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AN/AIC-22(V) INTERCOMMUNICATIONS SET
FIBER OPTIC LINK
ENGINEERING ANALYSIS REPORT

August 1990

Prepared Under Contract N00014-90-C-2033
For
The Naval Research Laboratory
Optical Sciences Division (Code 6503)

Prepared by

ARC Professional Services Group 1375 Piccard Drive, Rockville, MD 20850

Technical Report # TR 2917

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FIBER OPTIC LINK
ENGINEERING ANALYSIS REPORT

August 1990

Prepared Under Contract N00014-90-C-2033
For
The Naval Research Laboratory
Optical Sciences Division (Code 6503)

Prepared by: Roland D. Hickson, Jr.

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ABSTRACT

Electromagnetic interference (EMI) problems constitute a serious threat to operational Navy aircraft systems. The application of fiber optic technology is a potential solution to these problems.

EMI reported problems in the P-3 patrol aircraft AN/AIC-22(V) Intercommunications System (ICS) were selected from an EMI problem database for investigation and possible application of fiber optic technology. A "proof-of-concept" experiment was performed to demonstrate the level of EMI immunity of fiber optics when used in an ICS.

A full duplex single channel fiber optic audio link was designed and assembled from modified government furnished equipment (GFE) previously used in another Navy fiber optic application. The link was taken to the Naval Air Test Center (NATC) Patuxent River, Maryland and temporarily installed in a Naval Research Laboratory (NRL) P-3A aircraft for a side-by-side comparison test with the installed ICS. With regards to noise reduction, the fiber optic link provided a qualitative improvement over the conventional ICS. In an effort to obtain a quantitative measure of comparison, audio signals were injected into both the fiber optic link and the aircraft ICS. Data was recorded from both the AN/AIC-22(V) and the fiber optic link over a limited portion of the audio frequency range both with and without operation of the aircraft VHF and UHF radio transmitters.[1]

Lessons learned from this "proof-of-concept" demonstration suggest a reduction of radio frequency interference from incorporation of fiber optics in future ICS designs. A recommendation is made for further fiber optic ICS link development and parallel in-flight testing with an installed ICS. Data on fiber optic link performance obtained during this development will be used as input to aircraft fiber optic specifications and standards for future ICS installations.

[1] Very High Frequency (VHF) and Ultra High Frequency (UHF) transceivers.

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1.0 INTRODUCTION

1.1 Purpose

The purpose of this report is to document technical activities performed to investigate the application of fiber optics as a potential solution to known electromagnetic interference (EMI) problems in a Navy P-3A aircraft AN/AIC-22(V) Intercommunications System (ICS). This report was developed under a Naval Research Laboratory (NRL) contract N00014-90-C-2033, Contract Data Requirements List (CDRL) 00101.

1.2 Scope

The work performed under this task included: (1) review of the NAVAIR ASEMICAP (Air Systems EMI Corrective Action Program) Management Information and Tracking System (AMITS) database for initial problem definition; (2) investigation of EMI problems in the system selected from the AMITS, AN/AIC-22(V) ICS in a Navy P-3A aircraft; (3) development of a concept by which certain identified EMI problems might be solved through application of fiber optic technology; (4) modification of government furnished equipment (GFE) for a single channel voice ICS link; (5) ground testing of the prototype link in a side-by-side comparison with the installed ICS; (6) analysis of the test data collected; and (7) submission of this final report. The technical activities discussed herein were performed during the period September - December 1989. Since this task was performed under the purview of the Naval Air Systems Command Electromagnetic Environmental Effects/Fiber Optics Working Group (NAVAIR E^3/FOWG) a preliminary briefing of the link demonstration and data results was presented to that group during January 1990.

1.3 Background

In a 1989 Memorandum,[2] the Chief of Naval Operations (CNO) refocused the fiber optic program "to ensure Navy-wide implementation in a well structured, carefully planned and expedient manner." Responding to CNO direction, NAVAIR developed a Plan of Action & Milestones (POA&M) for fiber optics in naval aircraft programs.[3] Key milestones in this POA&M involved the identification of candidate systems and platforms for application of fiber optic technology and the development of fiber optic specifications and standards.

A specific NAVAIR action, under the cognizance of AIR-5161, was the establishment of the E^3/FOWG. The objective of this working group is to identify and investigate aircraft system EMI problems which might benefit from the inherent immunity to EMI of fiber optic technology.

As a baseline for reference, EMI is defined as any electromagnetic disturbance which interrupts, obstructs, or otherwise degrades or limits the effective performance of electronic and

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2. Chief of Naval Operations Memorandum Ser 00/9U500170 Dtd 4 May 1989.

3. NAVAIR Ltr. Ser AIR-933E/0713 Dtd 3 Aug 1989.

electrical equipment. For the purpose of this report, EMI refers to any electromagnetic disturbance occurring on the audio portion of the ICS.

Under the direction of the Communications, Navigation and Identification (CNI) subgroup of the E^3/FOWG, ARC was tasked to conduct an engineering analysis of the P-3 ICS EMI problem, perform a "proof-of-concept" demonstration of a fiber optic solution, report the results to the working group, and recommend future action.

1.4 Summary of Conclusions and Recommendations

Major conclusions reached as a result of this task performance were:

- The fiber optic link demonstrated a marked improvement compared to the installed AN/AIC-22(V) ICS in the presence of a known source of EMI.

- A low level of EMI (in comparison to the EMI present in the conventional ICS) was observed in the fiber optic link when the aircraft VHF and UHF transmitters were operated. It was concluded that this EMI was due in part to the unshielded electronic components in the GFE used in the fiber optic link and in part to the coupling paths between the test equipment power lines and the aircraft.

Based on the conclusions, the following actions are recommended:

- Brief the results to NAVAIR class desks and engineering support codes involved with aircraft ICSs to report the benefits of using fiber optic technology in the reduction of EMI susceptibility problems.

- Develop a more advanced multi-station fiber optic link with shielded electronics for an in-flight, side-by-side comparison test with an existing ICS.

- Initiate planning to address the design of an all fiber optic ICS.

2.0 TECHNICAL APPROACH

2.1 Summary of Technical Approach

In performing the ICS engineering analysis task, a technical approach was developed which consisted of the following steps:

- Review the AMITS database for initial problem definition.
- Conduct liaison with NATC personnel for both aircraft scheduling coordination and, with other users, detailed problem definition.
- Investigate the utility of an EMI sweep of the selected P-3A aircraft.
- Acquire and study engineering information for the installed AN/AIC-22(V) ICS and conduct aircraft walk-through.
- Receive and study GFE from a previous shipboard installation for potential use in a single channel voice ICS link.
- Redesign the GFE to create a prototype fiber optic voice link and test the link for compatibility and integration with conventional ICS.
- Install and check operation of the prototype fiber optic voice link in the P-3 aircraft.
- Conduct a side-by-side comparison of the fiber optic voice ICS link with the installed AN/AIC-22(V).
- Conduct preliminary data analysis, report results to the E^3/FOWG and recommend further actions.
- Prepare inputs for draft fiber optic specifications and standards for aircraft ICSs.
- Prepare a final report on the P-3 ICS engineering task.

Prior to task start, a briefing was presented to NRL which included a complete engineering approach to the ICS EMI problem. The full program was not possible due to time (aircraft availability) and funding constraints. During the initial planning period, NRL provided GFE for a fiber optic link development. This GFE had previously been part of a fiber optic Radar Display and Distribution System (RADDS) demonstration in USS Nimitz (CVN-68). GFE was provided through coordination with Naval Sea Systems Command (SEA 56ZC).[4]

2.2 Candidate System Identification

Early in 1989 the CNI Subgroup was directed to identify EMI problems in aircraft systems which would benefit from use of fiber optic technology.

Under the cognizance of NAVAIR 5161, and as a part of the ASEMICAP, aircraft are routinely tested at NATC Patuxent River, Maryland for susceptibility to EMI. Results and data from these tests are entered into the AMITS data base. A review of the unclassified portion of the AMITS database revealed a common thread for all reported aircraft: **The ICS was entered as either the source or victim (or both) of EMI in every reported aircraft type.**

Since NRL operates P-3A aircraft at NATC as research platforms, it was suggested that this model was a convenient vehicle for the ICS problem investigation. Although the AMITS database included only one P-3 ICS problem ("ICS at normal volume modulates any COMM keyed"), that problem had serious security implications.

During the NAVAIR E^3 Semi-Annual Review in the Spring of 1989, Naval Air Development Center (NADC) representatives reinforced the selection of the P-3 ICS by reporting that significantly more EMI problems existed than were recorded in the AMITS. Subsequent discussions with NRL Patuxent River aircrewmen, civilian engineers and maintenance personnel further amplified and verified the ICS EMI problems.

Following these discussions, access to an NRL P-3A aircraft was established through the NRL Detachment at NATC. The P-3A ICS, AN/AIC-22(V), was accepted as the target system to be investigated and the CNI subgroup was tasked to conduct an engineering analysis and to demonstrate a fiber optic solution.

2.3 Considerations for EMI Elimination

When the AN/AIC-22(V) EMI problem was presented to the E^3/FOWG, some discussion arose regarding solutions which included filtering, shielding of cables and the use of fiber optic components. One approach included the location and correction of problems through modification of the ICS system without use of fiber optics. This approach is the conventional approach and normally involves the investigation and determination of the most EMI susceptible system units and cabling (such as grounding schemes, power supply filtering, shielding effectiveness of components, antenna loop elimination, wiring runs optimization and other routine gsusceptibility considerations) followed by recommendations for improvements to the ICS.

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4. Documentation for the GFE was available in Johns Hopkins University/Applied Physics Laboratory (JHU/APL) Report FS-88-044 of October 1988 entitled "Fiber Optic Radar Link USS NIMITZ Shipboard Demonstration, Final Report, Volume I". The USS Nimitz link was one of several fiber optics demonstrations systems sponsored by NAVSEA 56ZC to aid in the development of standards and specifications for future shipboard installations. ISC Cardion fabricated the USS Nimitz Link.

During the initial stages of problem definition, it was suggested that a radio frequency (RF) sweep of the P-3 aircraft be accomplished to localize the EMI problems. Detecting the source and location of EMI historically has been difficult, time consuming, and inconclusive. In addition to time constraints, these techniques require a dedicated aircraft for assessment and funding for the instrumentation and data recording effort. These factors were the primary considerations in the decision not to perform an RF sweep as part of the ICS engineering analysis task. Without information to localize EMI within the system, it was not possible to recommend specific modifications to the conventional system to reduce EMI susceptibility.

Because the charter of the working group involves the investigation of fiber optics as a possible solution to EMI problems (not the development of system modifications), it was decided that a test be performed comparing the installed ICS to a single channel, fiber optic ICS link constructed from modified GFE. The primary objective of this investigation was to show that a fiber optic audio link could be operated in an aircraft environment and not be affected by EMI. A secondary objective was to gain information which could be used as input to future specifications and standards for fiber optics use in aircraft.

2.4 Problem Investigation

Following the initial problem definition, discussions were held with personnel involved in the maintenance and operations of the NRL P-3A aircraft. A physical survey of the aircraft installation was conducted to examine the layout of the ICS. Technical drawings for the AN/AIC-22(V) were obtained from the Naval Air Development Center (NADC), Warminster, Pennsylvania. The NRL detachment at NATC provided a copy of the AIC-22 technical manual, ICS components, ICS information, materials, and access to both facilities and an aircraft.

A detailed study of the available data was accomplished and maintenance technicians from NRL and the NATC Aircraft Intermediate Maintenance Department were consulted to gain practical advice, failure data, operating procedures, and other insight into probable problems to be expected. Since the primary P-3 mission involves Antisubmarine Warfare (ASW), engineers from the Force Warfare Directorate of NATC, whose task is to develop ASW tactics and to test airborne ASW equipment, were consulted. These engineers were queried to take advantage of their intimate knowledge of P-3 (Series) systems gained from years of experience in operating the aircraft. They were helpful in providing first-hand knowledge of the aircraft, differences between systems in P-3A and P-3C aircraft, and a history of the evolution of the ICS in the P-3 (Series). They acknowledged that **EMI had been a continuing problem in the P-3 ICS**, and they were very enthusiastic about the prospect of a fiber optic solution to those problems. They expressed a desire to participate in the project, if possible. Unfortunately, schedule conflicts precluded full utilization of their valuable assistance.

2.5 Introduction of Fiber Optics In The ICS

Several concepts were investigated for introducing fiber optics into the ICS to measure reduction of reported EMI. The first concept, shown in Figure 2-1, envisioned using the major components of the ICS (see Appendix A for a brief description of the AN/AIC-22(V) ICS configuration). The C-4164(V)/AIC-22(V) Interphone Interconnecting Box Control would act as the central point of the fiber optic interface with two C-4162(V)/AIC-22(V) Interphone Master

Control stations. It appeared that all audio communications signals, both internal ICS and external transmit/receive audio sig..als passed through the Interconnect Box unit. Upon investigating the ICS documentation and talking to maintenance personnel at NATC, it was found that all but two radio receiver audio signal lines pass through the interconnect box for distribution to the crew station. The audio signal lines also connect to many aircraft terminal blocks, both to and from that interconnecting box and throughout the aircraft. The interconnect box, terminal blocks and aircraft cabling introduce convenient coupling paths for any EMI which might be in close proximity.

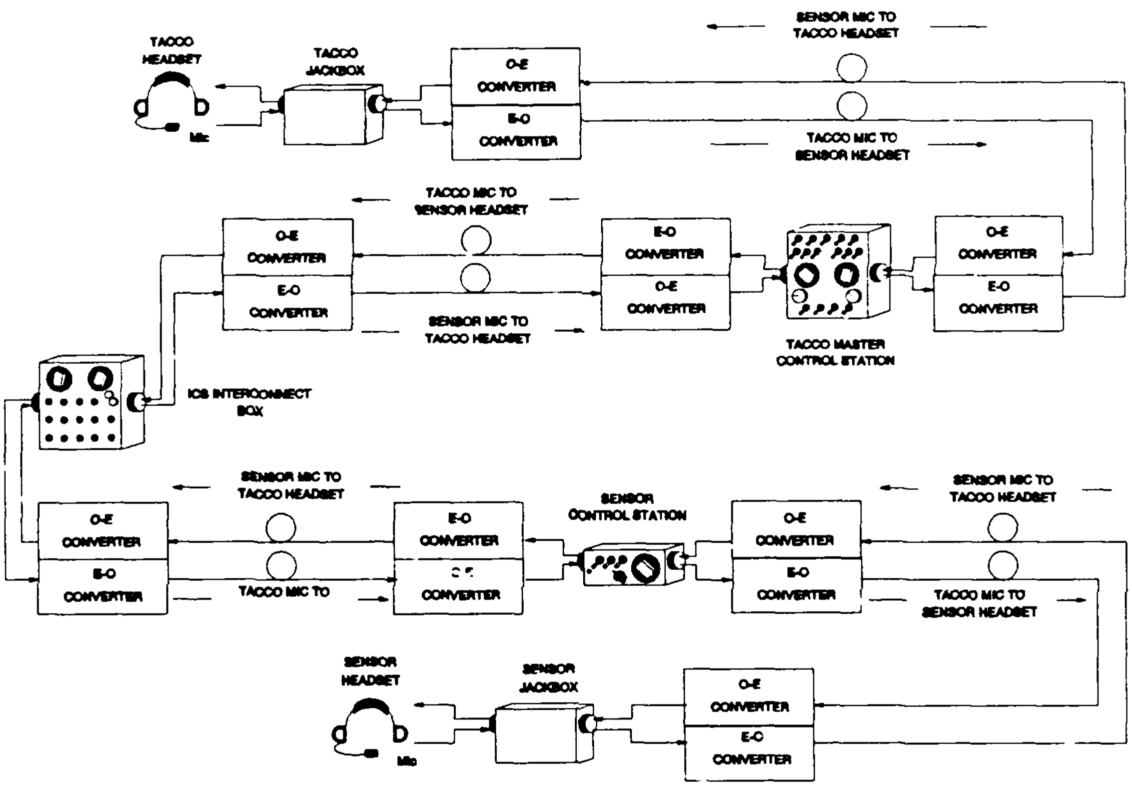


Figure 2-1

In order to run a full duplex fiber optic link from two crew control stations through the interconnect unit, eight optical transmitters (electrical-to-optical converters) and eight optical receivers (optical-to-electrical) would have been required. Unfortunately, there were insufficient numbers of operable transmit/receive units available from GFE for eight E-O/O-E conversions, and a simpler link had to be designed. The tight space constraints associated with the interconnect unit (wiring to a backplane connector through a large number of pins) also made this concept impractical within task constraints.

