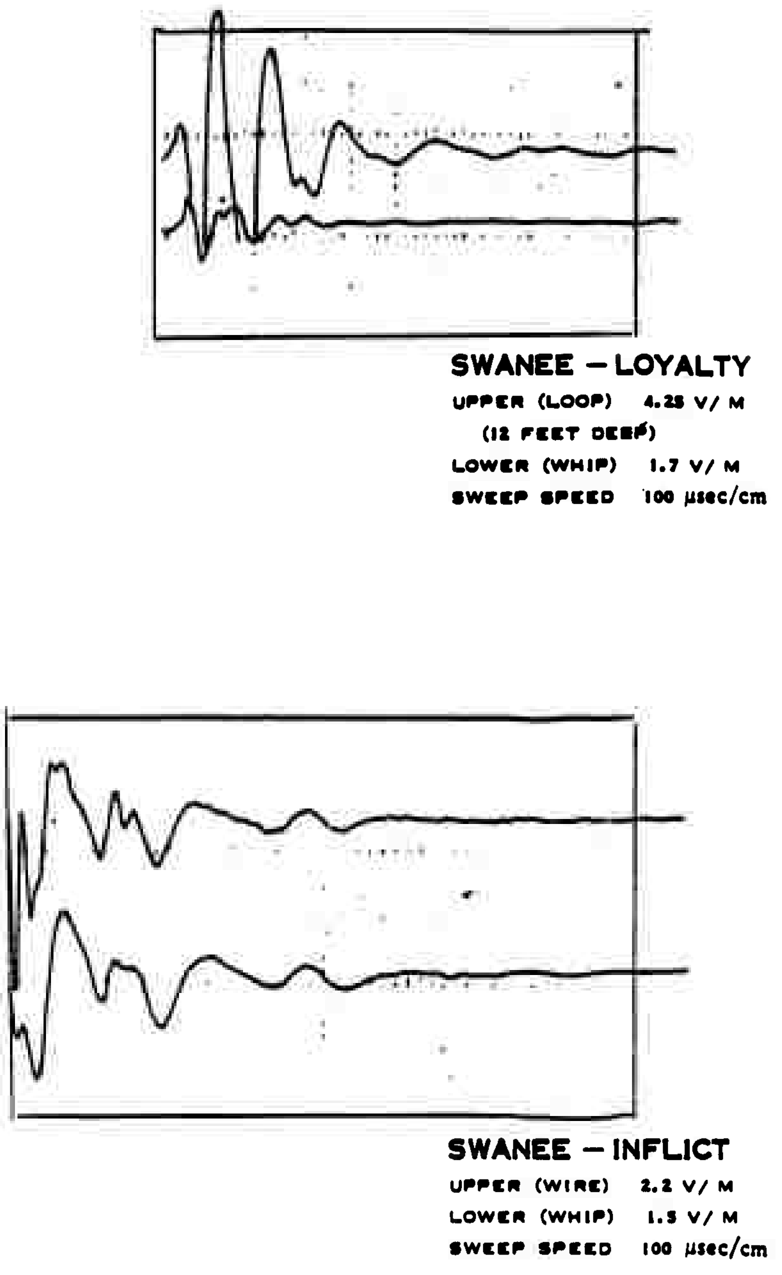
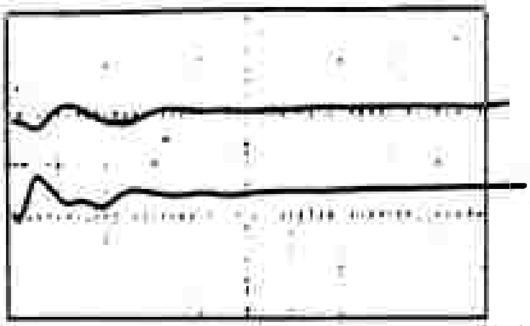
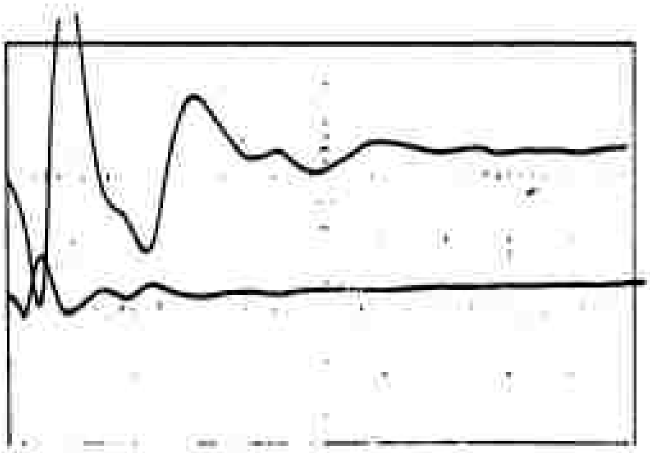


Figure 3.7 Experimental signal, film, Shot Swanee.

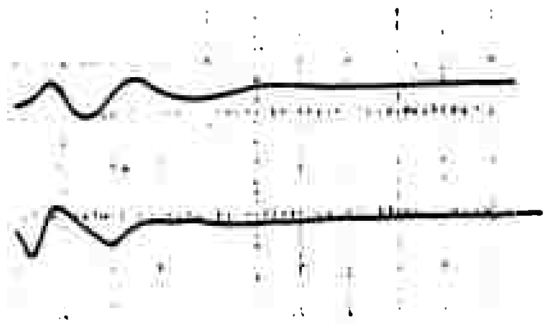


CHETCO — LOYALTY
UPPER (LOOP)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm

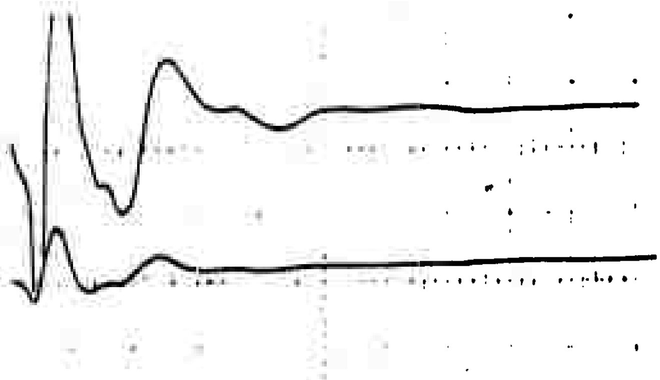


CHETCO — INFLICT
UPPER (LOOP) .75 V/ M
(23 TURN LOOP - 12 FT. DEPTH)
LOWER (WHIP) .8 V/ M
SWEEP SPEED 50 μsec/cm

Figure 3.8 Experimental signal, film, Shot Chetco.

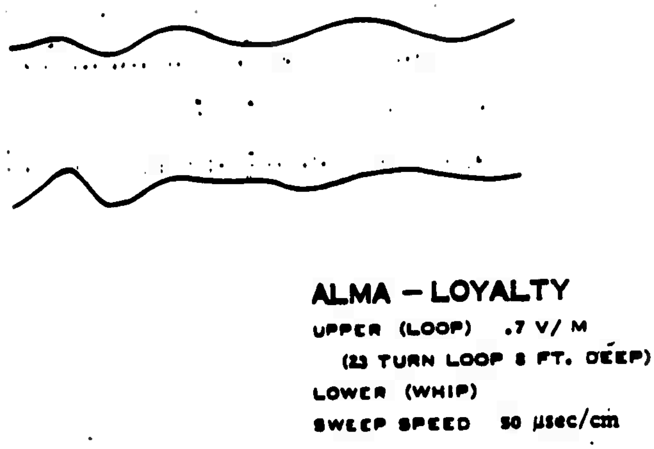


NAMBE — LOYALTY
UPPER (LOOP)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm



NAMBE — INFLICT
UPPER (WIRE)
LOWER (WHIP)
SWEEP SPEED 50 μsec/cm

Figure 3.9 Experimental signal, film, Shot Nambe.



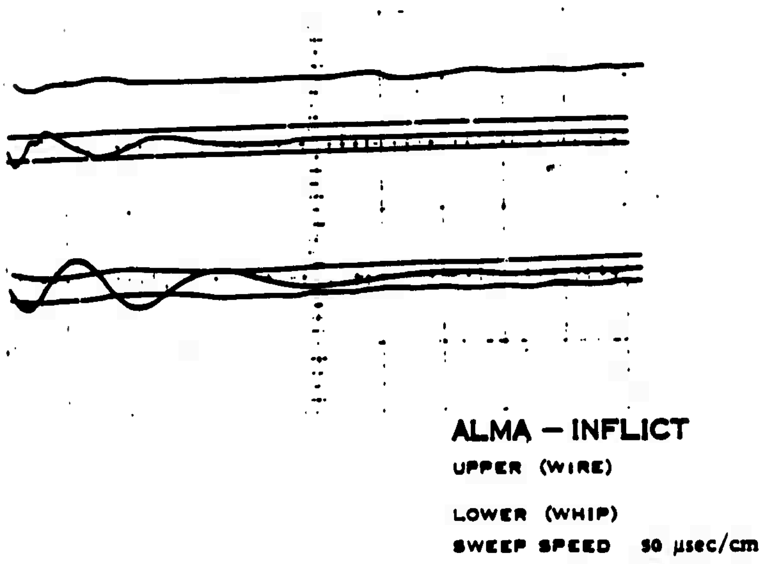
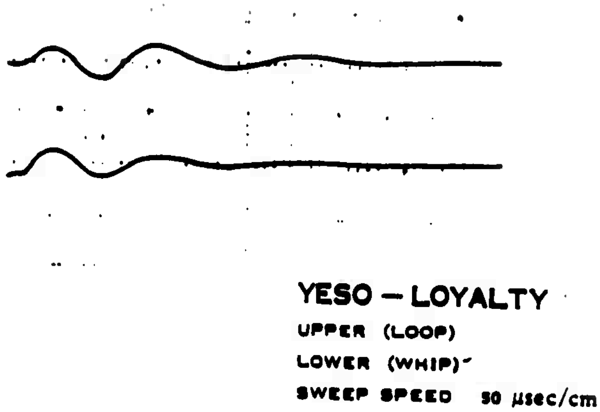


Figure 3.10 Experimental signal, film, Shot Alma.



