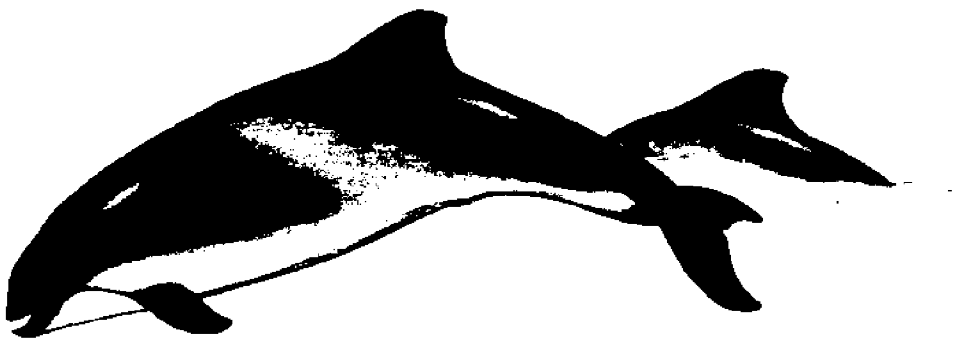
PASSIVE UNDERWATER ACOUSTICS

A Study Concerning the Acoustic Interaction Between Commercial Gillnets and Harbor Porpoise



John R. Quinn

Charlie Atwood
Jay Murray
Heather Shaw
Advisor: Dr. Ken Baldwin

TECH 697
OCEAN RESEARCH PROJECTS

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INTRODUCTION

Gillnets are widely used by commercial fishermen in the Gulf of Maine, landing approximately twenty percent of groundfish catch in the area (Polachek, 1989). Unfortunately, these nets have also been responsible for entangling and drowning the harbor porpoise, *Phocoena phocoena*. Due to the lack of accurate population counts and estimates of mortality, the actual impact incidental takes have on the harbor porpoise is difficult to determine. Indirect evidence indicates that porpoises in the Bay of Fundy and Gulf of Maine form a single population unit (Read and Gaskin, 1990). Further evidence from studies of summer distribution patterns and life history parameters suggest that this population is in a state of decline (Read and Gaskin, 1990). The primary cause for this decline is incidental mortality by commercial gillnetting (Gaskin, 1984).

Harbor porpoises are vulnerable to entanglement in gillnets because they are relatively small, they inhabit near shore waters, and they feed on commercial fish. The problem is enhanced because gillnets are made of monofilament line, which is very difficult for the harbor porpoise to detect. Detection of obstacles can occur by vision, echolocation, or hearing. Monofilament line is transparent, making it difficult to visualize.

The relationship between the acoustical properties of the gillnet and harbor porpoise can be broken down into two parts, active and passive acoustics (See Figure 1). The active acoustics deal with the target strength of the gillnet. The net's target strength is the intensity of reflection to an incident signal (i.e. echolocation clicks produced while harbor porpoise foraging). If the target strength of the net is below a certain threshold level, the porpoise will not detect the net by echolocation. The active acoustics of the net have been well studied, including experiments in which the net has been modified in hopes to increase its target strength (Hembree and Harwood, 1987; Ogiwara et.al, 1985; also see review by Dawson, 1990).

Passive acoustics can be defined as the interaction between a non-echolocating harbor porpoise and sound emitted by the gillnet. The acoustic signal from the gillnet results mainly from current flow through the net, causing it to strum and emit noise over a certain frequency bandwidth and intensity. If this signal occurs at a frequency within and at a source level above the auditory sensitivity threshold of the porpoise, the harbor porpoise

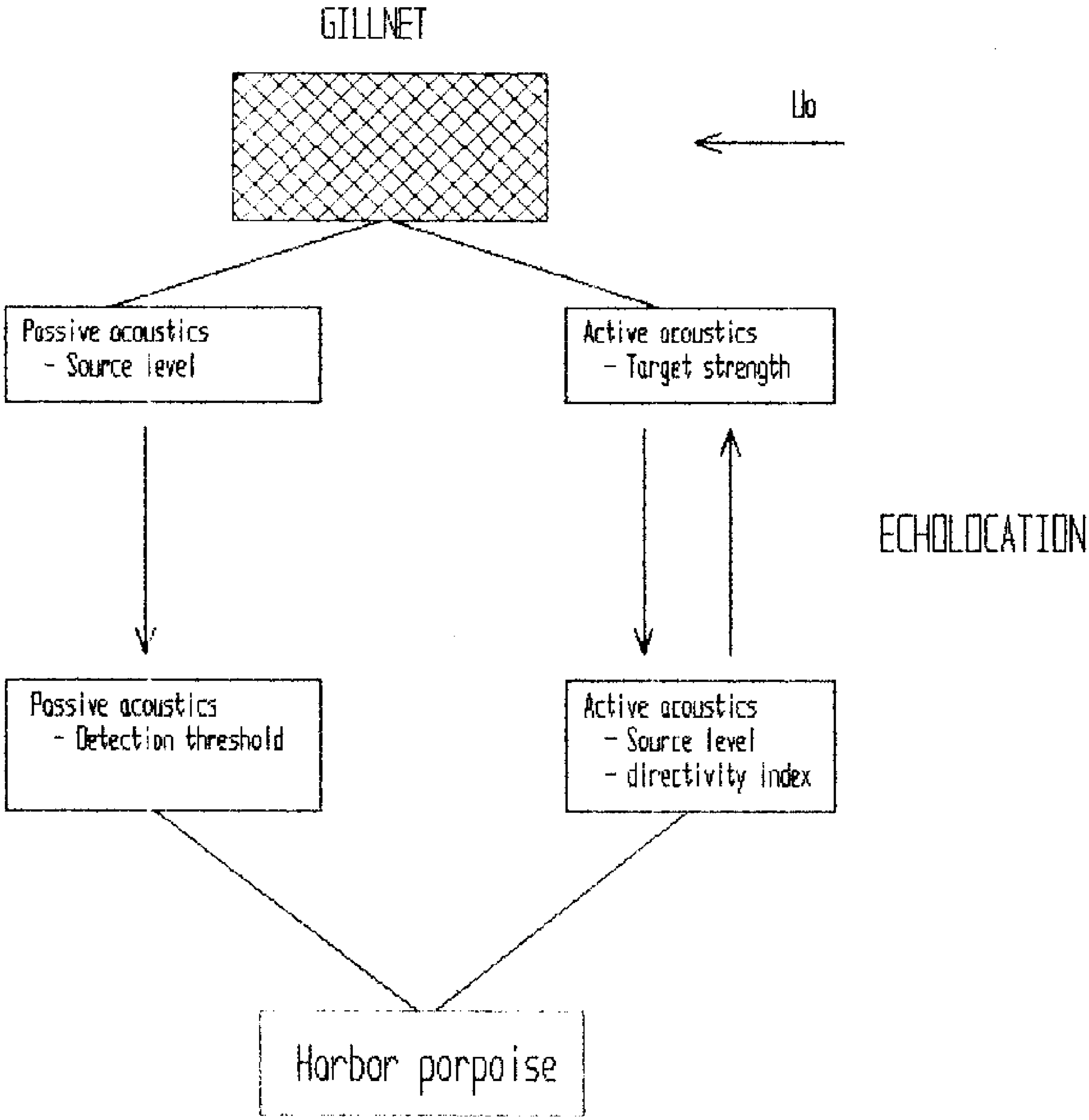


FIGURE 1 : ACOUSTIC INTERACTION

should be able to detect the gillnet's presence (unless masked by more detectable deterrents). Researchers have found that porpoise often travel through familiar areas using passive navigation techniques, listening to noise from the environment or following one or more lead swimmers (Hatakeyama,1986; Goodson et al,1990). It is therefore somewhat surprising that very few studies have focused on this system.

This project concentrated on the basic passive acoustic interaction between the harbor porpoise and gillnet as described above. Our goal was to analyze passive underwater acoustical characteristics of standard and modified gillnets and to determine how these may relate to the auditory senses of the harbor porpoise. The main objective of this report is to present our findings and to provide a foundation for future research. A keen understanding of this problem must be acquired so that action can be taken to reduce the number of porpoises killed in gillnets in this area.

BACKGROUND INFORMATION

HARBOR PORPOISE (*Phocoena phocoena*)

ASSESSMENT:

The harbor porpoise, *Phocoena phocoena*, is a fairly small (3-6 feet long) odontocete, or toothed whale. It inhabits many places around the world. Research has concentrated on those appearing in the near-shore waters off the northeast coasts of the United States. Current estimates of harbor porpoise abundance in the Bay of Fundy and Gulf of Maine region range from 8,000 to 16,000 (Read and Gaskin, 1990; Read and Kraus,1990). Approximately 100 porpoises in the Bay of Fundy and approximately 600 porpoises in the Gulf of Maine are killed annually (Read and Gaskin,1990; Read and Gaskin,1988; Polachek,1989). An average of 5.5 porpoises per gillnet fisherman were reported to be caught in 1986 in this combined area (Read and Gaskin, 1988). These estimates are very rough for two main reasons. Harbor porpoises are very elusive and difficult to observe at sea, rendering it near impossible to perform significant counting methods. Second, fishermen are reluctant to report incidental takes because they fear for their livelihood, which is becoming more threatened as the problem heats up. In order to facilitate the assessment of the population and incidental catch numbers, the Marine Mammal Protection Act (MMPA) was amended in 1988 to provide a five year interim during which incidental takes are not penalized and sighters are permitted aboard gillnetting vessels.

This estimated rate of mortality, however, seems to be high enough to cause a decrease in harbor porpoise density. Read and Gaskin (1988 and 1990) have demonstrated a correlation between the reduction of density with changes in the parameters in life history of the porpoise. Changes that have occurred since 1969 include females reaching sexual maturity at a younger age and an increase in calf length. These trends suggest the need of the species to alter its reproductive strategy, attempting to increase its reproductive life span and ensure the survival of its offspring, respectively.

SONAR:

It has been known for a very long time that the harbor porpoise is capable of echolocation, emitting sound signals and receiving their echoes from objects in the environment. The actual mechanisms used for sound production and reception are controversial. Therefore, it is suffice to say that *Phocoena* has a relatively efficient acoustical system with which it can accurately perceive and identify most objects in its surroundings.

Phocoena emits echolocating "clicks" at both high and low frequencies. Clicks have been recorded from both frontal and ventral angles from the porpoise. High frequency clicks are usually beamed forward through a narrow emission field. These clicks are primarily used while hunting for prey, typically small fish. Their frequencies range from 110 - 150+ kHz. Low frequency clicks (2 - 8 Khz) are produced at longer durations and are radiated frontally through a broader emission field. They are thought to be used for communication and navigation, especially while cruising in unfamiliar territories (Amundin, 1990; Johnson, 1966; Goodson et.al, 1990). It has been postulated that both low and high frequency clicks can be, and are, produced simultaneously. This suggests that the harbor porpoise can utilize two acoustical systems at the same time (Norris, 1968).

Perception of these signals is crucial to echolocation, but the porpoise's hearing mechanism must also be sensitive to a broad range of frequencies at variable source levels in order to form a true picture of its environment. The minimum power level of sound required for detection can be called the "auditory threshold." Few attempts have been made to explain the mechanisms by which sound is received and interpreted by small cetaceans. Kellogg (1952 and 1953) reported that the bottlenosed porpoise *Tursiops truncatus* responded with an avoidance reaction to short sound bursts between 400 Hz and 80 Khz and with an attack reaction to sound between 100 Hz and 400 Hz. A threshold for sensitivity can not be determined from Kellogg's data since he did not give source levels for the bursts of sound.

In 1966, Johnson obtained an audiogram of threshold values for the bottlenosed porpoise over the frequency range from 75 Hz to 150 Khz. The maximum hearing sensitivity appeared to be around 50 Khz at a level of -55 decibels (Db) re 1 microbar. The upper limit of hearing was determined to be 150 Khz at +35 dB re 1 microbar. Figure 2 shows Johnson's resulting auditory threshold curve for *Tursiops*. Below 50 kHz, the threshold continuously increases (sensitivity decreases) with decreasing frequency, reaching +37 dB re 1 ubar at 75 Hz. The threshold slowly increases between 50 kHz and 100 kHz,

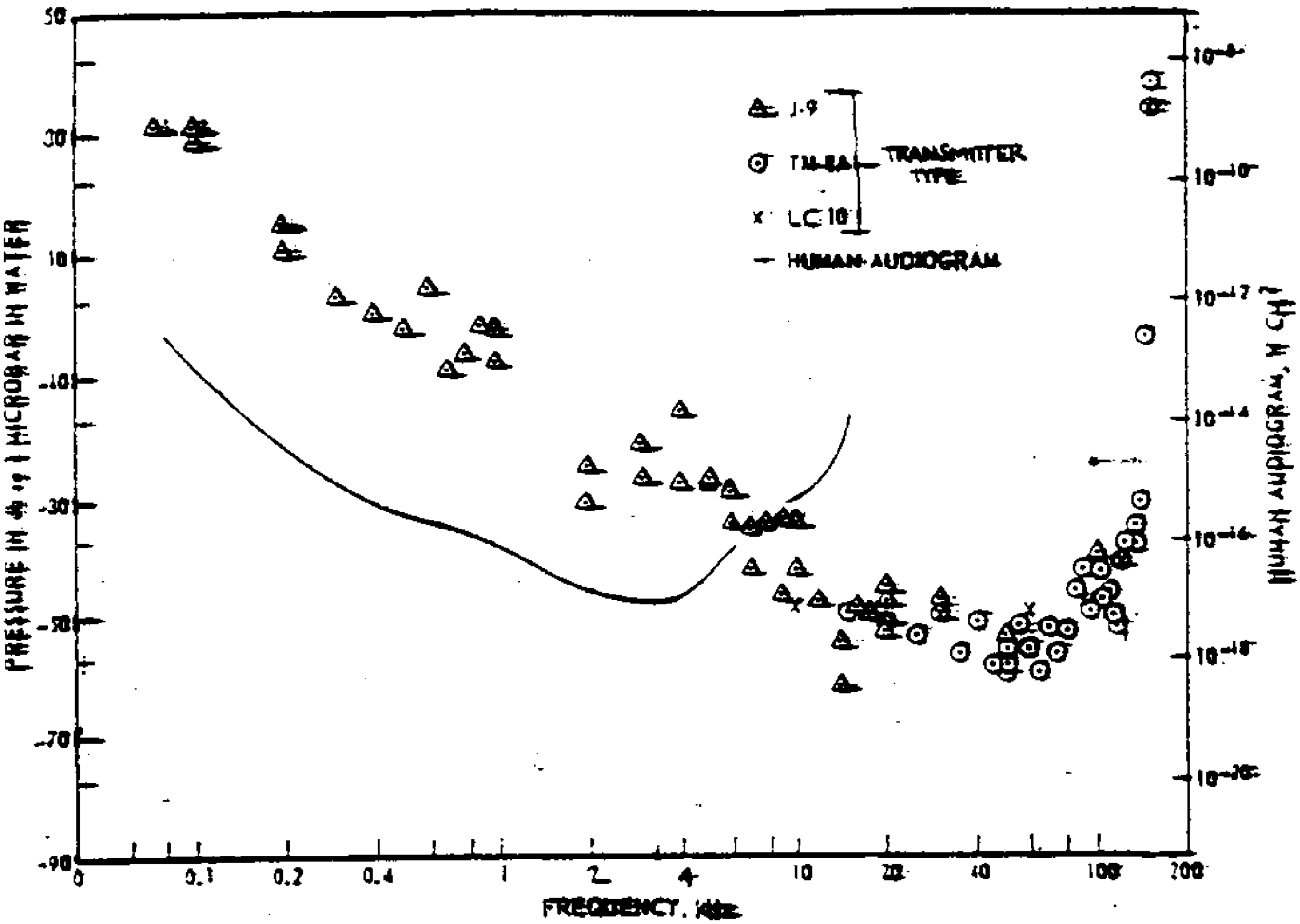


Figure2: Auditory Threshold - *Tursiops truncatus* (Johnson, 1966)

where it occurs at -45 dB re 1 ubar. Sensitivity falls off rapidly above 100 kHz. Johnson also included a human audiogram as shown Figure 2. This can be used as a reference for understanding the ranges over which the bottlenosed porpoise and other small cetaceans can hear.

Hatakeyama has been interested in the hearing capabilities of porpoises since the early 1980's. Experiments involving Dall's porpoise indicated that the strongest avoidance response occurred from sound pulses with a frequency of 115 kHz at $\geq$96 dB (Hatakeyama, 1983). Hatakeyama (1986) also found that the Dall's porpoise was insensitive to low frequency (1-3 kHz) sound waves at pressure levels up to 70 dB. This insensitivity may reflect the porpoise's adaptation to common ambient, or "background" noise.

The only information available concerning the harbor porpoise *Phocoena phocoena* is from Hatakeyama et al's (1988) observations of this animal's behavior to a salmon gillnet. Their audiogram (see Figure 3) showed best hearing sensitivity ranging from 4 kHz to 40 kHz with a threshold at 50 dB. The threshold increases by about 15 dB/octave below 4 kHz and between 40 kHz and 140 kHz and rapidly above 140 kHz.

The auditory capabilities of *Phocoena* seem to be worse than both *Tursiops* and Dall's porpoise (Hatakeyama et.al, 1988). Figure 3 compares an audiogram for *Tursiops* with *Phocoena*, demonstrating the greater sensitivity of the bottlenosed porpoise. This difference is not unusual. Hatakeyama et.al (1988) stated that the harbor porpoise shows better hearing capabilities at low frequencies (below 40 kHz; up to 20 dB better below 10 kHz) than Dall's porpoise. However, Dall's porpoise is more sensitive at frequencies above 40 kHz, with an auditory threshold about 15 dB lower between 80 kHz and 140 kHz. From these reports, the harbor porpoise appears to have a weaker auditory threshold shifted towards lower frequencies. We must realize that these assumptions have arisen from only a few studies (only one of which refers to the harbor porpoise). With the present data available, it is difficult to determine how a harbor porpoise will respond to sounds of certain frequencies and source levels.

ENTANGLEMENT:

Although *Phocoena* possesses highly sophisticated mechanisms for hearing and perceiving its environment, it still manages to become entangled in gillnets and drown. The

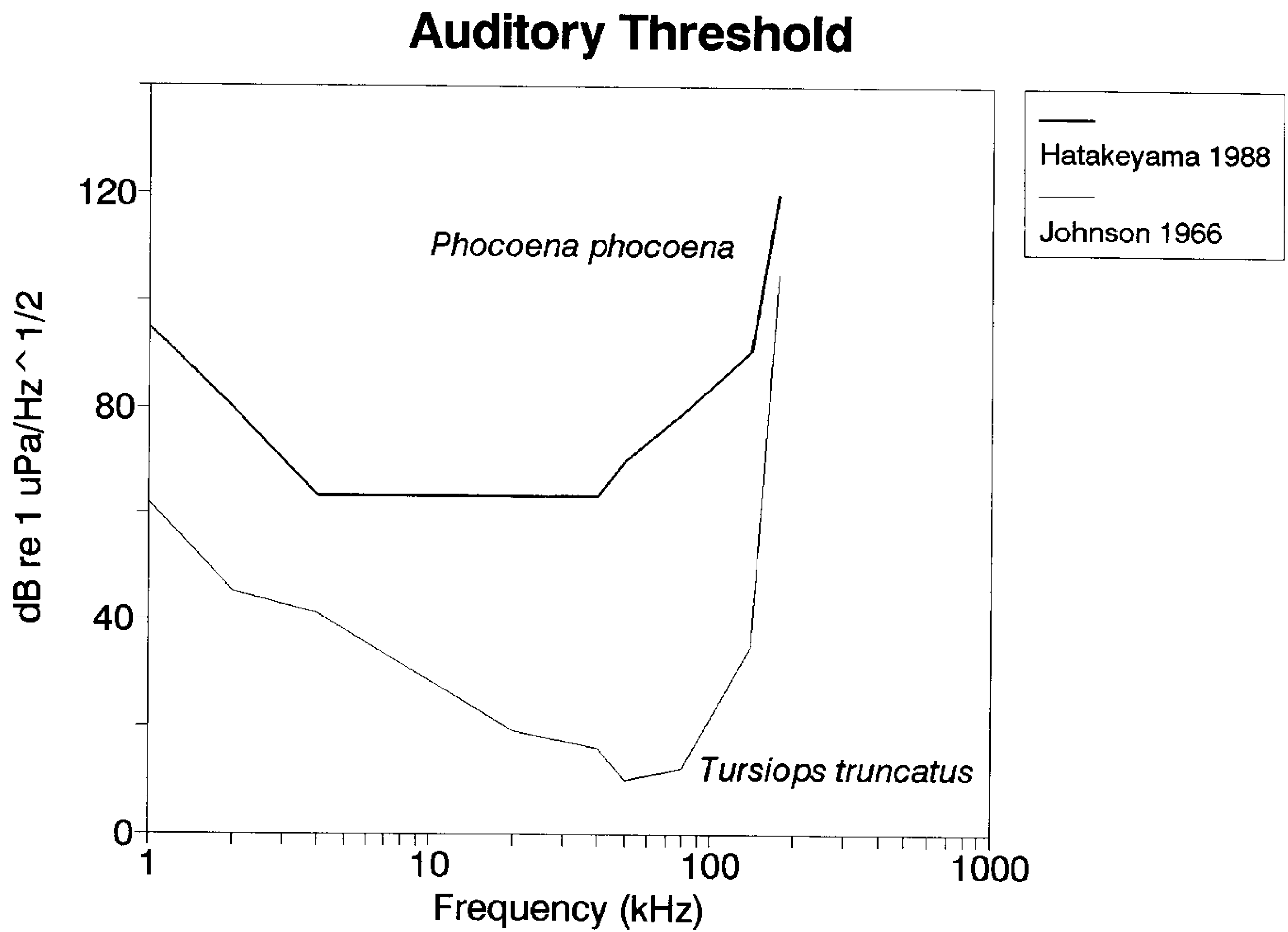

Auditory Threshold
Hatakeyama 1988
Johnson 1966
Phocoena phocoena
Tursiops truncatus
120
80
40
0
dB re 1 uPa/Hz ^ 1/2
1
10
100
1000
Frequency (kHz)

FIGURE 3

mechanism of entanglement is simple. The animal does not detect the net until it is within 2 meters from the net. It attempts to turn around, but its caudal fin (tail) gets caught. The porpoise panics, becoming further entangled while emitting sporadic high frequency clicks. It eventually drowns (Hatakeyama et al, 1988). The nets are difficult to perceive because they are made of transparent monofilament line making it very difficult to visualize; they may not emit much noise via resonation (to be determined); and their target strength is weak. Experiments have been performed on fine line detection abilities of the porpoise, demonstrating the difficulty in perceiving gillnet mesh (Busnel et al, 1965; Hatakeyama et al, 1988).

Other reasons for entanglement may include "masking" of the net due to fish, desensitization of objects in the far field, and the possible lack of echolocation upon encountering the net (Goodson et al, 1990). The harbor porpoise forages bottom-dwelling fish (the same fish at the same depths that gillnetters catch). The combination of active pursuit of its prey and its inability to detect the gillnets can be deadly. Desensitization of the far field comes into play when the animal is honing in on its prey. High frequency sonar at very short durations are emitted at this time. Therefore, stronger signals are being perceived from objects in the near field and the weaker far field signals may be ignored. The ignorance is not by choice, but by the mechanical shut down of hearing immediately following perception of one reflected signal. The third explanation for entanglement is the simple fact that the harbor porpoise may not be echolocating and will not detect the net, as explained above.

STANDARD GILLNETS AND THE GILLNETTING INDUSTRY

The gillnetting industry in the New England area employs over 800 crew members working on 350 fishing vessels. The industry accounts for 31% of the pollock catch and 40% of the cod catch. Dogfish and flounder are also caught with gillnets. The primary advantage of the gillnet is its ability to selectively catch fish. Sometimes referred to as a "web", the net sits on the ocean floor and waits for potential victims. A fish, if large enough, will swim into the undetected net and in its attempt to escape, the gills will entangle in the net (hence the name "gillnet"),while smaller fish are allowed to swim right through. Fishermen argue that this selective approach to commercial fishing is environmentally sound.

The dimensions of a standard gillnet are 300 feet long by 15 feet high (see Figure 4). Fishermen may string up to 20 nets together and set out 3-5 strings at a time. Figure 5 represents a string setup. The two end markers indicate the net's location. The lead line along the bottom weighs the net down on the ocean floor. Floats are attached to the polypropolyne line to suspend the net, giving it a "web" affect. The monofilament mesh ranges in thickness, or gauge, depending on the type of fish to be caught. A towing line (not shown) is typically attached to the top corner of the net for retrieval.

To avoid entanglement, the lead line and polypropylene line are separated during the deployment process. The entire length of the net is fed out the back of the boat as the vessel creeps forward. This is known as flaking the net and ensures that the net is fully stretched along the ocean floor. The nets are retrieved by an enormous "spool-like" apparatus which reels the net onto the boat.

The fishing vessels range from 30 - 60 feet in length depending on the fisherman and the type of fish he is going after. Some fishermen strictly fish inshore (within 70 miles from shore) during the season from January to June. Other fishermen venture offshore. Offshore fishing occurs beyond 70 degrees parallel latitude and its season is year round.

UNDERWATER ACOUSTICS

Even though the ocean realm was once referred to as a "silent world", a wide variety of sounds and sound generating mechanisms exists. The noise from these sources is commonly called background, or ambient, noise. Ambient noise is an underlying, variable phenomenon that must be accounted for in all fields of ocean discipline.