After investigating a number of intermediate concepts, it was decided to build the laboratory setup shown in Figure 2-2, consisting of a full duplex voice link incorporating fiber optic components from the USS Nimitz RADDS and only one type of aircraft ICS component: the AM-3364/AIC-22(V) Interconnecting Box Amplifier (or jackbox), The function of this unit in the ICS is to provide both amplification of the microphone audio and impedance matching for the headphone. Since all-fiber optic headsets were not available, the existing headsets were used. Distributed 28 V DC for the jackbox operation and standard 115V AC, 60 Hz, power receptacles for the fiber optic link were available in the aircraft. The existing GFE boxes from USS Nimitz were modified to provide a full duplex capability. Interface cables with cannon type connectors were fabricated to connect the Nimitz units to the jackboxes. Provision for the push-to-talk mode on the input/output devices was also considered. The final configuration, illustrated in Figure 2-3, did not require the use of the AM-3364/AIC-22(V) Interconnecting Box Amplifier (or jackbox) and provided the least complex alternative for the demonstration.

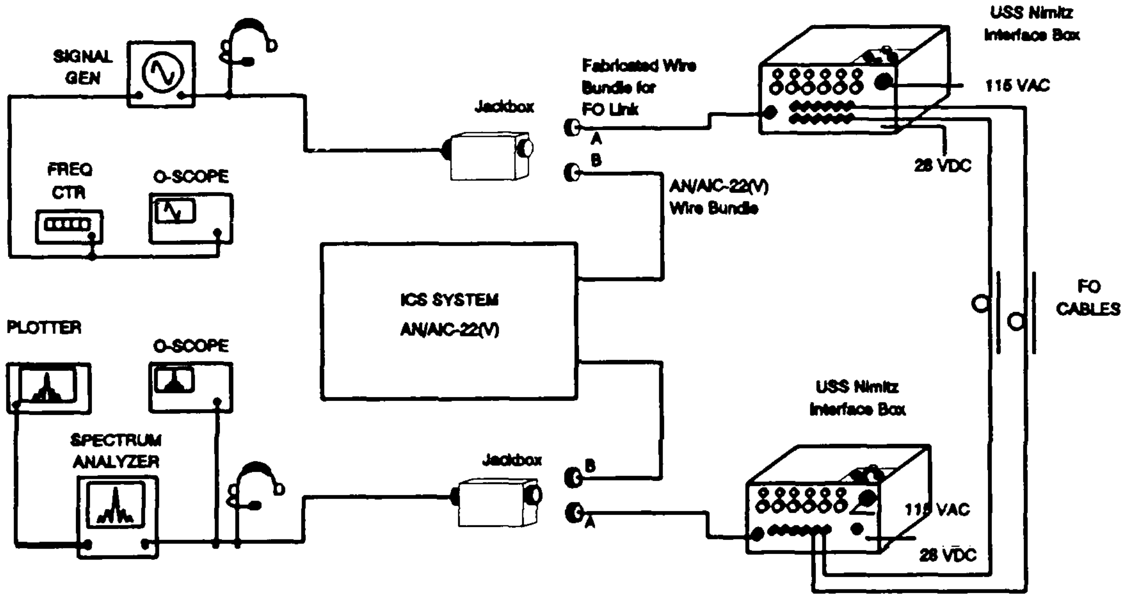


Figure 2-2

A disadvantage of the selected approach was the opportunity for EMI coupling into the fiber optic link components through aircraft power connections. The standard headset/mic unit with its long connecting cord also presented a potential antenna to fields which might be present in the aircraft. To mitigate these potential problems the copper wire interface cables between the headsets and the GFE units were kept as short as possible and components were shielded where practical.

2.6 Fiber Optic Link Preparation

Once the link concept was finalized, the GFE was modified and the fiber optic link constructed. Appendix B contains the details of the GFE modifications and link construction. The following summarizes steps taken to prepare the GFE for the fiber optic voice link:

- o Identify GFE component operation.
- o Test light emitting diodes (LED) and avalanche photodiodes (APD) in the GFE modules to select best components.
- o Remove excess circuitry from GFE boxes.
- o Acquire and mount fiber optic connectors.
- o Install interface cabling for 28 V DC operation.
- o Build Pi filter for power supply units.
- o Construct jackbox interface cabling and connectors.
- o Design, build and mount audio amplifier units.

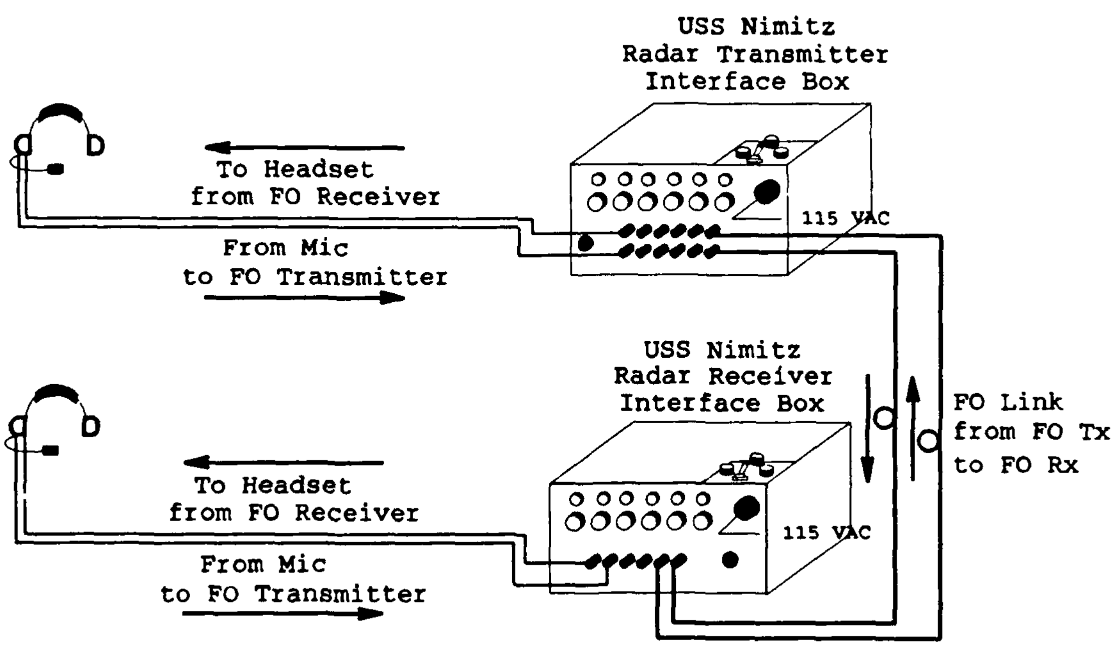


Figure 2-3

The optical cable used to connect the two units were two government furnished 100 foot lengths of 100/140 µm, step index, multi-mode optical fiber. These cables were equipped with ST connectors which matched the connectors of the GFE LEDs. The GFE APDs had been fitted with SMA connectors, so it was necessary to use SMA-ST jumper cables which were also 100/140 µm, step index, multi-mode fibers.

Since the primary purpose of the experiment was to demonstrate the immunity level of the fiber optic link to EMI, shielding of the associated electronics in the fiber optic units and filtration of primary power were considered to be important. The GFE units were built of steel and were considered to be reasonably shielded when closed. The highest frequency of the EMI was 400 MHz; hence, further shielding of the entry points into the GFE boxes was not considered necessary since the 115 V AC power line to the GFE had already been filtered, and a Pi filter was designed to filter the 28 V DC power in the jackbox.

Following modification, the GFE went through a laboratory checkout prior to aircraft testing. It should be noted at this point that the laboratory link configuration performed well and without any interference effects. Complete details of the test plan and procedures are discussed in Appendix C. The preliminary tests of the link in the laboratory used the same configuration and procedures as had been planned for the tests in the aircraft with the exception of primary AC and DC power sources. (The lab link used commercial AC power and a DC power supply.) However, due to unexpected problems with test equipment operation in the aircraft environment, the test plan had to be modified slightly. That modification is discussed in the next section.

2.7 Test Equipment Setup and Data Acquisition

The fiber optic link was tested in December 1989 at NATC in an NRL P-3A. Once the test setup was in place, both links were qualitatively checked by use of voice. Both links performed well and data acquisition for a quantitative test began with the recording of background noise on both systems without the injection of an audio reference signal. An audio reference signal was then injected into both the ICS and the fiber optic link, and the respective audio outputs were monitored while aircraft VHF and UHF radio transmitters were being operated at 131 MHz, 252 MHz, and 400 MHz. Data was recorded by a frequency spectrum analyzer for later analysis. Figure 2-4 is a diagram of the actual fiber optic link test set up. Note that the headset input is shown only for the AN/AIC-22(V). The original test plan was to inject the audio reference signal inputs through the headset connector into both the ICS and the fiber optic link (through an ICS jackbox) and to monitor the EMI effects on those signals. However, during the initial UHF operation, the monitored signals through both the ICS and the fiber optic link (using the ICS jackbox) showed essentially the same level of EMI. The test was repeated with the audio reference signal injected directly into the fiber optic link, and the monitored output for the fiber optic link showed significant reduction of EMI. Therefore, the test plan was modified to inject the audio reference signal into both the ICS (through the headset connector) and directly into the fiber optic link.

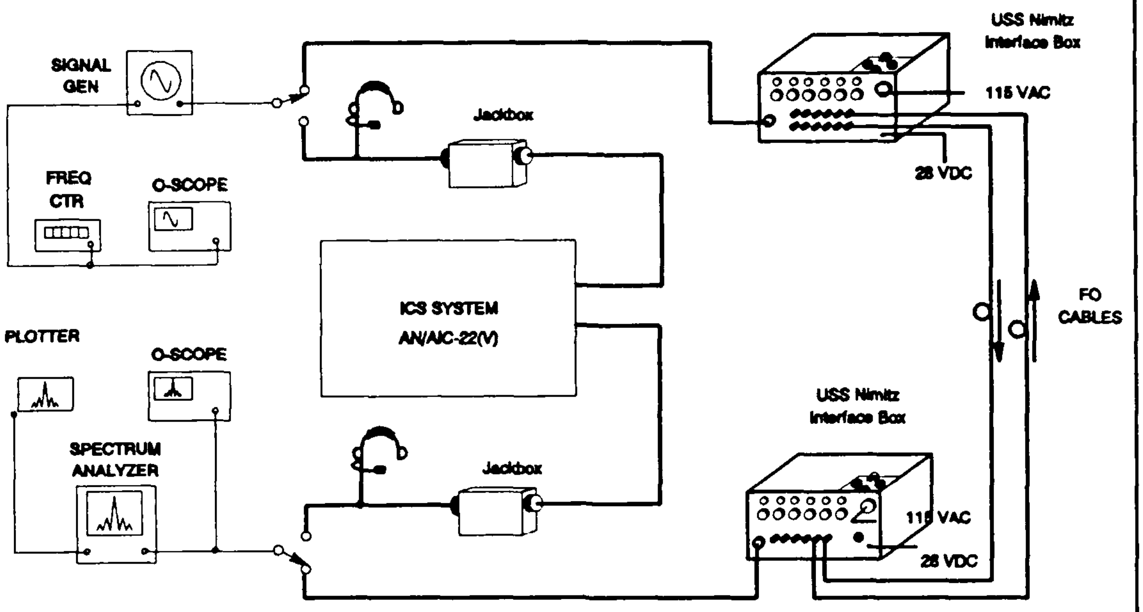

SIGNAL GEN
FREQ CTR
O-SCOPE
PLOTTER
O-SCOPE
SPECTRUM ANALYZER
Jackbox
Jackbox
ICS SYSTEM
AN/AIC-22(V)
USS Nimitz Interface Box
115 VAC
28 VDC
FO CABLES
USS Nimitz Interface Box
115 VAC
28 VDC

Figure 2-4

3.0 TEST RESULTS AND DATA ANALYSIS

Subsequent to aircraft testing, data reduction and analysis was performed. All recorded data appears in the data catalog, Appendix D. Comparisons of both the aircraft ICS and the fiber optic link were done using three selected radio frequency sources, and the signal-noise ratio was computed as a rough figure of merit. The data was analyzed to account for the various audio frequency components which appeared in the bands of interest.

Figures 3-1 A,B,C and D are representative samples of data taken during aircraft testing. The figures permit a comparison of the noise on the ICS to that on the fiber optic link at each frequency of the generated RF (131 MHz, 252 MHz and 400 MHz). The graphs show the amplitude of the conventional ICS and fiber optic link output signal voltages as a function of frequency. The conventional ICS is shown on the left portion of the graph and the fiber optic link on the right. Figure 3-1A shows the two links operating without aircraft radio transmissions for a baseline reference. Figures 3-1A is shown with Figure 3-1B, Figure 3-1C and Figure 3-1D for comparison purposes. The graphs show the signal output taken from a spectrum analyzer. The data is annotated with the x and y coordinates of the signal, the frequency band of interest, and output signal level in dB above a one microvolt level. Although the test plan called for the audio input to be swept from 100 Hz to 8 kHz, the actual test used two audio frequencies because of problems in maintaining a one volt reference signal as the signal generator was varied. Hence, the input reference signal is 1 kHz in Figure 3-1A, 3-1B, and 3-1D and the input signal is 2 kHz in Figure 3-1C. Signal-to-noise ratios were determined by visual examination of the data plots for those frequencies which were not associated with the audio reference signal. Table 3-1 shows these signal-to-noise ratios for each of the radio frequencies tested.

TABLE 3-1 S/N AS A FUNCTION OF TRANSMITTER FREQUENCY

TRANSMITTER FREQUENCY (MHz)	ICS (dB)	FO LINK (dB)
0	57	70
131	45	70
252	39	64
400	40	70

The baseline graph (Figure 3-1A, no intentional RF transmissions present) shows large interference amplitudes at 60 Hz, 400 Hz, and their respective harmonics. These frequency components are indicative of common mode coupling and are attributed to aircraft power sources. These interference frequencies can be seen on both ICS and fiber link graphs.

When the radio transmitters were keyed, the frequency spectrums of the fiber link remained relatively constant, while the ICS graphs show considerable susceptibility in the form of large perturbations on both sides of the audio input reference signal amplitudes. These pertubations are due to EMI (labeled as RFI - Radio Frequency Interference in Figures 3-1A through D). The audio output was recorded in both systems when the VHF and UHF transceivers, internal to the aircraft, were transmitting. The transceivers were keyed separately and modulated with a voice signal.

The frequency composition of the ICS data is only slightly different for each of the RF frequencies used. In Figure 3-1B, 131 MHz, sharp peaks are noted at 120 Hz and harmonics (two frequency components, 300 Hz and 450 Hz) of almost equal amplitude in the DC - 1 kHz range. In Figure 3-1C, 252 MHz, the input signal is at 2 kHz and the observed EMI is composed of the frequencies at the the same harmonics as in Figure 3-1B.