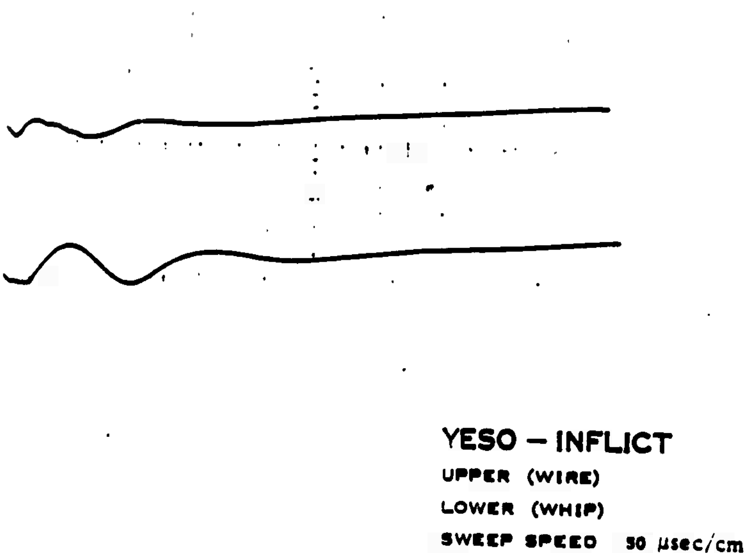
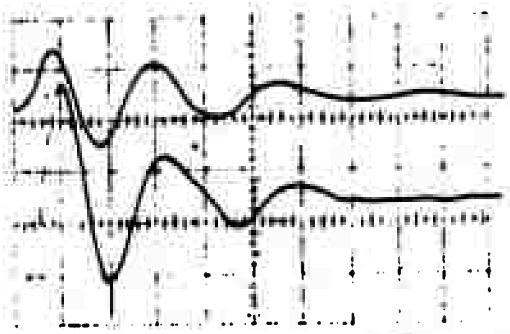


Figure 3.11 Experimental signal, film, Shot Yeso.



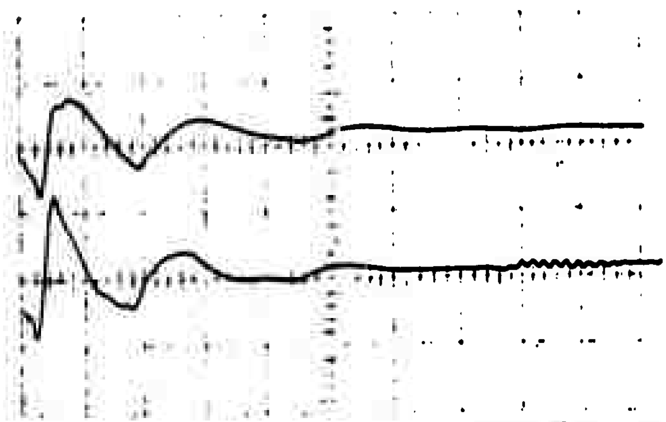
HARLEM – LOYALTY

UPPER (LOOP) 3.4 V/ M

(23 TURN LOOP 8–10 FT. DEPTH)

LOWER (WHIP) 2.2 V/ M

SWEEP SPEED 50 μsec/cm



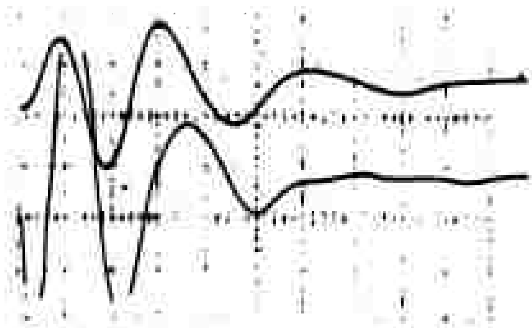
HARLEM – INFLICT

UPPER (WIRE) 1.62 V/ M

LOWER (WHIP) 2.83 V/ M

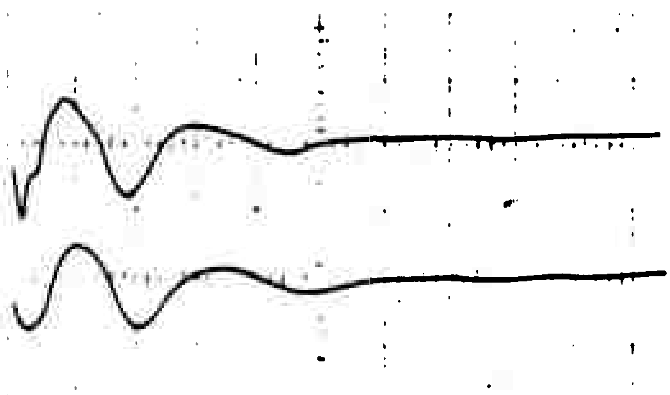
SWEEP SPEED 50 μsec/cm

Figure 3.12 Experimental signal, film, Shot Harlem.



RINCONADA — LOYALTY

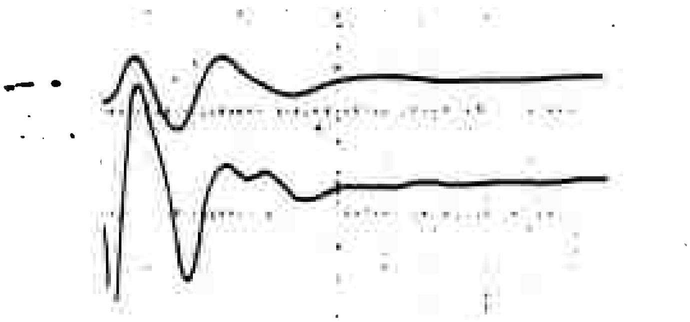
UPPER (LOOP) 3.2 V/ M
(23 TURNS 8 FT. DEPTH)
LOWER (WHIP) .8V/ M
SWEEP SPEED 50 µsec/cm



RINCONADA — INFLICT

UPPER (WIRE) 1.35 V/ M
LOWER (WHIP) .92 V/ M
SWEEP SPEED 50 µsec/cm

Figure 3.13 Experimental signal, film, Shot Rinconada.



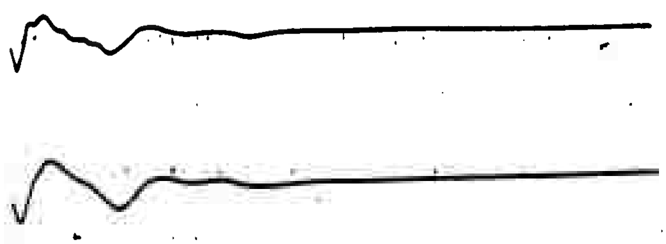
DULCE – LOYALTY

UPPER (LOOP) 1.33 V/ M

(23 TURN LOOP 2 FATHOM DEPTH)

LOWER (WHIP) .32 V/ M

SWEEP SPEED 50 μsec/cm



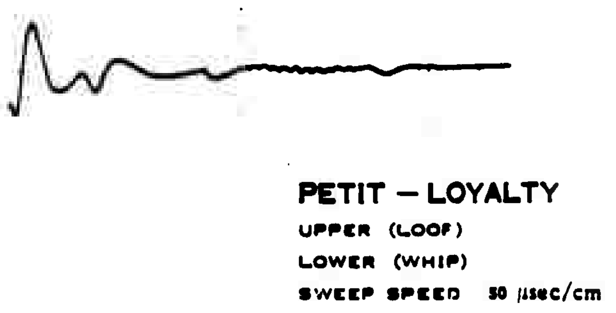
DULCE – INFLICT

UPPER (WIRE) .58 V/ M

LOWER (WHIP)

SWEEP SPEED 50 μsec/cm

Figure 3.14 Experimental signal, film, Shot Dulce.



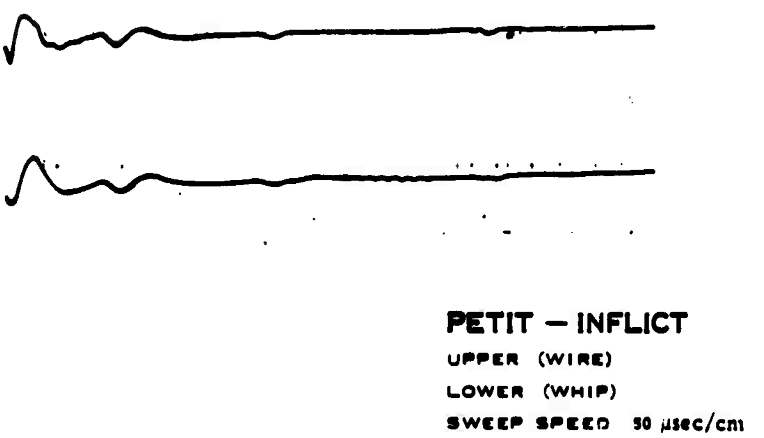


Figure 3.15 Experimental signal, film, Shot Petit.