Several mechanisms are responsible for generating ambient noise in the ocean. The most intense and common signals are due to ocean turbulence, shipping, surface generation, biological, surf, seabed flow, rainfall, and thermal agitation. Figure 6 is a representation of the deep water ambient noise over a frequency range of 1 to 1000 Hz. It is important to note that the noise spectrum for a deep water environment is different than that of a shallow

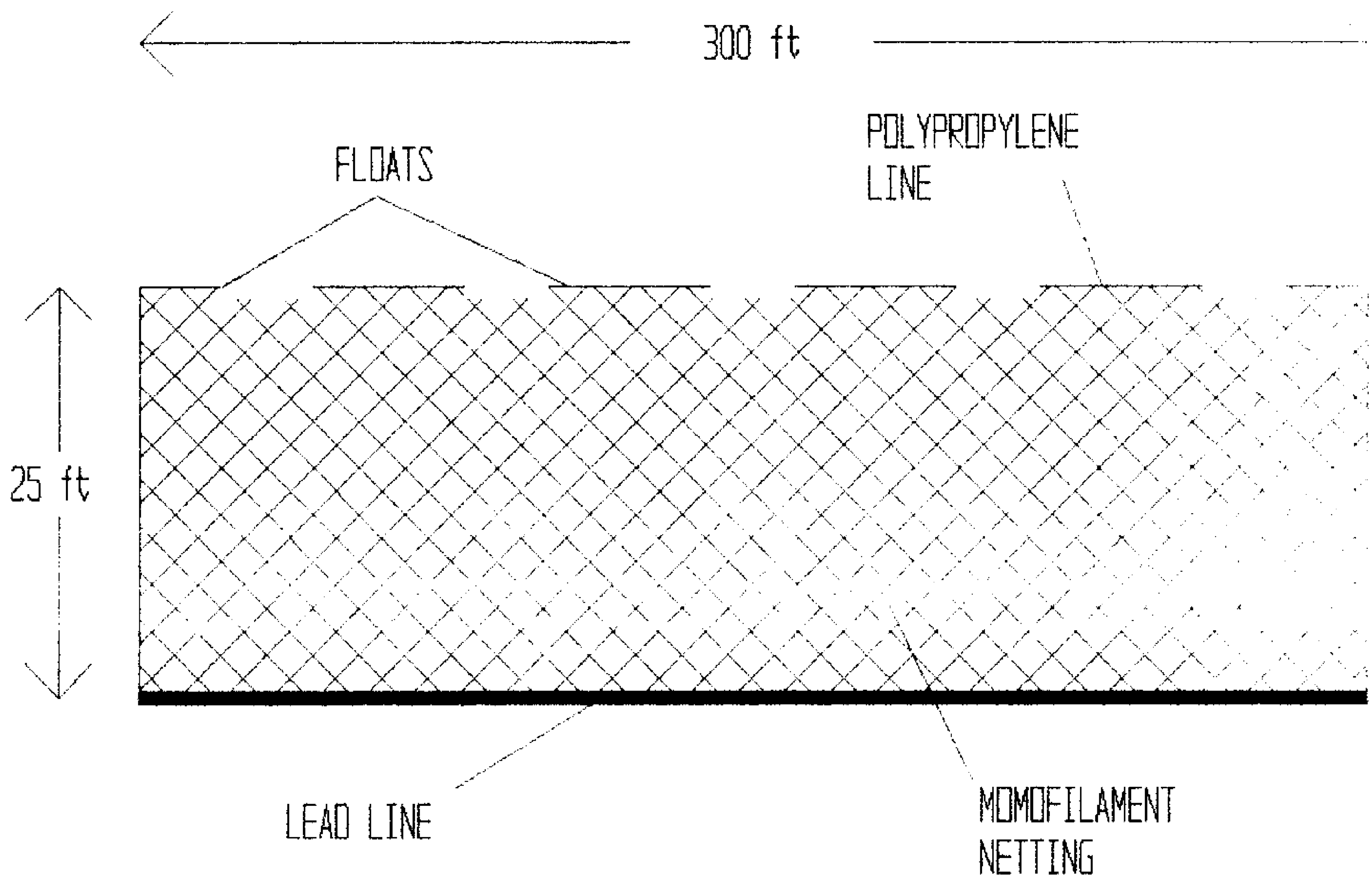


FIGURE 4: STANDARD GILLNET

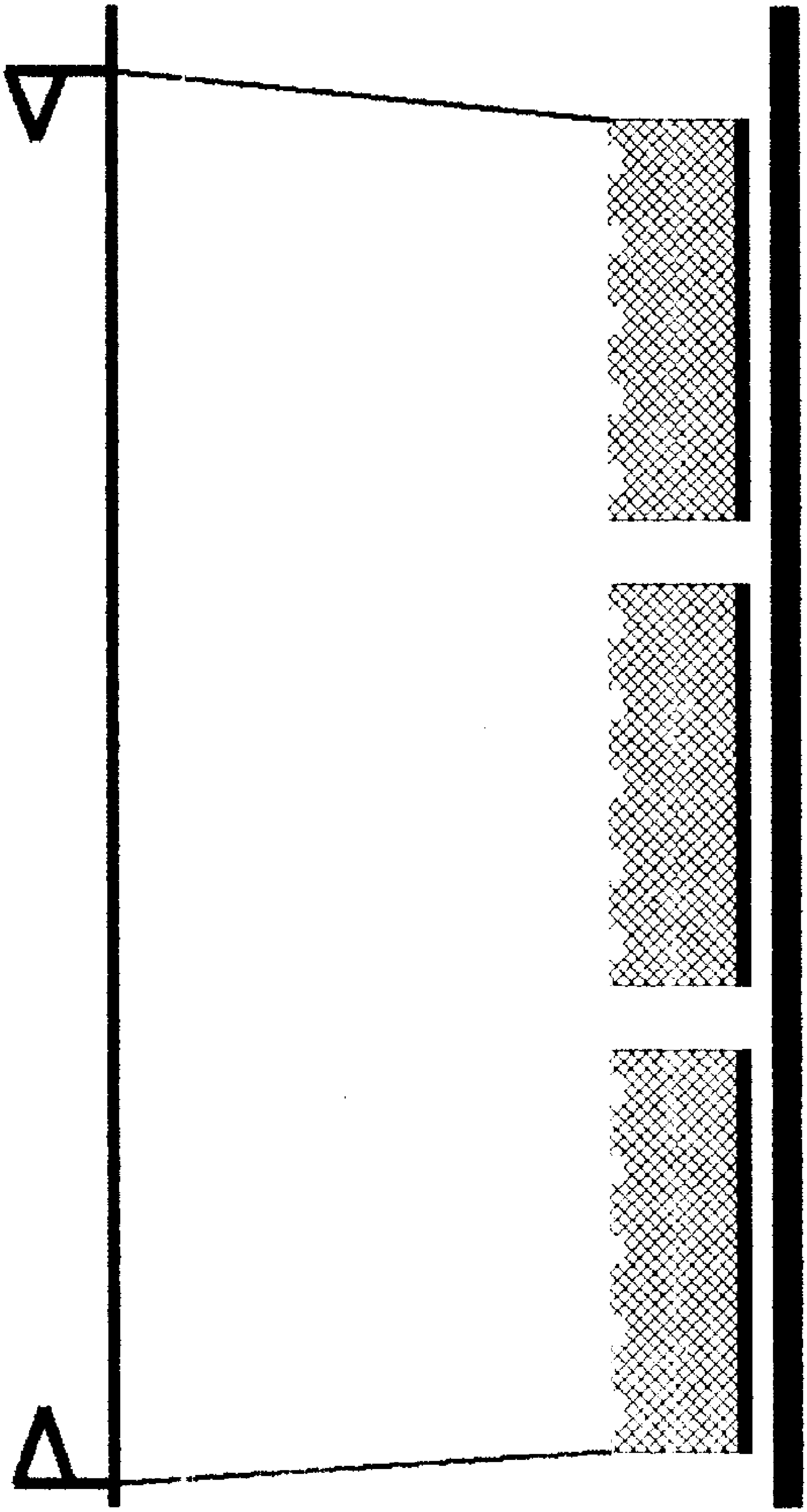


FIGURE 5: GILLNET STRING

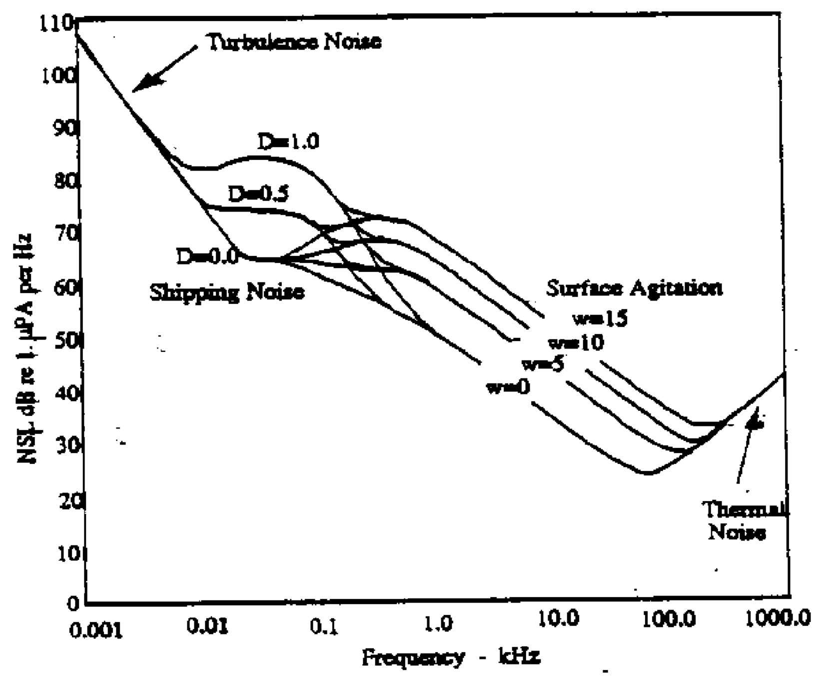


Figure 6.1. Deep-water ambient noise spectrum level

FIGURE 6: DEEP WATER AMBIENT NOISE

water environment.

At the low frequencies, 1 Hz to 10 Hz, ocean turbulence is responsible for the majority of the noise. An empirical equation for the noise spectrum level is:

$$NSL = 17 - 30(\log f)$$

The sea surface is the main source of ambient noise in the frequency range of 100 Hz to 100 kHz. There are four predominant methods of noise production at the surface, the first being wind turbulence. The turbulent pressure of the wind across the sea appears as acoustic pressures in the water column by the same phenomena that is responsible for producing waves. This surface motion creates noise that arise from high frequency capillary patches of turbulence. Acoustic pressures can also be produced from the interaction between surface waves. Spray and cavitation are perhaps the most prevalent form of surface generated noise. Waves, upon breaking, introduce bubbles into the water column, which in turn generate acoustic pressure waves. Obviously, waves that are violent enough to produce white caps generate noise from the splash. However, the process also occurs in small waves that are not associated with white caps. The noise produced by bubbles will be discussed later. An empirical equation for the noise spectrum level due to surface agitation is

$$NSL = 50 + 7.5w^{1/2} + 20(\log f) - 40(\log(f+0.4) \quad \text{(Coates, 1989)}$$

The ambient noise produced by shipping is a large factor due to the extensive amount of shipping activity. In deep water locations, distant shipping is a predominant factor because of the long propagation of sound in the deep sound channel. Propeller cavitation creates noise that produces a broadband continuous spectrum which peaks in the high tens of hertz and then falls off at 20 dB per decade. The spectrum level is approximated by

$$NSL=40 + 20(D-0.5) + 26(\log f) - 40(\log(f+0.4))$$

where D is the shipping density and has a range from 0 to 1. Noise can also be generated from "singing" of a poorly designed blade, as well as from a reciprocating pistons, gears, and drive shafts.

Animal life is also responsible for ambient noises, most of which occur in the 500 to 1500 Hz range. Some of the various marine life responsible for noise production are crustacea, marine mammals (whales, harbor porpoises, etc), and certain fish, suck as croakers. Interestingly enough, no commercially caught fish produce sounds in during normal activity. However, Urick (1984) reports "Nearly all fish make noise......when subject to stimuli such as electric shock".

A significant amount of noise in the shallow underwater environment is caused by breaking surf. Wilson (1985), in a study off the southeastern coast of Monterey Bay, California, determined the anisotropy (seaward versus shoreward) of the noise generated from breaking surf. His experiment covered a frequency range of 20 to 700 Hz at a range of up to 15 km from shore. Using a steerable carnoid receiving pattern, he reported a anisotropy of a 10 dB increase in intensity at 300 Hz and 9 km from shore.

In a shallow water environment, significant noise can be produced at the seabed. High near-bed current flow induces particular motion, resulting in particle collisions from which sound is generated. Thorne (1990) compares marine and laboratory spectras with rigid body radiation theory of this phenomena. As the particle size is decreased he notes an increase in frequency, realizing a 7 kHz peak for 1.2 cm radius and a 200 kHz peak for a 0.0016 cm radius. He observed that the spectral levels "...are similar in magnitude to those generated by surface agitation at high sea states..". Along with this, Thorne noticed a noise level of "..approximately 70 dB re: 1 uPa $Hz^{-1/2}$ in the 10 kHz region." as compared to levels of 50 - 60 dB for moderate to high wind states.

The results of this study have a great deal of significance to the acoustical data gathered in this project. The measurements were taken in the Great Bay Estuary, where a strong tidal current (up to 1 knot) exists.

When it is present, rainfall can be a dominant source of noise in the 1 the 15 kHz region. The shape of the spectrum is influenced by the drop size while the spectrum level is a function of the intensity of the rain. For these reasons, a broadband spectrum with a general peak at 15 is exhibited.

Above 100 kHz, the spectrum is usually dominated by thermal noise. This is a result of molecular motion in the ocean and it's noise spectral limits can be approximated by

$$NSL = -15 + 20(\log f)$$

As mentioned before, bubbles play an important role in underwater acoustics, and are the main source for the noise exhibited by the Knudsen curves (Figure 7). When a wave brakes and cavitates, substantial energy is imparted into the bubbles clouds that are formed. They can then be circulated deeper into the water column by Langmuir circulation or turbulence. After excitation, sound is emitted by means of a volume pulsation. Large

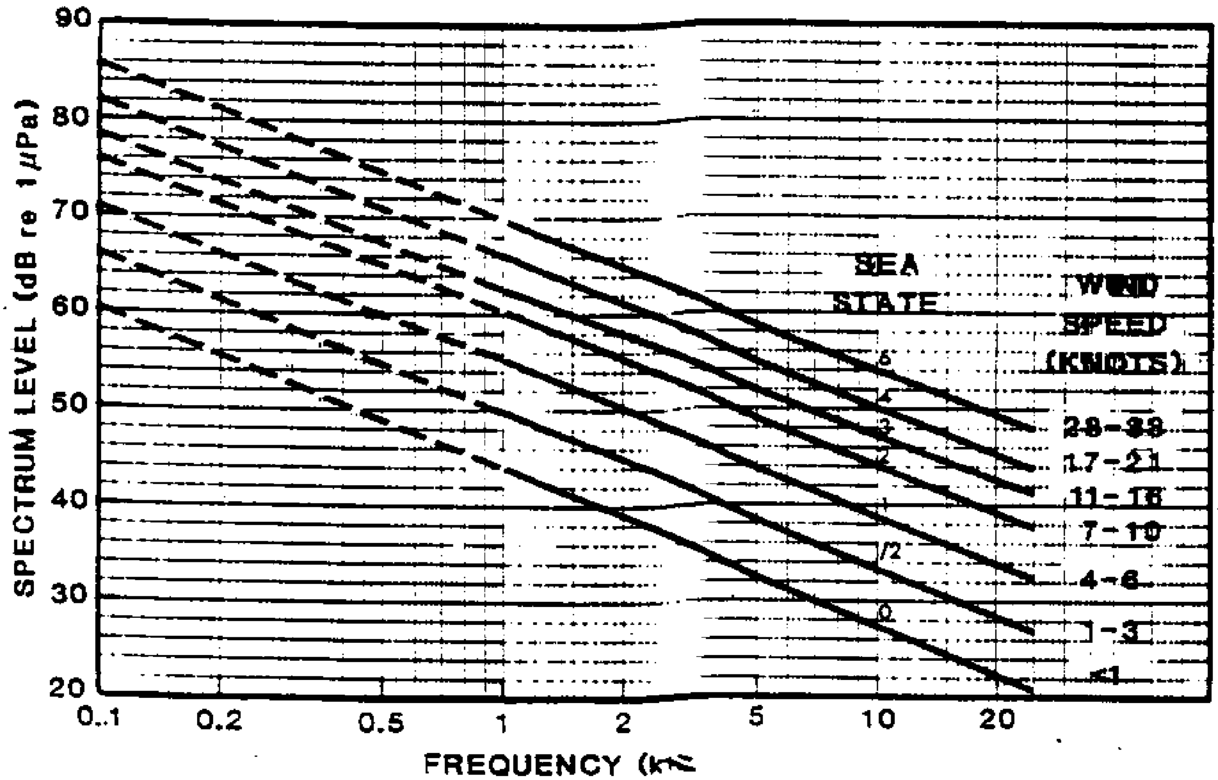


FIGURE 7: KNUDSEN CURVES (1948)

amounts of research has been performed on this phenomena. Prosperetti (1990) and Pumphrey (1990) have shown that the noise emitted due to bubble clouds peaks at 500 Hz and decreases in intensity level with decreasing frequency. Large bubbles, which are less probable to be formed, are required to radiate sound at lower frequencies.

Ambient noise exhibits a great deal of variability with time, depth of the water column, and increasing depth at a certain location. On a time scale, shipping noise exhibits the shortest time variance, showing a diurnal variation, while wind generated noise is slow to change. This is due to the inertia in building up and decaying a fully arisen sea. Zakarauskas (1990) observed a long term seasonal variance in the noise. In the summer a small mixed layer and a negative velocity gradient exist which causes downward refraction of the rays. Therefore, he noted a 3 to 9 dB increase in noise levels for winter over summer.

Ambient noise exhibits a vertical directionality. A directional hydrophone placed at a certain depth will see different intensities depending on the angle that the main lobe is oriented on. Sotrin observed a spatial distribution at low frequencies of an increase of 25 dB over a +/- 20° horizontal range. Urick (1984) also reported a horizontal directionality at 200 and 400 Hz, which corresponds to the frequencies due to shipping. The noise generated by distant shipping is transmitted through the deep sound layer and arrives at a horizontal. At these frequencies, very little noise is observed from the vertical. An opposite pattern is seen at frequencies corresponding to surface generated noise, with minimum intensities on the horizontal and strong signals coming from the vertical.

METHODS

The first phase of our project consisted of an extensive literature review. During this phase, the study was divided into three parts, as defined in the background information (i.e. harbor porpoise behavior, gillnetting industry and modifications, and acoustical and physical measurements). Delegating the tasks in this fashion allowed each member of the group the freedom to examine their specialty in great depth. We held weekly meetings to inform the group of our findings and to determine our plan for phase two.

The second phase included all field measurements. For a conclusive study, we needed to record not only sounds emitted by a gillnet, but also data concerning ambient noise and current speeds and directions. Data on ambient noise allows the understanding of sounds that are normally present in the ocean due to wind, weather, and various biological factors. This could be compared to recordings with a gillnet in the water (gillnet and modified gillnet noise) to isolate sounds produced by the net. Information about currents provides a reliable reference to correlate consistent trends in noise variance over time. We were also interested in testing modifications of the standard gillnet to determine whether the frequency band or source level of sound would change. If it could be shown that standard gillnet noise does not fall within the hearing sensitivity range of the harbor porpoise, perhaps a modified gillnet could alter the sound production in such a way to increase the animal's awareness of the net's presence. In order to obtain this information, various pieces of equipment were utilized. The equipment used along with considerations for use of each for this project is described below.

EQUIPMENT

GILLNET:

The gillnet used in this project was 300 ft. long and 25 meshes high, with a mesh size of 5.5 inches. Mesh size refers to the distance between adjacent parallel lines of monofilament. The net was set up with a 0.5 hanging ratio, typical for a commercial gillnet. This represents the ratio of the net height in the water to the net height when fully stretched out of water. The proper scope for the hauling lines was determined from information regarding the depth and tidal height fluctuations. The hauling lines were made of 3/8 inch sheepline, which were attached to our markers. Simple stick buoys were used for floatation markers. The net was anchored with a cinder block and a 16 lb. danforth anchor on either end.

A permit was obtained from New Hampshire Fish & Game allowing the deployment of a gillnet in the estuary for experimental purposes on the dates shown in the following section.

CURRENT METER & MOORING:

An Endeco Type 174 Solid State Memory Tethered Current Meter was used to determine the speed and direction of the current. It is an axial flow meter with a ducted impeller that is designed for use in continental shelf and estuarine locations. The four major components are the sensor endcap assembly, the pressure case with shrouds and fins, the impeller assembly, and the electronic chassis.

The sensor endcap assembly encases the various sensors on the current meter. The temperature sensor uses a stainless steel sheathed thermistor to determine the temperature within a range of -5 to 45°C with a sensitivity of +/- 0.2°C. A conductivity sensor uses an inductive probe to produce a voltage linearly proportional to conductivity. The instrument has a range of 0 to 80 mS/cm and a sensitivity of +/- 0.80 mS/cm. Using the conductivity and temperature data, the salinity can be found by an external calculation. A potentomentric pressure transducer is used to measure the pressure, which is directly proportional to the depth. The instrument is good up to 152 meters within 0.6 meters. The endcap assembly also houses an external cable connector which can be used to transmit the data to an external PC.

The pressure case is an external PVC cylindrical casing. It consists of the fins and shrouds which protect the impeller from debris and also serves as a platform on which to stand the instrument. The pressure case also contains a bubble level and 0.25 kg lead disks trim weights that can be used to ensure the meter is correctly trimmed.

A rotating impeller is used to determine the current speed. The current speed is proportional to the rate of rotation of the impeller, which is sensed by magnets. The speed threshold is 1.54 cm/s and the full scale value can be set at 5 or 10 knots (257 or 514 cm/s, respectively).

The electronic chassis contains the battery compartments, printed circuit boards, compass, and memory module. The battery compartment contains 8 alkaline D cell batteries as the main power supply and 8 AA alkaline cells for backup power, with a life of one year of operation. The compass is a gimballed, two axis, flux gate instrument that is free to swing 30° on both axes. It is accurate to within +/- 5 degrees. Three circuit boards control the input/ output functions. Various default switches, such as internal sampling time, speed range, sensor selection, are located on a PC card. The electronic chassis also holds the Endeco Type 1069 Solid State Memory Data Logger with 128 kbytes of memory that can be used to store the data internally and then dumped into a PC when the instrument is retrieved.

The overnight mooring for the current meter consisted of a surface buoy tied to a deadweight, an old heavy brake drum off a truck, by a 1/4 inch nylon rope. For added safety, a Danforth anchor was attached to the weight. The current meter was hung perpendicular to the rope by means of a Cook Clamp assembly and a tether. The Cook Clamp is attached to a two foot wire rope section fixed in two positions to the rope. The clamp consists of the inner section which is fixed to the wire rope and an outer shell that is free to rotate and is connected to the tether. This set up allows the current meter to rotate freely with any change in direction and isolates the instrument from small disturbances is the rope. A small buoy was then attached to the rope above the meter.

The current meter was deployed after the R/V Jere Chase was anchored in the desired position south of Fox Point and the final steps were performed. The mooring line should be to be fairly taut, with a minimal amount of slack, to allow for the tidal changes. The PC and the current meter are then connected via the cable, and the meter manually reset by touching a TDK magnet to the magnetic reset. The Endeco 174OPS program was accessed to set the clock, fix the sampling interval at two minutes, and start the data logging. The cable is then detached from the meter. The data is stored in the internal data logger and can be dumped to the computer upon retrieval of the unit.

After the data logging is started, the meter is ready to be deployed with careful consideration not to tangle the rope and equipment. The surface buoy and rope are first put into the water and allowed to drift away from the boat. The current meter is then lowered into the water. After the lines are tautly streamed behind the boat, the dead weight is lowered into the water. A rope is then looped freely around the Danforth anchor and is used to lower the anchor into the water and down to the bottom. When it reaches the bottom, the rope is retrieved by letting go of one end and hauling in the other one.

HYDROPHONES & MOORING:

In recording the data, an ITC-6050C hydrophone was used. The sensitivity of the instrument is -158 dB re 1 uPa/ Hz^1/2, and it possesses a fairly flat response over a bandwidth of the required measurement for this project.

A permanent hydrophone mooring (Figure 8) was designed and deployed to facilitate the data gathering procedure. The system consisted of a granite block, a 1/2 mooring line, a pulley attached a few feet from the block, a surface buoy, and a free flowing line. The second line was passed between the pulley and the mooring, and was free to rotate through the system. It was joined by two shackles that could be unhooked and attached to each end of the hydrophone cage, which could then be lowered into the water column.

When deploying the hydrophone, the RV Jere Chase was anchored and a zodiac run over to put the cage on its mooring. The hydrophone cable was then brought back to the boat and connected to amplifier.

OSCILLOSCOPE & AMPLIFIERS:

A schematic diagram of the equipment used in the acoustical measurements is shown in Figure 9. An Itheco 451 Data Acquisition Amplifier was first used to increase the signal strength. Usually, a gain of 50 to 70 dB was used for the acoustical measurements of this project, but the amplifier is capable of imparting a gain of up to 800 dB. The signal was then sent thru an Ithaco 4113 Variable Electronic Filter, which applies a Butterworth filter to the signal. The filter has high pass capabilities of 1 Hz to 100 kHz and a low pass of 1 Hz to 1 MHz. The cutoff frequency accuracy is +/- 1%.

After the signal was amplified and filtered, it is sent to a Nicolet 320 digital oscilloscope, which contains a 4000 point window. The time resolution set from a maximum of 500 mS down to 5 nS per point. A faster time per point results in a shorter sweep time. For the acoustical measurements of gillnet and ambient noise, a 5 us TPP is used, which results in a 20 mS window of data. The decision to use a time per point of five micro seconds was determined from the Nyqist frequency.

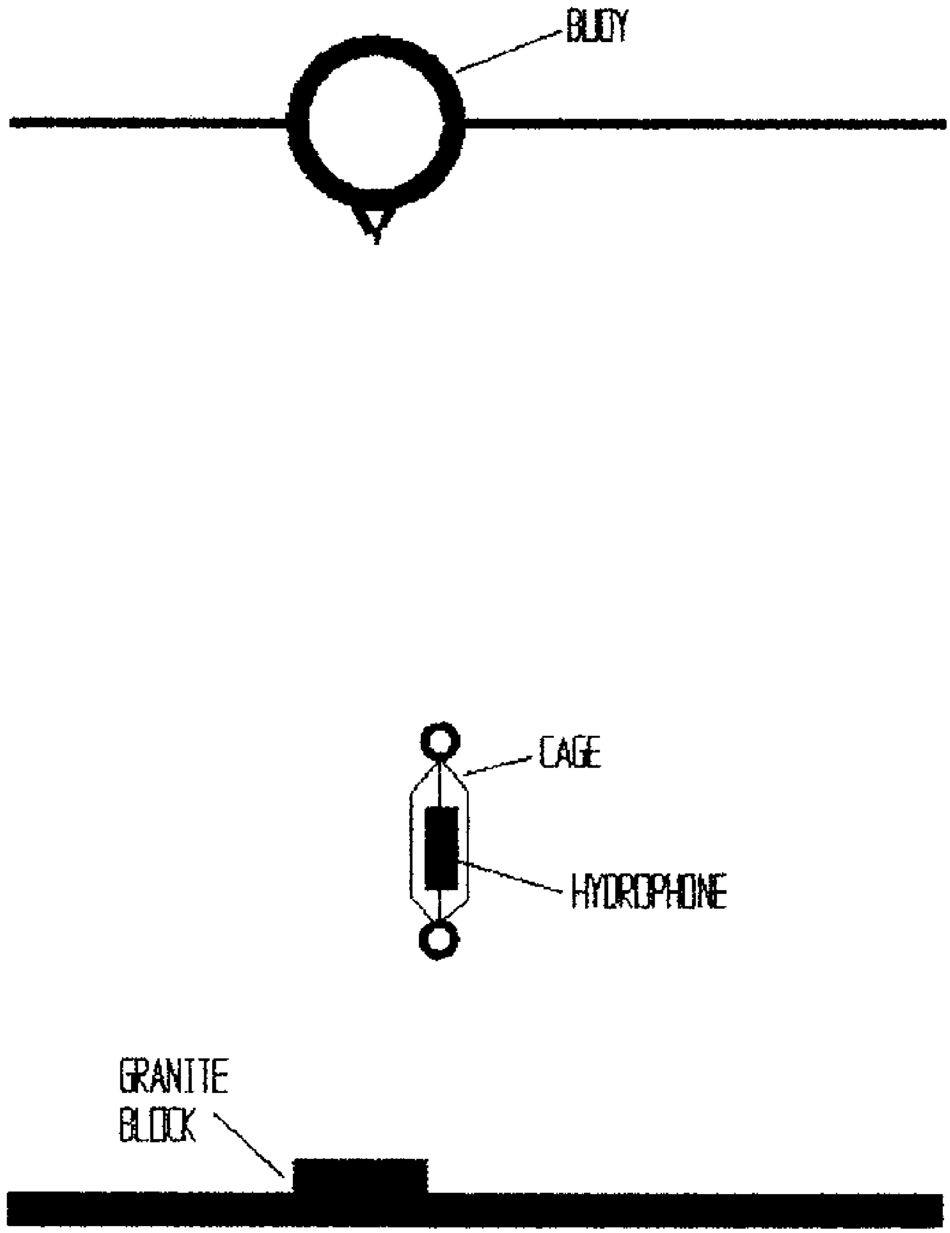


FIGURE 8: HYDROPHONE MOORING

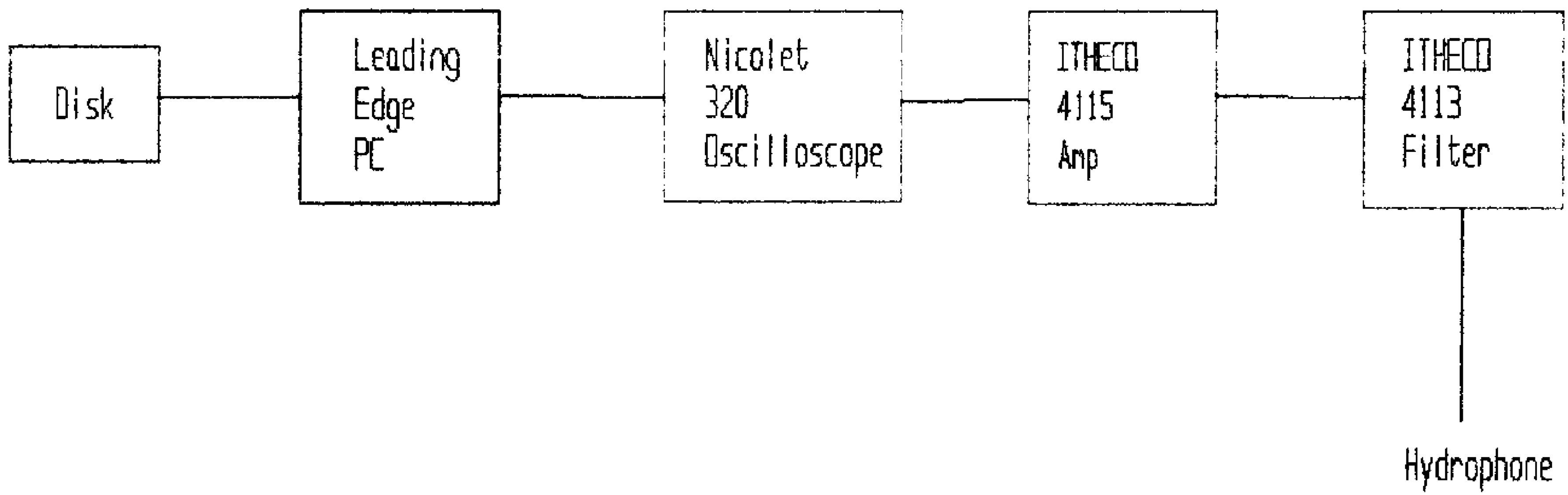


FIGURE 9: EQUIPMENT SCHEMATIC

MODIFIED GILLNET:

Past studies have involved modifications of the gillnet in attempt to alter its target strength since the monofilament alone was found to have considerably low target strength (Whitlow and Jones,1991). The target strength of an object under water is related to its difference in density from the water. To increase the net detectability, items such as polyrope, lightswitch chain, rubber tubing, and diablos have been attached to the net (Hembree and Harwood, 1987; Hatakeyama, 1986). This project intended to incorporate one of these modifications onto a standard gillnet and test its passive acoustics.

In order to decide which type of modification to try, some important feasibility factors had to be considered. The item which is attached to the net must be inexpensive. As mentioned earlier, one gillnetter may use up to 20 nets in one string. If modifications on one 300 ft. net costs even a small percentage more than the standard net, modified nets will not be economically practical. The modification must also not interfere with the deployment, retrieval, or success fish catch rate of the gillnet.

Our final decision was to modify the net with a #3 bead chain (similar to those used as lightswitch cords). 300 feet of chain was ordered and used. The chain was cut into 5 ft. strands and attached in a "zig zag" fashion down the height of the net with 3 foot intervals between each (see Figure 10).