Signal Composite Summary

Figure 3-1A
BASELINE

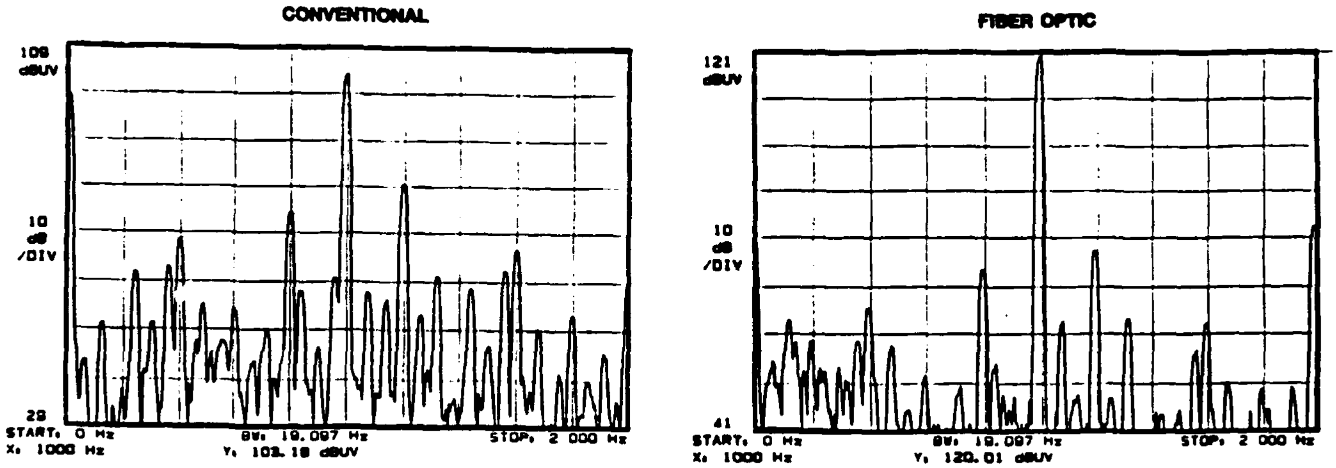
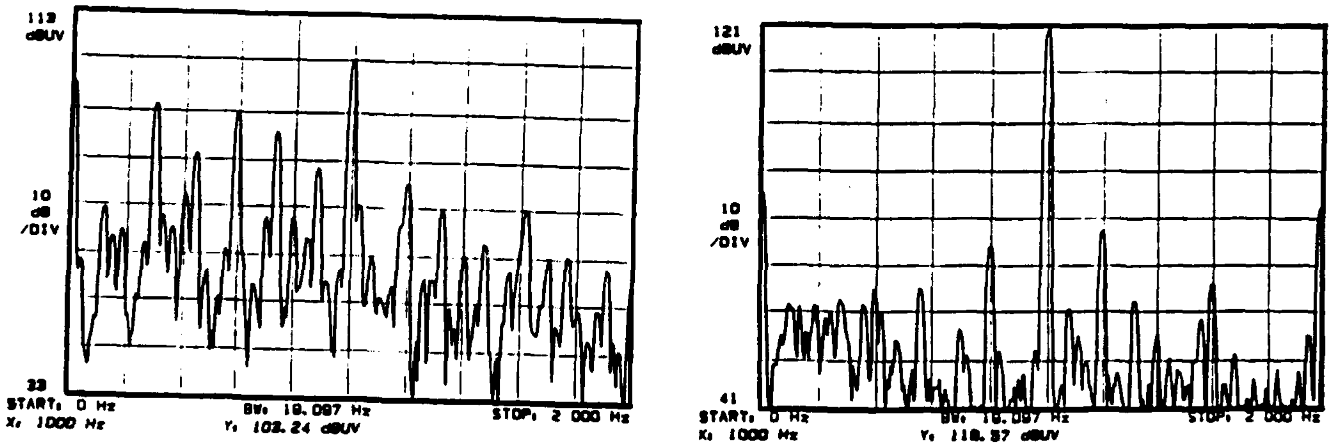


Figure 3-1B
EMI at 131 MHz



Signal Composite Summary (Con't)

Figure 3-1A
BASELINE

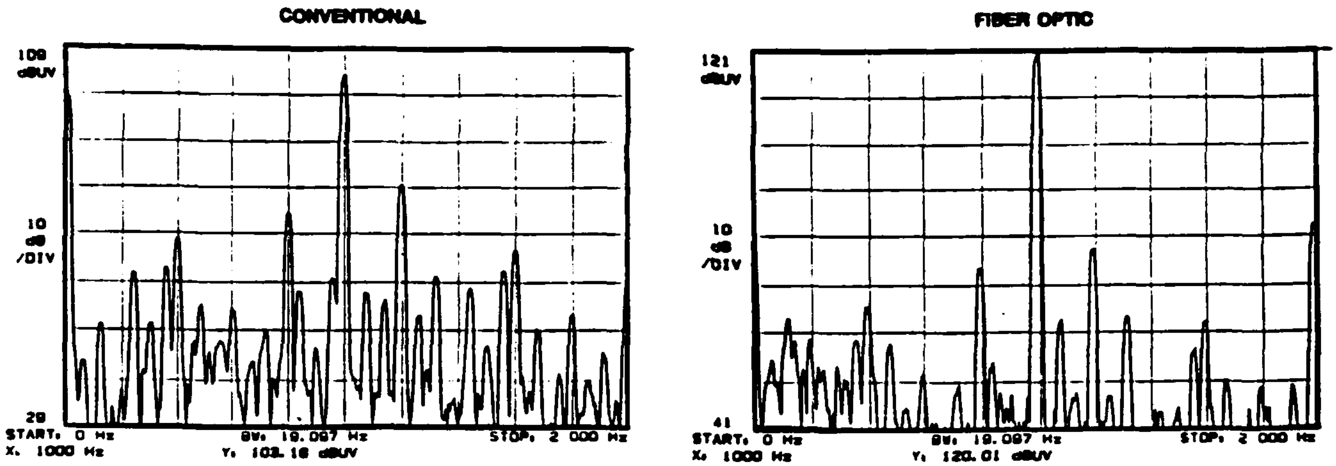
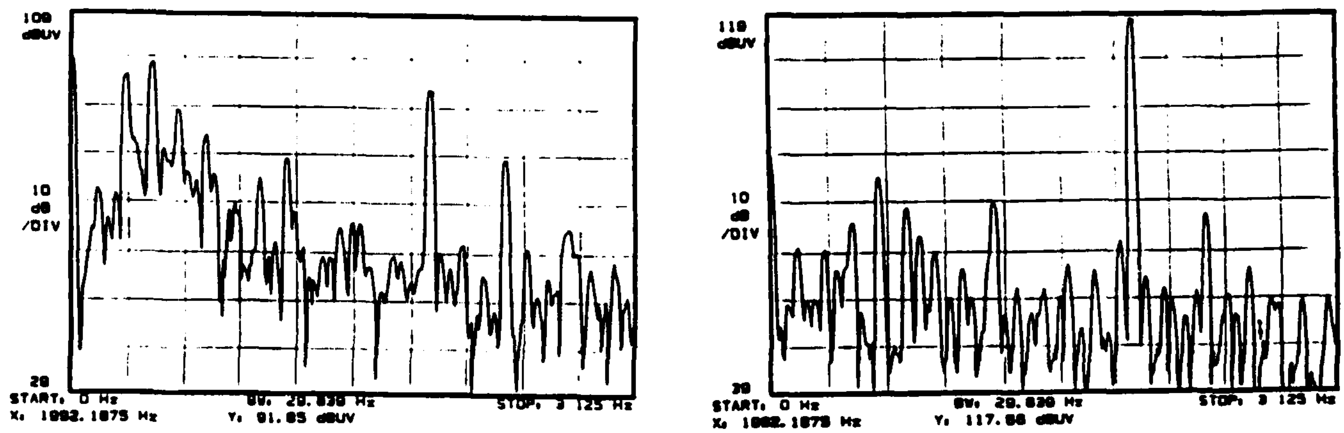


Figure 3-1C
EMI at 252 MHz



Signal Composite Summary (Con't)

Figure 3-1A
BASELINE

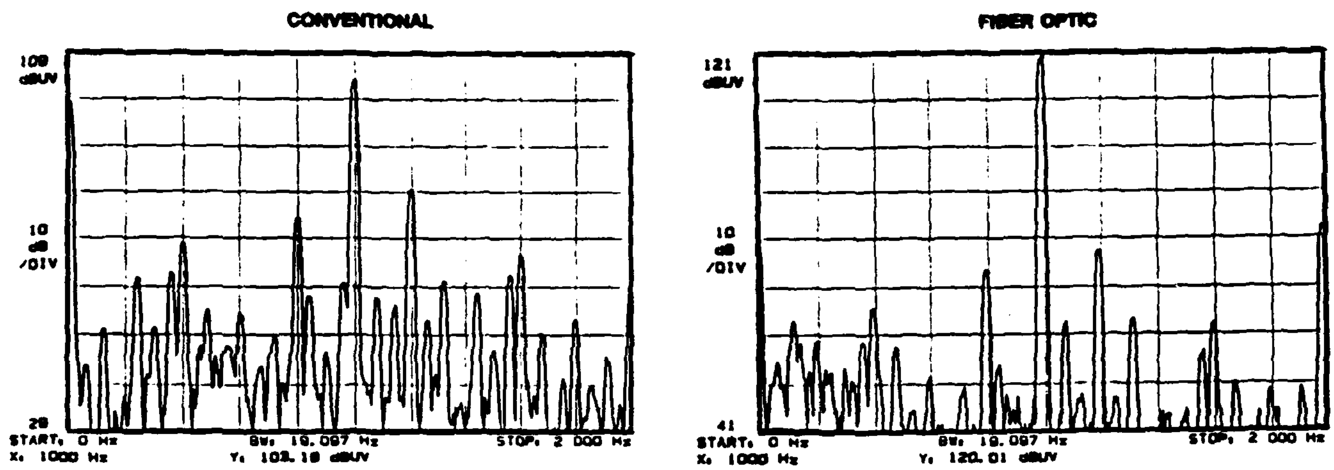
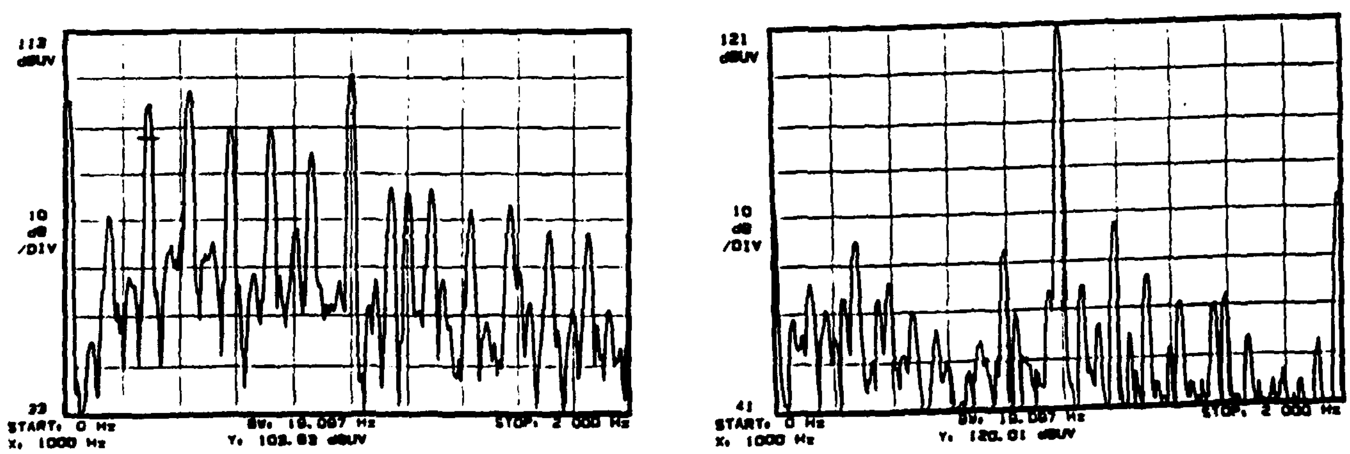


Figure 3-1D
EMI at 400 MHz



In summary, although the audio spectrums differ in each of these cases, similar audio frequency components can still be identified, leading to the conclusion that a common path for RF induced interference (EMI) exists between the transmitters and the ICS, fiber optic link, and/or the test equipment. It is possible that such interference is entering into the test and recording equipment through the various power lines via common mode coupling.

Fiber optic link data shows very little change due to EMI induced by operating transceivers at 131 MHz and 400 MHz. At 252 MHz, the amplitude of the 460 Hz frequency component increased 20 dB. This increase is probably due to inadequate power line filtering of the GFE.

The signal-to-noise (S/N) ratio was calculated by averaging the noise amplitude across the audio band of interest and comparing that to the respective reference signal amplitude. The spectrum analyzer gives the value of the output voltage in dB. Therefore, the signal-to-noise ratio calculated from the spectrum analyzer, can be written as:

$$\frac{S}{N} = 20\log(V_{SIG}) - 20\log(V_{NOISE})$$

Referring to Figure 3-2, with no keying of the radio transmitters, the fiber link had an S/N ratio 13 dB higher than that of the ICS. When the two systems were subjected to RF transceiver induced EMI, it was found that the average S/N ratio was 27 dB higher for the fiber than the ICS. The S/N ratio remained relatively constant for the fiber link, except for EMI induced by transmission at 252 MHz. A direct comparison cannot be made between the 70 dB S/N ratio in Figures 3-1A, B, and D with the 64 dB S/N ratio in Figure 3-1C because the audio band widths, injected audio reference, and sweep bandwidth vary significantly. That is, in the data for Figure 3-1C, the bandwidth was 3.125 kHz vice 2.0 kHz, the audio was 2 kHz vice 1 kHz, and the sweep bandwidth was over 50% greater at 29.839 Hz.

On the other hand, the ICS suffered a considerable decrease in S/N ratio when the RF transeivers were transmitting. The average EMI-related S/N ratio for the ICS was 16 dB less than its normal operating value. This susceptibility to RF transmission induced EMI was evident across the respective audio spectrums with some EMI frequency components having magnitude equal to that of the audio reference signal.

The objective of this test was to demonstrate the immunity of fiber optics to EMI caused by RF sources, not to determine and pinpoint the probable causes of the RF-induced interference. A basic problem with the ICS was the amount of noise observed. This noise probably resulted from sources either on or near the aircraft. The key observation to be noted is that the fiber optic link noise level was significantly lower both qualitatively and quantitatively than that observed in the ICS.