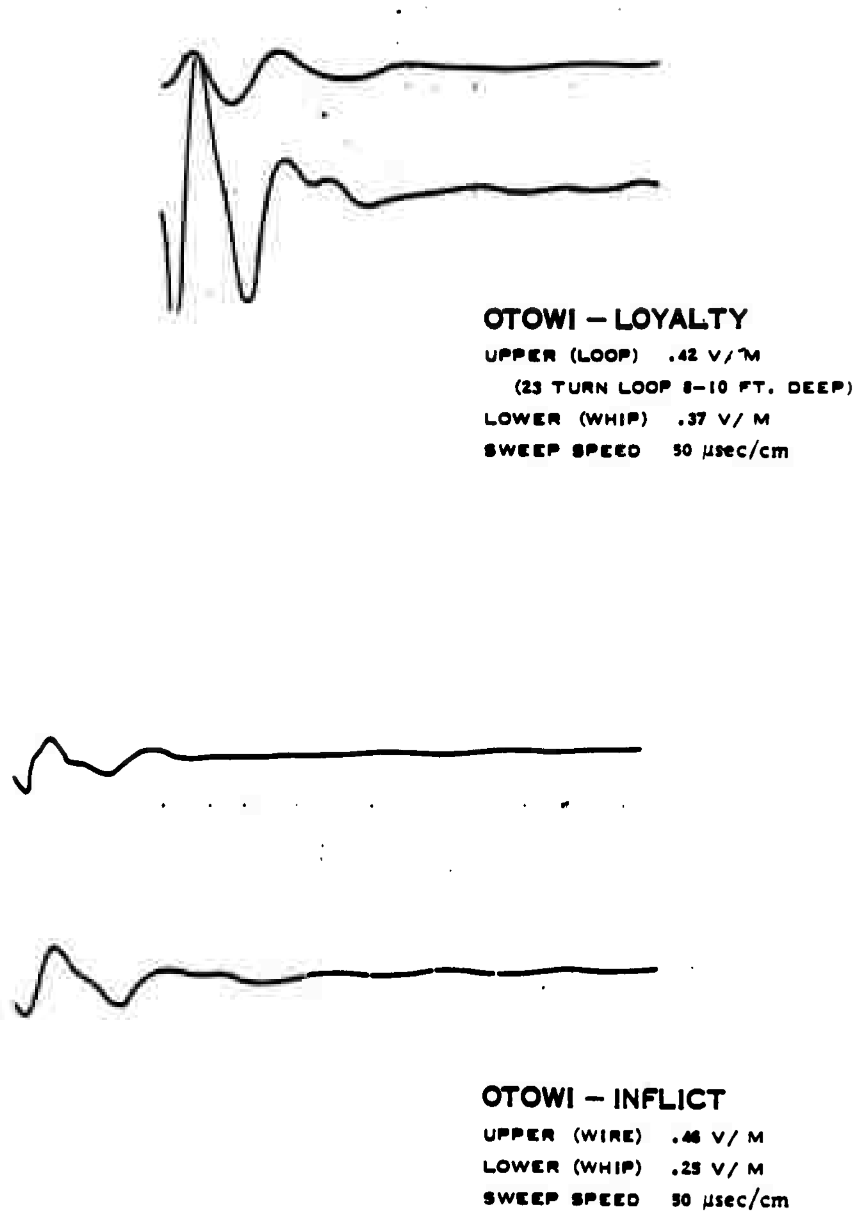
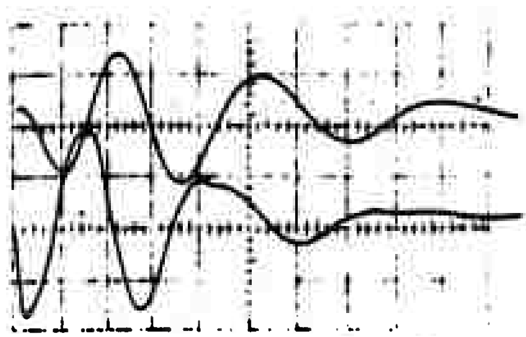
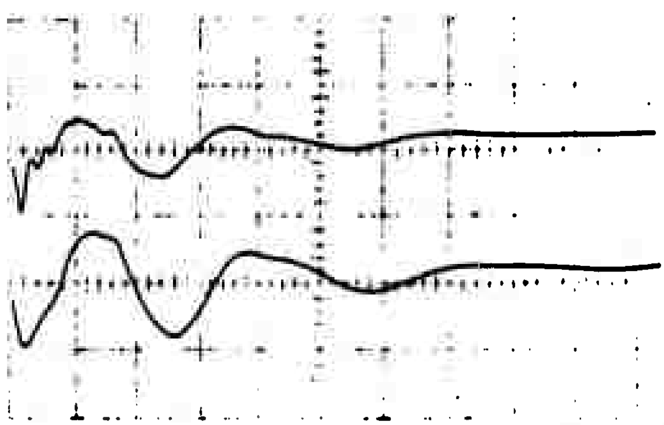


Figure 3.16 Experimental signal, film, Shot Otowi.

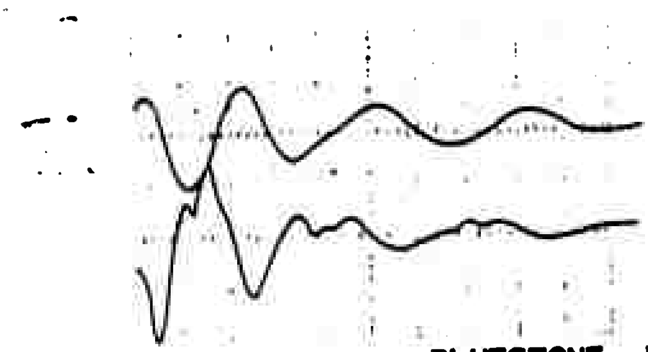


BIGHORN — LOYALTY
UPPER (LOOP) 1.95 V/ M
(23 TURN LOOP 8–10 FT. DEEP)
LOWER (WHIP) 1.4 V/ M
SWEEP SPEED 50 μsec/cm



BIGHORN — INFLICT
UPPER (WIRE) 2.26 V/ M
LOWER (WHIP) 1.56 V/ M
SWEEP SPEED 50 μsec/cm

Figure 3.17 Experimental signal, film, Shot Bighorn.

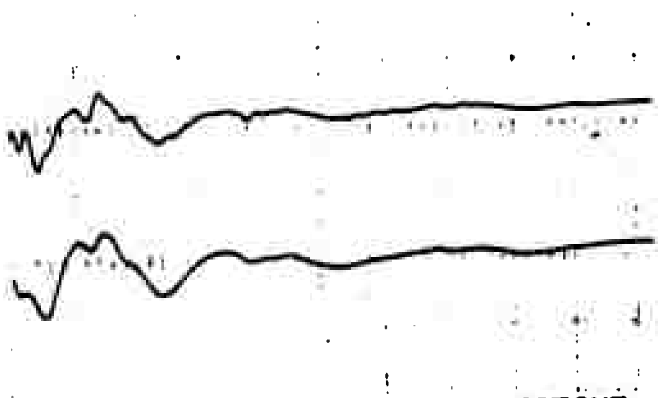


BLUESTONE — LOYALTY

UPPER (LOOP) 2.01 V/ M

(23 TURN LOOP 8–12 FT. DEPTH)

SWEEP SPEED 50 μsec/cm



BLUESTONE — INFLICT

UPPER (WIRE) .99 V/ M

LOWER (WHIP) .62 V/ M

SWEEP SPEED 50 μsec/cm

Figure 3.18 Experimental signal, film, Shot Bluestone.