STUDY SITE

An important consideration was the location for conducting the measurements of ambient noise, gillnet noise, and currents. After careful analysis, the Little Bay Estuary was decided upon. The possibility of deployment in the open ocean was also contemplated, but the estuary was a more feasible option.

In reaching this decision the advantages and disadvantages of both the estuary and the ocean were discussed. The main advantages of the ocean are that gillnetting is operational, and the ambient noise and sea state are directly related to a gillnetting situation. The disadvantages include the problems associated with maintaining the geometric situation of the deployed equipment. A rough sea state and a deep depth make it difficult to determine the position of the gillnet and hydrophone.

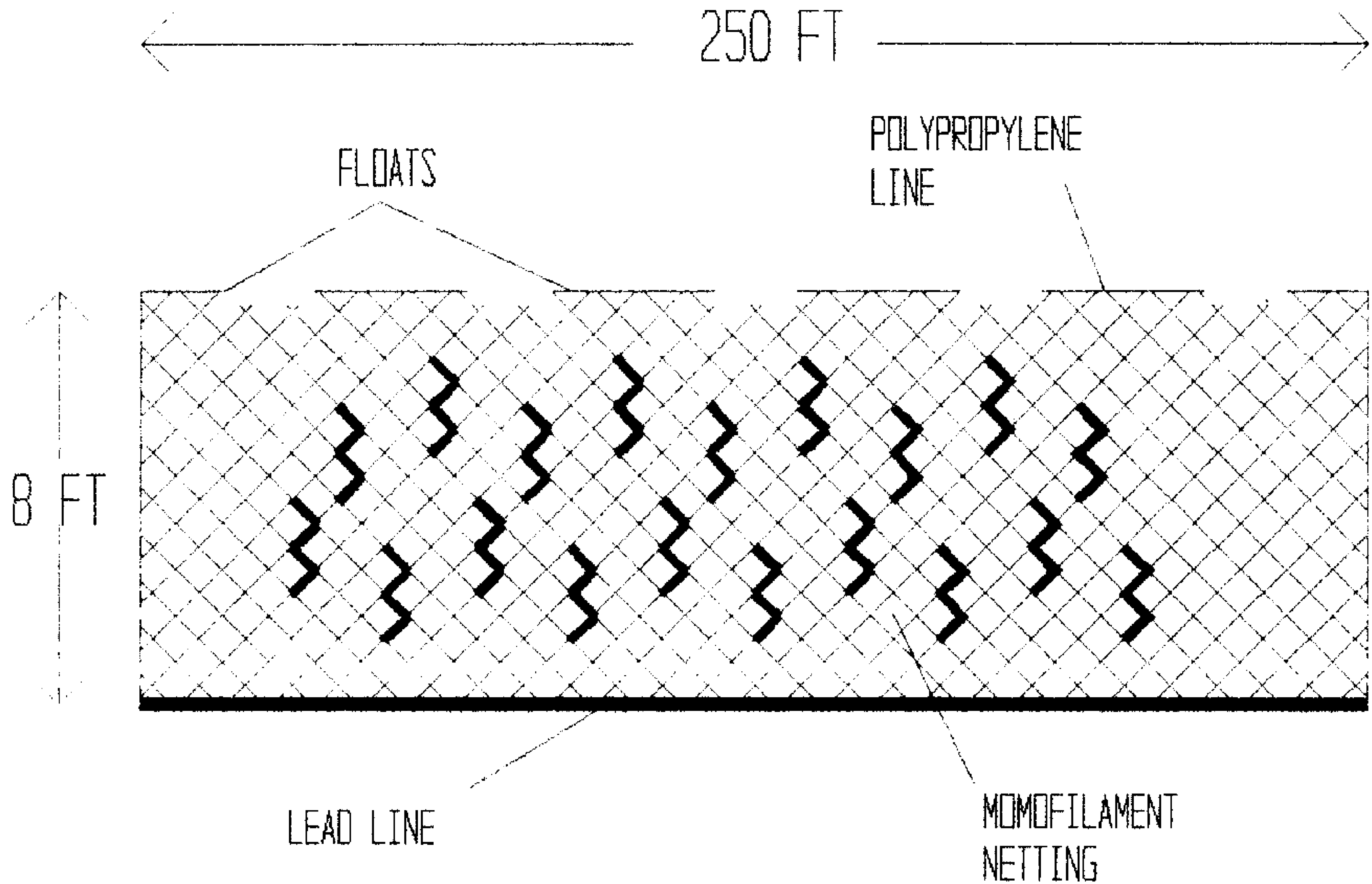


FIGURE 10: MODIFIED GILLNET

There are several advantages to deploying the instruments in the estuary. First, the influencing factors on the positioning of the hydrophone and gillnet are decreased as compared to the open ocean - the water depth is less and the sea state is calmer. The strong tidal currents in the estuary are also beneficial to the collected data. By deploying the hydrophones and the current meter at the same time, the generated net noise can be understood as a function of the current speed. Further benefits of the estuary are based on feasibility of completing the project. It was easier to attain boat time on the estuary. Valuable time could be spent performing measurements instead of traveling to a location ten miles off shore. Finally, considering our limited budget, the costs were substantially lower.

The disadvantages of using the estuary for the measurements are that gillnets are not typically deployed at such depths and differences in the sea state and in the sea properties (density, salinity, temperature, etc.) exist. However, these problems had minimal effect on the data collected.

TRIP PROCEDURES

February 14, 1992:

Our initial goal was to determine a specific location in Little Bay Estuary at which to perform field measurements. After studying a map of the estuary, it was decided to profile an area between Fox Point and Adam's Point, a little south of the N" 4" buoy. Vertical profiles using the current meter were performed in this area to gather data on current speed and direction. Several profiles were taken across the estuary in order to generate a picture of the current speeds as a function of depth and horizontal position across the transect.

The first profile was taken 50 meters off the east shore with the Research Vessel Jere Chase anchored at this location. At this time, the tide was ebbing and the boat settled with its bow facing south west (up the estuary). In order to ensure a straight transect across the estuary, a marker buoy was used to indicate the location of the first profile. Profiles were then taken at 25 meter intervals across the estuary.

To begin profiling, the weight and current meter were placed into the water and lowered to one or two meters depth. While the meter was visible, it was checked to see if it was suspended level in the water column. The instrument was then continuously fed out a meter of cable and held in position for 90 seconds until it reached the bottom. It was then retrieved without pausing every meter.

February 20,1992:

Since the magnitude of tidal flow may vary over time, the current meter was deployed at 10:12am on a fixed mooring at profile sites 7 and 8 (from Feb. 14's transect) for the course of a full tidal cycle. The overnight deployment scheme described earlier was used. The current meter was retrieved at 12:52pm on February 21,1992.

February 27, 1992:

Due to the importance of understanding the current dynamics at the location the gillnet is to be fished, the current meter was again deployed over a complete tidal cycle (10:18am 2/27 - 12:44pm 2/28), using the same mooring system and sampling procedures used on the 2/20 trip.

Also during this trip, the mooring system for the hydrophone described above was devised and deployed in the estuary. Sixteen samples of ambient noise were recorded from the low frequency hydrophone 12:19pm - 12:41pm.

February 28, 1992:

One hundred-one samples of low frequency ambient noise were recorded 10:31am - 2:48pm. The current meter was retrieved at 12:44pm.

March 6, 1992:

The current meter is capable of recording and saving data over an extended period of time. In order to observe the diurnal, weekly and biweekly variance in current (neap and spring tides) we decided to deploy it over a complete tide series (one month). With this true information on currents at our study site, correlations with each sampling of noise can be identified. The current meter was deployed on a permanent mooring at 10:47am.

March 18, 1992:

We deployed the standard gillnet perpendicular to the current to see what, if any, additional noise would be created by currents running through the mesh. The low frequency hydrophone was used to record this noise. Eighty-six samples were obtained 12:31pm - 2:25pm. 4 samples of low frequency ambient noise were taken 3:12pm - 3:18pm, after the net was removed from the water.

March 26, 1992:

We deployed the standard gillnet parallel to the current to test the differences in sound production that may occur with respect to the deployment method. In this case, the current runs along the net instead of through it. The hydrophones were moored together as described above. Fifteen samples of each were alternately recorded 12:03pm - 12:27pm.

Upon retrieving the gillnet, the mesh and float line became entangled around the keel of the boat. In order to release the net, it had to be cut in several places. Once the net was hauled aboard and examined, we deemed it useless for future work. A request for another net was placed soon thereafter.

April 9, 1992:

While awaiting the arrival of a new gillnet, we took the hydrophone out for more ambient noise measurements. Twenty-five samples of ambient noise was recorded 12:31pm - 1:27pm.

April 22, 1992:

Our last boat day consisted of testing the modified gillnet. The net had previously been used commercially and had to undergo some minor repairs. It was approximately 3/4 the size of our original net. Modifications were made as described above and as shown in Figure 10. This net was deployed perpendicular to the current. From 10:23am - 11:10am, 25 samples of ambient noise was recorded. After the net was retrieved, 19 additional samples were taken 11:42am - 12:22pm.

Three scheduled boat trips (3/12/92, 4/2/92, and 4/17/92) were canceled due to poor weather conditions.

MEASUREMENTS - Method and Data Analysis

CURRENTS:

After the computer and current meter were linked through the cable, the Endeco program 174PRF was accessed. This program receives data from the current meter, applies the required calibration coefficients, converts the received data from hexadecimal code to engineering units, calculates the salinity from the temperature and conductivity data, and then displays the data on the screen. Using a TDK magnet, the current meter was reset by touching the magnet to the manual reset. After the 174PRF menu is used to enter the time, date, and sampling interval into the computer, the data logger is started. Upon retrieving the current meter, the 174PRF program was exited and 174OPS entered, upon which the data logger was stopped by typing Q. The data was then dumped from the data logger to a disk in the computer, where it occupied 130 kbytes.

In order to analyze the data, the hexadecimal code that is received from the data logger must be converted into standard units. The Endeco program 174PROC is first used to convert the data into binary compacted processed data. The program requests an output sample interval, the beginning and ending time of the data to be analyzed, and the magnetic variation. This program is exited and 174RPT is entered. This program uses the files created by 174PROC to create one of four standard reports: standard, record period summary, component. and spectral density. In a standard report, the time of each output sample interval is displayed with the corresponding current speed, direction, temperature, conductivity, depth, and salinity. A report period summary generates a matrix of current speed versus direction. The data can also be displayed in a component report, which breaks down each vector-averaged sample into positive or negative North and East components. In a spectral density report a fast fourier transform is performed on either the current or component data. The energy and 95% confidence limit are given for 35 frequency bands.

At this point, there are two Endeco programs that can be used to graphically display the data: 174TPLOT and 174DPLOT. Time series plots are generated by the TPLOT program. Any of the recorded data channels can be plotted. A Component plot, which shows North and East current components versus time, is also an available option. The DPLOT program is used to produce either an oyster plot, a polar histogram, or a vector plot.

An oyster plot is a series of concentric contours with magnitudes equivalent to the number of samples with currents in that direction, and speed in that range. A polar histogram is a set of rays that show the number of data points that had current in a particular direction. In a progressive vector plot, North/South and East/West displacements are shown in a X-Y plot.

ACOUSTICS:

From February 27th to April 22nd, over 325 data samples were aquired. At this point, the data was in the form of an acoustic pressure, and the temporal behavior can be seen in Figure 11. The 20 second window contains a wave with the amplitude scaled in volts instead of acoustical pressure. However, the voltage intensity is proportional to pressure. To understand the relationship, the mechanisms of recording must be understood.

The signal that arrives at the hydrophone was in the form of an acoustical pressure, and was then transformed into an electrical signal. The sensitivity of the hydrophone, -158 dB re 1 uPa/$Hz^{1/2}$, relates the input pressure to the output voltage, as shown in Figure 12 and 13. The modified signal was then sent to the Itheco 413 Amplifier, where a significant gain was added to the signal. The relationship between the output and input is:

Gain in dB's = $10 * \log(^{\text{output voltage}}/_{\text{input voltage}})$

After a gain was added, the signal was passed through the Itheco 4115 Filter, where a Butterworth filter cut the signal between a high and low frequency corresponding to the low and high pass setting that were used, respectively. Understanding of the signal modifications occuring through the system allows the observed data to be scaled down to an acoustic pressure time series.

The next step in the analysis procedure was to determine the spectral behavior of the data. The samples that were compiled are stationary, finite power processes. The average of these samples are fairly consistent over time compared to the time for the fastest amplitude fluxuation. For these samples, the power spectral densities, power per Hertz of measuring systems bandwidth, were determined. A Fast Fourier Transform and power spectrum level conversion was used to convert the time series into its corresponding spectral series, as shown in Figure 14.

The data analysis for the project was extensive and required a software package that is capable of handling the task. For the processing, Matlab, which is a signal processing

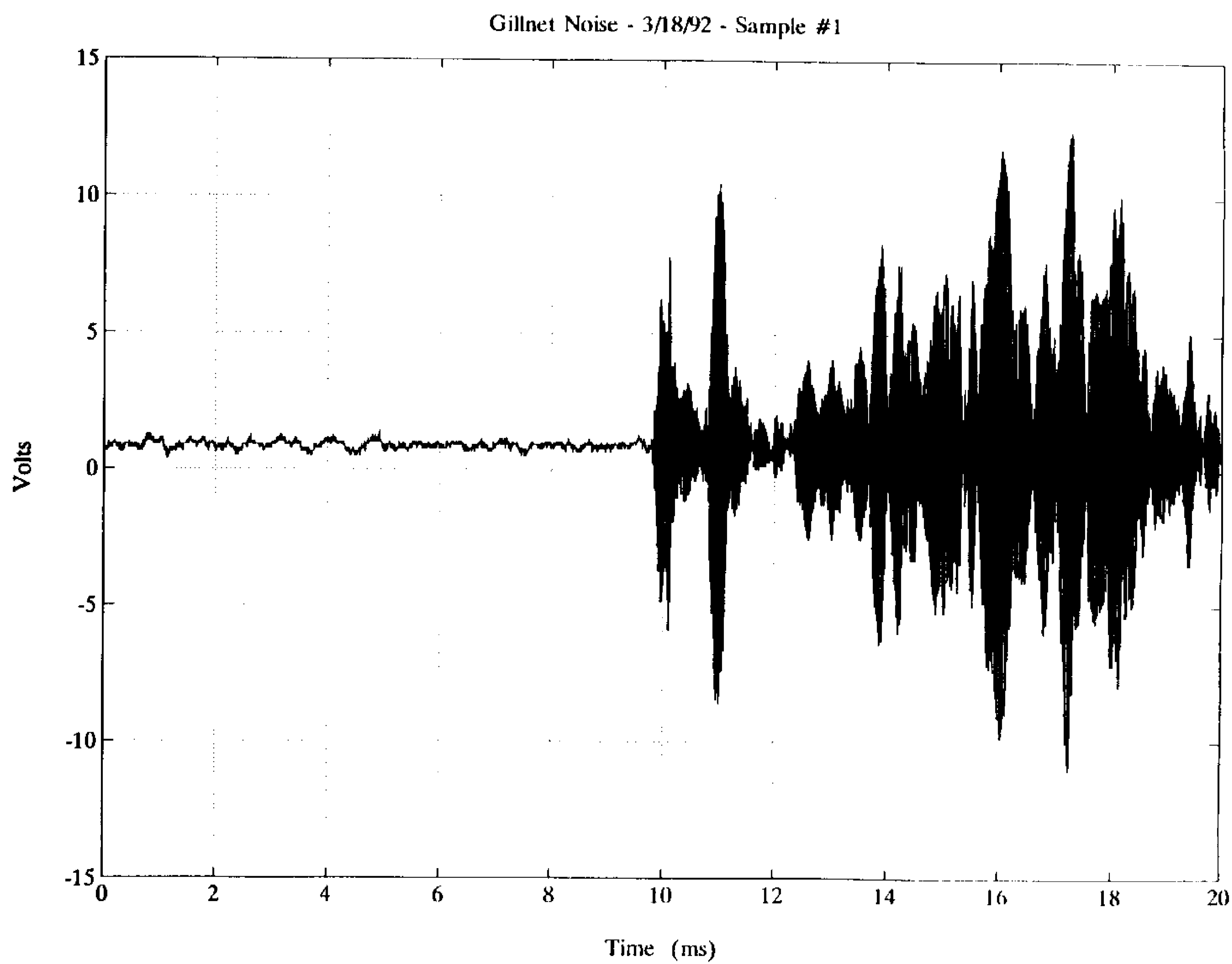

Gillnet Noise - 3/18/92 - Sample #1
15
10
5
0
-5
-10
-15
Volts
0
2
4
6
8
10
12
14
16
18
20
Time (ms)

Figure 11

ITC-6050C HYDROPHONE

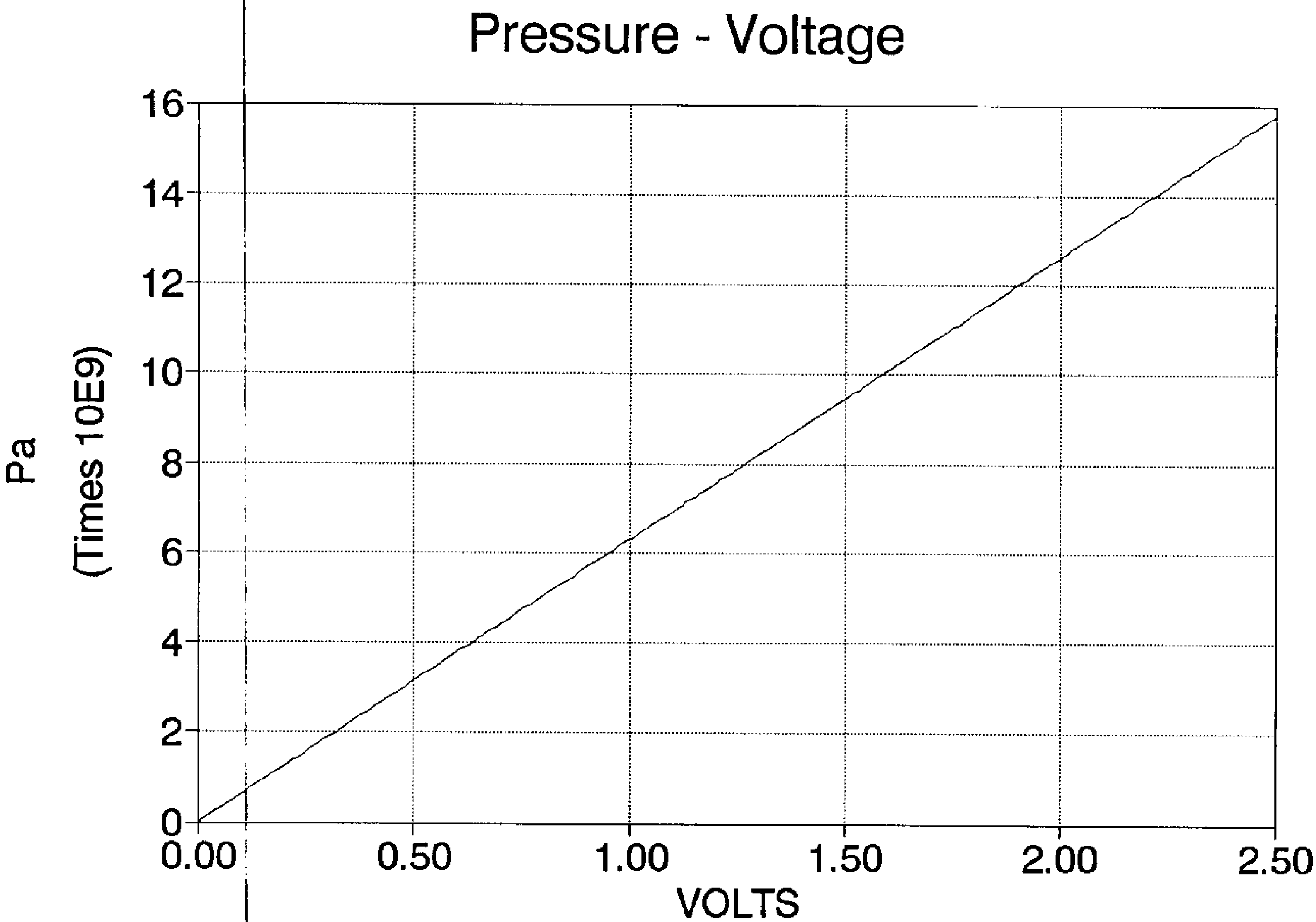


FIGURE 12

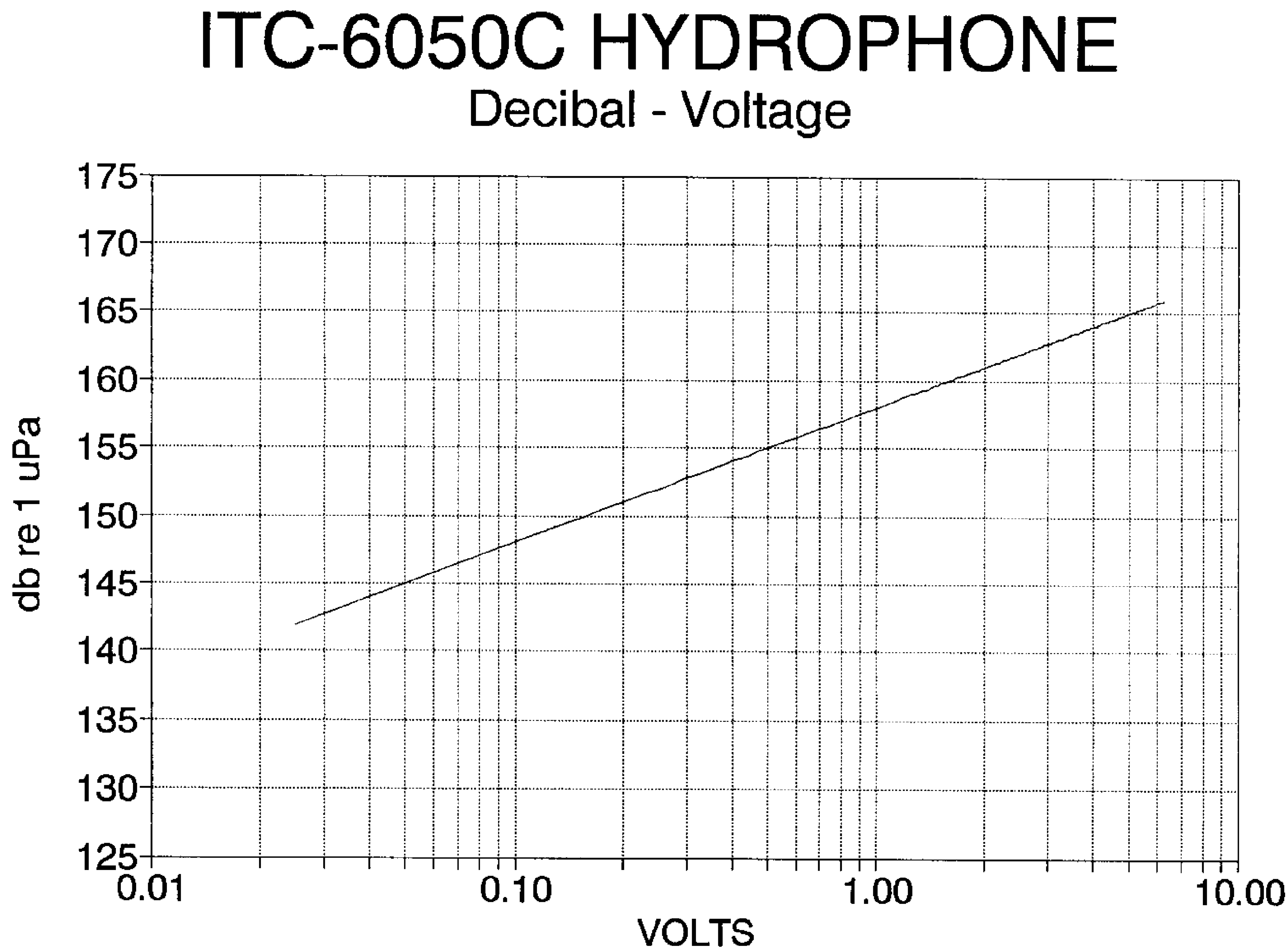

ITC-6050C HYDROPHONE
Decibal - Voltage
175
170
165
160
155
150
145
140
135
130
125
db re 1 uPa
0.01
0.10
1.00
10.00
VOLTS

FIGURE 13

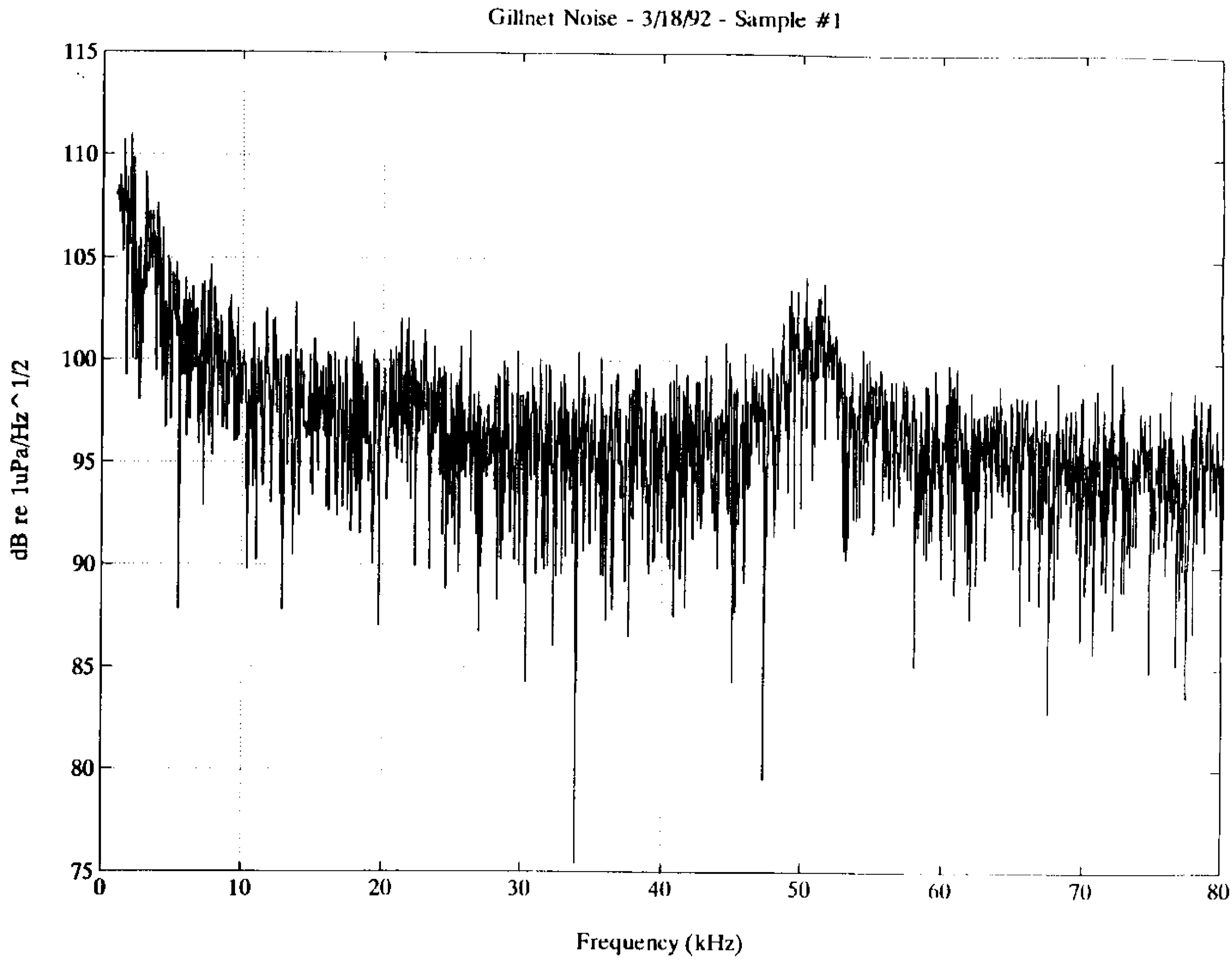

Gillnet Noise - 3/18/92 - Sample #1
dB re 1uPa/Hz^1/2
115
110
105
100
95
90
85
80
75
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Figure 14

program, by The MathWorks was used. Matlab also contains excellent graphics. Since a large number of samples were obtained for each test period, the data was best analyzed in graphical form. To use Matlab, the WFBASIC data has to be converted to a readable format for Matlab. Each sample was first changed to asci format and the text and commas removed. In this format the data could be loaded into Matlab, where it was put into matrix form. A FFT of the matrix was then performed and the power spectral density determined. From this point, any individual sample could be plotted or, as shown in Appendix C, mesh plot can be generated. These show the spectral behavior of several data samples in a comprehensive manner and effectively communicate the general trend of the data during the time period of the meshed samples. In order to have a feel for how individual mesh plots fit in relation to one another, a second set of the plots were generated. In these, a reference spectrum level is included in each plot. It has been color coded to distinguish it from the valid data points. By referencing the plots in this manner, a comparison can be made between the different data groups. Once again, these plots are beneficial for a general understanding of the data trends.

For a more definite comparison of the spectrum levels, average cumulative spectrum level plots (frequency versus dB re 1 uPa/$Hz^{1/2}$) were generated and are shown in Appendix B. The number of samples included in the averages are a function of the various filter settings used when recording the data (see Appendix A) for the various high and low passes employed during the acoustic measurements.