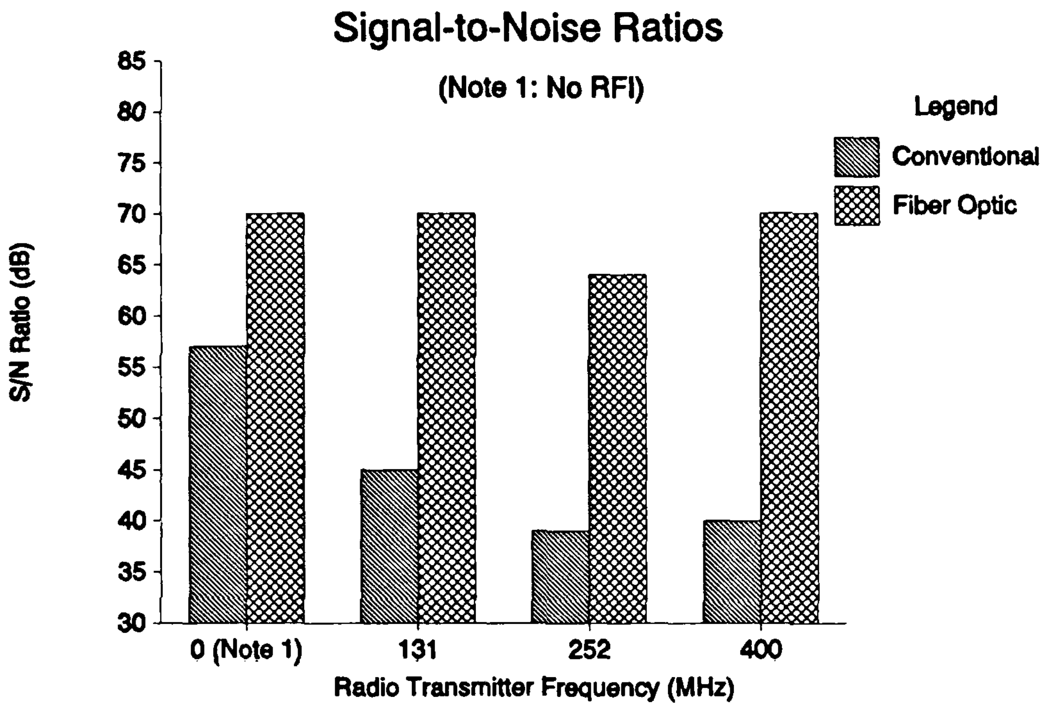

Signal-to-Noise Ratios
(Note 1: No RFI)
Legend
Conventional
Fiber Optic
S/N Ratio (dB)
85
80
75
70
65
60
55
50
45
40
35
30
0 (Note 1)
131
252
400
Radio Transmitter Frequency (MHz)

Figure 3-2

4.0 CONCLUSIONS AND RECOMMENDATIONS

The primary goal of this project, to demonstrate the ability of fiber optics to offer a solution to EMI problems in an aircraft ICS system, was achieved. The susceptibility of the ICS was confirmed and the fiber optic link showed an average signal to noise ratio improvement of 27dB in the presence of known EMI.

Cognizant NAVAIR representatives should be made aware of results of this limited demonstration and the benefits of fiber optics use in EMI reduction.

It is known that some equipment manufacturers have considered fiber optics in future ICS designs, and one such system has been briefed to the E^3/FOWG. Although next generation ICS equipment will be reviewed by an on-going NAVAIR EMI reduction/certification program to ascertain the level of EMI susceptibility, all ICS equipment upgrade programs engineering change proposals (ECP) should include consideration for the incorporation of fiber optic technology. The use of fiber optics in these new systems should follow existing equipment standards and specifications.

This investigation merely evaluated one known property of fiber optics: i.e., the investigation exploited the relative EMI immunity of a dielectric transmission medium as compared to that of copper wire. The laboratory model used in this particular comparative analysis was a single-channel system that could not be expected to be operated in parallel with an actual aircraft ICS in an in-flight mode. It is recommended that a further step be accomplished in the investigation of EMI reduction in the aircraft ICSs. Specifically, a more compact, self-contained, multichannel fiber optic ICS link should be developed and evaluated in a side-by-side comparison under in-flight conditions in an operational Navy aircraft.

APPENDIX A

Description of AN/AIC-22(V) ICS

The AN/AIC-22(V) is a relatively old system, having been installed in P-3 series aircraft in the 1960's. The system is an integrated voice network which accepts and distributes audio from external communications links (HF, UHF, VHF), beacon, sonobouys, and other aircraft systems; and provides interior station-to-station intercom capability. The intercom portion has capability for conference calling. Some versions have crypto-capable stations for secure voice communications.

The ICS system services 10 aircraft stations as shown in Figure A-1. The system has four stations that utilize Master Control Boxes and six crew stations which use less complex Crew Selector Boxes. The four Master Control Stations are provided to the pilot, co-pilot, Navigator/Communicator (NAVCOM) and Tactical Control Officer (TACCO). These stations are in the forward section of the aircraft with the pilot and co-pilot units being in the cockpit area. The six lesser capable stations are provided to sensor, ordnance, observer and galley locations throughout the mid and after sections of the aircraft. All stations are switched through an interconnect box which is located aft of the TACCO on the portside of the aircraft. This particular unit is difficult to access and has cable terminations in the rear. The control stations also have somewhat restricted access. The headset interface unit (jackbox) is the most easily accessible and is simplest in design. It should also be noted that interconnecting cables do not necessarily run from unit-to-unit, but patch into bulkhead terminal boards throughout the aircraft.

Figure A-2 is a diagram of the main components between two stations of the ICS. From discussions with technicians and operators and from studying the theory of operation, it was determined that EMI could be introduced virtually throughout the system. The most likely entry point is the Interconnect Box, through which all communications and peripheral systems audio signals are routed for distribution in close proximity to exterior voice communications wiring.

A more complete description of the ICS is available in NAVAIR document NAVAIR 01-75PAA-2-27.5 "Technical Manual, Maintenance Instructions, Organizational, Integrated Communications Station Wiring Diagrams, Navy Model, P-3A/B Aircraft."

Figure A-1

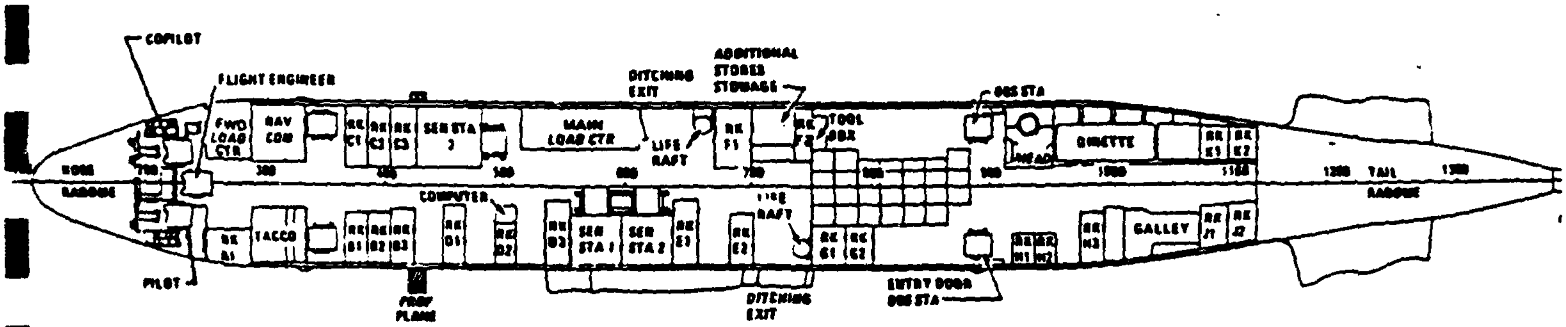
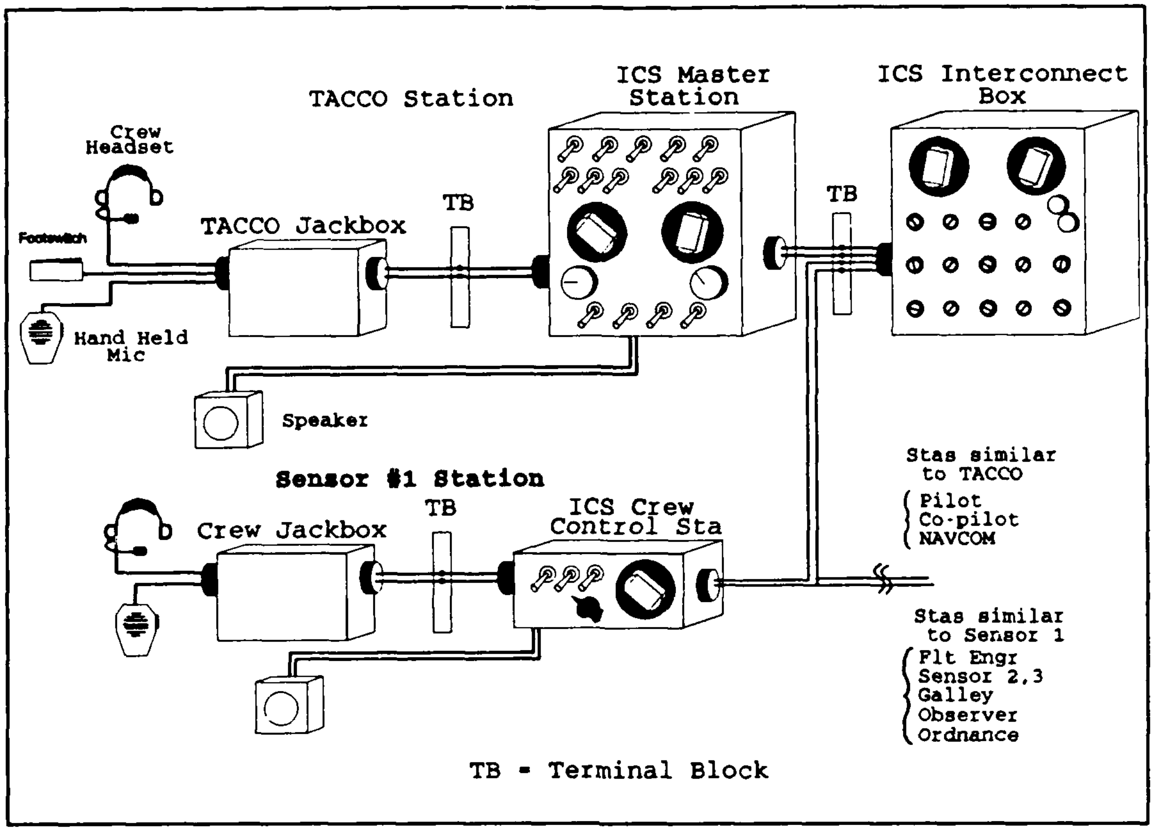

COPILOT
FLIGHT ENGINEER
PILOT
FWD LOAD CTR
NAV COM
TACCO
SEN STA 3
MAIN LOAD CTR
COMPUTER
SEN STA 1
SEN STA 2
DITCHING EXIT
LIFE RAFT
ADDITIONAL STORES STOWAGE
TOOL BOX
OBS STA
HEAD
DINETTE
GALLEY
ENTRY DOOR OBS STA
DITCHING EXIT
TAIL RADOME
NOSE RADOME

Figure A-2


TACCO Station
ICS Master Station
ICS Interconnect Box
Crew Headset
Footswitch
TACCO Jackbox
TB
TB
Hand Held Mic
Speaker
Sensor #1 Station
TB
Crew Jackbox
ICS Crew Control Sta
Stas similar to TACCO
Pilot
Co-pilot
NAVCOM
Stas similar to Sensor 1
Flt Engr
Sensor 2,3
Galley
Observer
Ordnance
TB = Terminal Block

APPENDIX B

FIBER OPTIC LINK PREPARATION

B.1 Modification of USS NIMITZ Fiber Optic Equipment

The first step in modifying the GFE for this effort was to identify the contents of the RADDS modules and to determine their method of operation (no detailed schematics were provided). The GFE consisted of two transmitter units and one receiver unit. The transmitters each contained six light emitting diodes (LED) pigtailed with 900 μm OD buffered fiber to ST connectors and voltage dividers that reduced a 5 Volt signal to a 1 Volt signal (the operating level of the optic components). The receiver consisted of six avalanche photo diodes (APD) attached to SMA 906 connectors and amplifiers biased at ±15 Volts to return a 1 Volt signal back to a 5 Volt signal. Both the transmitting and receiving units were powered by 115 Volts AC 60 Hz and a power supply which produced DC voltages of +15 V, +5 V, and -15 V. Each unit also contained related electronics circuitry.

The fiber optics of the system was used not only as a means of data communication but also as a test method. A twelve strand color coded PVC buffered 62.5/125 μm graded index multi-mode fiber was used to connect the transmitter to the receiver. Of the twelve strands, only six were used. Inside these units, the fibers were connected to Amphenol Interfuse 946 series multi-mode 2x2 directional couplers which were used as a reference channel, test monitoring, and optical time domain reflectometry applications.

B.2 Laboratory Testing And Checkout

Having researched the functional capabilities of the RADDS system, the next step was to reconfigure the components so that a laboratory-type ICS could be built. Each unit required modification so that it could both transmit and receive. A general optical power level test was run on all of the LEDs and APDs to determine how many of the units functioned and how well. It was found that four APDs and six LEDs were usable. Of these, two LEDs and two APDs were placed in each unit. Most systems are designed "from the top down" with parts that have already been extensively tested. Although the GFE had been tested, but not for applications with the ICS. In order to utilize the available equipment and save time, the fiber optic ICS was designed "from the top down." To ensure that this procedure would be successful, the design was accomplished in several stages. First, a single channel communications link was assembled and tested using conventional AIC-22 components. This provided a good background of the system's operation and determination of which parts of the system could be incorporated into the fiber optic system. Second, using the RADDS components, a fiber optic transmission link was built which would carry a test signal. Next, these systems were combined, and the fiber optic link was used to carry a voice signal.

The basic problem in modifying the fiber optics centered around the incompatibilities in power supplies requirements. Because the voltage levels of the GFE were different, a new voltage divider and amplifier had to be designed and built (Figure B-1). The amplifier underwent several design changes in order to match the impedance of the ICS which proved to be a trade off with the linear range of operation. The output signal level of the APD circuitry, and

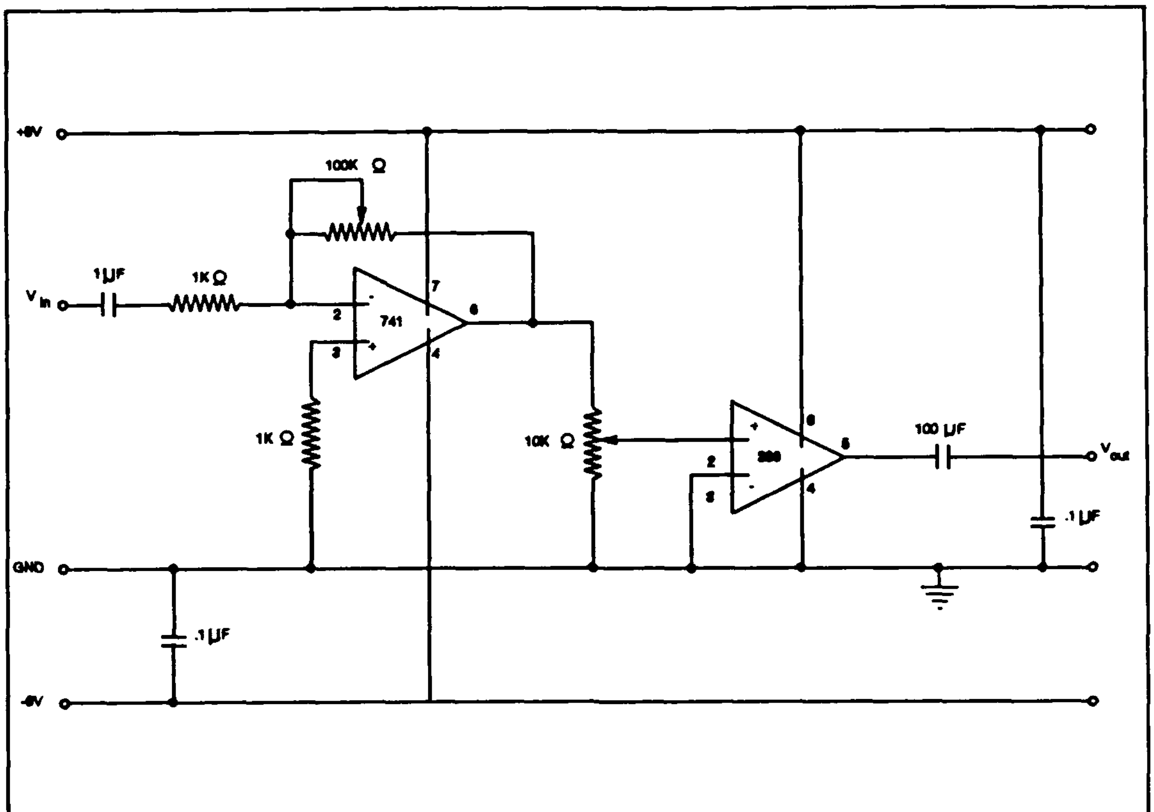


Figure B-1

therefore the input to the amplifier, was fixed. The signal required amplification to a level which would be audible in an aircraft environment. This dictated the amplifier's linear range, which was chosen to minimize distortion. Since the transmission is based on amplitude modulation, noise, which was amplified with the signal, was always a primary factor.