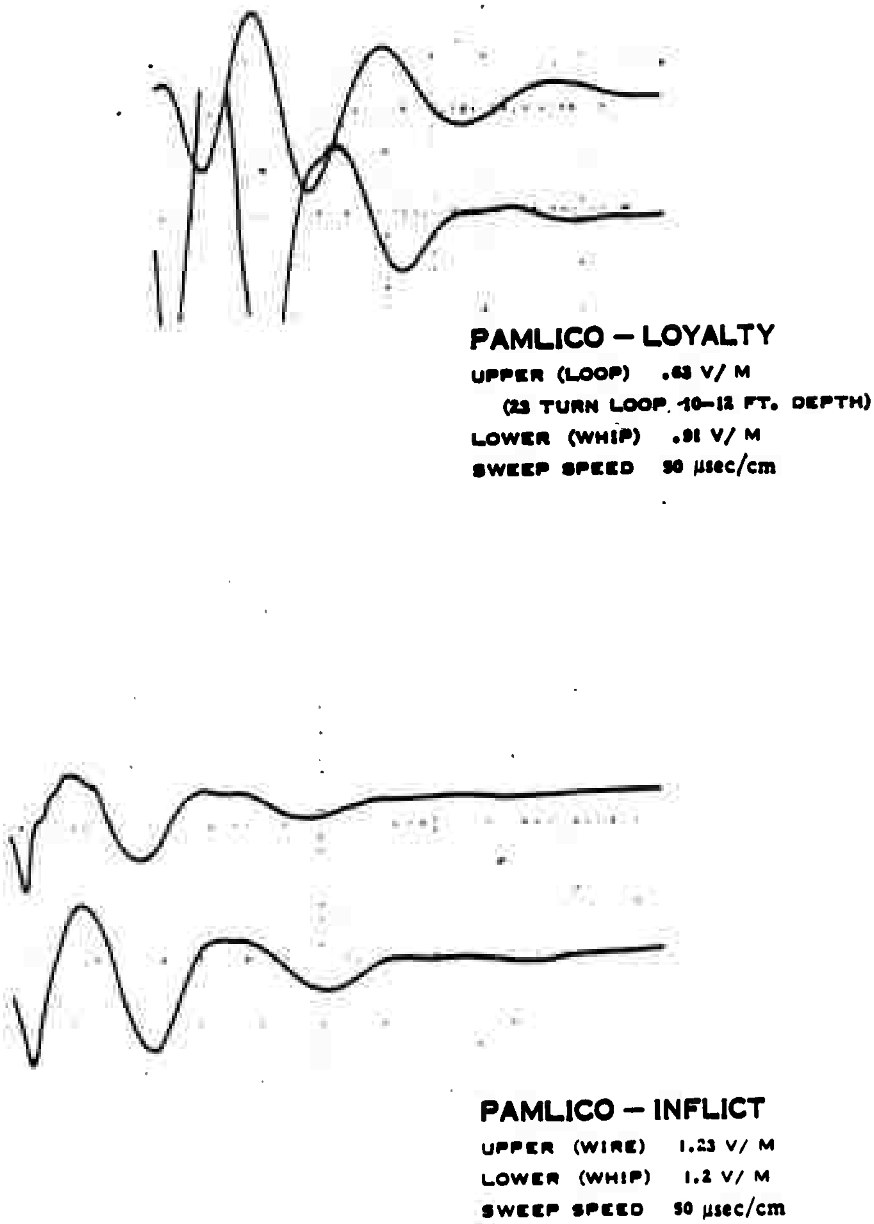
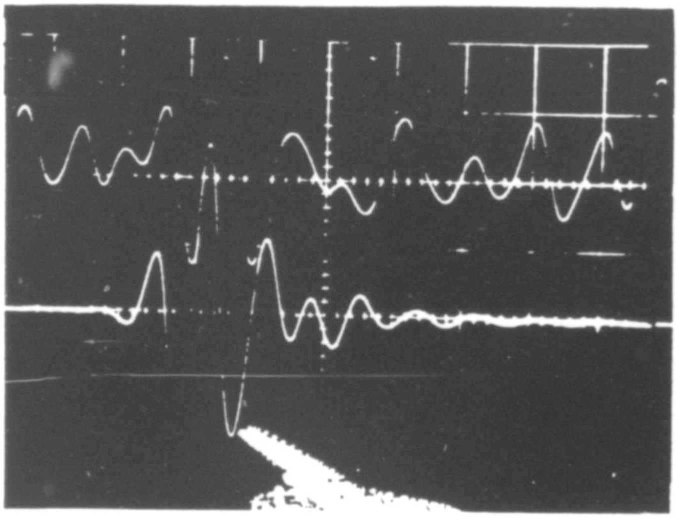
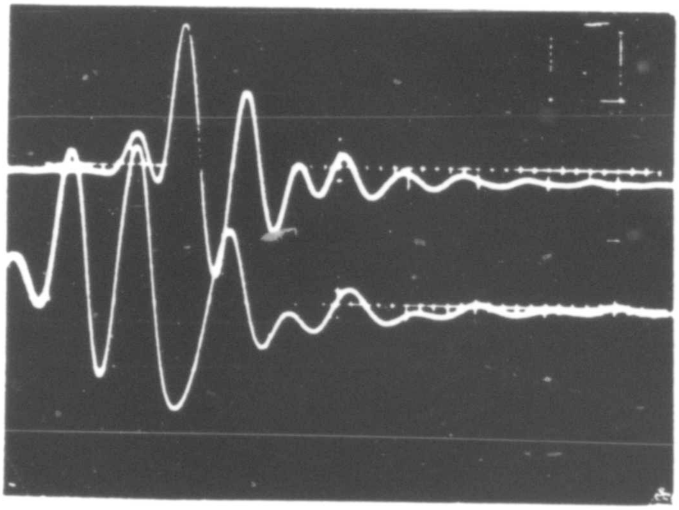


Figure 3.19 Experimental signal, film, Shot Pamlico.

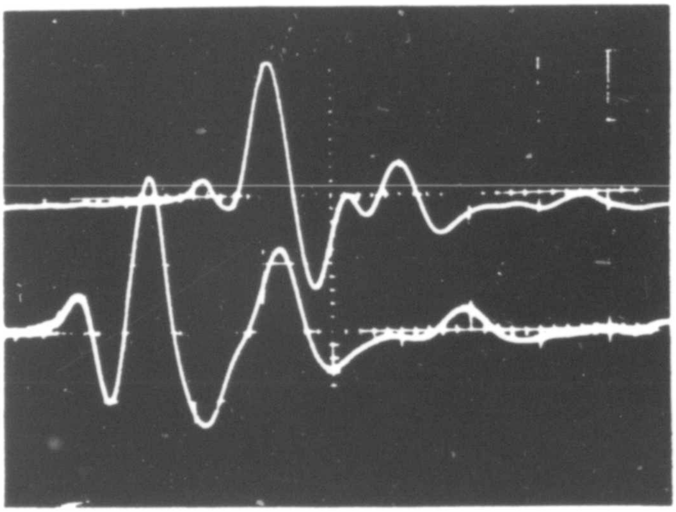


ADOBE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm



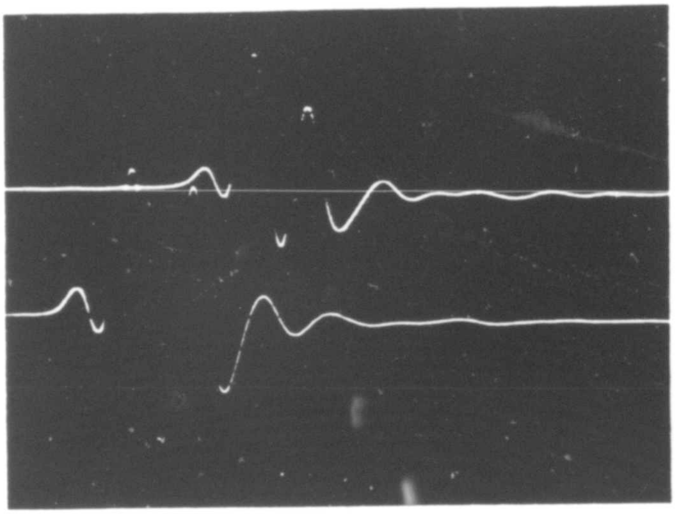
ADOBE: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.20 Experimental signal, tape, Shot Adobe.



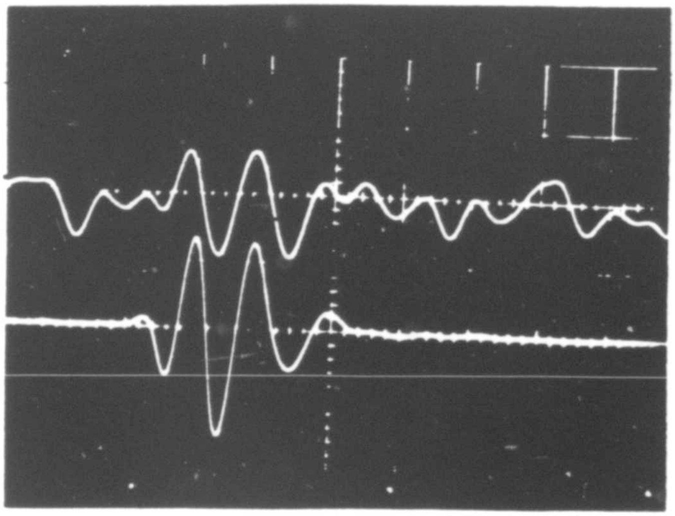
ARKANSAS: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.21 Experimental signal, tape, Shot Arkansas.

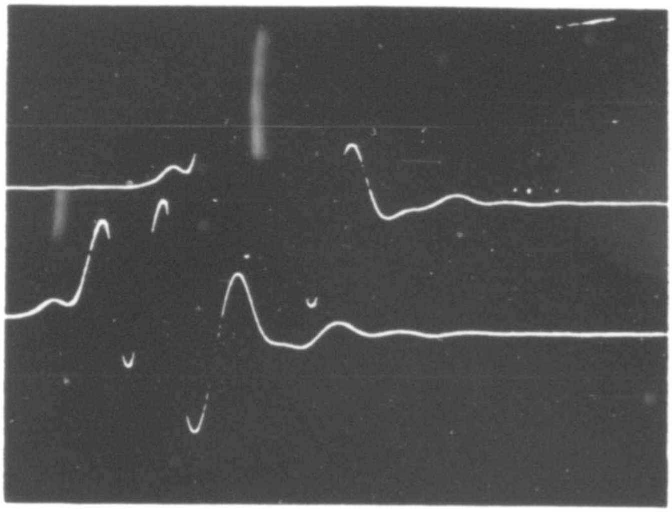


QUESTA: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.22 Experimental signal, tape, Shot Questa.

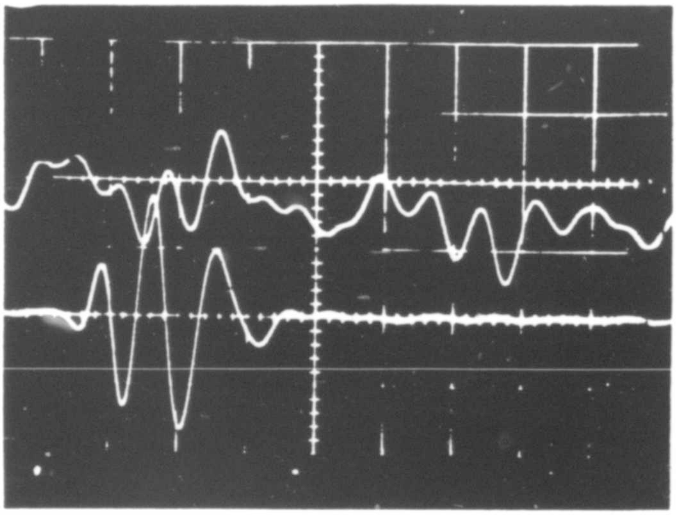


FRIGATE BIRD: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

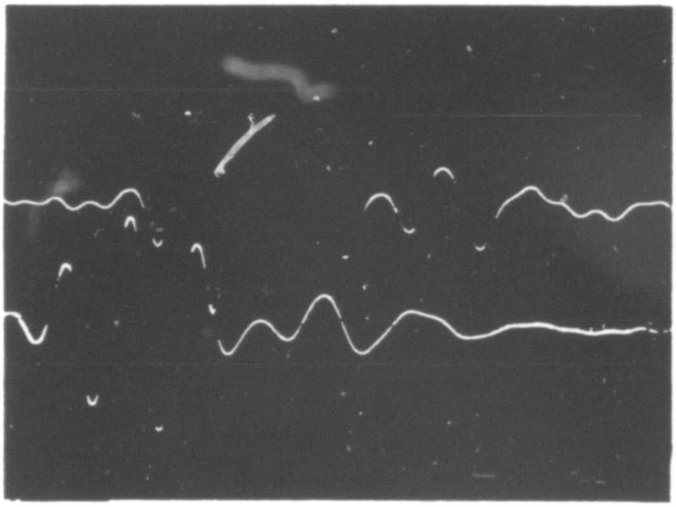


FRIGATE BIRD: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.23 Experimental signal, tape, Shot Frigate Bird.