RESULTS

CURRENTS:

Current Speed Transect of Estuary:

The time of deployment, Loran coordinates, and depth of the thirteen profiles that were performed in the Little Bay Estuary on 2/14/92 is shown in Table 1. The current speed at each meter interval was determined for each profile. For analysis, profiles 1,2,3 and 4 were replaced with profiles 10,11,12, and 13, respectively. When the profiling was started, the tide was just stating to ebb. Therefore, profile 9 occurred when the currents were stronger, and profiles 10 through 13 were taken in a more uniform current cycle than 1 through 4. Our objective was to find a location suitable for deployment of the gillnet (i.e. flat bottom for 300' and workable depth) with current speeds at an appropriate level to give significant acoustical results.

Currents over a full tidal cycle:

Two stationary profiles were performed to give an idea of the variation in the current speed and direction over tidal cycles.

The data from Thursday, February 20th shows an initial flood tide with a maximum speed of 47 cm/sec, slightly less than 1 knot. The ebb tide that follows has a maximum speed of 57 cm/sec. At high tide the Great Bay estuary is full. When the tide in Little Bay estuary changes, Great Bay estuary deploys a significant amount of water into it. When Little Bay estuary begins to flood, opposing currents arise due to the incoming flow from Great Bay. The discrepancy in current speeds between flood and ebb tides is due to these tidal dynamics.

Currents over a Full Tidal Series:

Figure 15 displays the magnitude of current speeds for the data collected between March 6,1992 and April 8,1992. Each peak depicts tidal surges. A trend of spring and neap tides is demonstrated by the envelope of the peaks.

The oyster plot (Figure 16) shows the strong north-south directionality of the currents, with the north component displaying a stronger magnitude and a greater number of samples

FEBRUARY 14, 1942
LITTLE BAY ESTUARY

PROFILE #	TIME	COORDINATES	DEPTH
1	9:07	N43 06.68' W70 51.40'	28 ft
2	9:23	N43 06.69' W70 51.42'	40 ft
3	9:43	N43 06.70' W70 51.45'	51 ft
4	10:00	N43 06.70' W70 51.49'	63 ft
5	10:17	N43 06.69' W70 51.51'	53 ft
6	10:34	N43 06.70' W70 51.55'	39 ft
7	10:50	N43 06.68' W70 51.63'	24 ft
8	11:13	N43 06.78' W70 51.69'	22 ft
9	11:24	N43 06.70' W70 51.75'	18 ft
10	12:16	N43 06.69' W70 51.40'	23 ft
11	12:40	N43 06.70' W70 51.43'	36 ft
12	13:02	N43 06.69' W70 51.46'	47 ft
13	13:30	N43 06.69' W70 51.50'	61 ft

TABLE 1: PROFILE DATA

Fox Point - 3/6/92 to 4/9/92 - Current Magnitude

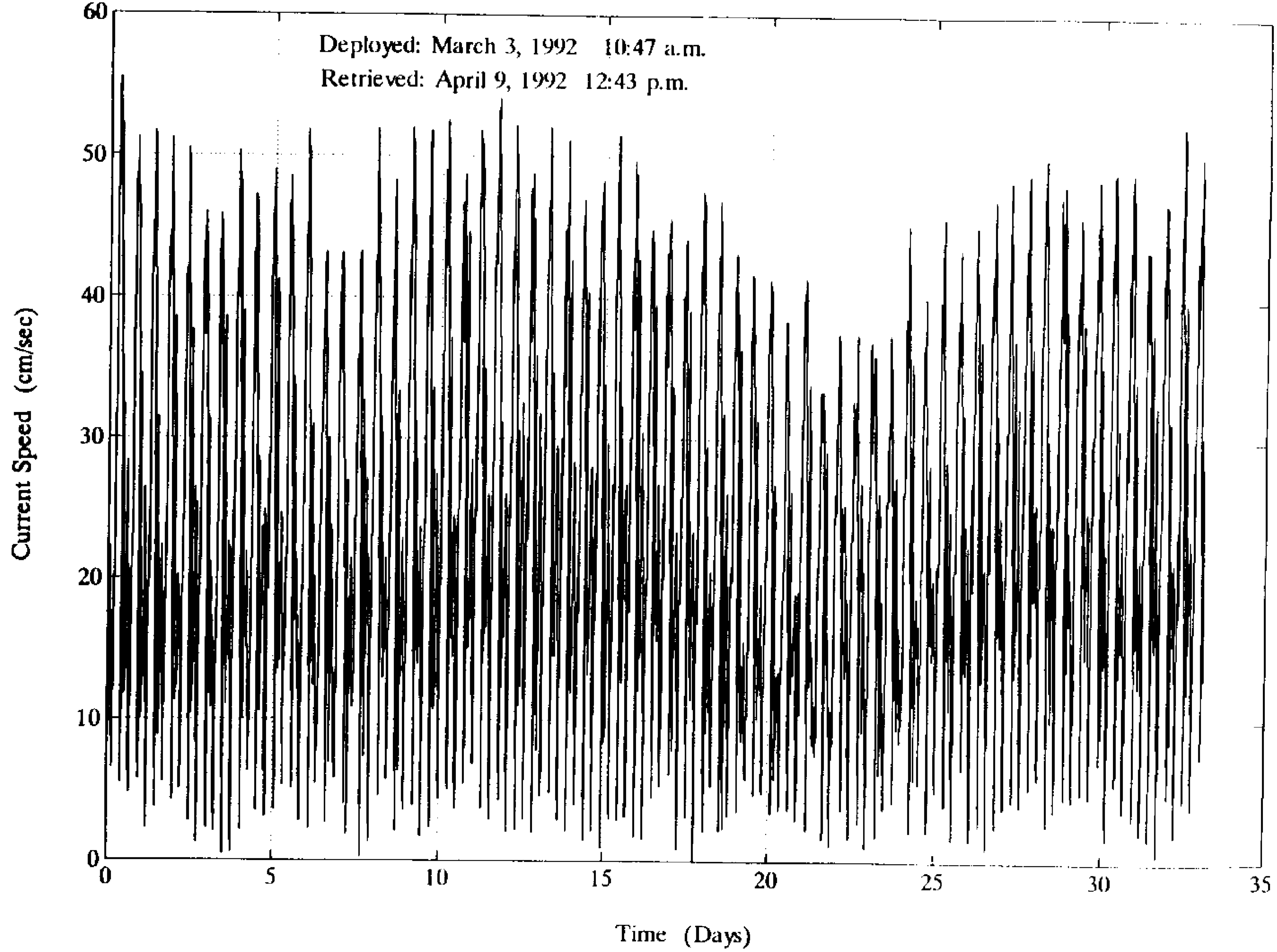
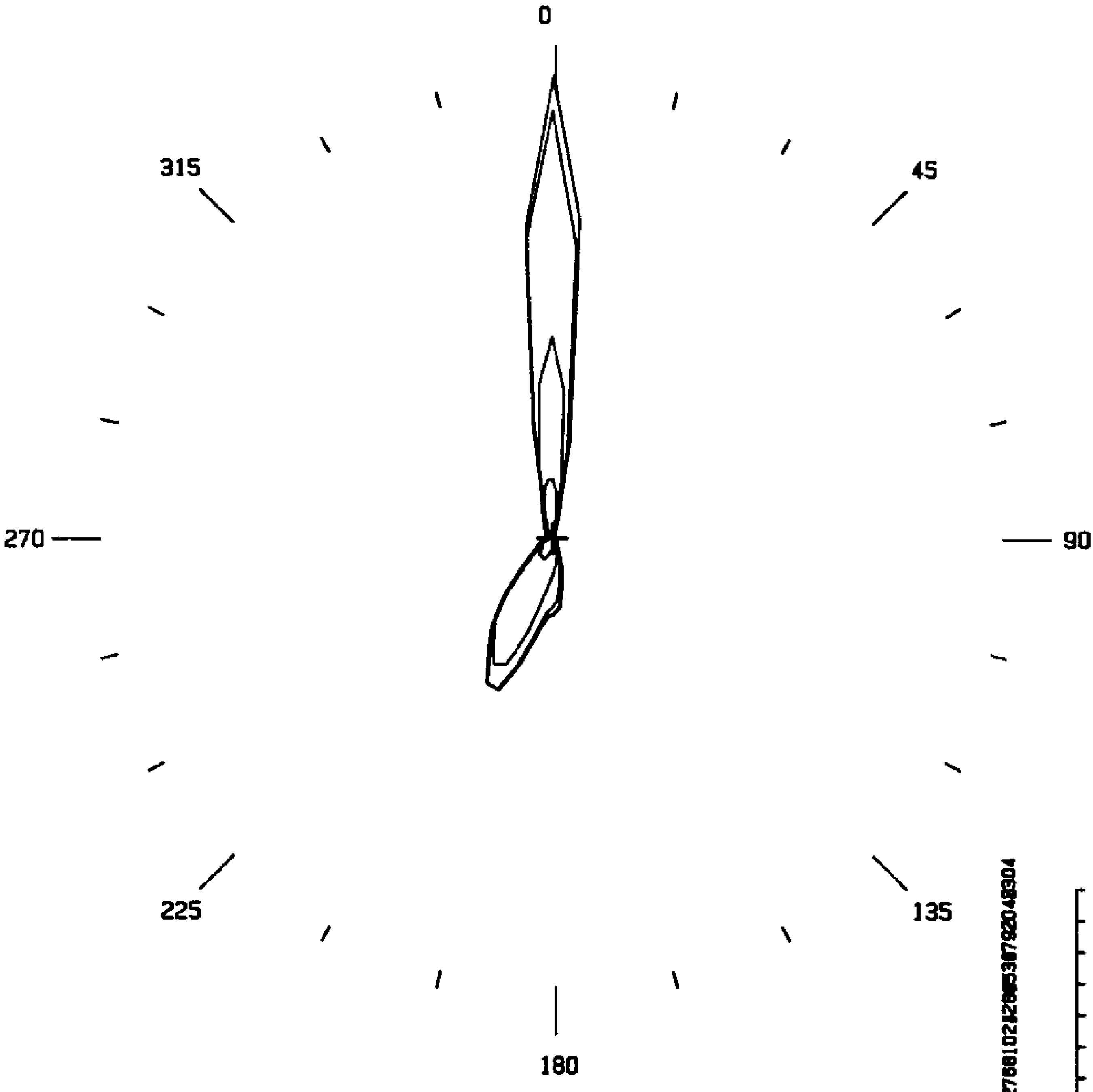


Figure 15

FOX POINT CURRENTS 3/6/92 - 4/8/92

Speed Class Interval = 12.00



OYSTER PLOT OF SPEED AND DIRECTION

From 6-MAR-92 To 8-APR-92

ENDECO Type 174SSM Solid State Memory Current Meter

Figure 16

than the southbound component. The data shows a clear cyclical pattern due to the current dynamics explained above.

AMBIENT NOISE:

Over the spring semester, ambient noise data was taken on four occasions. For each trip, a representative average ambient noise spectrum level plot is shown. This plot will be followed by a mesh plot, which is a three dimensional plot representing the trends observed over consecutive samples. Finally, a plot of the currents in the estuary at the time of sample measurements is shown.

2/28/92:

A representative average spectrum level for the data collected during this period is shown Figure 17. A broadband spectrum level is observed with a db level of 80 dB re 1 $uPa/hz^{1/2}$ above ten kHz. A mesh plot of the data (Figure 18) displays the consistently higher noise levels below 10 kHz as compared to the higher frequency. The current north and east magnitude is shown in Figure 19.

3/18/92:

An average noise spectrum plot and the currents corresponding to the data are shown in Figures 20 and 21. A slight decrease in the spectrum level is observed.

4/9/92:

Similar plots as those for 2/28 are shown in Figures 22 and 23. The noise level on this day was at 92 dBs above five kHz.

4/22/92:

The spectrum plot (Figure 24) for this day displays an unusual discrepancy at 50 kHz. The discontinuities at 10 and 63 kHz are due to the data averaging technique used to account for the different filter settings. The current data is shown in Figure 25.

GILLNET NOISE - perpendicular deployment (3/18/92):

Figure 26a demonstrates the individual average spectrum levels taken over time. The sample numbers appearing on this chart represent the chronological order in which these levels were recorded. Figure 26b represents the current speeds for 3/18.

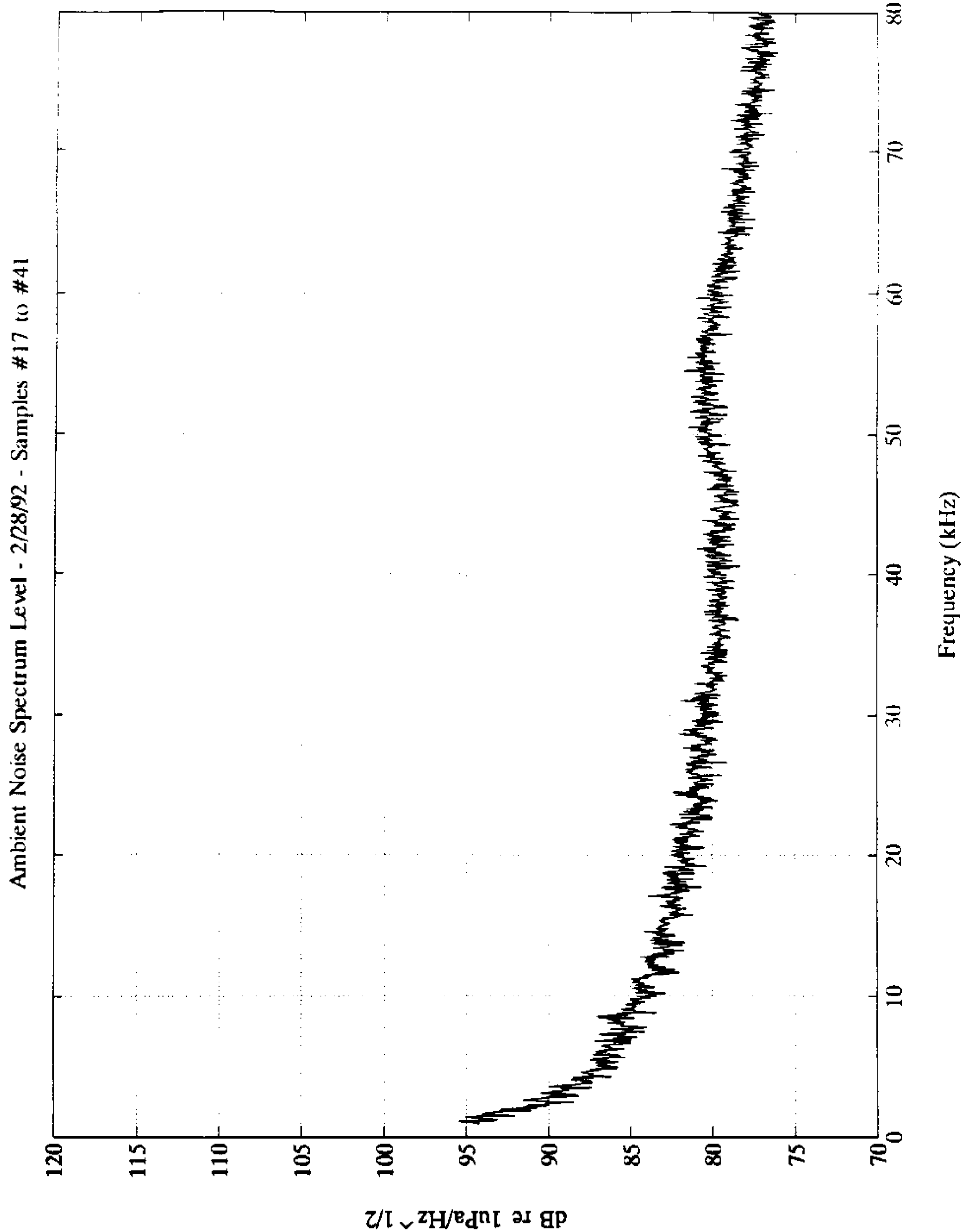

Ambient Noise Spectrum Level - 2/28/92 - Samples #17 to #41
dB re 1uPa/Hz^1/2
Frequency (kHz)
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80

Figure 17

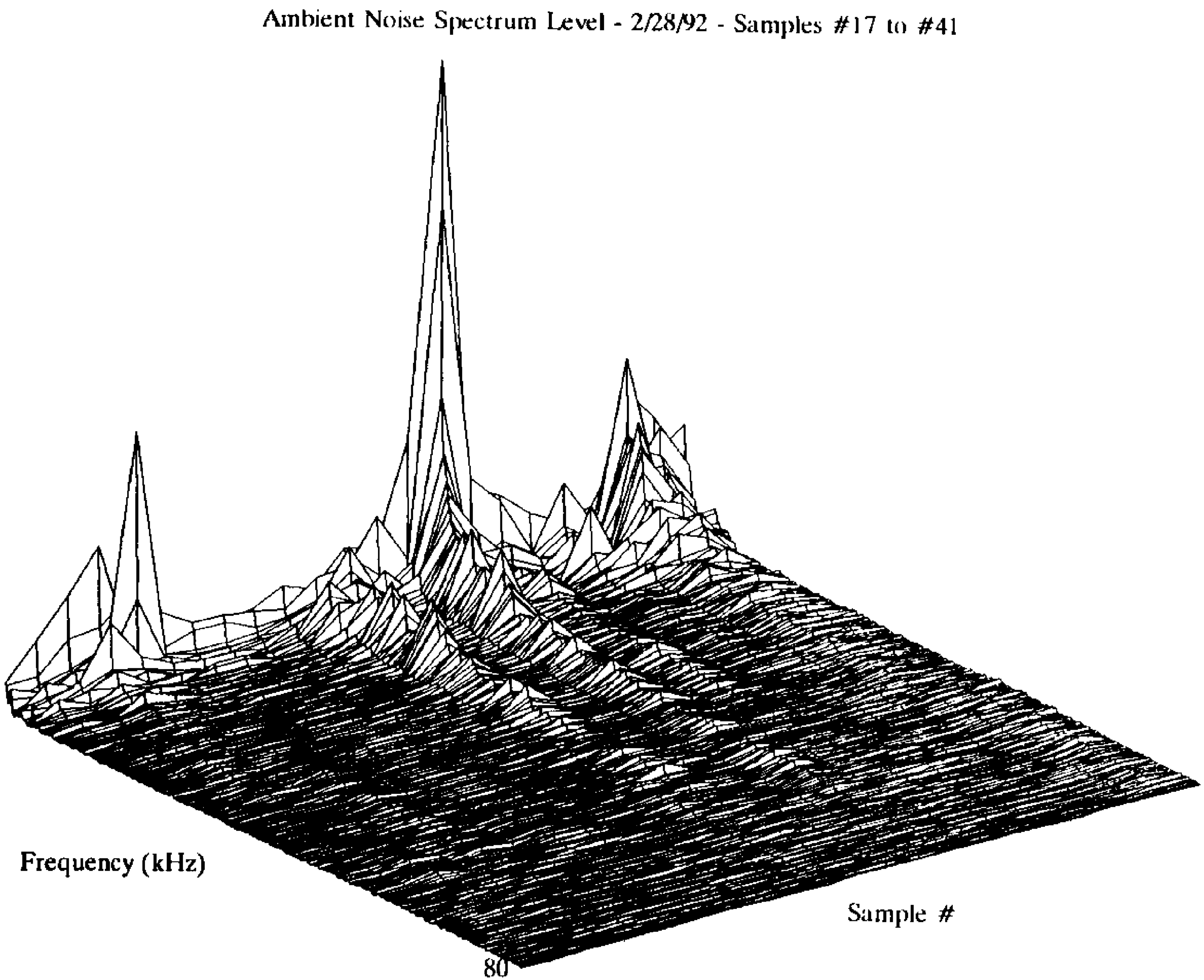

Ambient Noise Spectrum Level - 2/28/92 - Samples #17 to #41
Frequency (kHz)
Sample #
80

Figure 18

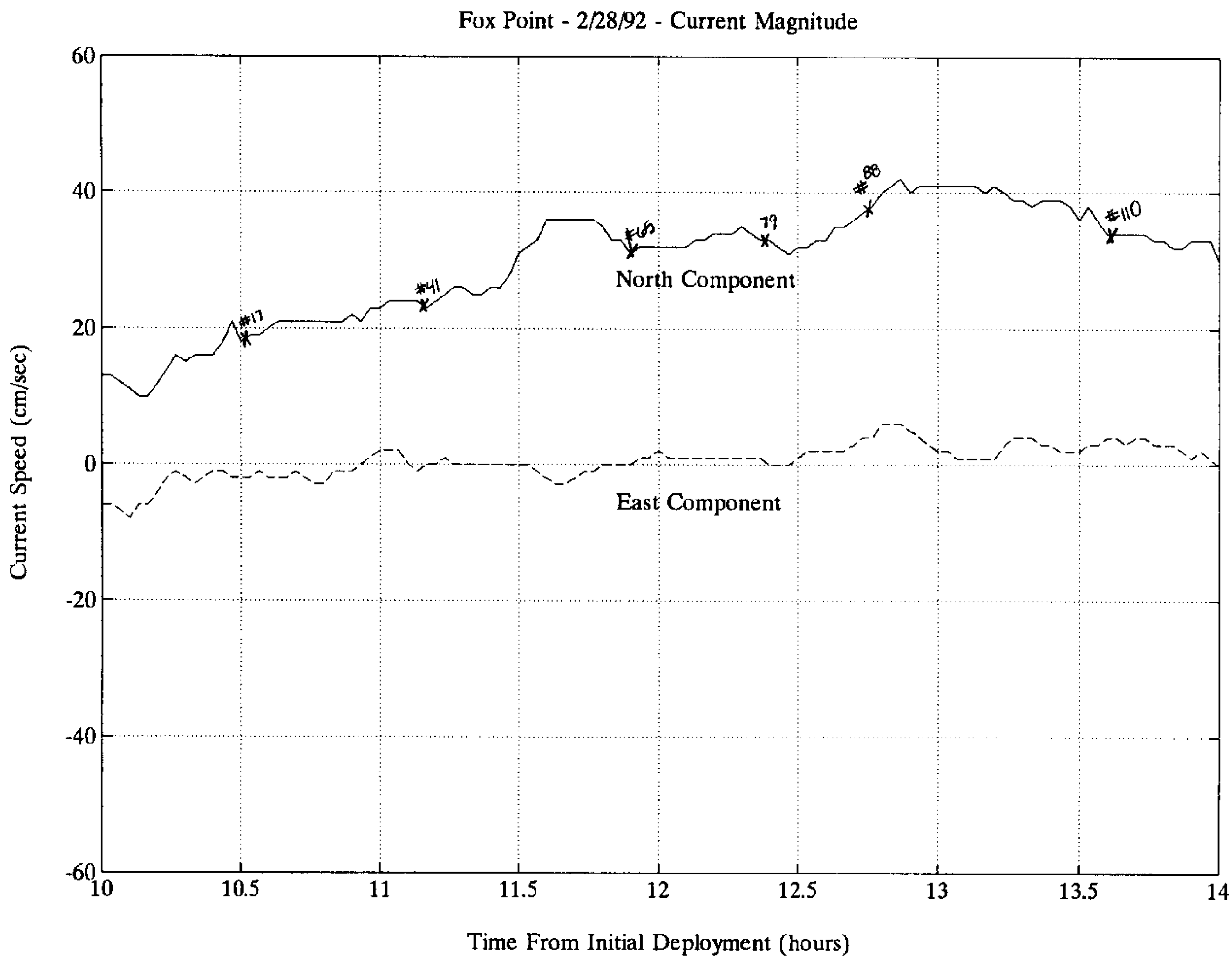

Fox Point - 2/28/92 - Current Magnitude
Current Speed (cm/sec)
60
40
20
0
-20
-40
-60
10
10.5
11
11.5
12
12.5
13
13.5
14
Time From Initial Deployment (hours)
North Component
East Component
#17
#41
#65
79
#88
#110

Figure 19

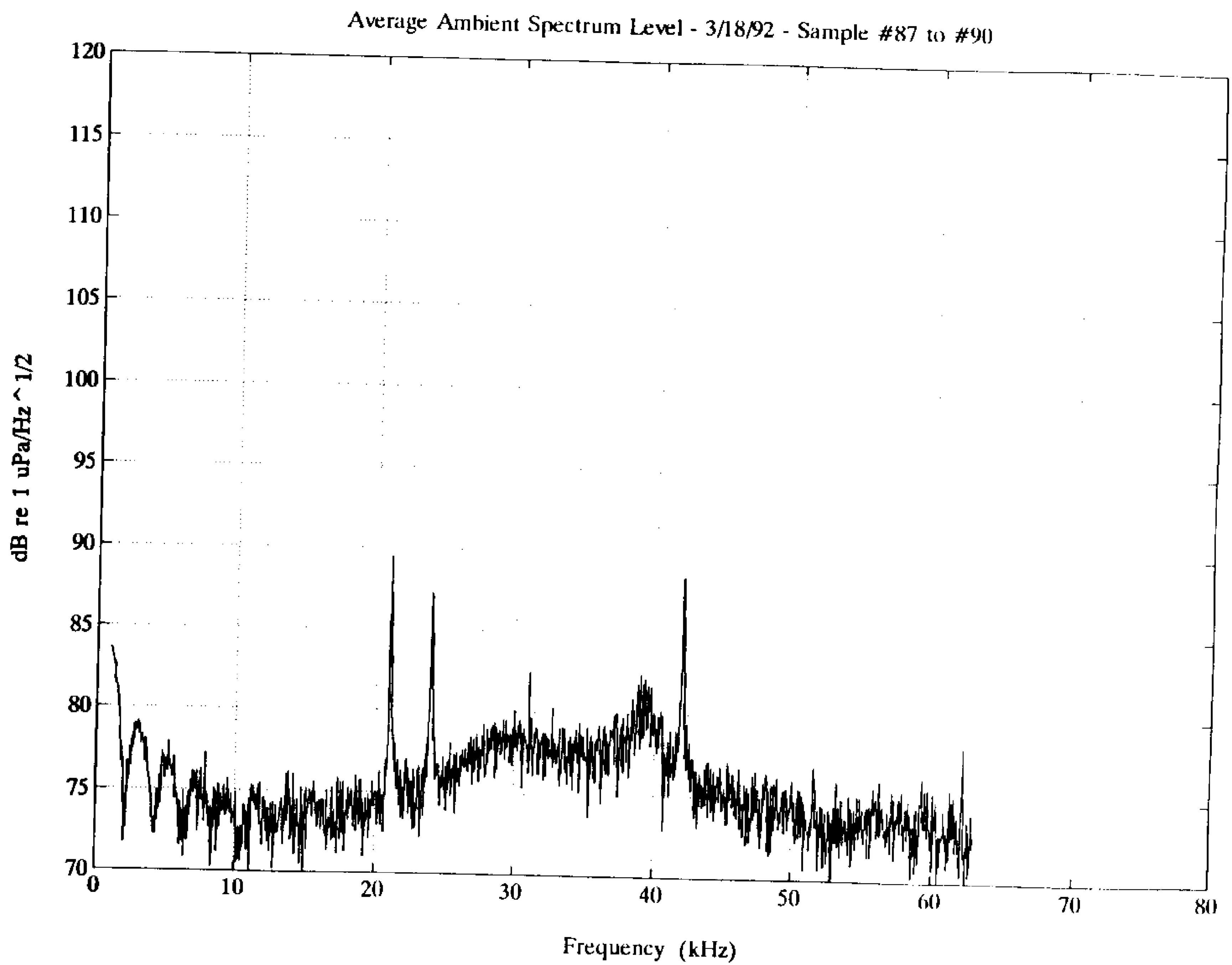
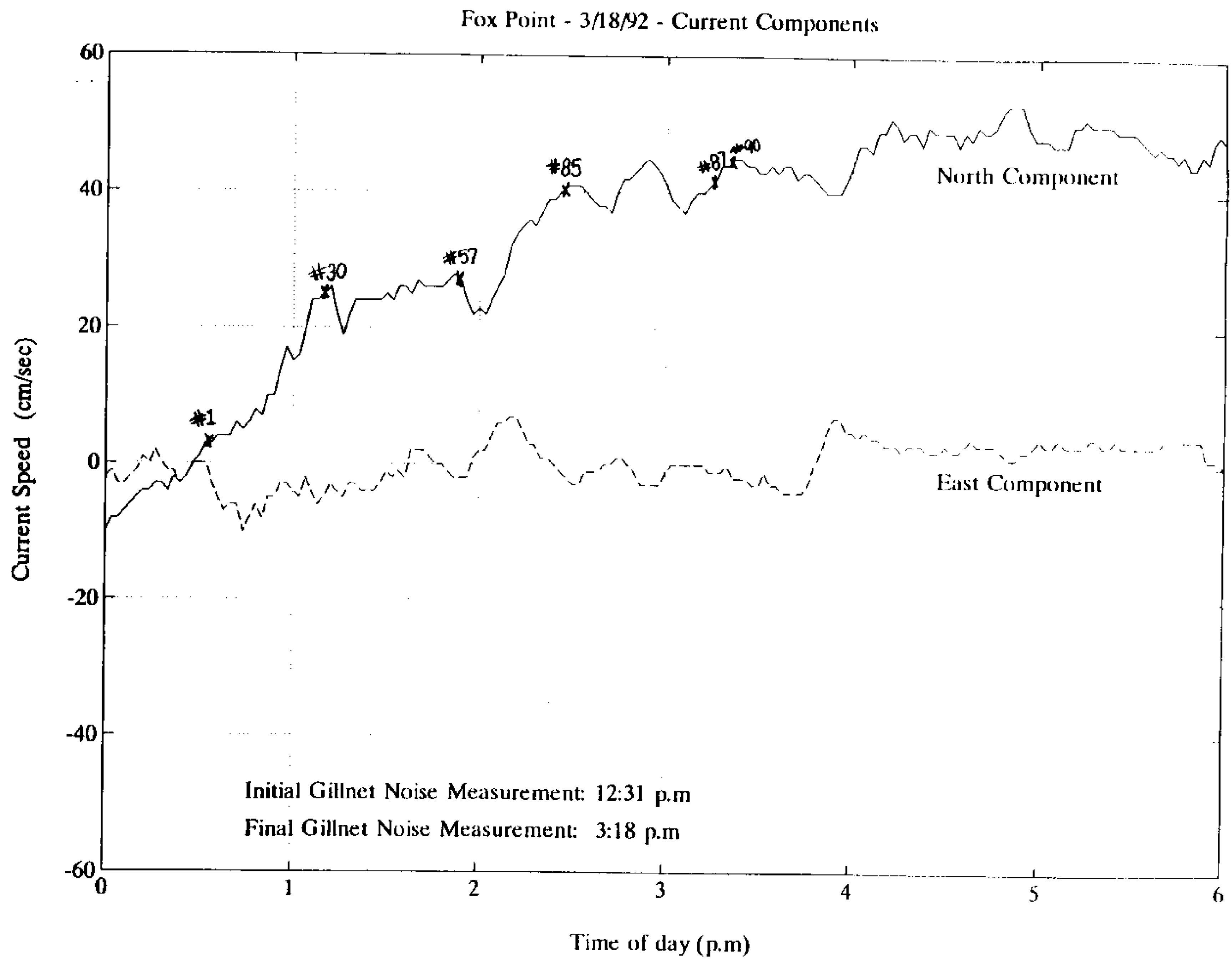