Personnel from NATC, Patuxent River, provided connectors used in the AN/AIC-22(V) ICS in the P-3A. Unfortunately, inadequate diagrams of the ICS components necessitated testing to determine the path of each connector pin and how best to incorporate the fiber optic communications link.

B.3 Specifications* For RADDS Analog Fiber Optics.

Transmitter (P/N 106823)

Signal Input:	BNC connector
Input Impedance:	50 ohms
Input Signal Range:	± 1.0 Volts
Light Source:	Light Emitting Diode (LED)
Wavelength:	840 nanometer
Spectral Width	50 nanometer
Output Power	
High Power Option:	80 microwatts (11 dBm) minimum mean (CW) into 50 micron fiber
Medium Power Option:	30 microwatts (-15.23 dBm) minimum mean (CW) into 50 micron fiber
Modulation	
High Power Option:	± 50 percent (± 40 microwatts)
Medium Power Option:	± 60 percent (± 18 microwatts)
Signal-to-Noise Ratio:	60 dB
Linearity:	Better than 2 percent
Bandwidth:	
Sinewave:	150 Hz to 80 MHz
Squarewave:	1,500 Hz to 80 MHz
Built-in-Test:	Fault / No Fault indicator
Power Requirements:	+ and - 15 Volts at 120 mA each; +5 Volts at 20 mA
Operating Temperature:	0 degree C to + 75 degree C
Dimensions:	5.5 in. x 2.75 in. x 1.0 in
Weight:	5.5 oz.
Specifications:	Qualified to DTA-1000 of Transport Canada
	Designed to meet MIL-E-16400 and MIL-E-5400

Receiver (P/N 106824)

Optical Input:	SMA 906 Series Connector
Input Range:	0.1 to 20 microwatt (CW) (-40 dBm to -17 dBm)
Optical Transducer:	Avalanche Photodiode (APD)
Input Responsivity:	128 Amperes per Watt at 830 nm
Output:	BNC Connector
Output Signal Range:	± 1.0 Volts into 50 ohms
Output Signal-to-Noise Ratio:	50 dB at 1.0 microwatt input power (-30 dBm)
Output Impedance:	50 ohms (short-proof)
Bandwidth	
Sinewave:	150 Hz to 120 MHz
Squarewave:	500 Hz to 120 MHz
Built-in-Test:	+ 15 Volts at 175 mA - 15 Volts at 100 mA + 5 Volts at 20 mA
Operating Temperature:	- 40 degree C to + 70 degree C
Dimensions:	5.5 in x 2.75 in. x 1.0 in
Weight:	6.0 oz
Specifications:	Qualified to DTA-1000 of Transport Canada Design to meet MIL-E-16400 and MIL-E-5400

* Given by ISC Cardion Electronics.

APPENDIX C

TEST PLANS, PROCEDURES AND EQUIPMENT

This Appendix contains the test plans, test procedures and equipments used in both the laboratory checkout and aircraft testing of the single channel fiber optic voice link.

C.1 Test Plan

1. Test Objectives:

The primary objective of this test is to show that a fiber optic (FO) full duplex, audio link can be operated on a P-3A aircraft and that it is relatively free of electromagnetic interference (EMI) generated by sources within the aircraft.

2. Test Prerequisites:

The installation and check-out procedure for the FO link shall be accomplished prior to conducting this test.

3. Test Description:

A fiber optic, full-duplex, audio link has been fabricated from government furnished equipment (GFE) components supplied by NRL and will be installed on an available NRL P-3A aircraft. The FO link will be connected parallel between two crew stations and run in a side-by-side comparison to the installed P-3A aircraft AN/AIC-22(V) intercommunications system (ICS). Following setup and communications checks of the equipment, an audio frequency signal will be injected into each system, the output spectrum swept and data recorded by a spectrum analyzer/plotter system. Radio frequency (RF) transceivers will be activated in the transmit mode to act as possible sources of EMI (this interference is referred to as RFI (radio frequency interference) on the test data sheets).

4. Evaluation Criteria:

Overall criteria for evaluation of this test are:

(a) FO link operates properly over audio spectrum
(b) AN/AIC-22(V) operates properly over audio spectrum
(c) Data is recorded to enable systems comparison

5. Safety Considerations:

Since this test involves the use of aircraft electrical power, all personnel are to be cautioned on the danger of electrical shock hazards and emergency procedures to be followed. Installation of electrical equipment shall be accomplished using correct procedures ensuring that two people are available in the vicinity of the test at all times. All personnel are to be briefed on safety issues.

6. Data Requirements:

Test data from both the ICS and FO systems shall be recorded on data sheets and data plots shall be run for evaluation following the testing.

7. Support Requirements:

The following support elements are required:

(a) P-3A aircraft with external power source for primary power
(b) Test equipment for data recording
(c) FO test system
(d) Operational AN/AIC-22(V) ICS system
(e) Personnel support for a/c test operations

8. Test Responsibilities:

Test Approval - NRL
Test Conduct - ARC
Test Data Analysis - ARC
Test Vehicle and Logistics - NRL
Documentation - ARC

9. Test Duration/Sequence:

The test is estimated to take approximately 8 hours. Additional tests may be conducted, time permitting, if EMI sources are not readily available.

10. Test Data Distribution:

NRL, NAVAIR, ARC, Other as directed by NRL.

C.2 Test Procedures

1. Locate fiber optic equipment at two crew stations on P-3A aircraft (Sensor Station/Galley Station)

2. Connect aircraft 115 V AC power to both fiber optic boxes (through convenience outlets)

3. Locate and connect aircraft 28 V DC to fiber optic boxes (power at Galley Station terminal boards)

4. Run fiber optic cable between crew stations and hookup to fiber optic boxes

5. Hook up crew station jackboxes (2) and connect headsets

6. Power up ICS system and hold communications checks on ICS

7. Disconnect both jackbox outputs and replace ICS system cables with fiber optic link cables

8. Power up fiber optic boxes and hold communications check on fiber optic link

9. Set up link test equipment on aircraft (Spectrum analyzer, plotter, signal generator, oscilloscope)

10. Hook-up signal generator to ICS system by removing jackbox headset cable and connecting to pins D (mic out) and B(ground)

11. Remove station 2 jackbox output cable and connect spectrum analyzer to Pins A/C (audio in) and B (ground)

12. Power up and make initial settings to test equipment

13. Signal generator input 1.0V peak-to-peak @ 100 Hz; set oscilloscope to record input signal. Record signal on plotter.

14. Sweep input frequency from across audio spectrum of interest and observe output signal. Record on plotter and note any noise anomalies.

15. Disconnect test equipment from ICS and connect to fiber optic link; repeat procedures in step 13.

16. With RF transceivers available as possible sources of EMI, rerun test with test equipment connected to both ICS and fiber optic link.

C.3 Test Equipment

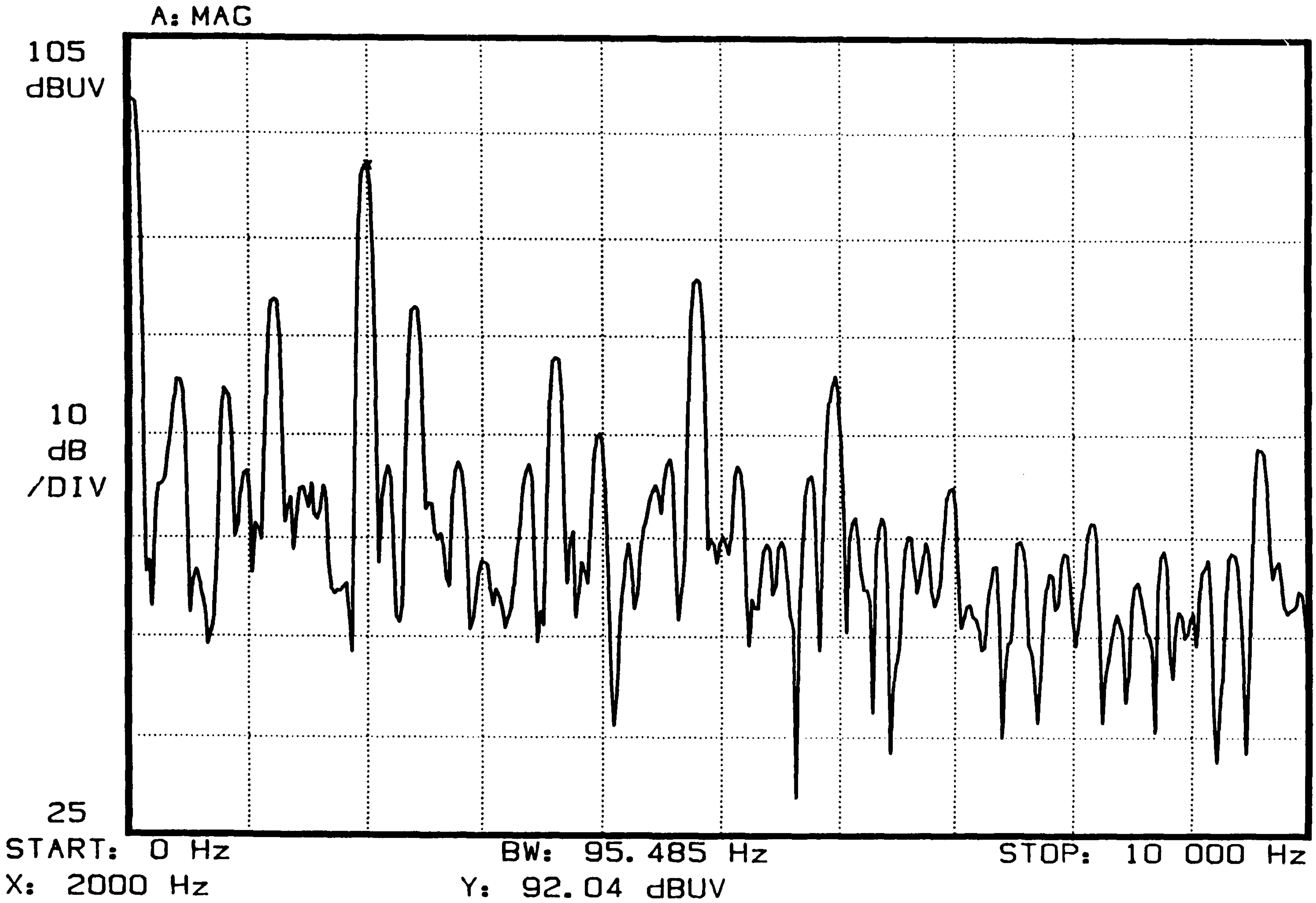
ITEM	QUANTITY	DESCRIPTION
1	2	Fiber optic units from USS Nimitz RADDS; S/N JHU/APL USN 087017/087037
2	2	Power strips
3	2	Headphone sets with cord/mikes USN P/N H178D300-1
4	2	Reels fiber optic cable (100 feet each)
5	2	Jackboxes from AN/AIC-22(V) system
6	2	5 conductor interconnect cables with connectors
7	1	HP Signal Generator ARC S/N 333-46620/035150
8	1	HP 3561A Spectrum Analyzer ARC S/N0045847S00
9	1	HP 7470A Plotter ARC S/N 0046721S00
10	2	Oscilloscopes Sony/Tektronic 314 and Kikusui S/N 3231443
11	1	Heathkit Digital Frequency Counter S/N 08-472301
12	1	28VDC Power Supply ARC S/N 204026
13	1	Micronta Digital Multimeter No. 22-195A

APPENDIX D

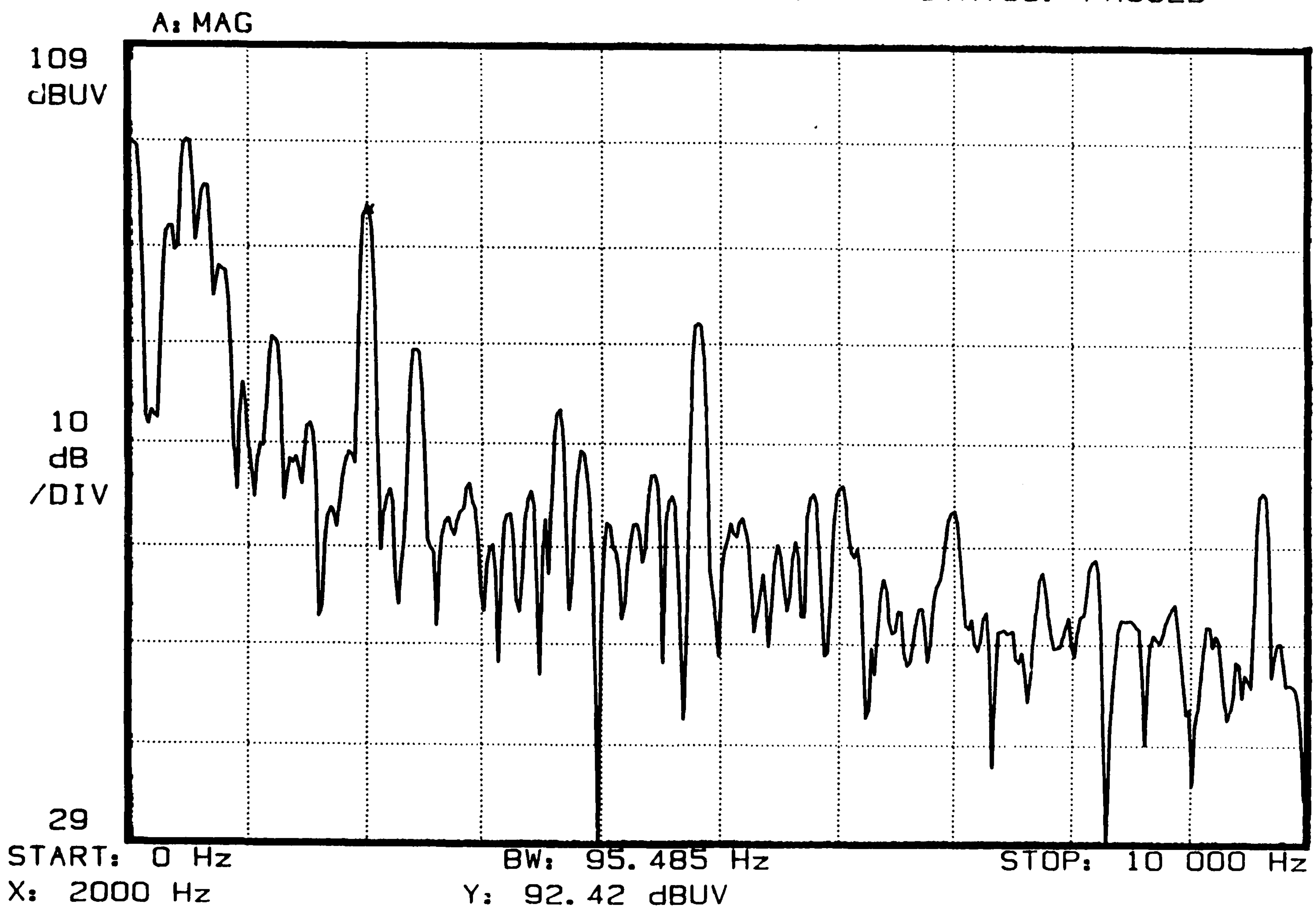
RAW DATA CATALOG

SHOT	SYSTEM	EMI	SIGNAL
1	ICS	No EMI	2 kHz
2	ICS	EMI 252 MHz	2 kHz
3	ICS	No EMI	2 kHz
4	ICS	EMI 252 MHz	2 kHz
5	FO Link	No EMI	2 kHz
6	FO Link	EMI 252 MHz	2 kHz
7	ICS	No EMI	1 kHz
8	ICS	EMI 400 MHz	1 kHz
9	ICS	EMI 131.6 MHz	1 kHz
10	ICS	EMI 131.6 MHz	1 kHz
11	FO Link	No EMI	1 kHz
12	FO Link	EMI 400 MHz	1 kHz
13	FO Link	EMI 131.6 Mhz	1 kHz