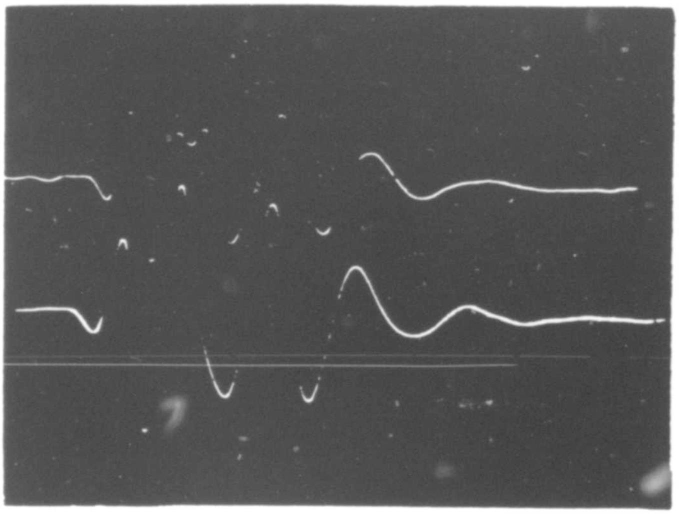


YUKON: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

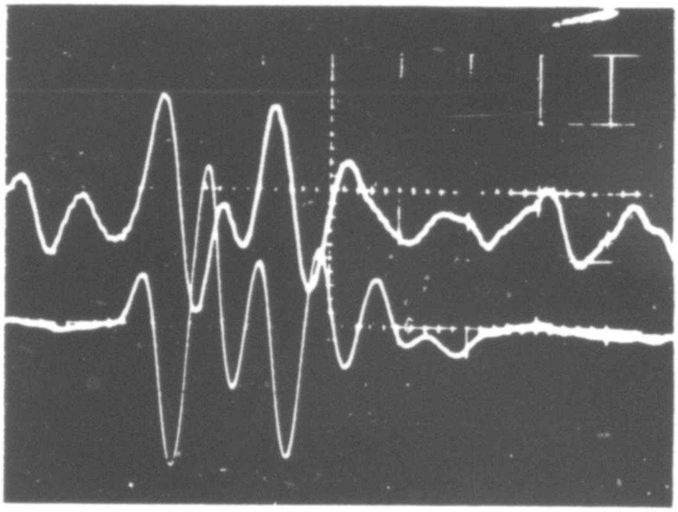


YUKON: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.24 Experimental signal, tape, Shot Yukon.

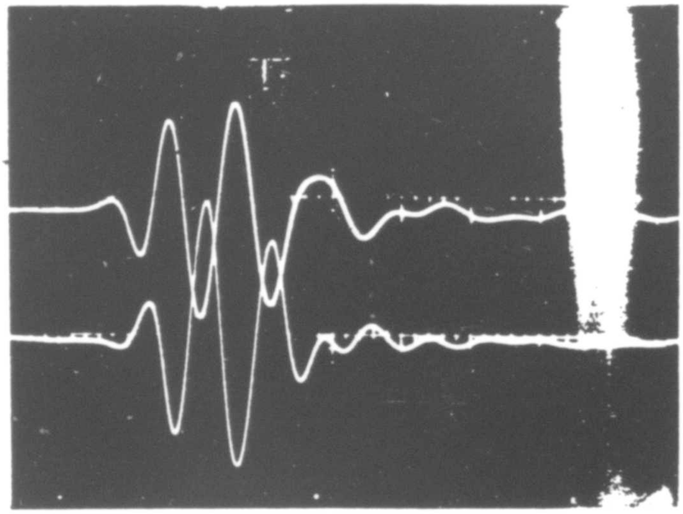


MESILLA: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

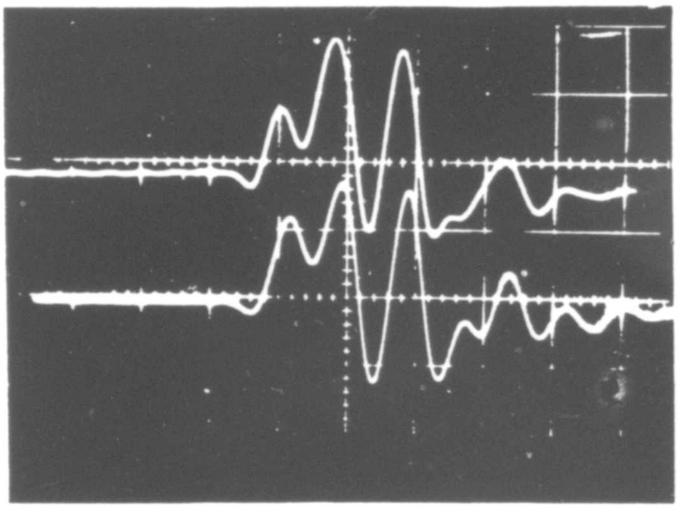


ENCINO: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.25 Experimental signals, tape, Shots Mesilla and Encino.

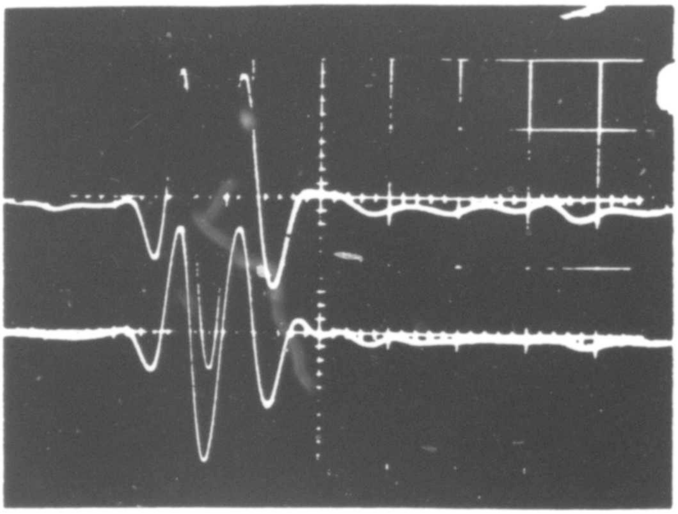


SWANEE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

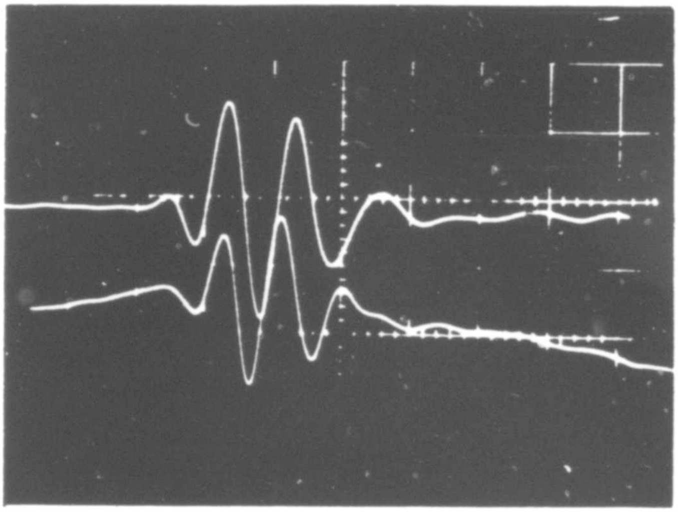


SWANEE: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.26 Experimental signal, tape, Shot Swanee.

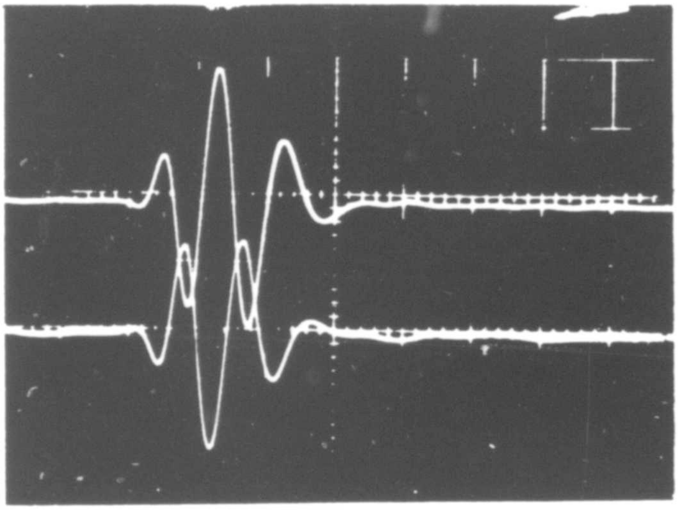


CHETCO: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm



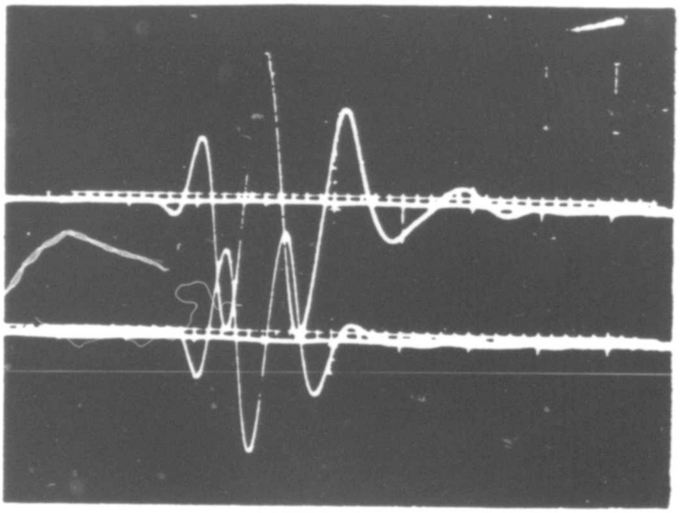
CHETCO: USS INFLICT
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.27 Experimental signal, tape, Shot Chetco.