Average Ambient Spectrum Level - 3/18/92 - Sample #87 to #90
dB re 1 uPa/Hz ^ 1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Figure 20



Fox Point - 3/18/92 - Current Components
Current Speed (cm/sec)
Time of day (p.m)
North Component
East Component
#1
#30
#57
#85
#87
#90
Initial Gillnet Noise Measurement: 12:31 p.m
Final Gillnet Noise Measurement: 3:18 p.m
60
40
20
0
-20
-40
-60
0
1
2
3
4
5
6

Figure 21

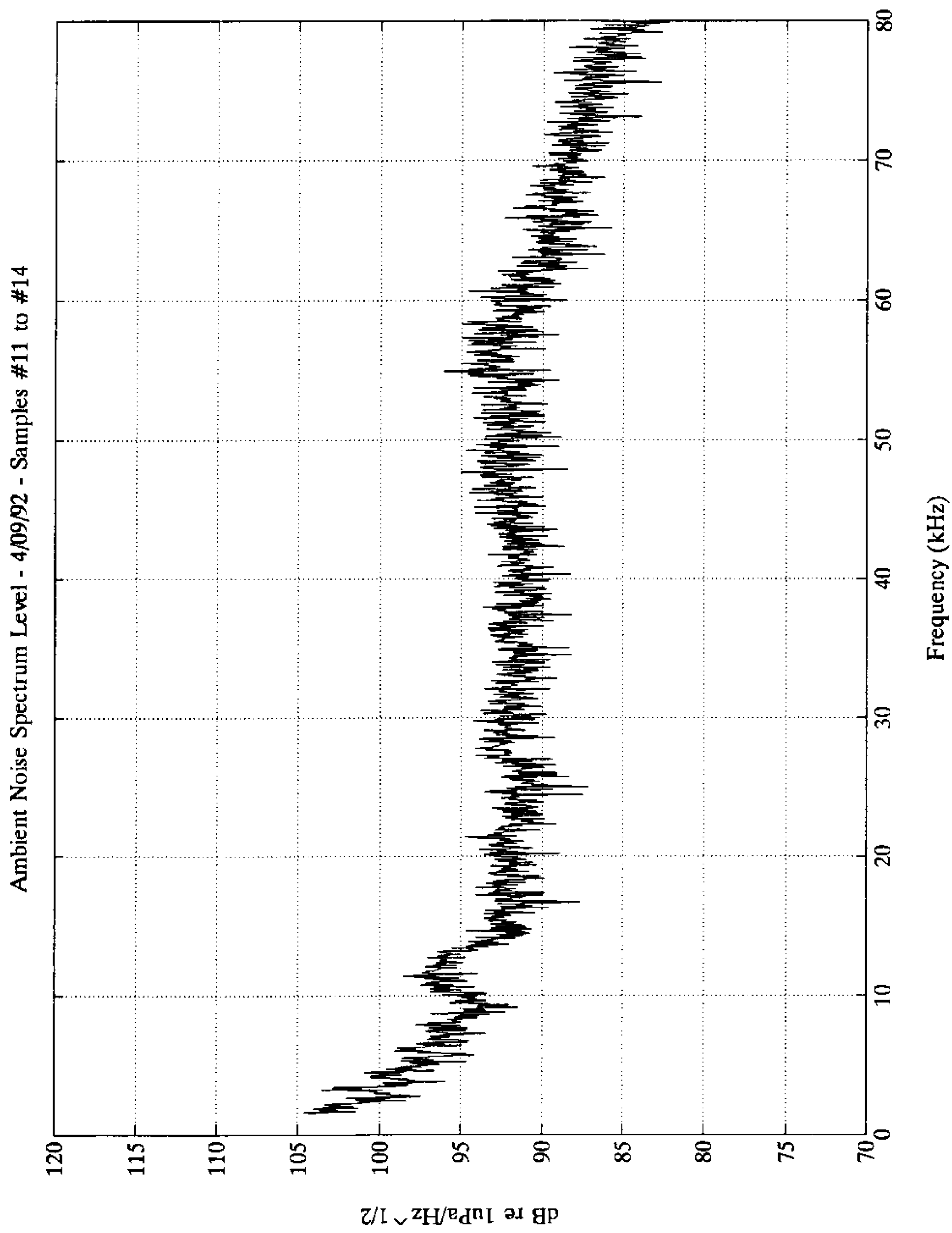

Ambient Noise Spectrum Level - 4/09/92 - Samples #11 to #14
dB re 1uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Figure 22

Ambient Noise Spectrum Level - 4/09/92 - Samples #26 to #45

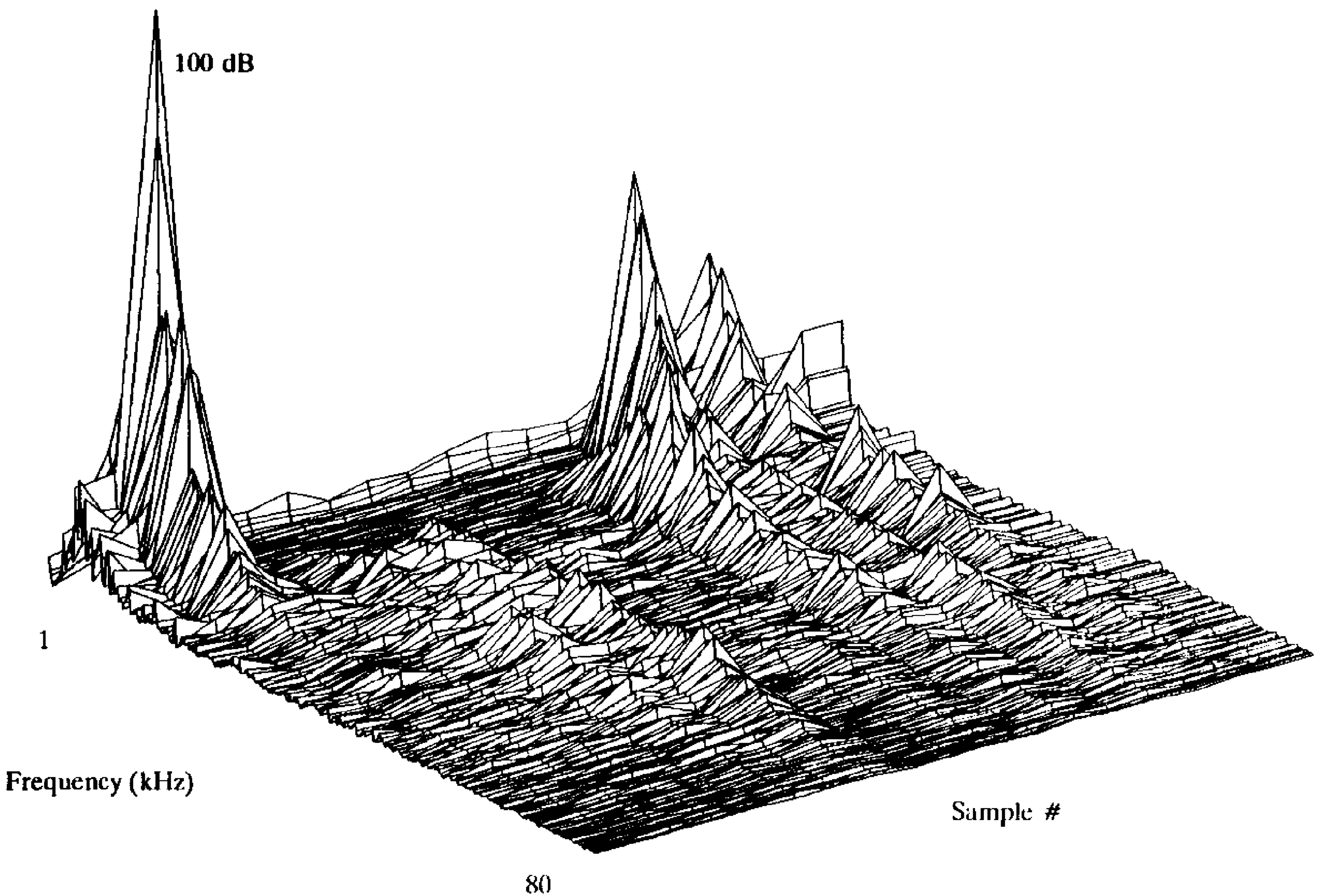


Figure 23

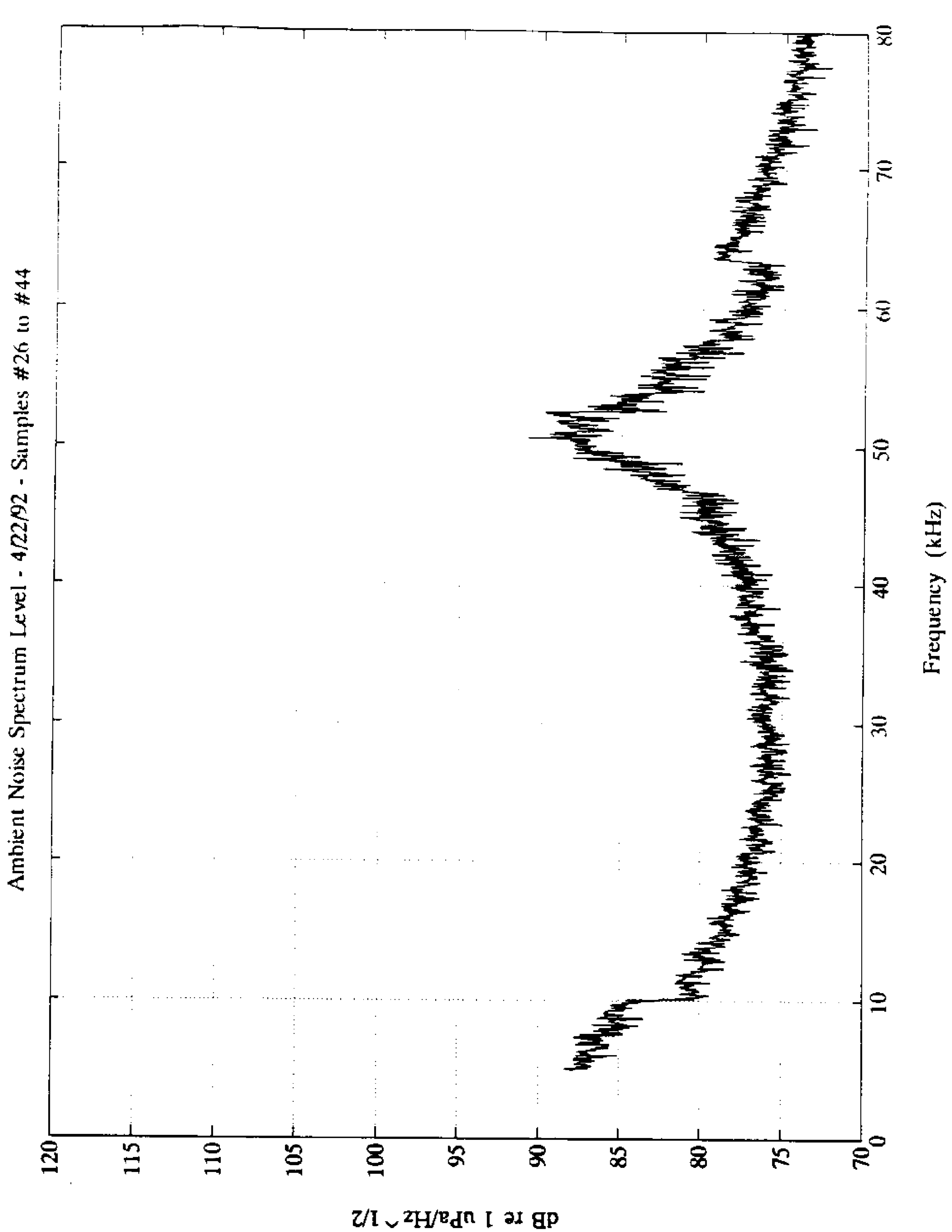

Ambient Noise Spectrum Level - 4/22/92 - Samples #26 to #44
dB re 1 uPa/Hz^1/2
Frequency (kHz)
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80

Figure 24

Fox Point - 4/22/92 - Current Components

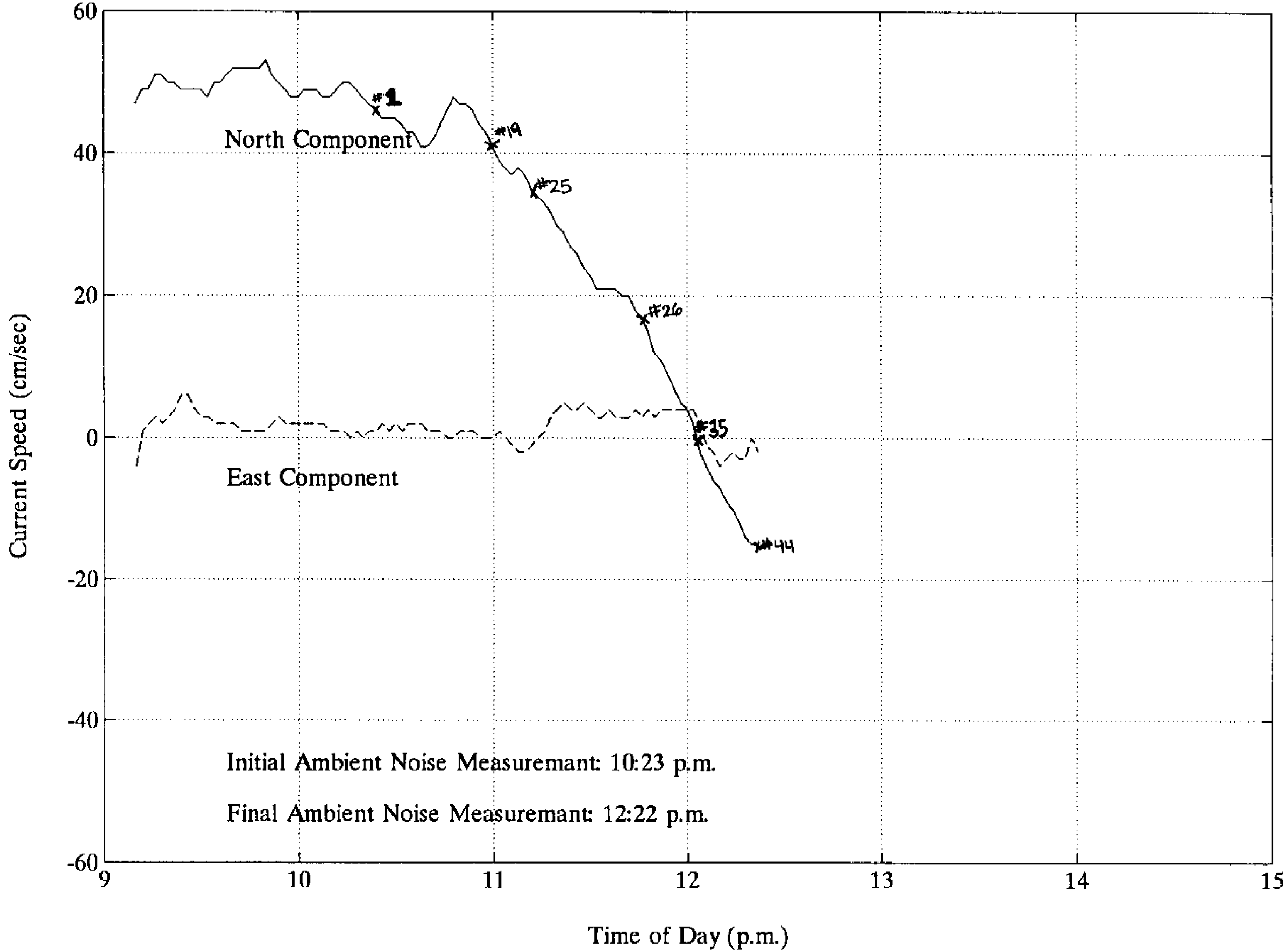
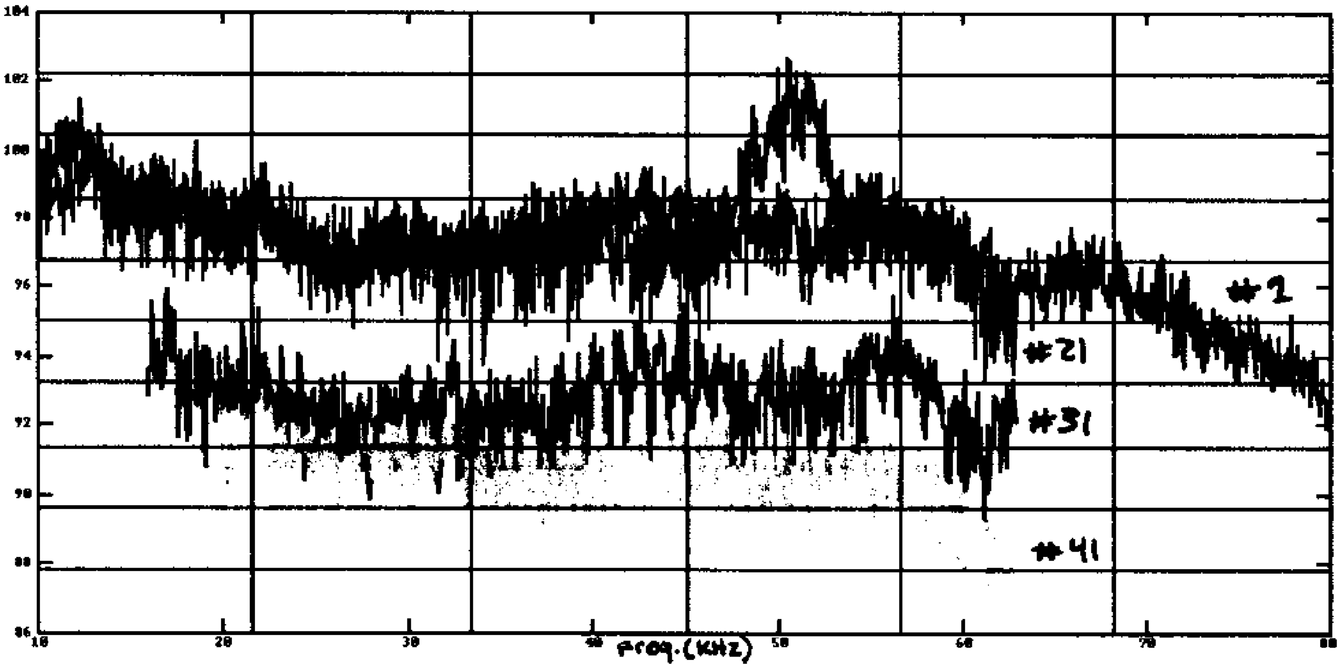


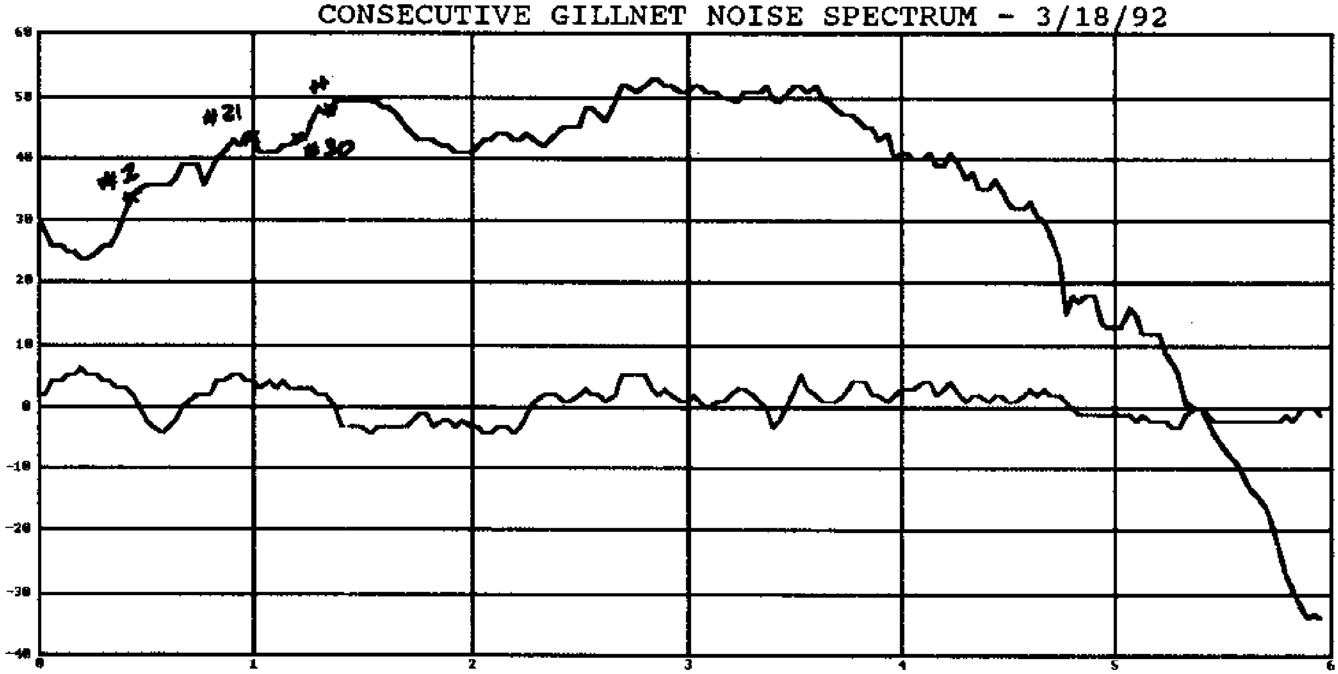
Figure 25

a.



CONSECUTIVE GILLNET NOISE SPECTRUM - 3/18/92

b



CURRENT SPEED 3/18/92

FIGURE 26 EFFECTS OF SEAWEED DAMPING ON NOISE PRODUCTION

Mesh plots (Figures 27 and 28) represent data points for the first 20 samples taken. Two extraordinary peaks were witnessed for samples 1 and 7 in figure 27. Figure 28 shows the levels for the other 18 samples when samples 1 and 7 are excluded. This mesh plot is representative of the remaining 85 windows.

GILLNET NOISE - parallel deployment (3/26/92):

The average spectrum level for samples taken during parallel deployment of the standard gillnet is shown in Figure 29. An even broadband level exists above 30 kHz at 85 dB re 1 uPa/Hz^$^{1/2}$.

MODIFIED GILLNET NOISE:

Figure 30 represents the average spectrum level for the modified gillnet noise. It shows an intensity level at 92 dB until reaching a peak of approximately 110 dB at 50 kHz. This peak is further represented by the mesh plot (Figure 31) for all samples from this day. Note the consistency over the entire sampling period.