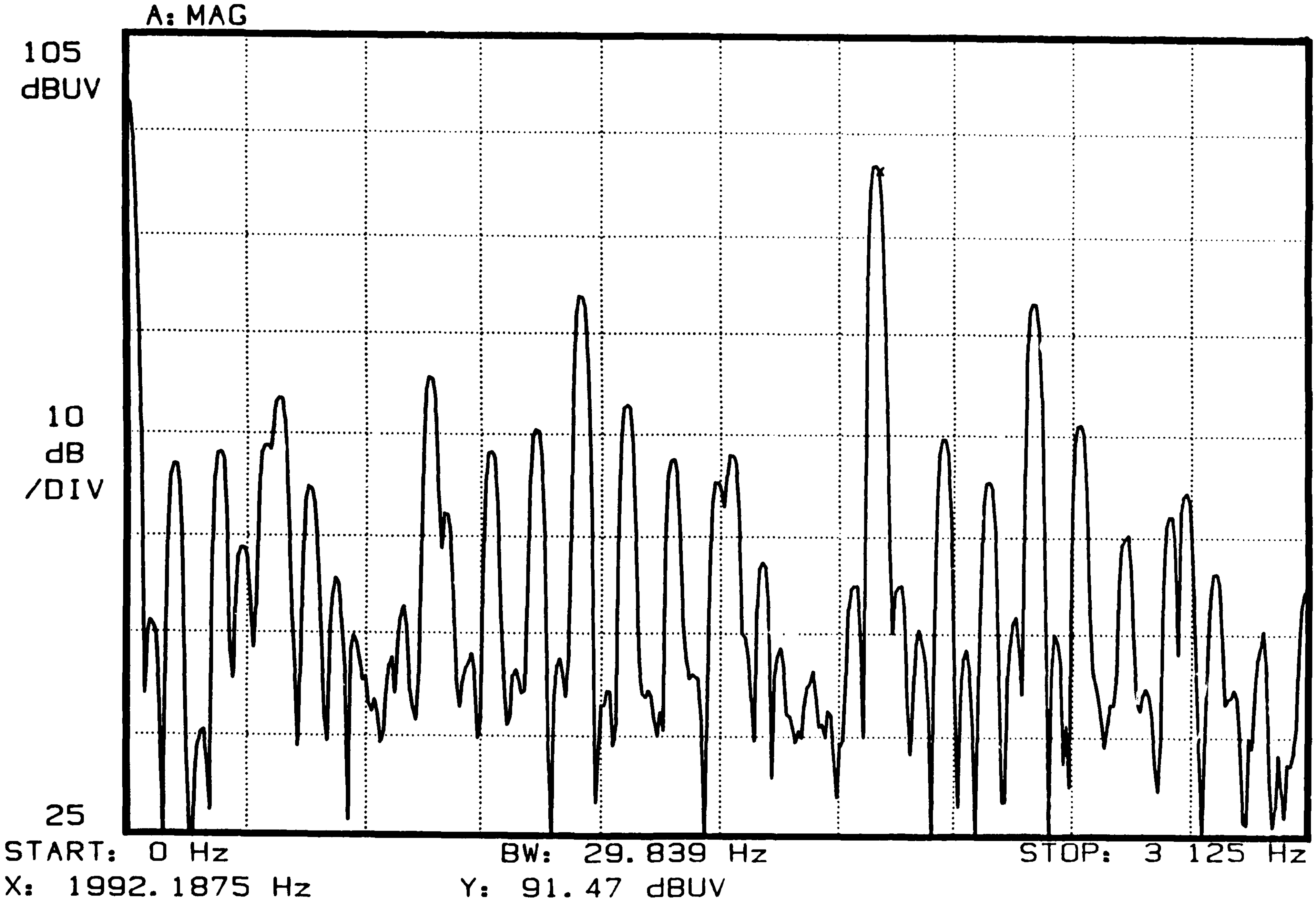
SHOT 1


RANGE: -15 dBV
STATUS: PAUSED
A: MAG
105 dBUV
10 dB /DIV
25
START: 0 Hz
BW: 95.485 Hz
STOP: 10 000 Hz
X: 2000 Hz
Y: 92.04 dBUV

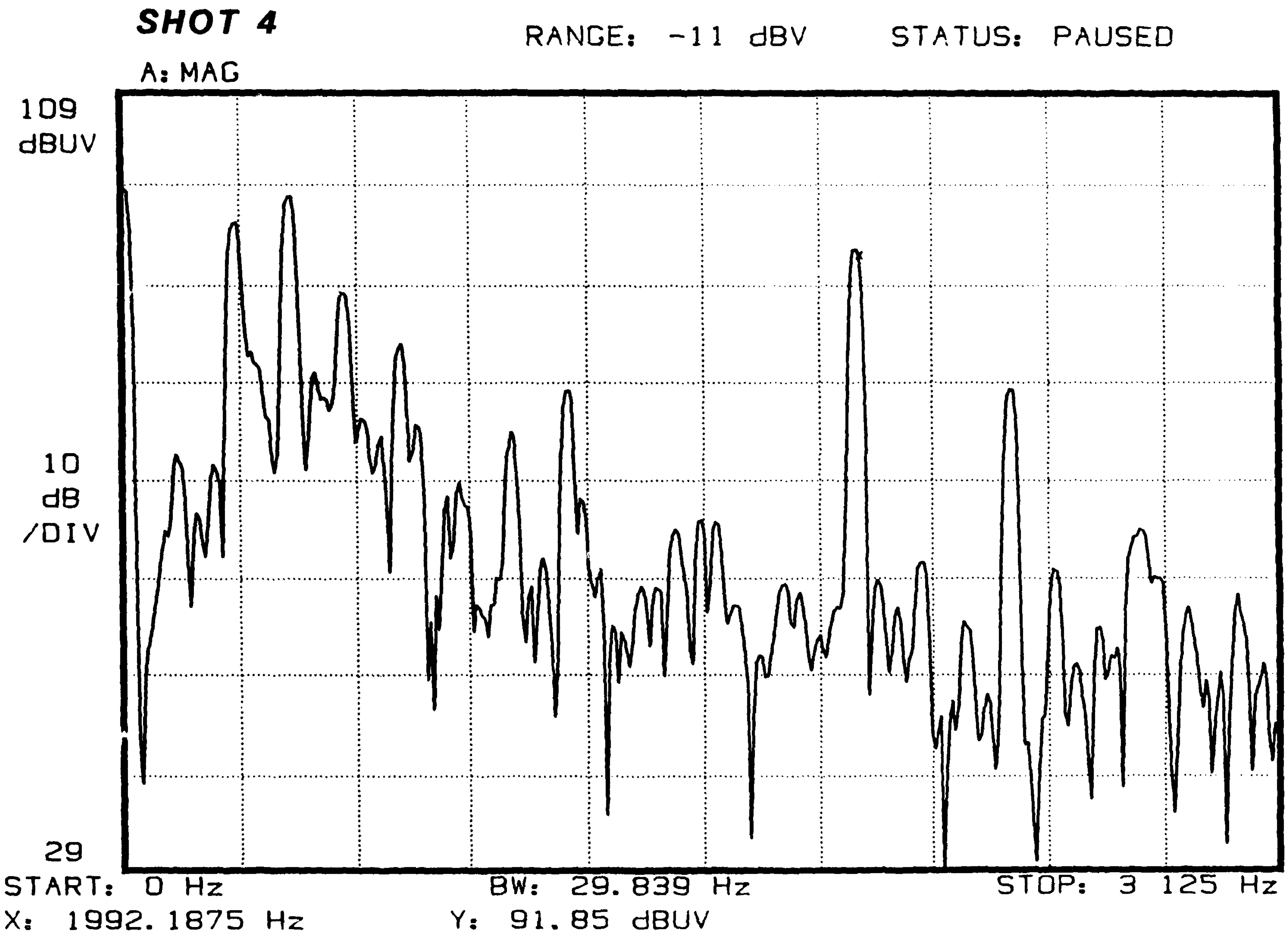
SHOT 2


RANGE: -11 dBV
STATUS: PAUSED
A: MAG
109
dBUV
10
dB
/DIV
29
START: 0 Hz
X: 2000 Hz
BW: 95.485 Hz
Y: 92.42 dBUV
STOP: 10 000 Hz

SHOT 3

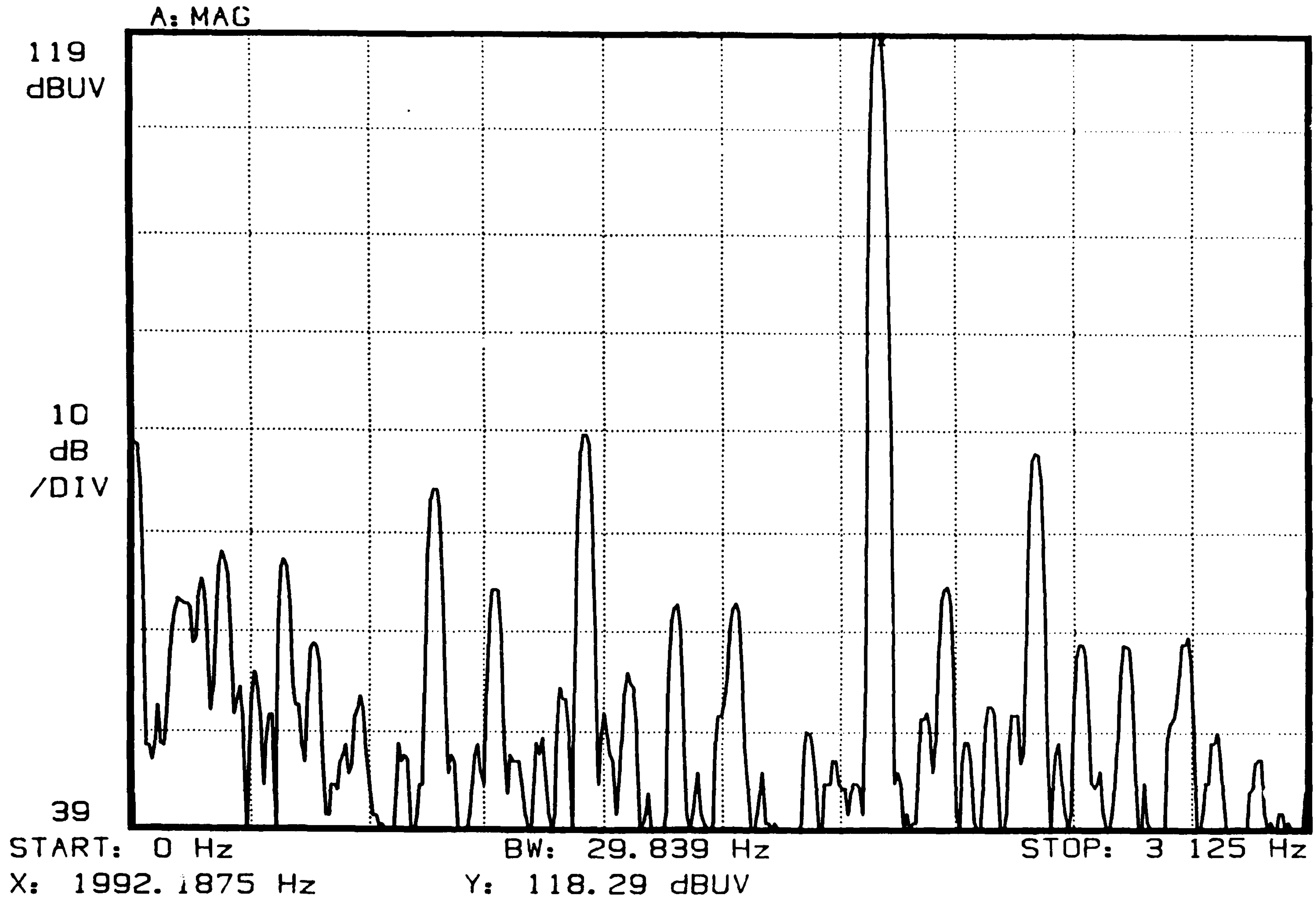


RANGE: -15 dBV
STATUS: PAUSED
A: MAG
105
dBUV
10
dB
/DIV
25
START: 0 Hz
BW: 29.839 Hz
STOP: 3 125 Hz
X: 1992.1875 Hz
Y: 91.47 dBUV

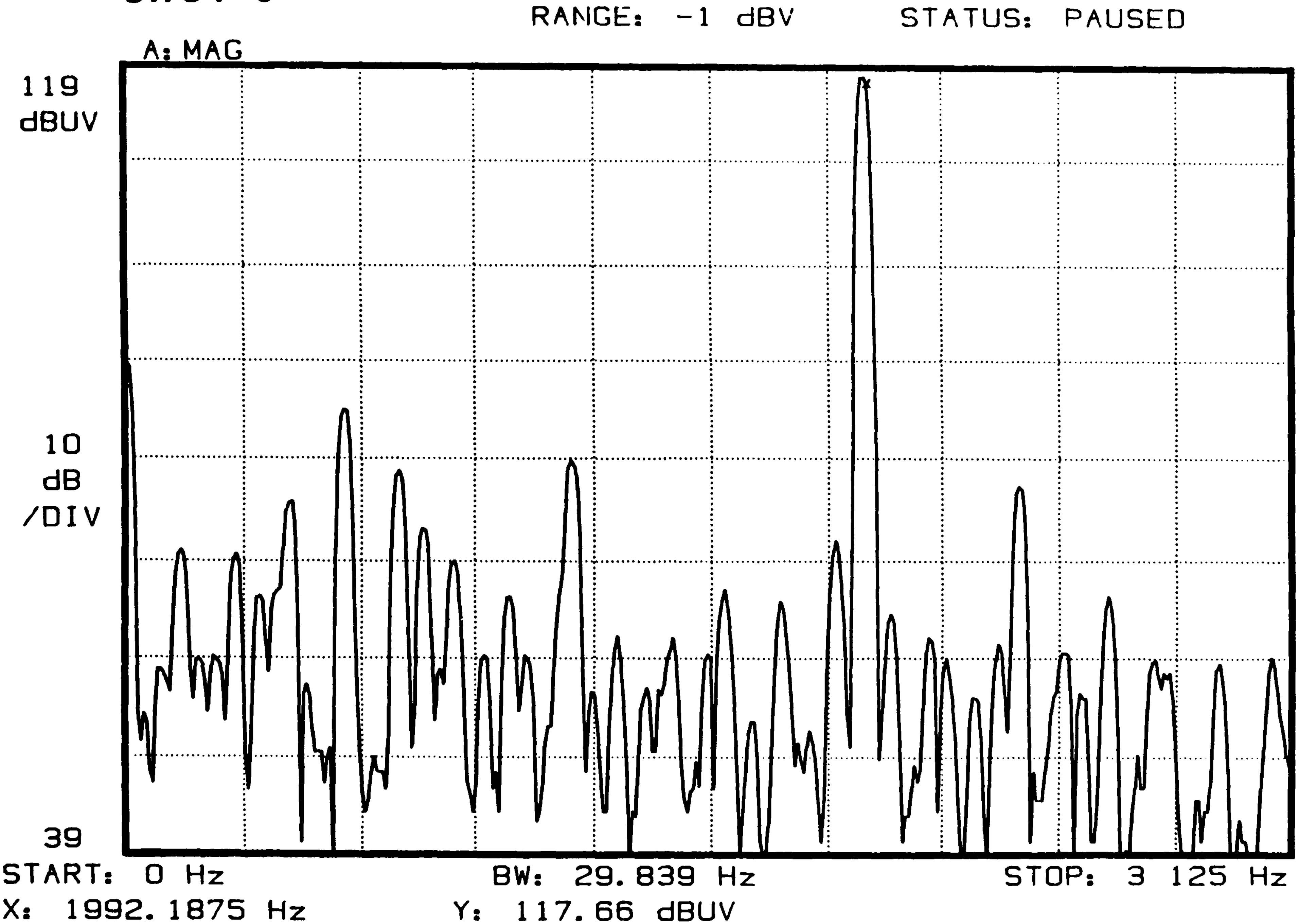


SHOT 4
RANGE: -11 dBV
STATUS: PAUSED
A: MAG
109
dBUV
10
dB
/DIV
29
START: 0 Hz
BW: 29.839 Hz
STOP: 3 125 Hz
X: 1992.1875 Hz
Y: 91.85 dBUV