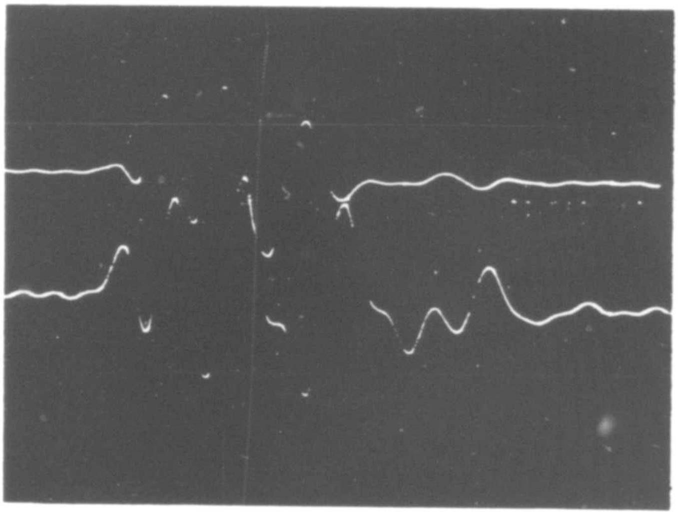


NAMBE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.28 Experimental signal, tape, Shot Nambe.

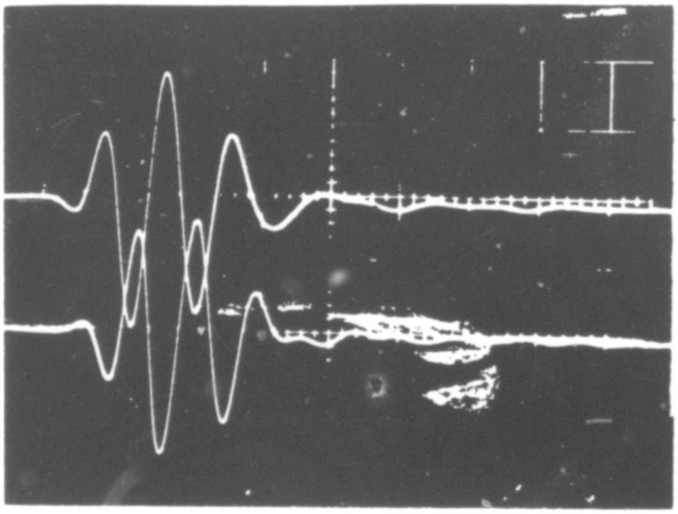


ALMA: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

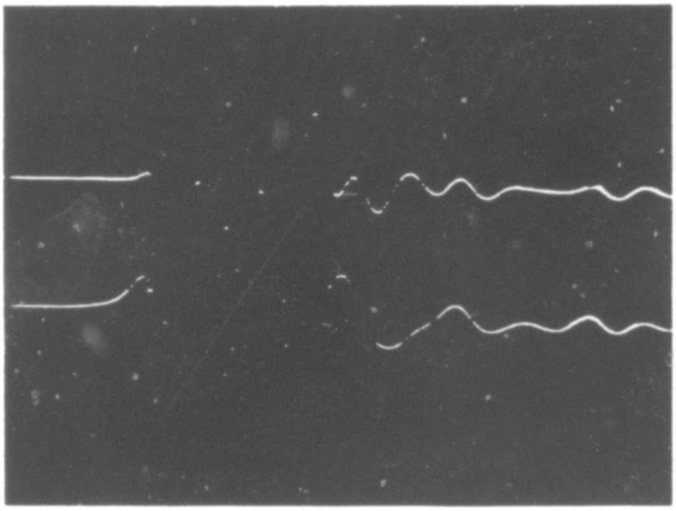


ALMA: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.29 Experimental signal, tape, Shot Alma.

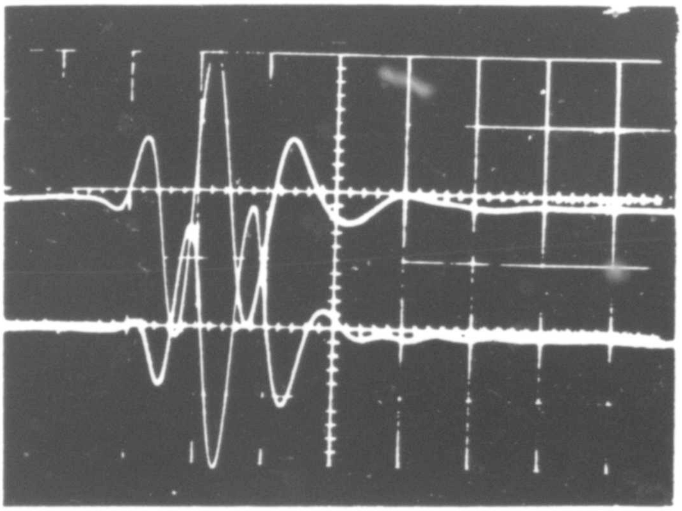


TRUCKEE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

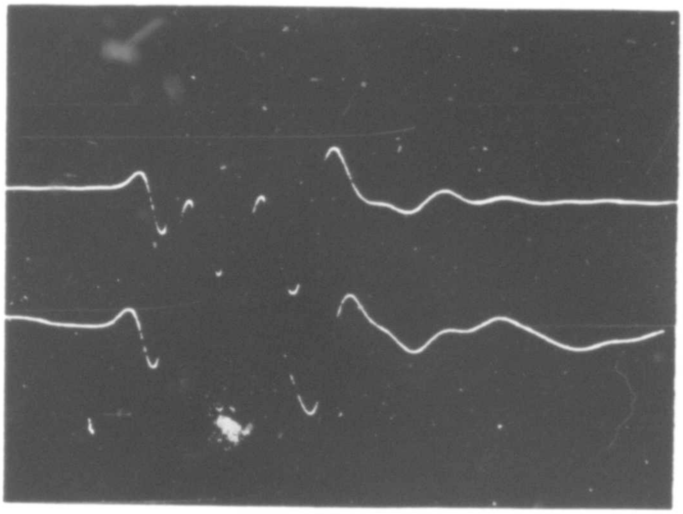


TRUCKEE: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.30 Experimental signal, tape, Shot Truckee.

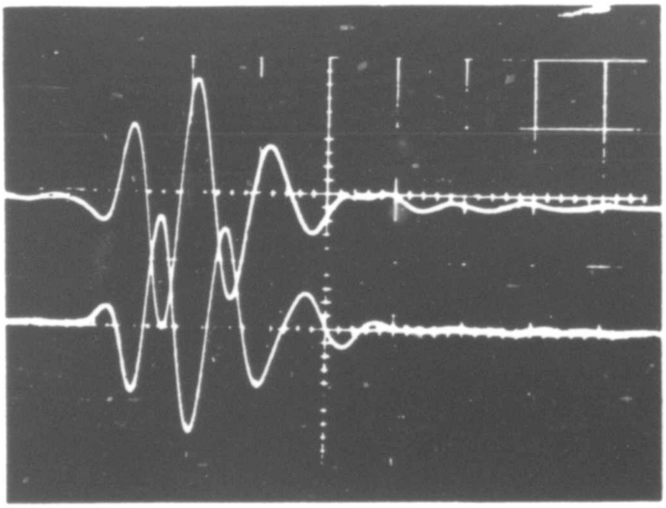


YESO: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

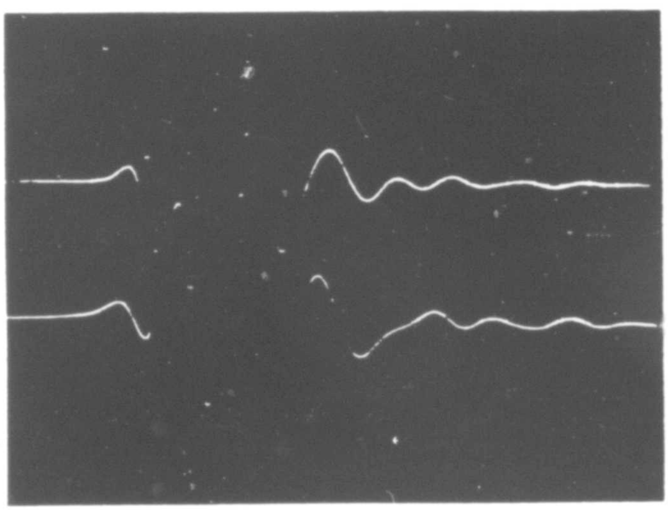


YESO: USS INFLICT
Upper-wire, lower-whip

Figure 3.31 Experimental signal, tape, Shot Yeso.