Gillnet Noise Spectrum Level - 3/18/92 - Samples #1 to #20

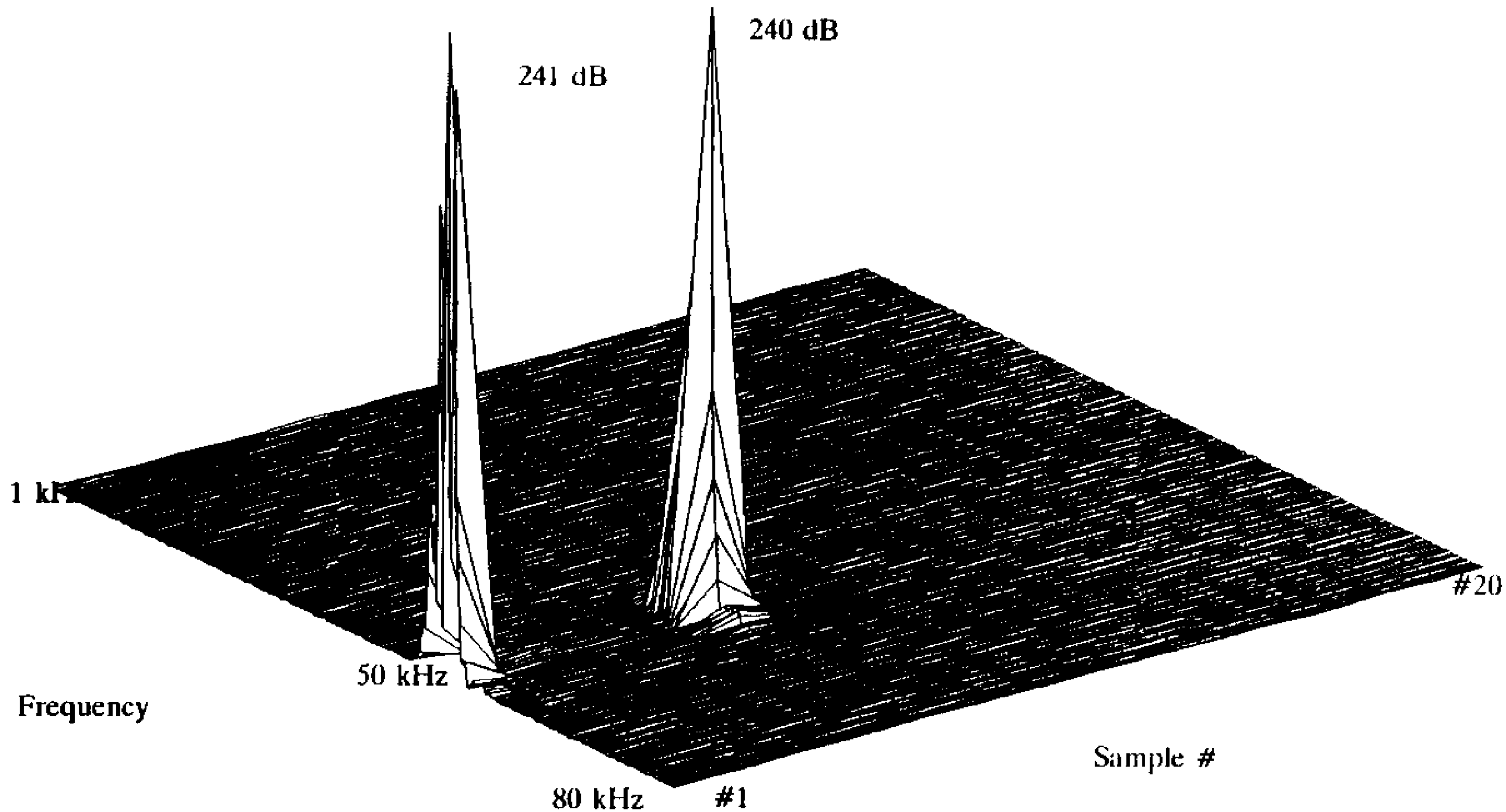


Figure 27

Gillnet Noise Spectrum Level - 3/18/92 -Sample #1 to #20

NOTE: EXCLUDES SAMPLES #1 AND #7

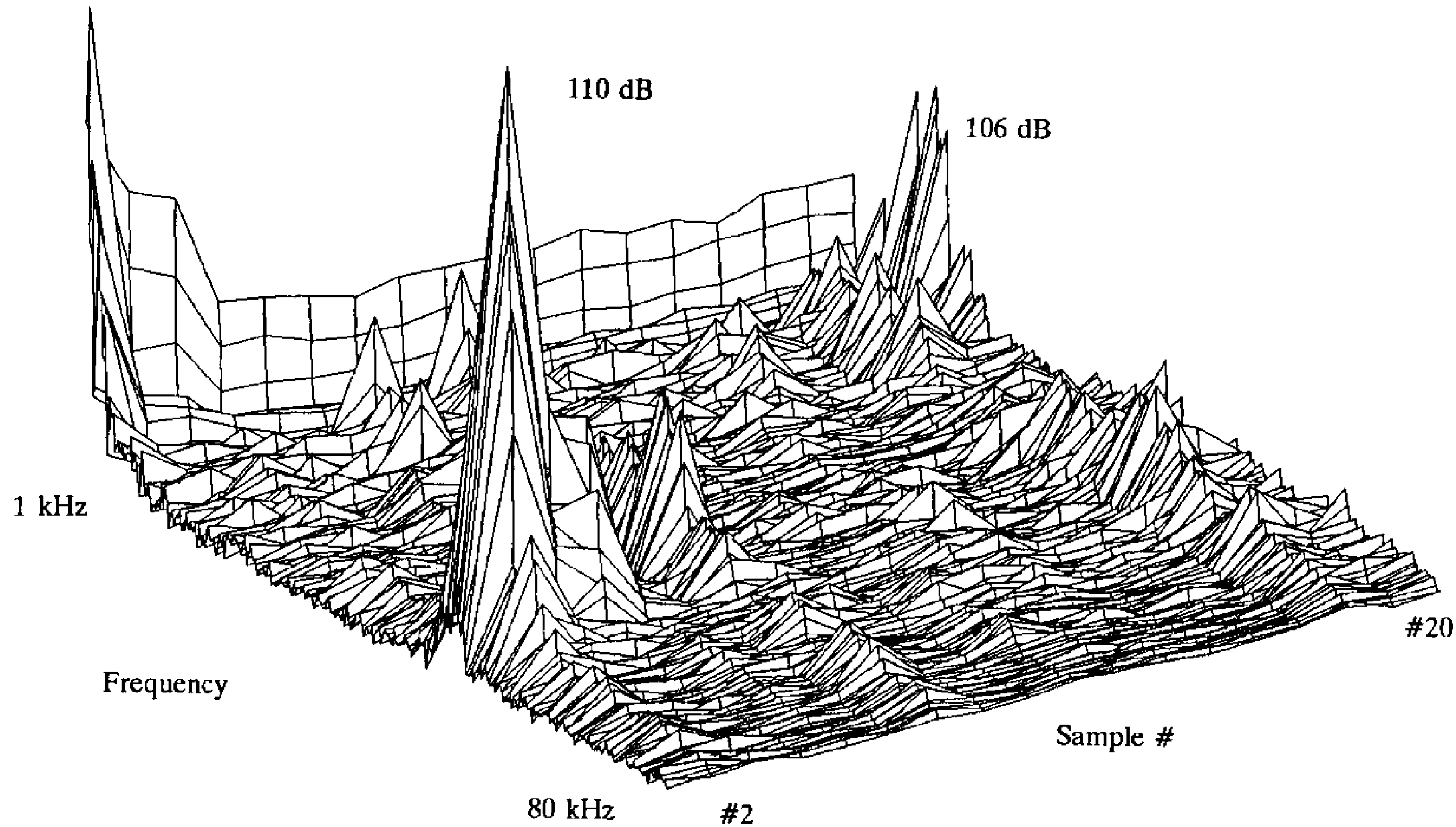


Figure 28

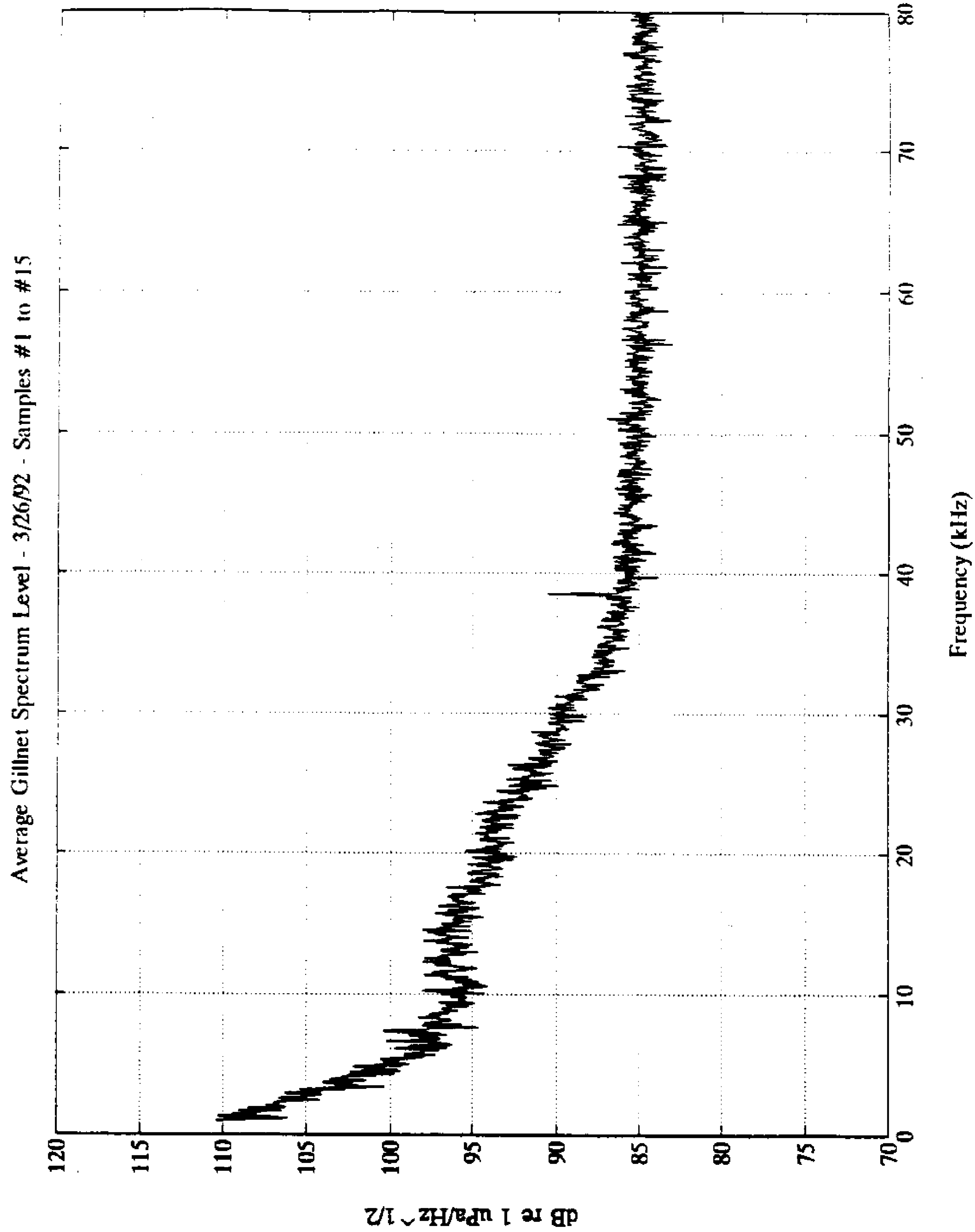
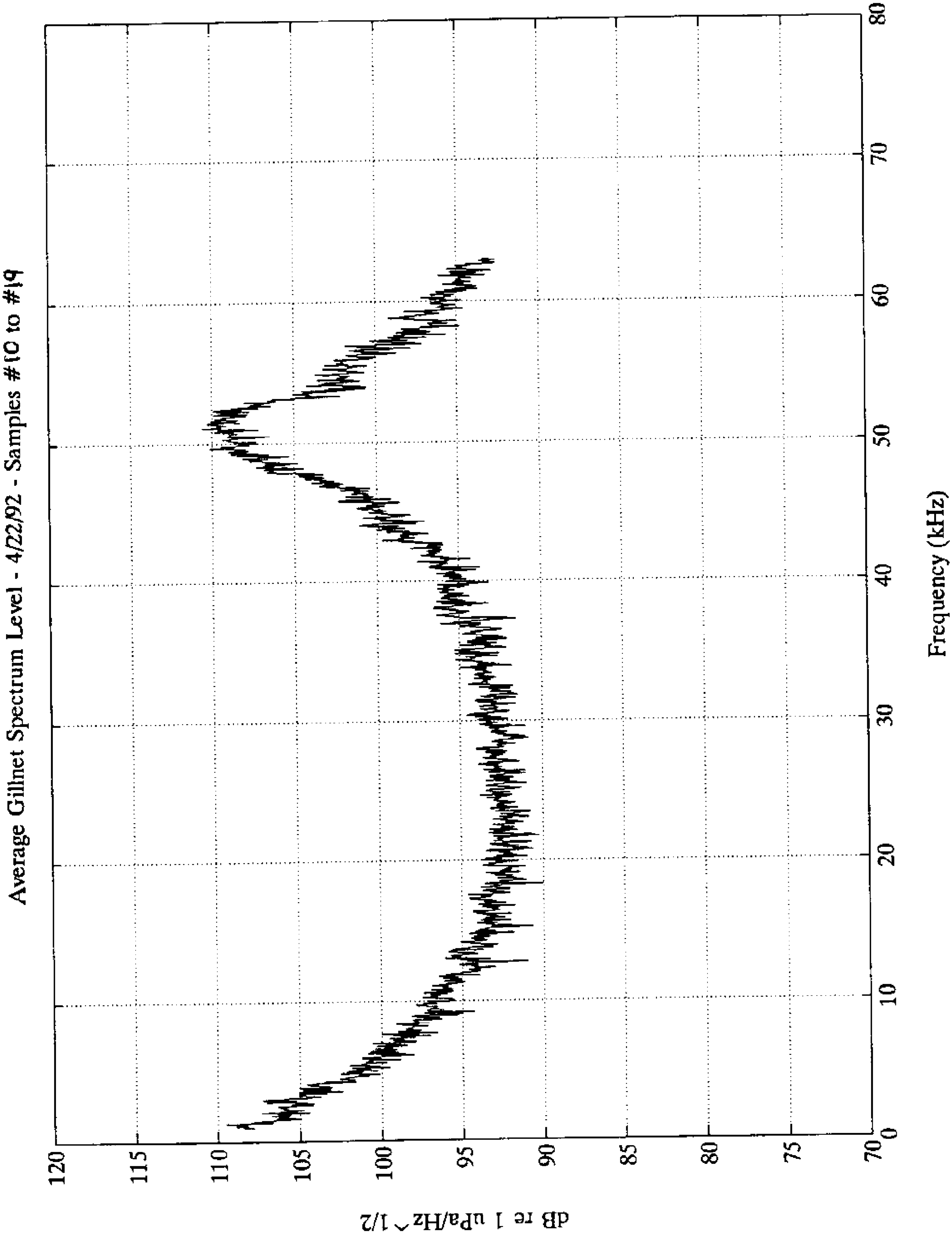

Average Gillnet Spectrum Level - 3/26/92 - Samples #1 to #15
dB re 1 uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Figure 29



Average Gillnet Spectrum Level - 4/22/92 - Samples #10 to #19
dB re 1 uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Figure 30

Modified Gillnet Noise Spectrum Level - Samples #1 to #25

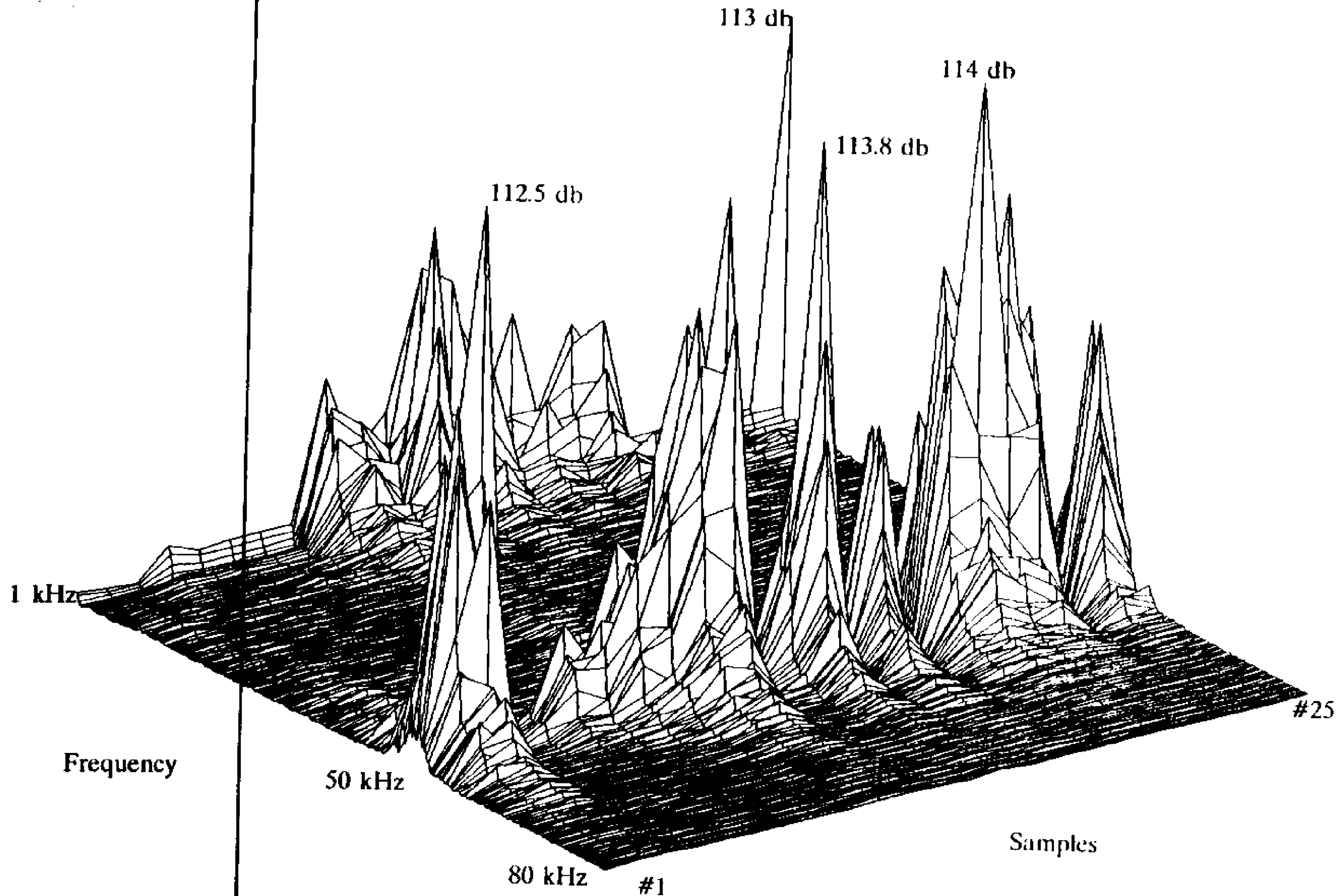


Figure 31

DISCUSSION

Current Speed Transect of Estuary:

After analysis of our vertical profile data, the region including profiles #7 and #8 was chosen as a potential site for field measurements. As shown in Figure 32, the depth is fairly constant at approximately 7 meters over a wide enough range for gillnet deployment. This depth allows relatively easier and more accurate equipment deployment and positioning than anticipated at deeper locations. The current flows at 30-40 cm/sec on average, providing significant speed to yield reliable results of noise in the water.

Ambient Noise:

Figure 33 demonstrates overall average spectrum levels for each day. These were obtained via a third degree polynomial fit of the individual average spectrum levels within each day, and are represented by single points. Three of the four averages occur within the pressure level range around 80 dB. An inexplicable rise in 3/18's level is seen at 50 dB. The average spectrum level for 4/9 appears at 92 dB, significantly higher than the others. This rise may be explained by a possible increase in sea state due to winds or weather or an increase in current speed on that day. However, there is no current data on the 9th because the internal memory of the Endeco current meter ran out of space on the 8th.

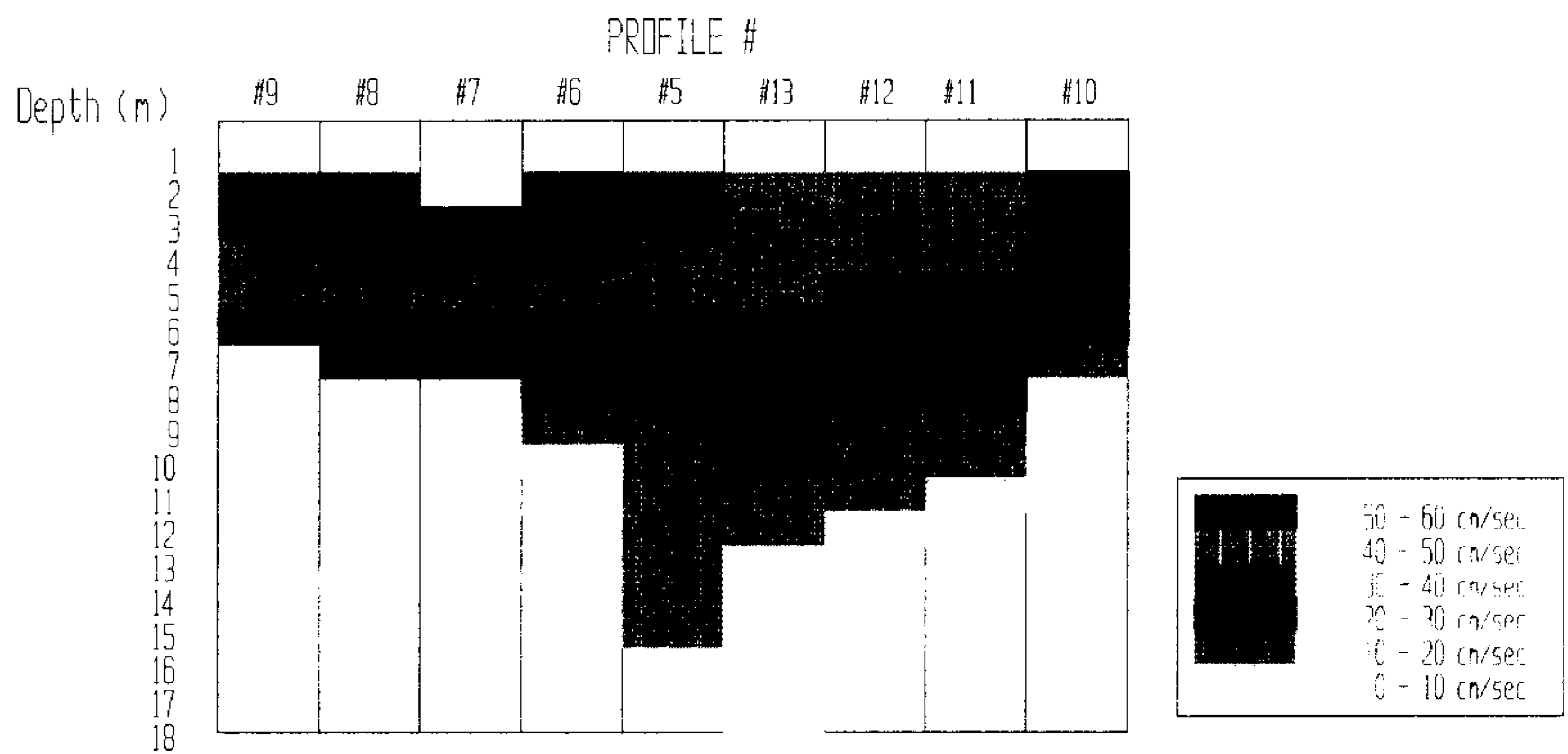
Gillnet Noise - perpendicular deployment (3/18/92):

Sometime between the time of net deployment and retrieval, the gillnet became filled with seaweed. This unexpected event lead to an interesting trend in the data. Over time, the average noise spectrum levels (see Figure 26) were dampened. A significant decrease in levels of nearly 10 dB re 1uPa/Hz$^{1/2}$. Clearly, the monofilament of the gillnet increased the emmited noise levels. When the net filled up with seaweed, this noise producing mechanism was silenced. The current speed at this day are shown to indicate that this trend is not a function of a decrease in current speed. In fact, an increase in current flow was noted, which would, if anything, increase the noise emitted from a perpendicularly deployed gillnet.

Within our first 20 samples taken, two extraordinary points appeared, as demonstrated in the results. We can offer no reasonable explanation for these occurrences. Since these

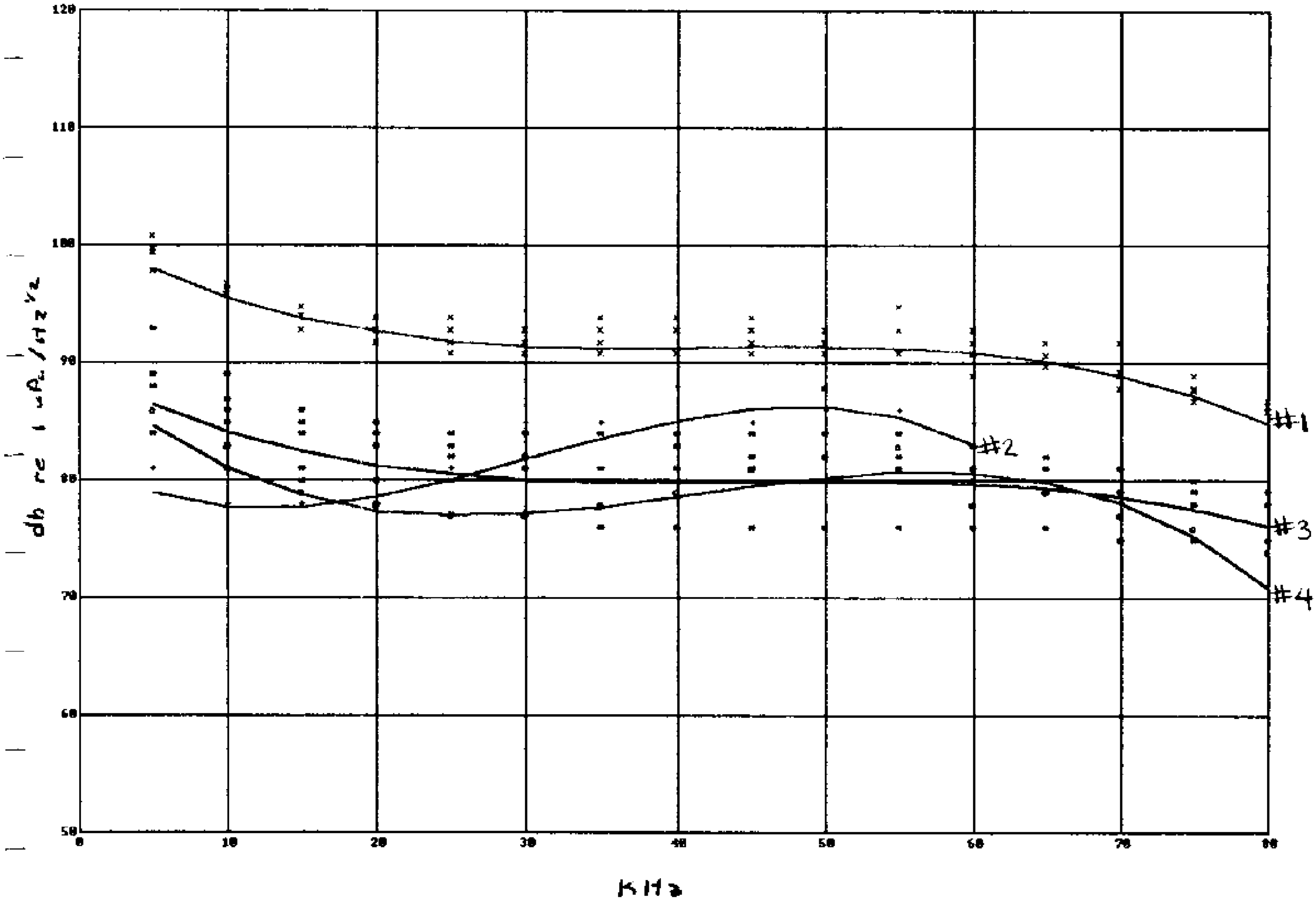
Current Speed Transect

Data from Little Bay Estuary 2/14/92



NOTE: Data taken with Endeco 774ssm Current Meter
Profiles taken at 25 meter intervals

FIGURE 32



LEGEND

#1 - Ambient noise from 4/9/92

#2 - Ambient noise from 3/18/92

#3 - Ambient noise from 2/28/92

#4 - Ambient noise from 4/22/92

Figure 33: Ambient Noise Spectrum Levels

were the only two points of this caliber out of 90 samples, and since each only represents a 20 millisecond window of time, we neglected them to obtain a more realistic average spectrum level.

As noted earlier, after we removed the gillnet from the water, we recorded 4 samples of ambient noise. Figure 34 graphically demonstrates the difference between the underwater acoustics with and without the net in the water on the same day. The ambient noise is approximately 10-15 dB lower than gillnet noise when deployed perpendicular to the current. We can therefore conclude that the gillnet may increase underwater acoustics over a broad bandwidth.

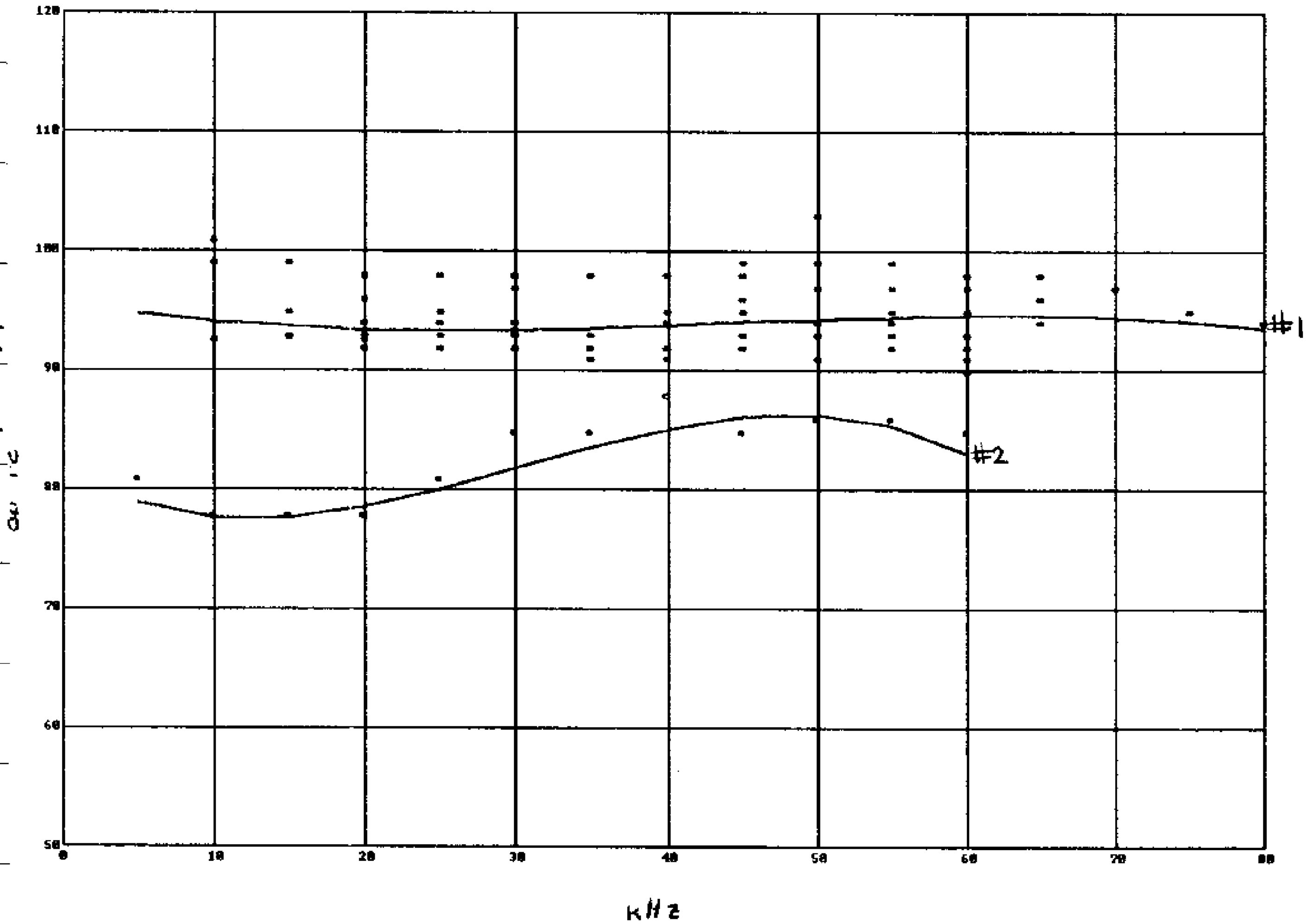
Gillnet Noise - parallel deployment (3/26/92):

When the noise recorded from the gillnet deployed parallel to the current with the noise from the gillnet perpendicular to the current, a noticeable drop of 10dB appears (see Figure 35. This difference may be related to the difference in acoustical properties of current flow along the net and current flow through the net.

Modified Gillnet Noise - perpendicular deployment (4/22/92):

After modification of a commercial gillnet with #3 bead chain, the spectral distribution seems to be slightly altered. Figure 36 shows the noise spectral levels of the perpendicularly deployed, parallel deployed, and modified net. A rise of approximately 4 dB occurs around 50 kHz.

When compared to ambient noise recorded on the same day, an interesting plot is produced (see Figure 37). The polynomial regression lines are nearly identical, but are separated by about 20dB. This provides support to the theory that a modified gillnet may increase the intensity level over an entire frequency bandwidth.