SHOT 5

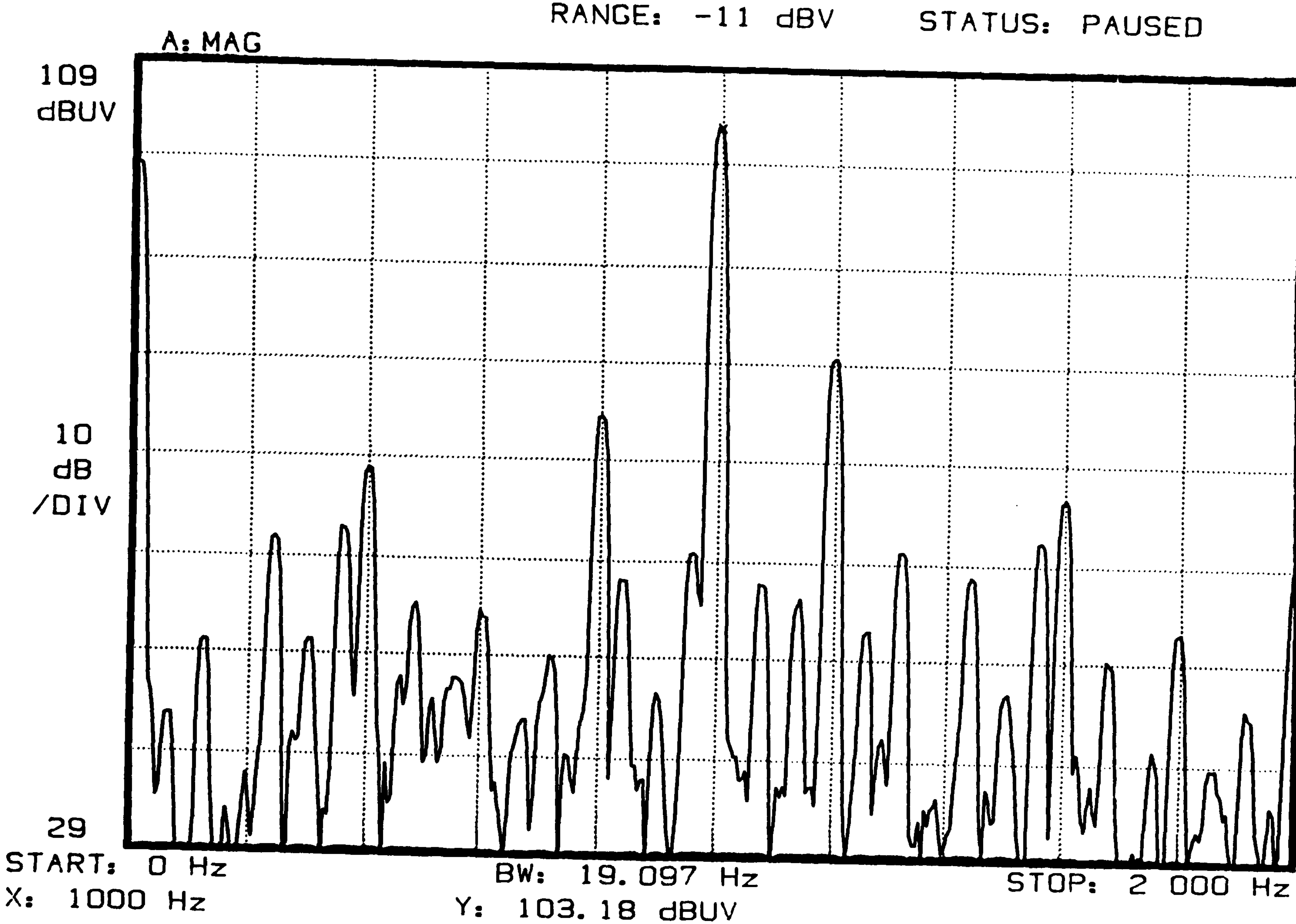

RANGE: -1 dBV
STATUS: PAUSED
A: MAG
119
dBUV
10
dB
/DIV
39
START: 0 Hz
BW: 29.839 Hz
STOP: 3 125 Hz
X: 1992.1875 Hz
Y: 118.29 dBUV

SHOT 6



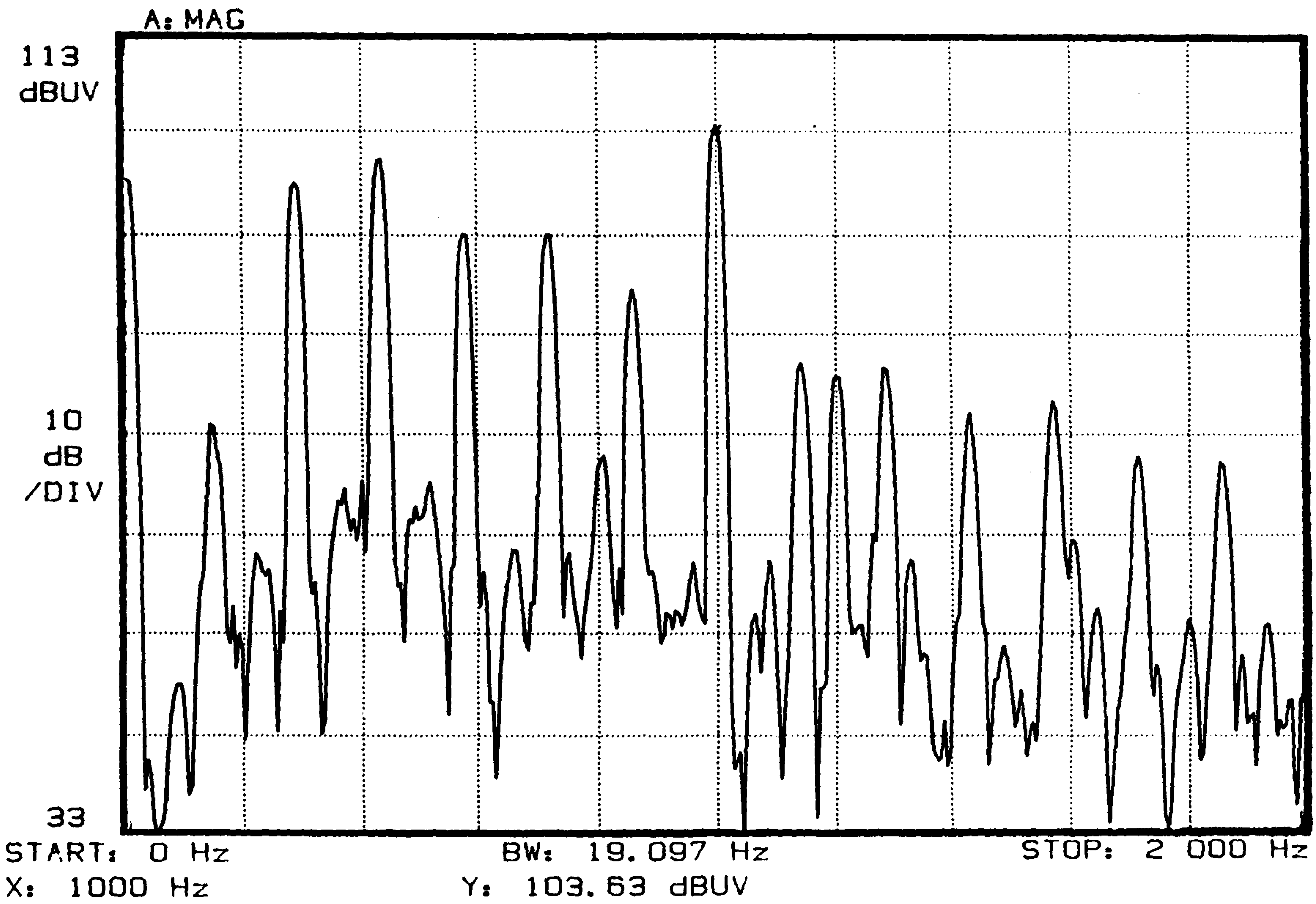
RANGE: -1 dBV
STATUS: PAUSED
A: MAG
119
dBUV
10
dB
/DIV
39
START: 0 Hz
BW: 29.839 Hz
STOP: 3 125 Hz
X: 1992.1875 Hz
Y: 117.66 dBUV

SHOT 7



RANGE: -11 dBV
STATUS: PAUSED
A: MAG
109
dBUV
10
dB
/DIV
29
START: 0 Hz
X: 1000 Hz
BW: 19.097 Hz
Y: 103.18 dBUV
STOP: 2 000 Hz

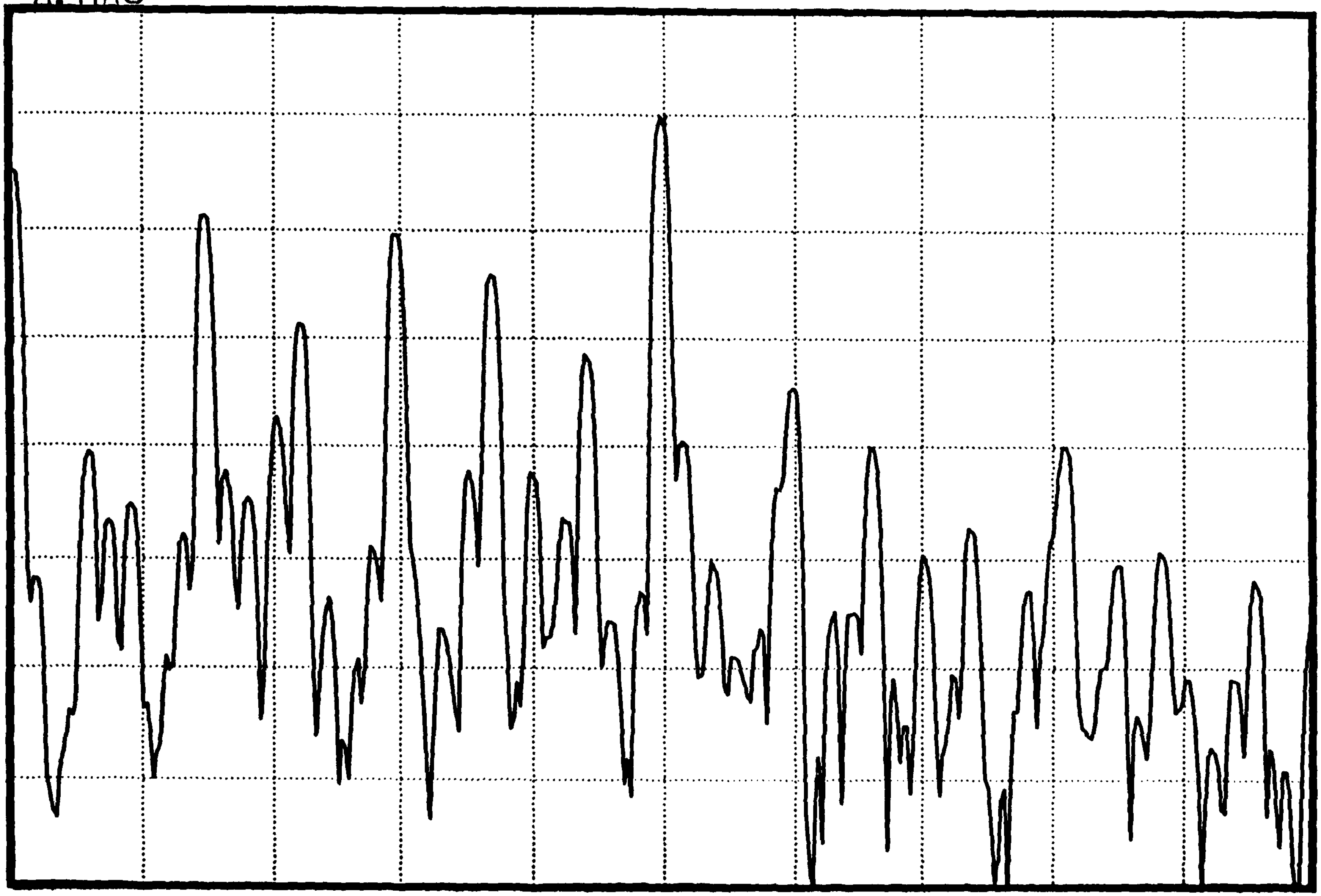
SHOT 8



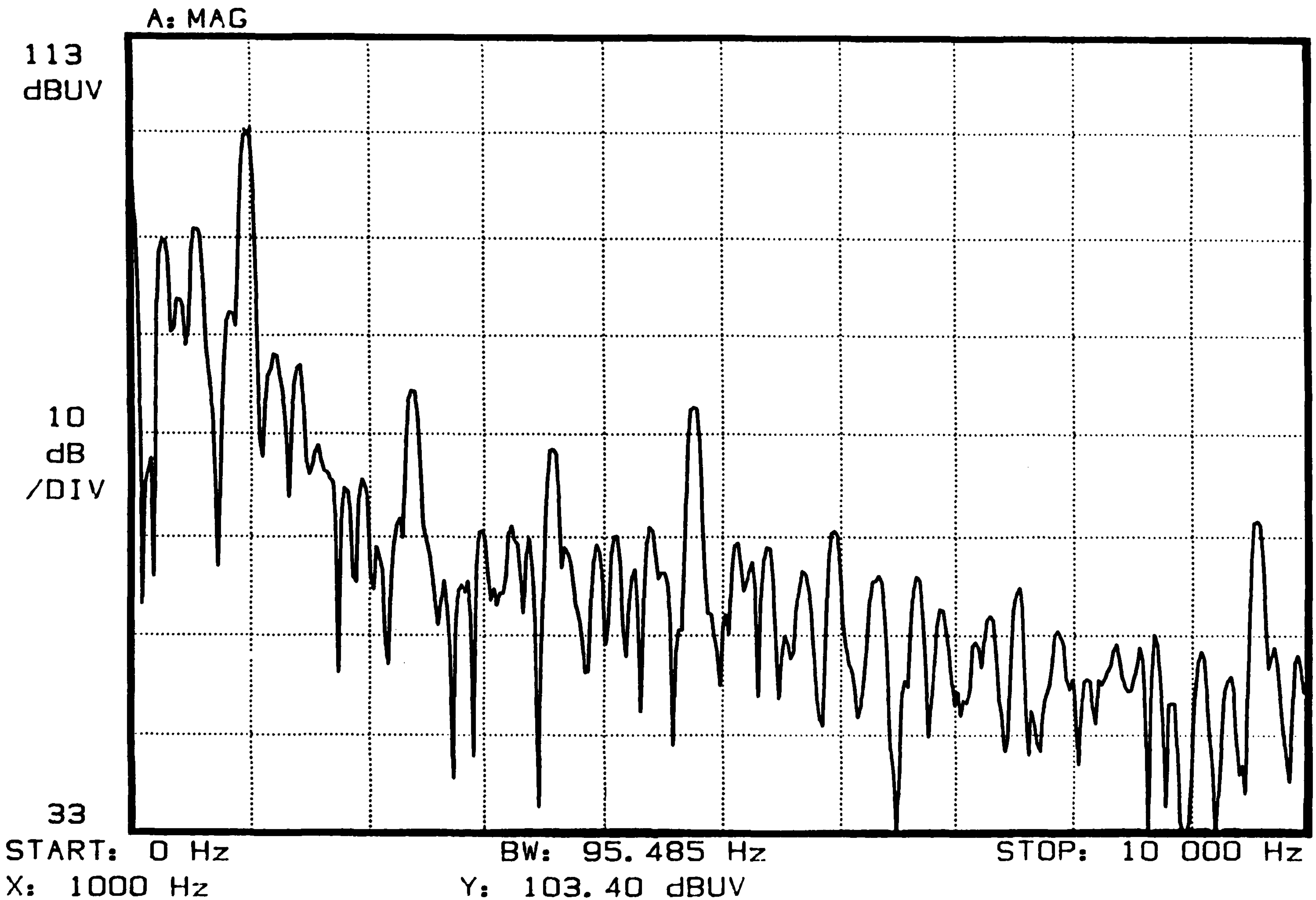
RANGE: -7 dBV
STATUS: PAUSED
A: MAG
113
dBUV
10
dB
/DIV
33
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz
X: 1000 Hz
Y: 103.63 dBUV