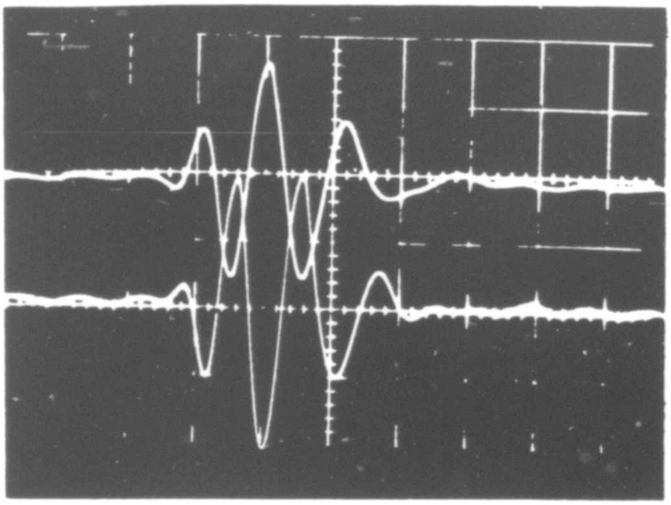


HARLEM: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

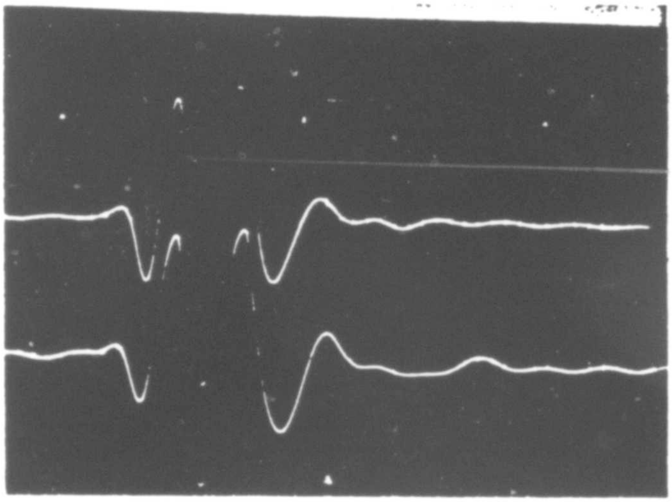


HARLEM: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.32 Experimental signal, tape, Shot Harlem.

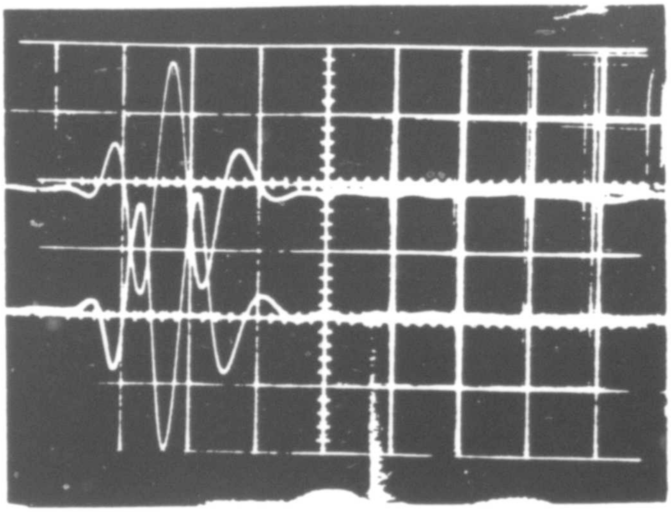


RINCONADA: USS LOYALTY
Upper-loop; lower-whip
Sweep speed, 0.1 msec/cm

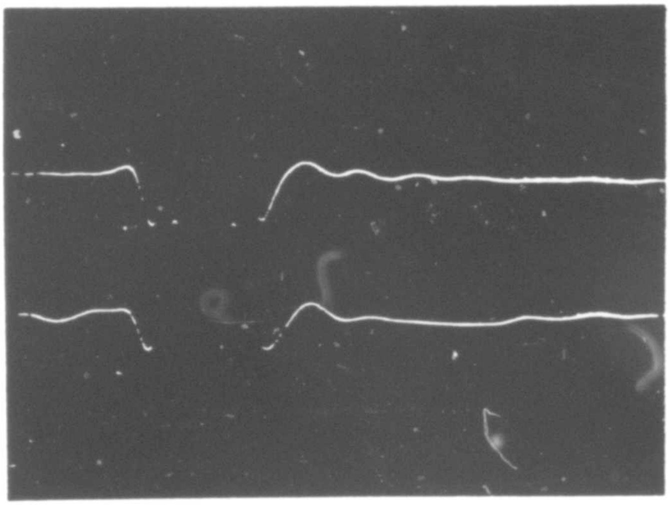


RINCONADA: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.33 Experimental signal, tape, Shot Rinconada.

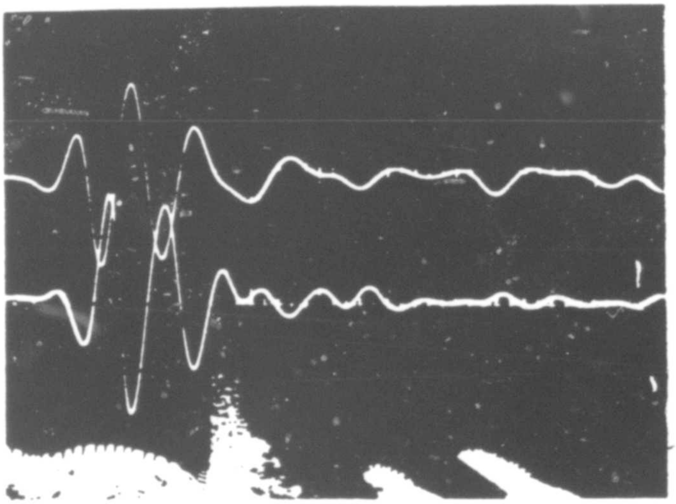


DULCE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

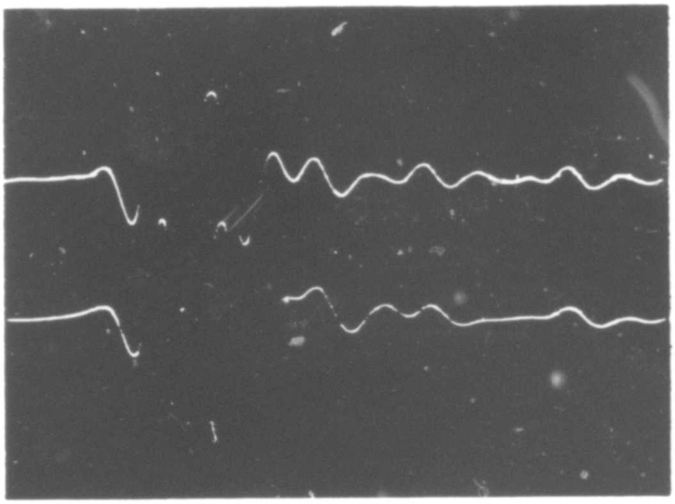


DULCE: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.34 Experimental signal, tape, Shot Dulce.

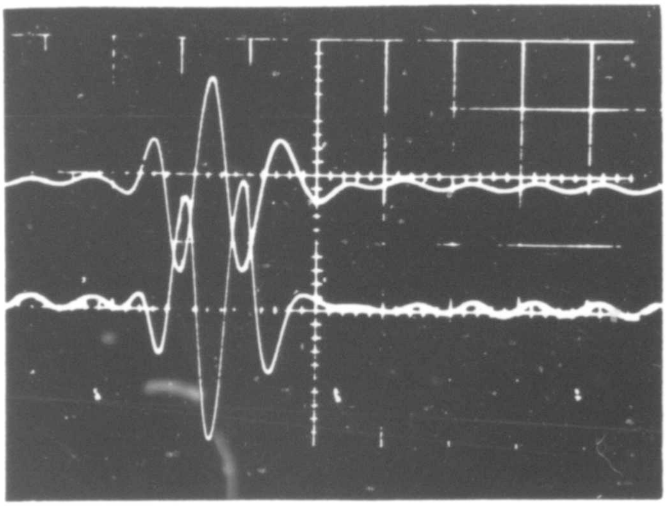


PETIT: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

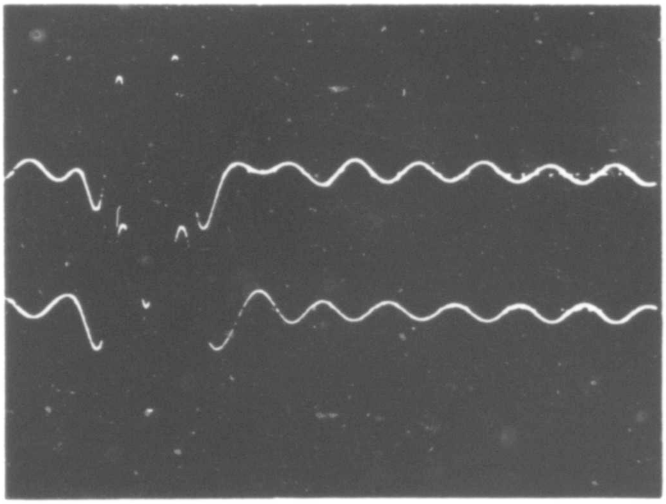


PETIT: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.35 Experimental signal, tape, Shot Petit.