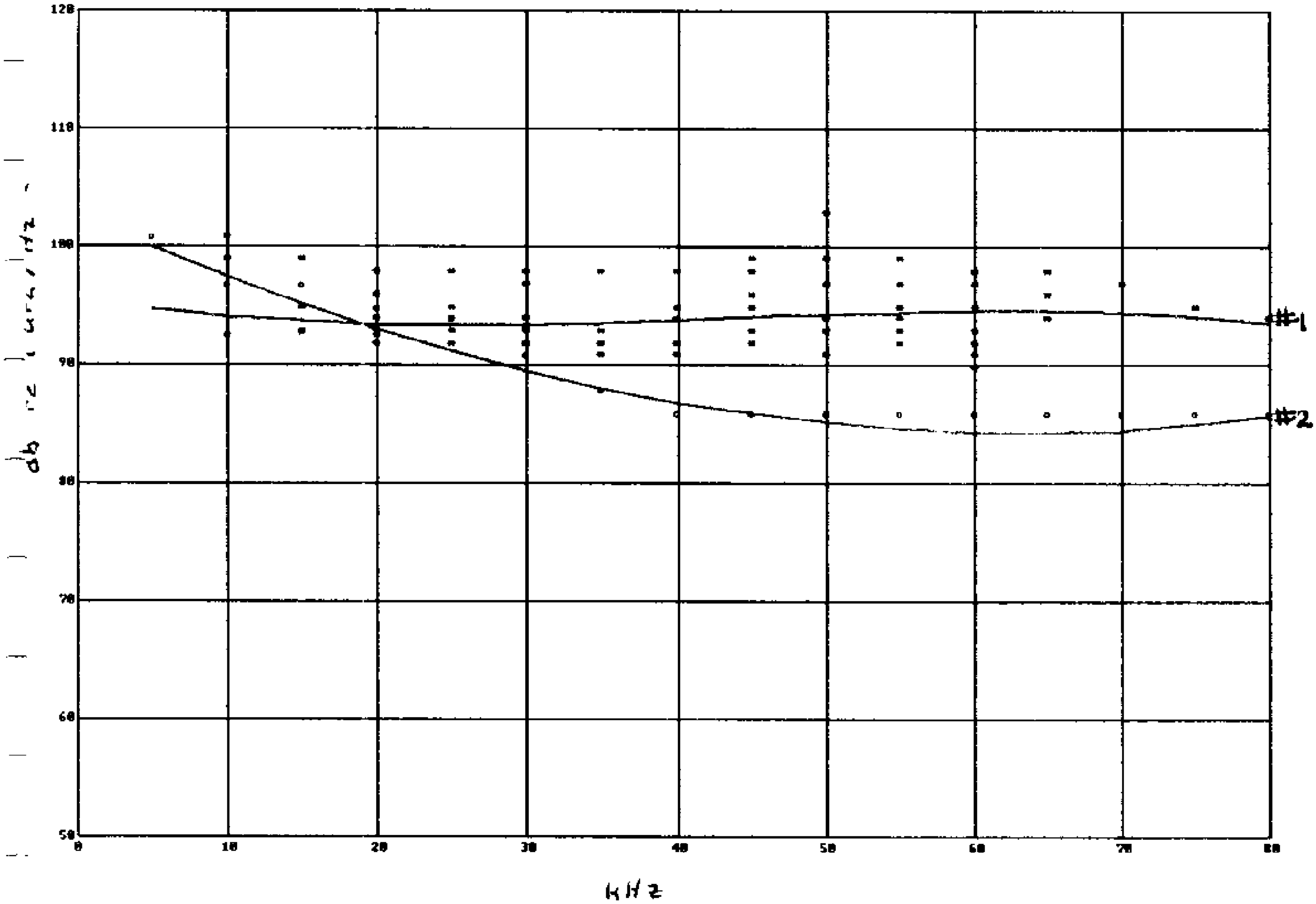


LEGEND

#1 - Gillnet noise - deployed perpendicular to current

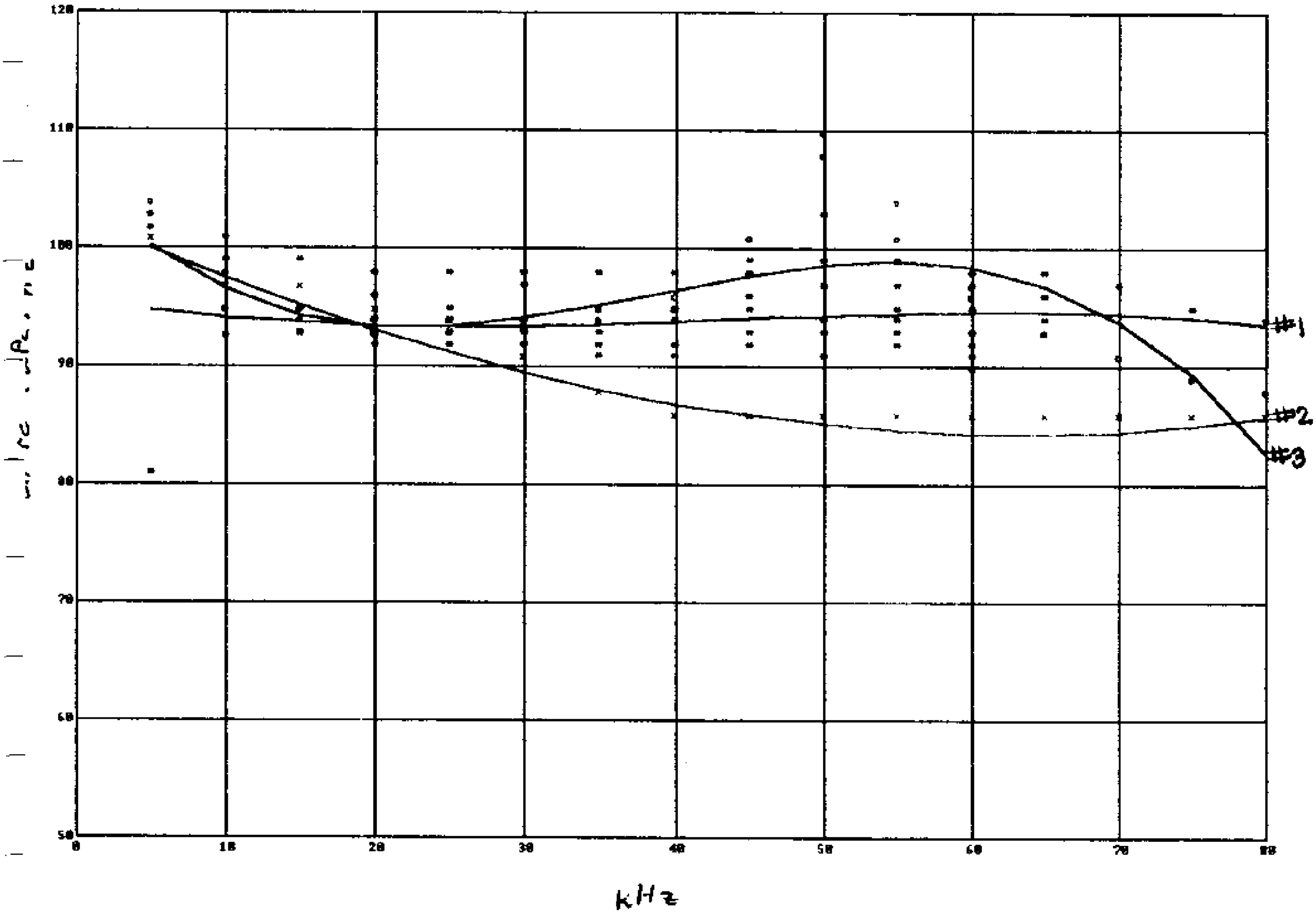
#2 - Ambient noise

Figure 34. Gillnet and Ambient Noise Spectrum Levels



LEGEND
#1 - Gillnet noise - deployed perpendicular to current
#2 - Gillnet noise - deployed parallel to current

Figure 35: Gillnet Noise Spectrum Levels



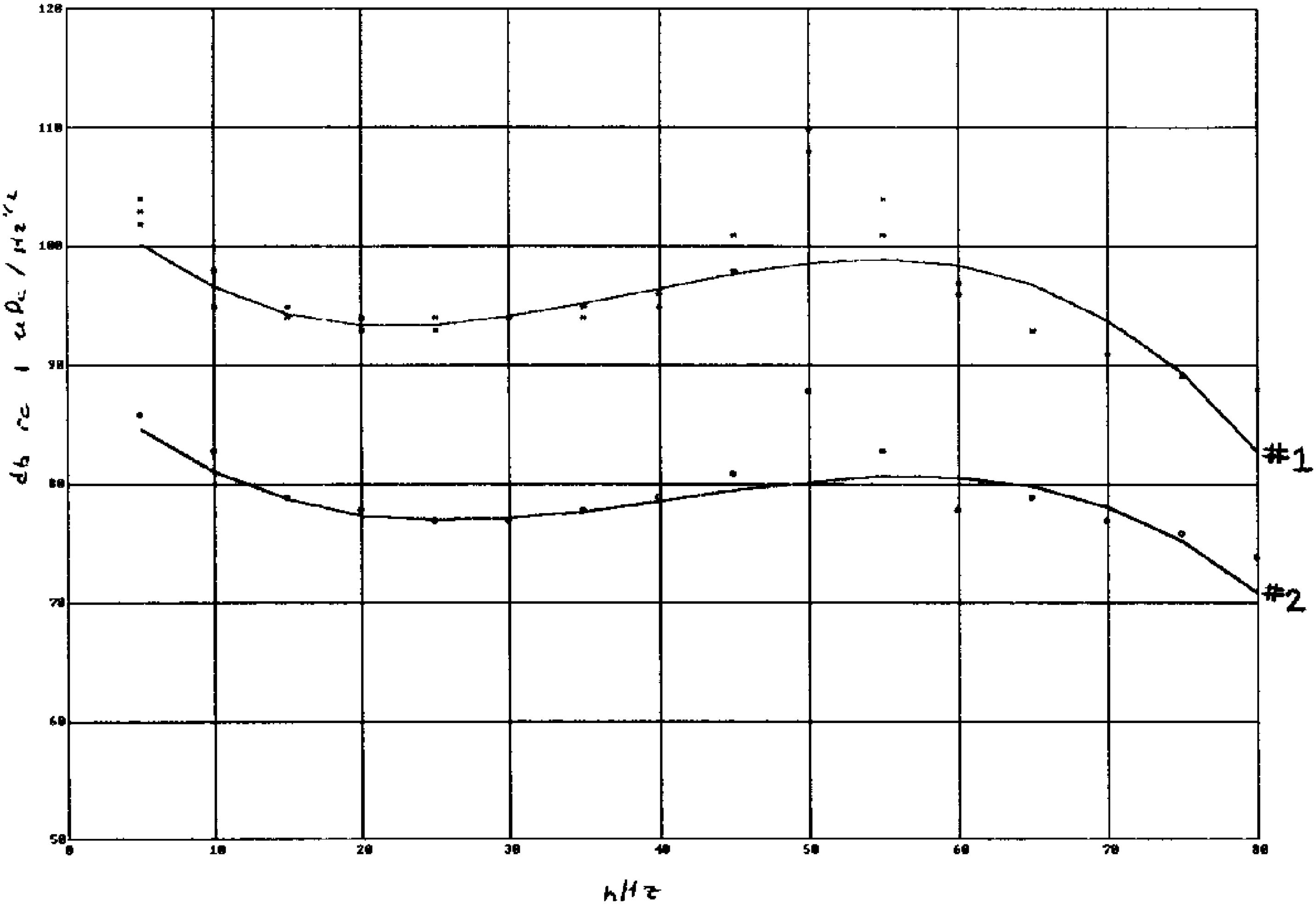
LEGEND

#1 - Gillnet noise - perpendicular deployment

#2 - Gillnet noise - parallel deployment

#3 - Modified gillnet noise

Figure 36: Gillnet Noise Spectrum Levels



LEGEND

#1 - Modified gillnet

#2 - Ambient noise

Figure 37: Modified and Ambient Noise Spectrum Levels

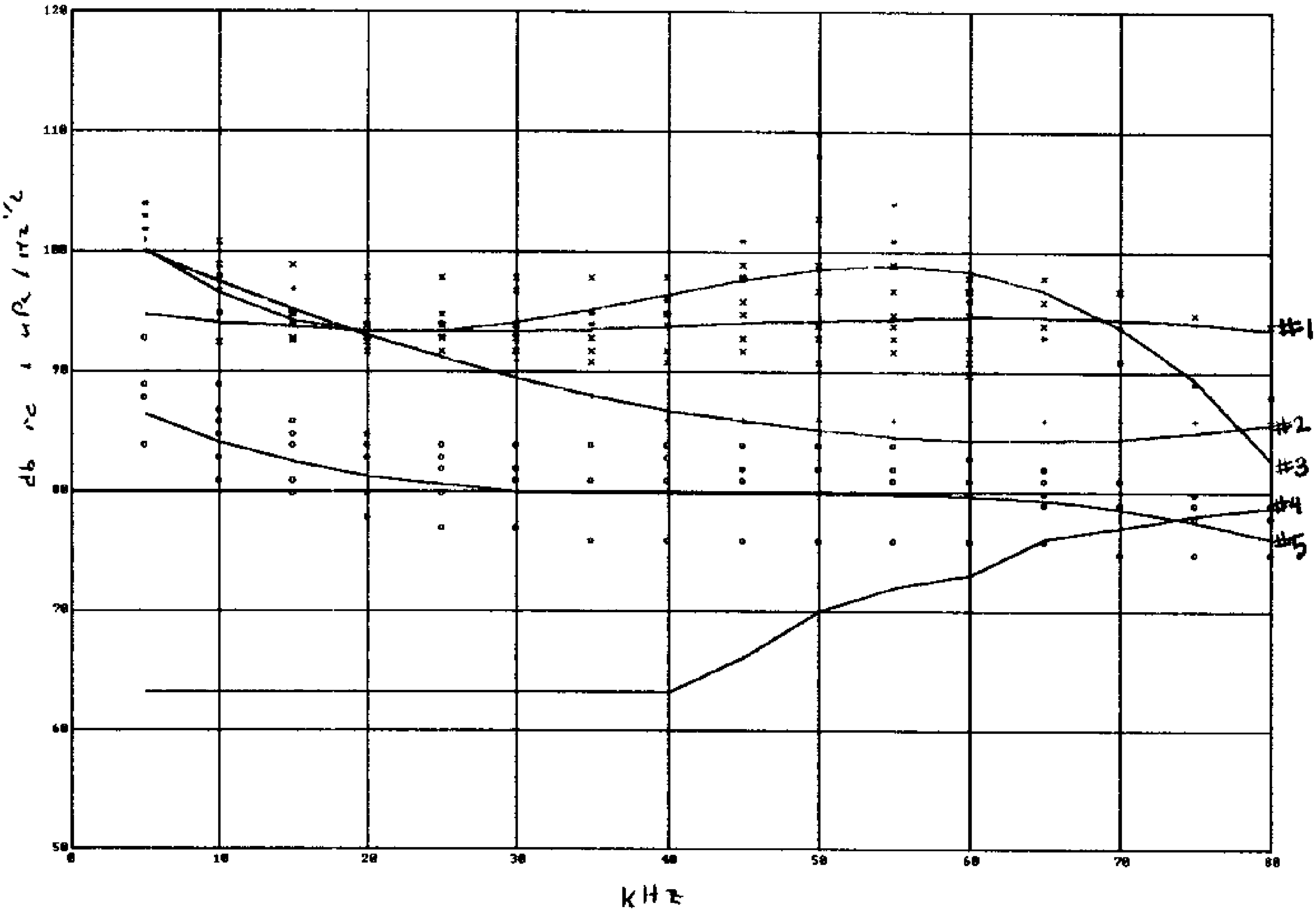
CONCLUSIONS

The correlation between the auditory senses of the harbor porpoise and gillnet noise is complex. This project was designed to investigate the passive acoustical interaction between the harbor porpoise and gillnet. In order to demonstrate a complete summary of our findings and to understand how the harbor porpoise relates to them, Figure 38 was generated. From this chart, four major conclusions have been drawn.

First, all measured acoustic spectrum levels fall above the auditory threshold of the harbor porpoise *Phocoena phocoena*, except for the ambient noise above 70 kHz. This indicates that the porpoise may be able to detect these levels of sound from the environment. In addition, the intensity of the signals when the gillnets were deployed shows a significant increase over ambient noise. This suggests that the porpoise may be able to distinguish gillnet noise from ambient noise.

Furthermore, the noise emitted from a gillnet perpendicularly oriented with respect to current flow is greater than that produced by a parallel set gillnet. Finally, signals of the greatest intensity were generated from the modified gillnet. It seem that the modification is also responsible for increasing the spectrum level at 50 kHz.

This project was designed as a primary analysis of an unstudied phenomenon. The results of this study warrant future research. The response of the harbor porpoise to the observed noise emitted from a gillnet must be determined. If the noise is found to cause an avoidance reaction, the scope of this project should be expanded. The effect of other modifications on the levels and shape of the spectrum should be analyzed. A positive foundation for future study in this area has been laid.



LEGEND

#1 - Gillnet noise - deployed perpendicular to current

#2 - Gillnet noise - deployed parallel to current

#3 - Modified gillnet noise

#4 - Harbor porpoise auditory threshold

#5 - Ambient noise

Figure38: All Inclusive Spectrum Levels

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We would like to extend our appreciation to people who assisted us at various stages of our project. First and foremost, we wish to thank our advisor, Dr. Ken Baldwin, for inviting us to become an integral part of a highly interesting ongoing problem. His continuous insight and support was invaluable over the entire course of this project. Paul Pelletier, captain of the research vessel Jere A. Chase, and Ken Houtler, first mate, helped out tremendously with our field measurements. Funding was provided by Sea Grant.

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APPENDIX A

AMBIENT NOISE SAMPLES

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
AL0001	2/27/92	12:19	200 Hz	80 kHz	70 db	5 uS
AL0002	2/27/92	12:21	200 Hz	80 kHz	70 db	5 uS
AL0003	2/27/92	12:22	200 Hz	80 kHz	70 db	5 uS
AL0004	2/27/92	12:24	200 Hz	80 kHz	70 db	5 uS
AL0005	2/27/92	12:25	200 Hz	80 kHz	70 db	5 uS
AL0006	2/27/92	12:28	200 Hz	80 kHz	70 db	5 uS
AL0007	2/27/92	12:29	200 Hz	80 kHz	70 db	5 uS
AL0008	2/27/92	12:30	200 Hz	80 kHz	70 db	5 uS
AL0009	2/27/92	12:31	200 Hz	80 kHz	70 db	5 uS
AL0010	2/27/92	12:32	200 Hz	80 kHz	70 db	5 uS
AL0011	2/27/92	12:33	200 Hz	80 kHz	70 db	5 uS
AL0012	2/27/92	12:35	200 Hz	80 kHz	70 db	5 uS
AL0013	2/27/92	12:39	200 Hz	80 kHz	70 db	5 uS
AL0014	2/27/92	12:39	200 Hz	80 kHz	70 db	5 uS
AL0015	2/27/92	12:40	200 Hz	80 kHz	70 db	5 uS
AL0016	2/27/92	12:41	200 Hz	80 kHz	70 db	5 uS
AL0017	2/28/92	10:31	200 Hz	80 kHz	70 db	5 uS
AL0018	2/28/92	10:33	200 Hz	80 kHz	70 db	5 uS
AL0019	2/28/92	10:34	200 Hz	80 kHz	70 db	5 uS
AL0020	2/28/92	10:35	200 Hz	80 kHz	70 db	5 uS
AL0021	2/28/92	10:36	200 Hz	80 kHz	70 db	5 uS
AL0022	2/28/92	10:38	200 Hz	80 kHz	70 db	5 uS
AL0023	2/28/92	10:39	200 Hz	80 kHz	70 db	5 uS
AL0024	2/28/92	10:41	200 Hz	80 kHz	70 db	5 uS
AL0025	2/28/92	10:43	200 Hz	80 kHz	70 db	5 uS
AL0026	2/28/92	10:44	200 Hz	80 kHz	70 db	5 uS
AL0027	2/28/92	10:55	200 Hz	80 kHz	70 db	5 uS
AL0028	2/28/92	10:55	200 Hz	80 kHz	70 db	5 uS
AL0029	2/28/92	10:57	200 Hz	80 kHz	70 db	5 uS
AL0030	2/28/92	10:57	200 Hz	80 kHz	70 db	5 uS
AL0031	2/28/92	10:58	200 Hz	80 kHz	70 db	5 uS
AL0032	2/28/92	10:59	200 Hz	80 kHz	70 db	5 uS
AL0033	2/28/92	11:00	200 Hz	80 kHz	70 db	5 uS
AL0034	2/28/92	11:01	200 Hz	80 kHz	70 db	5 uS
AL0035	2/28/92	11:02	200 Hz	80 kHz	70 db	5 uS
AL0036	2/28/92	11:05	200 Hz	80 kHz	70 db	5 uS
AL0037	2/28/92	11:05	200 Hz	80 kHz	70 db	5 uS
AL0038	2/28/92	11:06	200 Hz	80 kHz	70 db	5 uS
AL0039	2/28/92	11:07	200 Hz	80 kHz	70 db	5 uS
AL0040	2/28/92	11:08	200 Hz	80 kHz	70 db	5 uS
AL0041	2/28/92	11:10	200 Hz	80 kHz	70 db	5 uS
AL0042	2/28/92	11:11	200 Hz	80 kHz	70 db	5 uS
AL0043	2/28/92	11:13	200 Hz	80 kHz	70 db	5 uS
AL0044	2/28/92	11:15	200 Hz	80 kHz	70 db	5 uS
AL0045	2/28/92	11:17	200 Hz	80 kHz	70 db	5 uS
AL0046	2/28/92	11:18	200 Hz	80 kHz	70 db	5 uS

SAMPLE	DATA	TIME	HIGH PASS	LOW PASS	GAIN	TPP
AL0047	2/28/92	11:19	200 Hz	80 kHz	70 db	5 us
AL0048	2/28/92	11:20	200 Hz	80 kHz	70 db	5 us
AL0049	2/28/92	11:21	200 Hz	80 kHz	70 db	5 us
AL0050	2/28/92	11:22	200 Hz	80 kHz	70 db	5 us
AL0051	2/28/92	11:25	200 Hz	80 kHz	70 db	5 us
AL0052	2/28/92	11:27	200 Hz	80 kHz	70 db	5 us
AL0053	2/28/92	11:28	200 Hz	80 kHz	70 db	5 us
AL0054	2/28/92	11:30	200 Hz	80 kHz	70 db	5 us
AL0055	2/28/92	11:32	200 Hz	80 kHz	70 db	5 us
AL0056	2/28/92	11:33	200 Hz	80 kHz	70 db	5 us
AL0057	2/28/92	11:38	200 Hz	80 kHz	70 db	5 us
AL0058	2/28/92	11:42	200 Hz	80 kHz	70 db	5 us
AL0059	2/28/92	11:43	200 Hz	80 kHz	70 db	5 us
AL0060	2/28/92	11:44	200 Hz	80 kHz	70 db	5 us
AL0061	2/28/92	11:46	200 Hz	80 kHz	70 db	5 us
AL0062	2/28/92	11:47	200 Hz	80 kHz	70 db	5 us
AL0063	2/28/92	11:48	200 Hz	80 kHz	70 db	5 us
AL0064	2/28/92	11:50	200 Hz	80 kHz	70 db	5 us
AL0065	2/28/92	11:51	200 Hz	80 kHz	70 db	5 us
AL0066	2/28/92	11:52	200 Hz	80 kHz	70 db	5 us
AL0067	2/28/92	11:54	200 Hz	80 kHz	70 db	5 us
AL0068	2/28/92	11:58	200 Hz	80 kHz	70 db	5 us
AL0069	2/28/92	12:03	200 Hz	80 kHz	70 db	5 us
AL0070	2/28/92	12:07	200 Hz	80 kHz	70 db	5 us
AL0071	2/28/92	12:11	200 Hz	80 kHz	70 db	5 us
AL0072	2/28/92	12:13	200 Hz	80 kHz	70 db	5 us
AL0073	2/28/92	12:14	200 Hz	80 kHz	70 db	5 us
AL0074	2/28/92	12:19	200 Hz	80 kHz	70 db	5 us
AL0075	2/28/92	12:21	200 Hz	80 kHz	70 db	5 us
AL0076	2/28/92	12:26	200 Hz	80 kHz	70 db	5 us
AL0077	2/28/92	12:27	200 Hz	80 kHz	70 db	5 us
AL0078	2/28/92	12:29	200 Hz	80 kHz	70 db	5 us
AL0079	2/28/92	12:30	200 Hz	80 kHz	70 db	5 us
AL0081	2/28/92	12:33	200 Hz	80 kHz	70 db	5 us
AL0082	2/28/92	12:34	200 Hz	80 kHz	70 db	5 us
AL0084	2/28/92	12:38	200 Hz	80 kHz	70 db	5 us
AL0085	2/28/92	12:39	200 Hz	80 kHz	70 db	5 us
AL0086	2/28/92	12:41	200 Hz	80 kHz	70 db	5 us
AL0087	2/28/92	12:43	200 Hz	80 kHz	70 db	5 us
AL0088	2/28/92	12:44	200 Hz	80 kHz	70 db	5 us
AL0089	2/28/92	12:51	200 Hz	80 kHz	70 db	5 us
AL0090	2/28/92	12:52	200 Hz	80 kHz	70 db	5 us
AL0091	2/28/92	12:54	200 Hz	80 kHz	70 db	5 us
AL0092	2/28/92	12:56	200 Hz	80 kHz	70 db	5 us
AL0093	2/28/92	12:57	200 Hz	80 kHz	70 db	5 us
AL0094	2/28/92	12:58	200 Hz	80 kHz	70 db	5 us
AL0095	2/28/92	1:00	200 Hz	80 kHz	70 db	5 us
AL0096	2/28/92	1:01	200 Hz	80 kHz	70 db	5 us
AL0097	2/28/92	1:03	200 Hz	80 kHz	70 db	5 us
AL0098	2/28/92	1:09	200 Hz	80 kHz	70 db	5 us

SAMPLE	DATA	TIME	HIGH PASS	LOW PASS	GAIN	TPP
AL0100	2/28/92	1:12	200 Hz	80 kHz	70 db	5 uS
AL0101	2/28/92	1:14	200 Hz	80 kHz	70 db	5 uS
AL0102	2/28/92	1:18	200 Hz	80 kHz	70 db	5 uS
AL0103	2/28/92	1:19	200 Hz	80 kHz	70 db	5 uS
AL0104	2/28/92	1:20	200 Hz	80 kHz	70 db	5 uS
AL0105	2/28/92	1:23	200 Hz	80 kHz	70 db	5 uS
AL0106	2/28/92	1:24	200 Hz	80 kHz	70 db	5 uS
AL0107	2/28/92	1:35	200 Hz	80 kHz	70 db	5 uS
AL0108	2/28/92	1:36	200 Hz	80 kHz	70 db	5 uS
AL0109	2/28/92	1:38	200 Hz	80 kHz	70 db	5 uS
AL0110	2/28/92	1:39	200 Hz	80 kHz	70 db	5 uS
AL0115	3/06/92	2:35	200 Hz	80 kHz	70 db	5 uS
AL0116	3/06/92	2:37	200 Hz	80 kHz	70 db	5 uS
AL0117	3/06/92	2:38	200 Hz	80 kHz	70 db	5 uS
AL0118	3/06/92	2:41	200 Hz	80 kHz	70 db	5 uS
AL0119	3/06/92	2:42	200 Hz	80 kHz	70 db	5 uS
AL0120	3/06/92	2:42	200 Hz	80 kHz	70 db	5 uS
AL0121	3/06/92	2:43	200 Hz	80 kHz	70 db	5 uS
AL0122	3/06/92	2:44	200 Hz	80 kHz	70 db	5 uS
AL0123	3/06/92	2:46	200 Hz	80 kHz	70 db	5 uS
AL0124	3/06/92	2:48	200 Hz	80 kHz	70 db	5 uS