SHOT 9

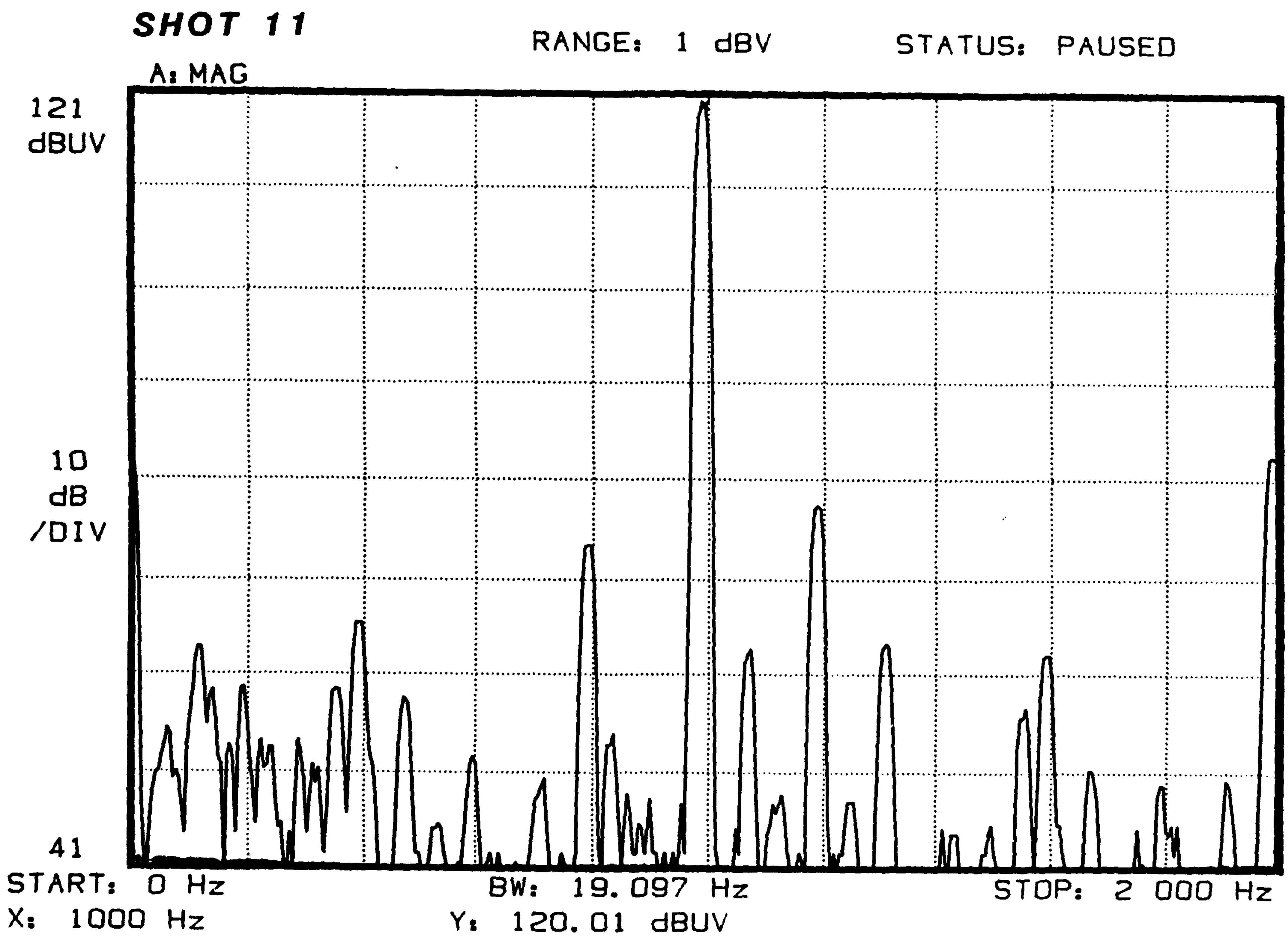
RANGE: -7 dBV STATUS: PAUSED



SHOT 10



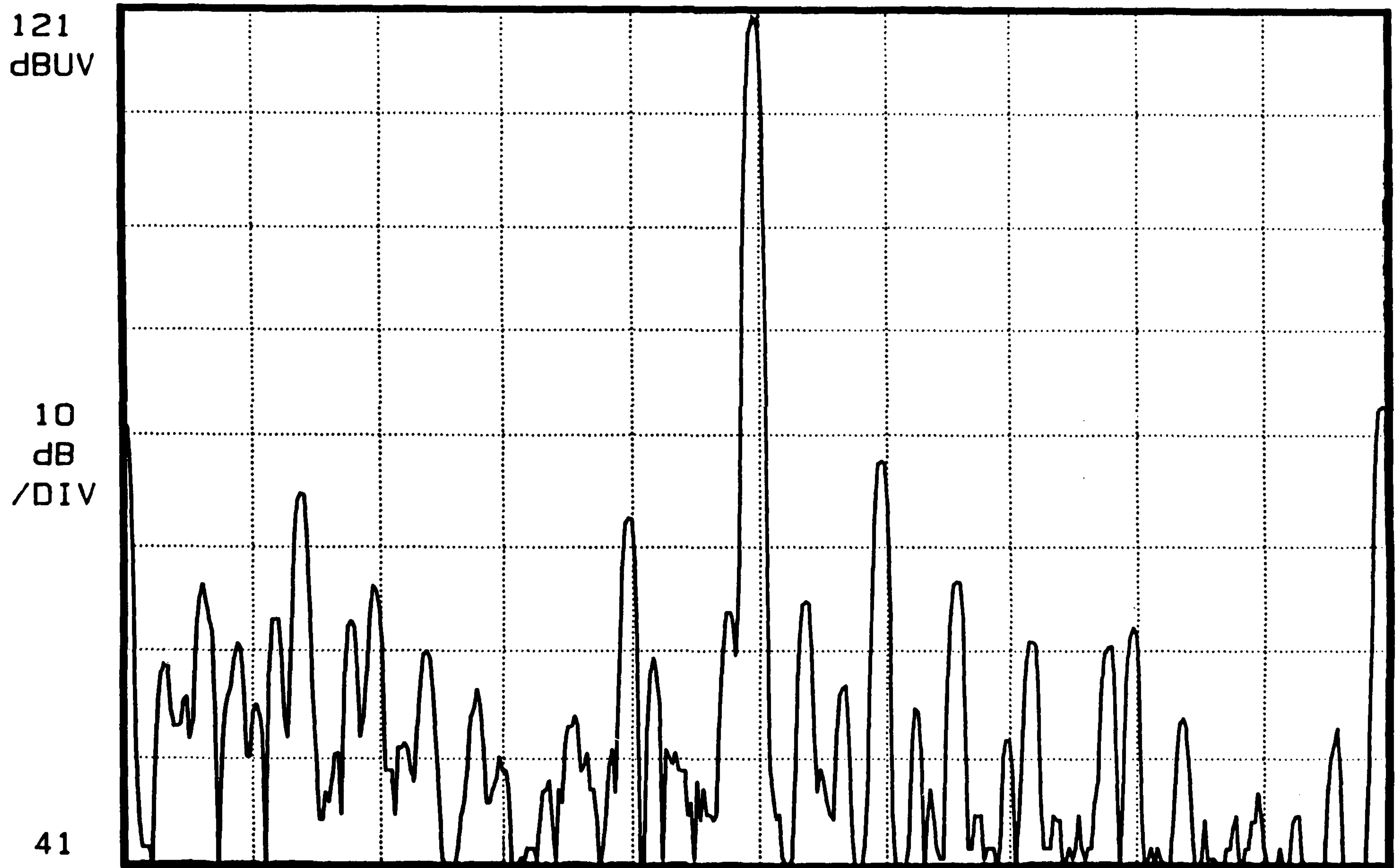
RANGE: -7 dBV
STATUS: PAUSED
A: MAG
113
dBUV
10
dB
/DIV
33
START: 0 Hz
BW: 95.485 Hz
STOP: 10 000 Hz
X: 1000 Hz
Y: 103.40 dBUV


SHOT 11
RANGE: 1 dBV
STATUS: PAUSED
A: MAG
121
dBUV
10
dB
/DIV
41
START: 0 Hz
X: 1000 Hz
BW: 19.097 Hz
Y: 120.01 dBUV
STOP: 2 000 Hz

SHOT 12

RANGE: 1 dBV STATUS: PAUSED

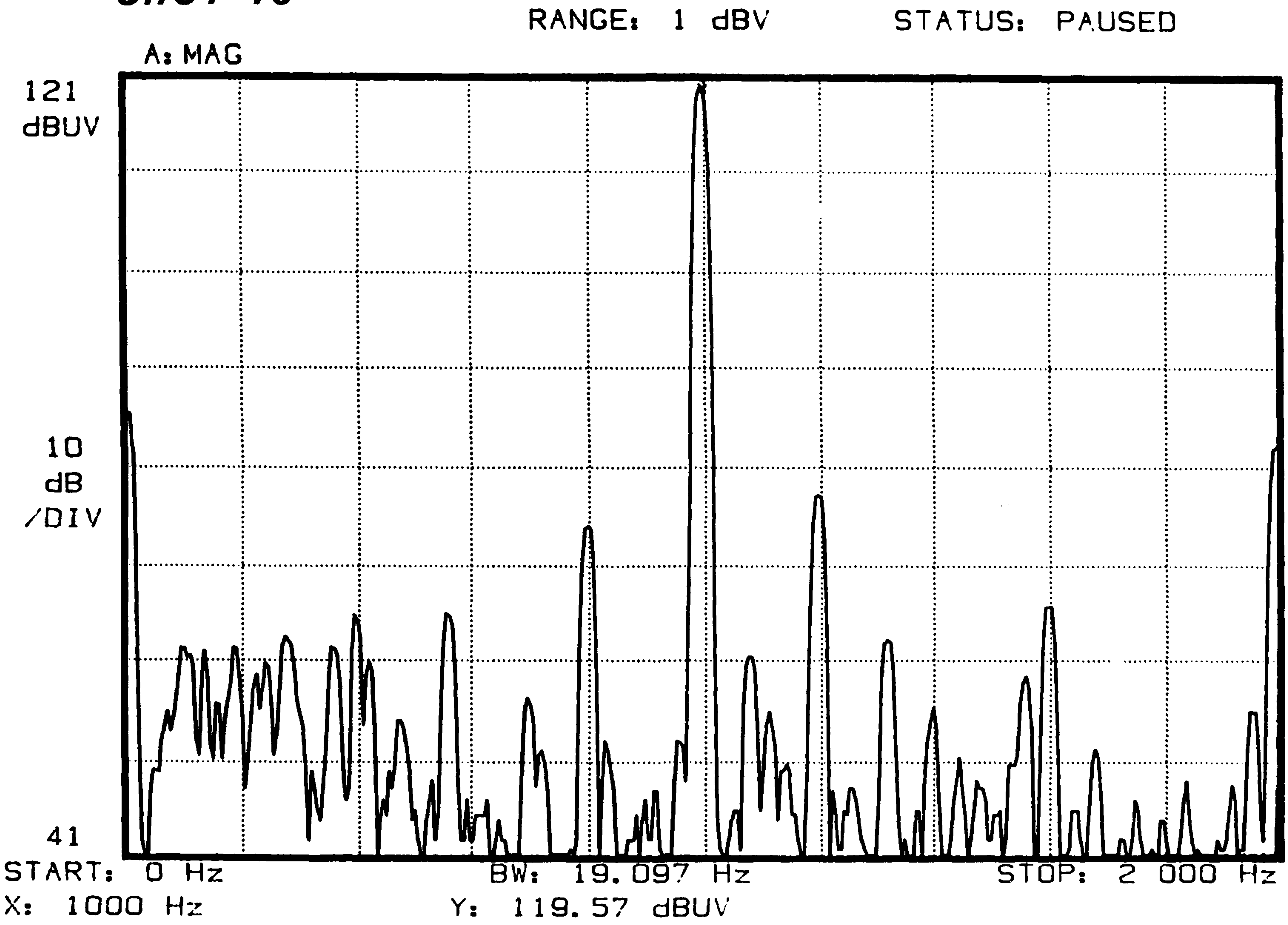
A: MAG



START: 0 Hz BW: 19.097 Hz STOP: 2 000 Hz

X: 1000 Hz Y: 120.01 dBUV

SHOT 13


RANGE: 1 dBV
STATUS: PAUSED
A: MAG
121
dBUV
10
dB
/DIV
41
START: 0 Hz
BW: 19.097 Hz
STOP: 2 000 Hz
X: 1000 Hz
Y: 119.57 dBUV

CATALOG VERSION
AS OF 08/20/90

CATALOG	VERSION	LOCATION	RMRKS
A-4	----------	----------	CANCELLED
E-2C	----------	----------	CANCELLED
A-6E	UPDTE 1	EG&G	FOR REVIEW
A-7E	UPDTE 1	NSWC	FOR REVIEW
AV-8B	UPDTE 2	EG&G	FOR REVIEW
P-3B/C	PRELIM	NSWC	FOR REVIEW
S-3A/B	UPDTE 1	EG&G	FOR REVIEW
SH-2F	UPDTE 2	CS2	FOR CORRECTION
SH-3G/H	UPDTE 1	CS2	FOR CORRECTION
OV-10	PRELIM	NSWC	FOR REVIEW
UH-1N	FINAL	NSWC	FOR REVIEW
AH-1J/T/W	*******	NAVAIR	FOR RELEASE 4/10/90
CH-46E	*******	NAVAIR	FOR RELEASE 7/26/90
CH-53D/E	*******	NAVAIR	FOR RELEASE 3/13/90
EA-6B	*******	NAVAIR	FOR RELEASE 4/10/90
F-14A/D	*******	NAVAIR	FOR RELEASE 4/4/90
F/A-18	*******	NAVAIR	FOR RELEASE 3/13/90
MH-53E	*******	NAVAIR	FOR RELEASE 7/26/90
SH-60B	*******	NAVAIR	FOR RELEASE 7/26/90
SH-60F	*******	NAVAIR	FOR RELEASE 7/26/90