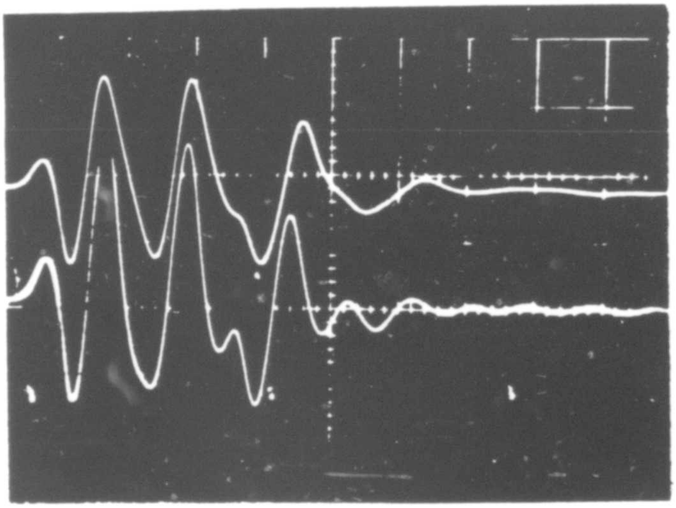


OTOWI: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

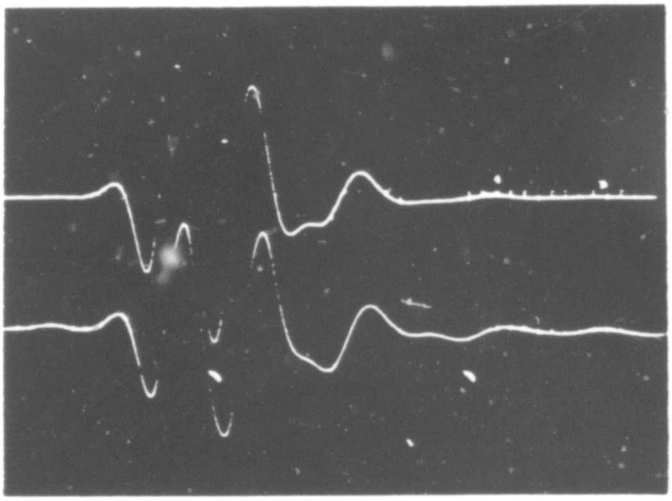


OTOWI: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.36 Experimental signal, tape, Shot Otowi.

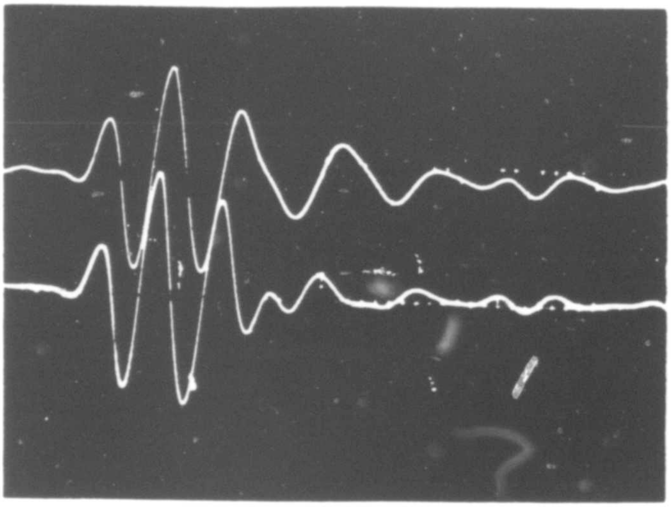


BIGHORN: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

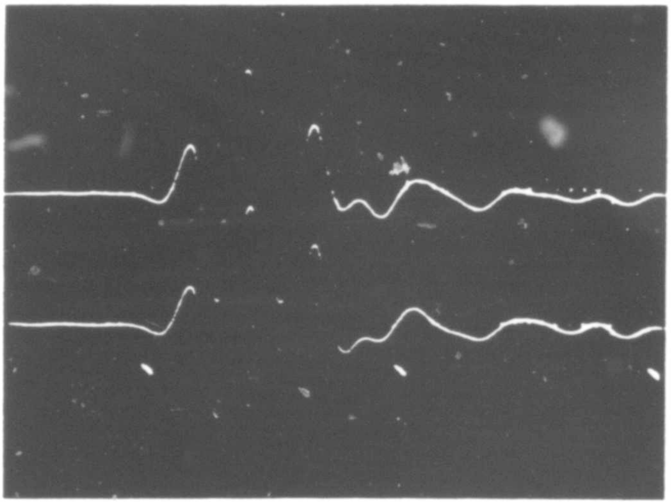


BIGHORN: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.37 Experimental signal, tape, Shot Bighorn.

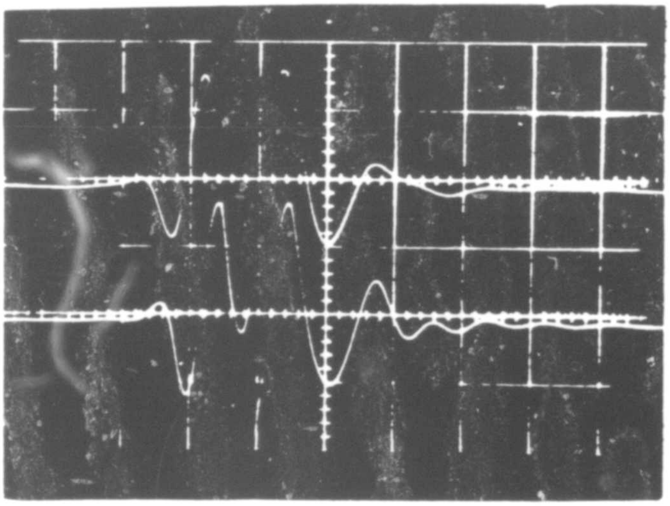


BLUESTONE: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm

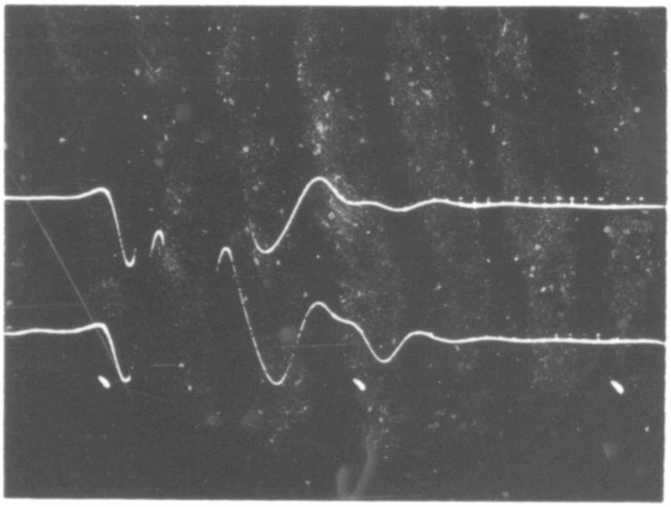


BLUESTONE: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.38 Experimental signal, tape, Shot Bluestone.



PAMLICO: USS LOYALTY
Upper-loop, lower-whip
Sweep speed, 0.1 msec/cm



PAMLICO: USS INFLICT
Upper-wire, lower-whip
Sweep speed, 0.1 msec/cm

Figure 3.39 Experimental signal, tape, Shot Pamlico.

CHAPTER 4

CONCLUSIONS

The data accumulated on the EM pulse generated by the series of shots in this test are sufficient to confirm the feasibility of an IBDA system. The desired information on the effect of air-water phase shift and attenuation on transmission of VLF signals is readily available using the recorded data.

Equipment limitations influenced the majority of data taken; nevertheless, the objectives of the program were fulfilled. If such a measurement program were to be undertaken in the future, sufficient lead time should be made available for the preparation of higher quality equipment.

The results illustrate that a submarine can be a useful observational station for detecting not only the self-launched nuclear weapons but could also detect other nuclear bursts. This has operational significance in cases where information on nearby nuclear action would be of value to the operational submarine.

The decrease in noise level for underwater antennas is very significant and results in further optimism regarding the depth to which underwater antennas could detect the relatively strong nuclear signals. This noise reduction was not observed on the long, floating wire antenna.

REFERENCES

1. "A Preliminary Study of A Surveillance System(U)", KN-62-790A(R), 12 January 1962, Kaman Nuclear, Secret Restricted Data.

2. "Feasibility of An Indirect Bomb Damage Assessment System for the Mark 2 Polaris Submarine(U)", KN-61-730(P), 25 April 1961, Kaman Nuclear, Secret Restricted Data.

3. "A Nuclear Surveillance System for the Polaris Submarine(U)", KN-60-7(R), 28 January 1960, Secret Restricted Data.

4. J. P. Wesley, "Theory of Electromagnetic Field From a Ground Shot:, UCRL-5177, Lawrence Radiation Laboratory, Livermore, California, July 1958, Confidential-Formerly Restricted Data.

5. R. E. Clapp, "Coherent Radiation From Nuclear Detonations(U)", Report No. 264E002, 27 July 1956, Ultrasonic Corporation, Secret Restricted Data.

6. J. A. Kemper and Herbert Reno, "HARDTACK, Phase I: Waveforms and Spectra", NBS Report 3CB107, September 1959, National Bureau of Standards, Secret Restricted Data.

7. A. G. Jean, Jr., and W. L. Taylor, "Quarterly Report On Project T/620/E-NBS for Period Ending December 30, 1955", NBS Report 3C121, Secret Restricted Data.

8. R. M. Kloepper, "Electromagnetic Measurements", WT-1223, Operation TEAPOT, Project 13.3C, 9 May 1957, Los Alamos Scientific Laboratory, Secret Restricted Data.

9. S. D. Abercrombie, "A Note on United Kingdom Electromagentic Recording System as at Present Used for Nuclear Surveillance and Possible Future Developments", Notes from Disarmament Conference.

10. W. C. Johnson, "Amateur V.L.F. Observation QST", March 1960, and private correspondence, 1961.

11. Chin-Lin Chen, "The Small Loop Antenna in a Dissipative Medium", Cruft Laboratory Technical Report 369.

END

Page 97 deleted