GILLNET NOISE SAMPLES

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
GNL0001	3/18/92	12:31	1 kHz	80 kHz	50 db	5 uS
GNL0002	3/18/92	12:31	1 kHz	80 kHz	50 db	5 uS
GNL0003	3/18/92	12:33	10 kHz	80 kHz	50 db	5 uS
GNL0004	3/18/92	12:35	10 kHz	80 kHz	50 db	5 uS
GNL0005	3/18/92	12:36	10 kHz	80 kHz	50 db	5 uS
GNL0006	3/18/92	12:37	10 kHz	80 kHz	50 db	5 uS
GNL0007	3/18/92	12:39	10 kHz	80 kHz	50 db	5 uS
GNL0008	3/18/92	12:40	10 kHz	80 kHz	50 db	5 uS
GNL0009	3/18/92	12:41	10 kHz	80 kHz	50 db	5 uS
GNL0010	3/18/92	12:42	10 kHz	80 kHz	50 db	5 uS
GNL0011	3/18/92	12:43	10 kHz	80 kHz	50 db	5 uS
GNL0012	3/18/92	12:44	10 kHz	80 kHz	50 db	5 uS
GNL0013	3/18/92	12:45	10 kHz	80 kHz	50 db	5 uS
GNL0014	3/18/92	12:47	10 kHz	80 kHz	50 db	5 uS
GNL0015	3/18/92	12:48	10 kHz	80 kHz	50 db	5 uS
GNL0016	3/18/92	12:49	10 kHz	80 kHz	50 db	5 uS
GNL0017	3/18/92	12:50	10 kHz	80 kHz	50 db	5 uS
GNL0018	3/18/92	12:54	10 kHz	80 kHz	50 db	5 uS
GNL0019	3/18/92	12:55	10 kHz	80 kHz	50 db	5 uS
GNL0020	3/18/92	12:56	10 kHz	80 kHz	50 db	5 uS
GNL0021	3/18/92	12:58	10 kHz	63 kHz	50 db	5 uS
GNL0022	3/18/92	12:59	10 kHz	63 kHz	50 db	5 uS
GNL0023	3/18/92	12:59	10 kHz	63 kHz	50 db	5 uS
GNL0024	3/18/92	1:01	10 kHz	63 kHz	50 db	5 uS
GNL0026	3/18/92	1:02	10 kHz	63 kHz	50 db	5 uS
GNL0027	3/18/92	1:03	10 kHz	63 kHz	50 db	5 uS
GNL0028	3/18/92	1:05	10 kHz	63 kHz	50 db	5 uS
GNL0029	3/18/92	1:06	10 kHz	63 kHz	50 db	5 uS
GNL0030	3/18/92	1:08	10 kHz	63 kHz	50 db	5 uS
GNL0031	3/18/92	1:09	16 kHz	63 kHz	50 db	5 uS
GNL0032	3/18/92	1:10	16 kHz	63 kHz	50 db	5 uS
GNL0033	3/18/92	1:11	16 kHz	63 kHz	60 db	5 uS
GNL0034	3/18/92	1:13	16 kHz	63 kHz	60 db	5 uS
GNL0035	3/18/92	1:14	16 kHz	63 kHz	60 db	5 uS
GNL0036	3/18/92	1:16	16 kHz	63 kHz	60 db	5 uS
GNL0037	3/18/92	1:17	16 kHz	63 kHz	60 db	5 uS
GNL0038	3/18/92	1:18	16 kHz	63 kHz	60 db	5 uS
GNL0039	3/18/92	1:19	16 kHz	63 kHz	60 db	5 uS
GNL0040	3/18/92	1:20	16 kHz	63 kHz	60 db	5 uS
GNL0041	3/18/92	1:22	20 kHz	63 kHz	60 db	5 uS
GNL0042	3/18/92	1:23	20 kHz	63 kHz	60 db	5 uS
GNL0044	3/18/92	1:25	20 kHz	63 kHz	60 db	5 uS
GNL0045	3/18/92	1:27	20 kHz	63 kHz	60 db	5 uS
GNL0046	3/18/92	1:28	20 kHz	63 kHz	60 db	5 uS
GNL0047	3/18/92	1:29	20 kHz	63 kHz	60 db	5 uS
GNL0048	3/18/92	1:31	20 kHz	63 kHz	60 db	5 uS

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
GNL0049	3/18/92	1:32	20 kHz	63 kHz	60 db	5 uS
GNL0050	3/18/92	1:33	20 kHz	63 kHz	60 db	5 uS
GNL0051	3/18/92	1:34	20 kHz	63 kHz	60 db	5 uS
GNL0052	3/18/92	1:36	20 kHz	63 kHz	60 db	5 uS
GNL0053	3/18/92	1:39	20 kHz	63 kHz	60 db	5 uS
GNL0054	3/18/92	1:41	20 kHz	63 kHz	60 db	5 uS
GNL0055	3/18/92	1:43	20 kHz	63 kHz	60 db	5 uS
GNL0056	3/18/92	1:50	20 kHz	63 kHz	60 db	5 uS
GNL0057	3/18/92	1:53	20 kHz	63 kHz	60 db	5 uS
GNL0058	3/18/92	1:54	16 kHz	63 kHz	60 db	5 uS
GNL0059	3/18/92	1:56	16 kHz	63 kHz	60 db	5 uS
GNL0060	3/18/92	1:57	16 kHz	63 kHz	60 db	5 uS
GNL0061	3/18/92	1:59	16 kHz	63 kHz	60 db	5 uS
GNL0062	3/18/92	2:00	16 kHz	63 kHz	60 db	5 uS
GNL0063	3/18/92	2:01	16 kHz	63 kHz	60 db	5 uS
GNL0064	3/18/92	2:02	16 kHz	63 kHz	60 db	5 uS
GNL0065	3/18/92	2:04	16 kHz	63 kHz	60 db	2 uS
GNL0066	3/18/92	2:05	16 kHz	63 kHz	60 db	2 uS
GNL0067	3/18/92	2:06	16 kHz	63 kHz	60 db	2 uS
GNL0068	3/18/92	2:07	16 kHz	63 kHz	60 db	2 uS
GNL0069	3/18/92	2:08	16 kHz	63 kHz	60 db	2 uS
GNL0070	3/18/92	2:09	16 kHz	63 kHz	60 db	2 uS
GNL0071	3/18/92	2:10	16 kHz	63 kHz	60 db	2 uS
GNL0072	3/18/92	2:11	16 kHz	63 kHz	60 db	2 uS
GNL0073	3/18/92	2:13	16 kHz	63 kHz	60 db	2 uS
GNL0074	3/18/92	2:14	16 kHz	63 kHz	60 db	2 uS
GNL0076	3/18/92	2:15	40 kHz	63 kHz	60 db	2 uS
GNL0077	3/18/92	2:16	40 kHz	63 kHz	60 db	2 uS
GNL0078	3/18/92	2:17	40 kHz	63 kHz	60 db	2 uS
GNL0079	3/18/92	2:19	40 kHz	63 kHz	60 db	2 uS
GNL0080	3/18/92	2:21	40 kHz	63 kHz	60 db	5 uS
GNL0081	3/18/92	2:22	40 kHz	63 kHz	60 db	5 uS
GNL0082	3/18/92	2:22	40 kHz	63 kHz	60 db	5 uS
GNL0083	3/18/92	2:23	40 kHz	63 kHz	60 db	5 uS
GNL0084	3/18/92	2:24	40 kHz	63 kHz	60 db	5 uS
GNL0085	3/18/92	2:25	40 kHz	63 kHz	60 db	5 uS
GNL0087	3/18/92	3:12	1 kHz	63 kHz	60 db	5 uS
GNL0088	3/18/92	3:15	1 kHz	63 kHz	60 db	5 uS
GNL0089	3/18/92	3:16	1 kHz	63 kHz	60 db	5 uS
GNL0090	3/18/92	3:18	1 kHz	63 kHz	60 db	5 uS

..st Removal

GILLNET NOISE SAMPLES

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
GNL2001	3/26/92	12:03	1 kHz	80 kHz	50 db	5 uS
GNL2002	3/26/92	12:06	1 kHz	80 kHz	50 db	5 uS
GNL2003	3/26/92	12:07	1 kHz	80 kHz	50 db	5 uS
GNL2004	3/26/92	12:09	1 kHz	80 kHz	50 db	5 uS
GNL2005	3/26/92	12:10	1 kHz	80 kHz	50 db	5 uS
GNL2006	3/26/92	12:12	1 kHz	80 kHz	50 db	5 uS
GNL2007	3/26/92	12:13	1 kHz	80 kHz	50 db	5 uS
GNL2008	3/26/92	12:15	1 kHz	80 kHz	50 db	5 uS
GNL2009	3/26/92	12:16	1 kHz	80 kHz	50 db	5 uS
GNL2010	3/26/92	12:18	1 kHz	80 kHz	50 db	5 uS
GNL2011	3/26/92	12:20	1 kHz	80 kHz	50 db	5 uS
GNL2012	3/26/92	12:20	1 kHz	80 kHz	50 db	5 uS
GNL2013	3/26/92	12:23	1 kHz	80 kHz	50 db	5 uS
GNL2014	3/26/92	12:25	1 kHz	80 kHz	50 db	5 uS
GNL2015	3/26/92	12:26	1 kHz	80 kHz	50 db	5 uS

AMBIENT NOISE SAMPLES

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
AL3001	4/9/92	10:20	1 kHz	80 kHz	60 db	5 uS
AL3002	4/9/92	10:21	1 kHz	80 kHz	60 db	5 uS
AL3003	4/9/92	10:22	1 kHz	80 kHz	60 db	5 uS
AL3004	4/9/92	10:22	1 kHz	80 kHz	60 db	5 uS
AL3005	4/9/92	10:23	1 kHz	80 kHz	60 db	5 uS
AL3006	4/9/92	10:24	2 kHz	80 kHz	60 db	5 uS
AL3007	4/9/92	10:25	2 kHz	80 kHz	60 db	5 uS
AL3008	4/9/92	10:26	2 kHz	80 kHz	60 db	5 uS
AL3009	4/9/92	10:26	2 kHz	80 kHz	60 db	5 uS
AL3010	4/9/92	10:27	2 kHz	80 kHz	60 db	5 uS
AL3011	4/9/92	10:28	1.6 kHz	80 kHz	60 db	5 uS
AL3012	4/9/92	10:28	1.6 kHz	80 kHz	60 db	5 uS
AL3013	4/9/92	10:29	1.6 kHz	80 kHz	60 db	5 uS
AL3014	4/9/92	10:30	1.6 kHz	80 kHz	60 db	5 uS
AL3016	4/9/92	10:32	10 kHz	80 kHz	60 db	5 uS
AL3017	4/9/92	10:32	10 kHz	80 kHz	60 db	5 uS
AL3018	4/9/92	10:33	10 kHz	80 kHz	60 db	5 uS
AL3019	4/9/92	10:34	10 kHz	80 kHz	60 db	5 uS
AL3020	4/9/92	10:35	10 kHz	80 kHz	60 db	5 uS
AL3021	4/9/92	10:35	10 kHz	80 kHz	60 db	5 uS
AL3022	4/9/92	10:36	10 kHz	80 kHz	60 db	5 uS
AL3023	4/9/92	10:37	10 kHz	80 kHz	60 db	5 uS
AL3024	4/9/92	10:38	10 kHz	80 kHz	60 db	5 uS
AL3025	4/9/92	10:39	10 kHz	80 kHz	60 db	5 uS
AL3026	4/9/92	10:42	5 kHz	63 kHz	60 db	5 uS
AL3027	4/9/92	10:43	5 kHz	63 kHz	60 db	5 uS
AL3028	4/9/92	10:43	5 kHz	63 kHz	60 db	5 uS
AL3029	4/9/92	10:44	5 kHz	63 kHz	60 db	5 uS
AL3030	4/9/92	10:45	5 kHz	63 kHz	60 db	5 uS
AL3031	4/9/92	10:47	20 kHz	63 kHz	60 db	5 uS
AL3032	4/9/92	10:48	20 kHz	63 kHz	60 db	5 uS
AL3033	4/9/92	10:49	20 kHz	63 kHz	60 db	5 uS
AL3034	4/9/92	10:50	20 kHz	63 kHz	60 db	5 uS
AL3035	4/9/92	10:51	20 kHz	63 kHz	60 db	5 uS
AL3036	4/9/92	10:51	20 kHz	63 kHz	60 db	5 uS
AL3037	4/9/92	10:52	20 kHz	63 kHz	60 db	5 uS
AL3038	4/9/92	10:53	20 kHz	63 kHz	60 db	5 uS
AL3039	4/9/92	10:53	20 kHz	63 kHz	60 db	5 uS
AL3040	4/9/92	10:54	20 kHz	63 kHz	60 db	5 uS
AL3041	4/9/92	10:56	5 kHz	80 kHz	60 db	5 uS
AL3042	4/9/92	10:58	5 kHz	80 kHz	60 db	5 uS
AL3043	4/9/92	10:59	5 kHz	80 kHz	60 db	5 uS
AL3044	4/9/92	10:59	5 kHz	80 kHz	60 db	5 uS
AL3045	4/9/92	11:01	5 kHz	80 kHz	60 db	5 uS

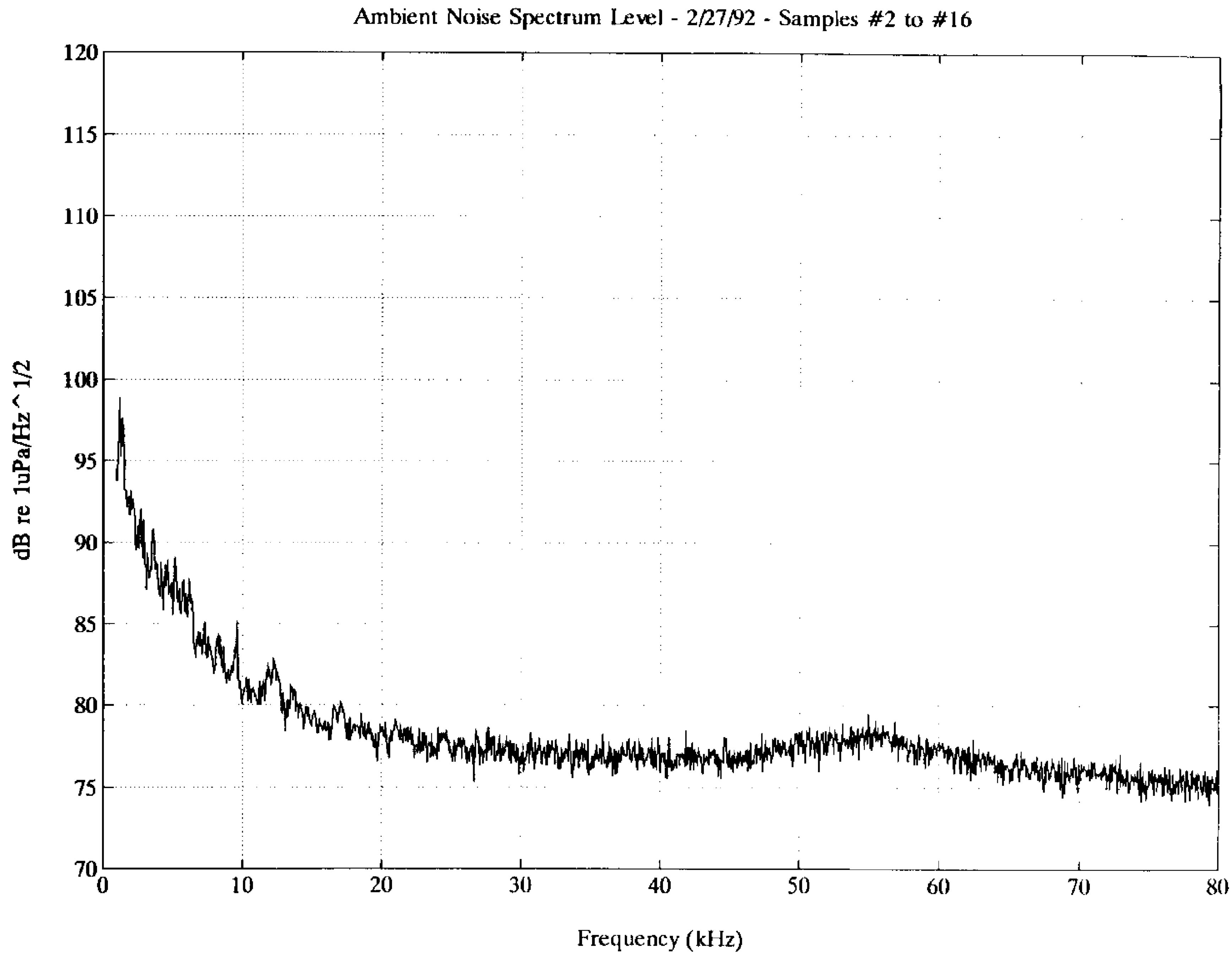
GILLNET NOISE SAMPLES

SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
GNL2001	3/26/92	12:03	1 kHz	80 kHz	50 db	5 uS
GNL2002	3/26/92	12:06	1 kHz	80 kHz	50 db	5 uS
GNL2003	3/26/92	12:07	1 kHz	80 kHz	50 db	5 uS
GNL2004	3/26/92	12:09	1 kHz	80 kHz	50 db	5 uS
GNL2005	3/26/92	12:10	1 kHz	80 kHz	50 db	5 uS
GNL2006	3/26/92	12:12	1 kHz	80 kHz	50 db	5 uS
GNL2007	3/26/92	12:13	1 kHz	80 kHz	50 db	5 uS
GNL2008	3/26/92	12:15	1 kHz	80 kHz	50 db	5 uS
GNL2009	3/26/92	12:16	1 kHz	80 kHz	50 db	5 uS
GNL2010	3/26/92	12:18	1 kHz	80 kHz	50 db	5 uS
GNL2011	3/26/92	12:20	1 kHz	80 kHz	50 db	5 uS
GNL2012	3/26/92	12:20	1 kHz	80 kHz	50 db	5 uS
GNL2013	3/26/92	12:23	1 kHz	80 kHz	50 db	5 uS
GNL2014	3/26/92	12:25	1 kHz	80 kHz	50 db	5 uS
GNL2015	3/26/92	12:26	1 kHz	80 kHz	50 db	5 uS

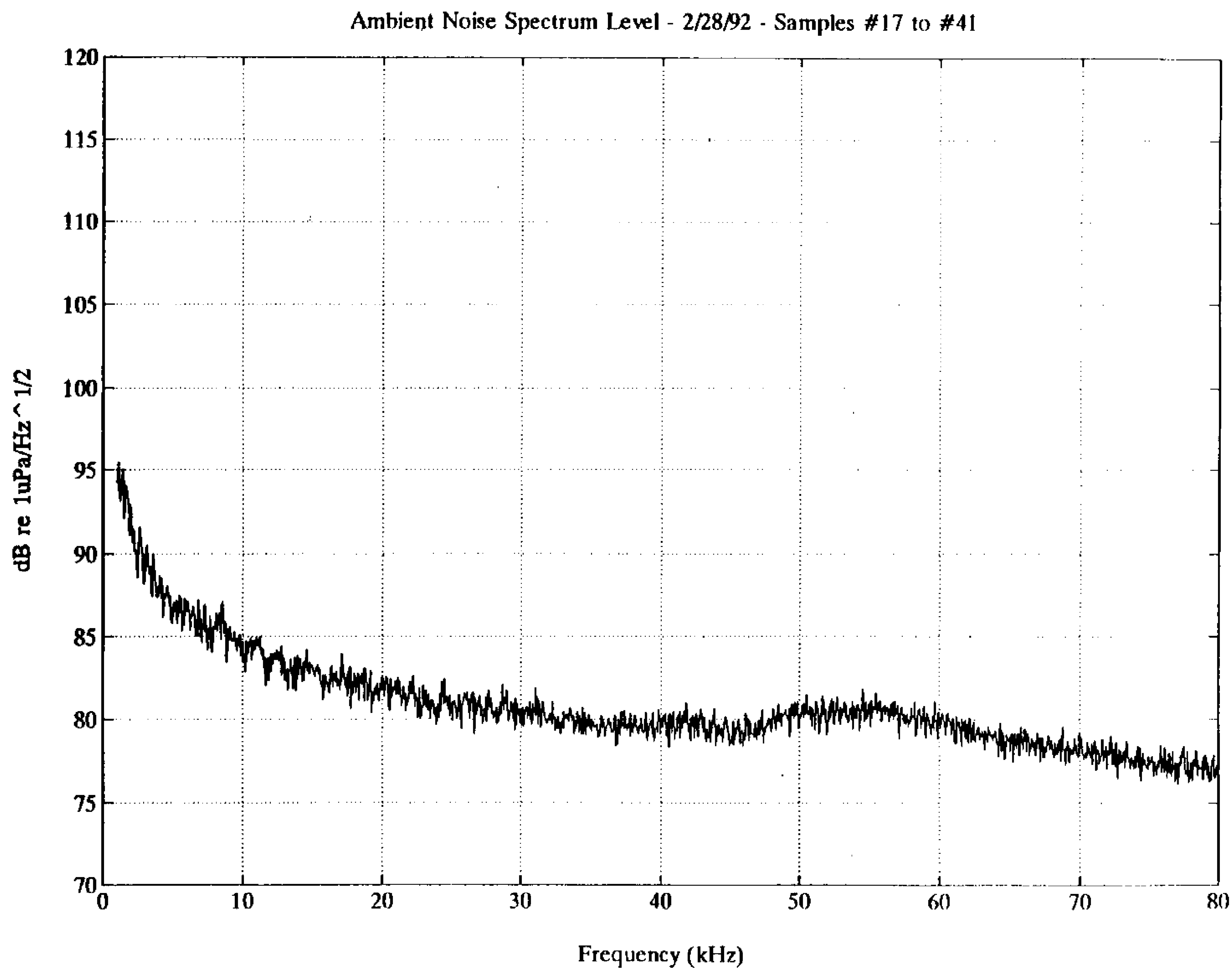
AMBIENT NOISE SAMPLES

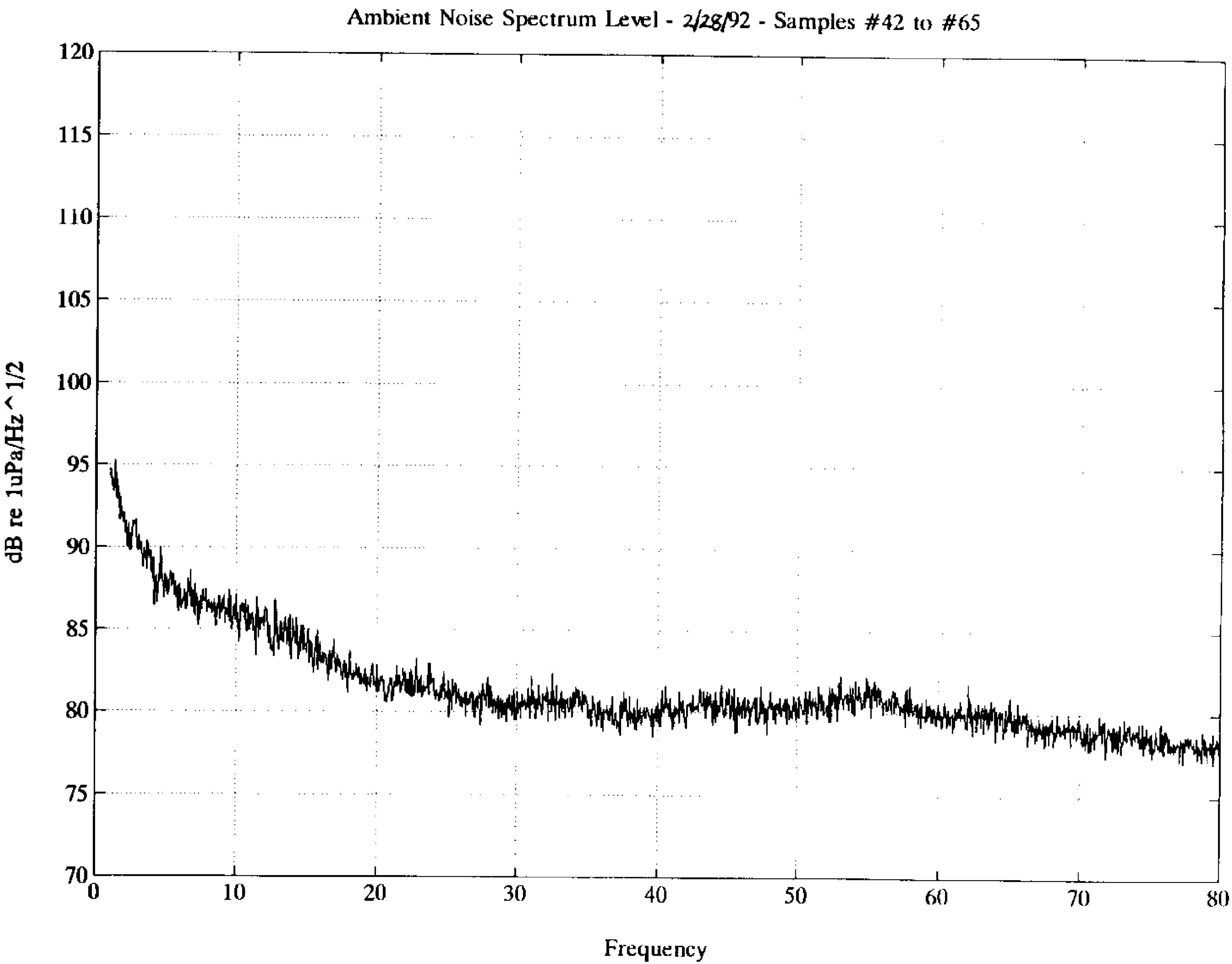
SAMPLE	DATE	TIME	HIGH PASS	LOW PASS	GAIN	TPP
AL4026	04/22/92	11:42	5 kHz	63 kHz	60 dB	5 uS
AL4027	04/22/92	11:44	5 kHz	63 kHz	60 dB	5 uS
AL4028	04/22/92	11:45	5 kHz	63 kHz	60 dB	5 uS
AL4029	04/22/92	11:47	5 kHz	63 kHz	60 dB	5 uS
AL4030	04/22/92	11:48	5 kHz	63 kHz	60 dB	5 uS
AL4031	04/22/92	11:51	10 kHz	80 kHz	60 dB	5 uS
AL4032	04/22/92	11:53	10 kHz	80 kHz	60 dB	5 uS
AL4033	04/22/92	11:54	10 kHz	80 kHz	60 dB	5 uS
AL4034	04/22/92	11:55	10 kHz	80 kHz	60 dB	5 uS
AL4035	04/22/92	12:02	10 kHz	80 kHz	60 dB	5 uS
AL4036	04/22/92	12:06	10 kHz	80 kHz	60 dB	5 uS
AL4037	04/22/92	12:08	10 kHz	80 kHz	60 dB	5 uS
AL4038	04/22/92	12:09	10 kHz	80 kHz	60 dB	5 uS
AL4039	04/22/92	12:11	10 kHz	80 kHz	60 dB	5 uS
AL4040	04/22/92	12:13	10 kHz	80 kHz	60 dB	5 uS
AL4041	04/22/92	12:16	5 kHz	63 kHz	60 dB	5 uS
AL4042	04/22/92	12:17	5 kHz	63 kHz	60 dB	5 uS
AL4043	04/22/92	12:20	5 kHz	63 kHz	60 dB	5 uS
AL4044	04/22/92	12:22	5 kHz	63 kHz	60 dB	5 uS

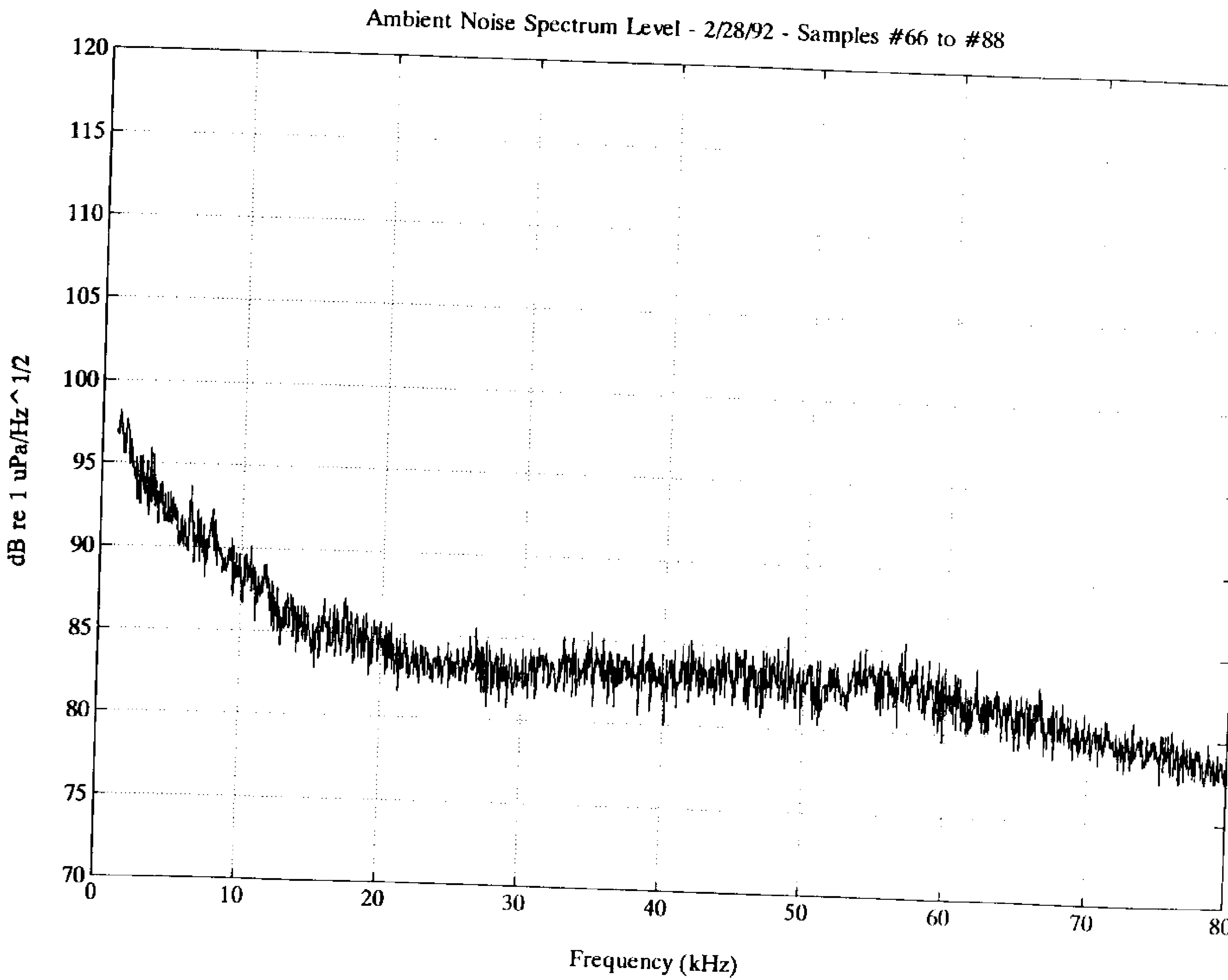
APPENDIX B



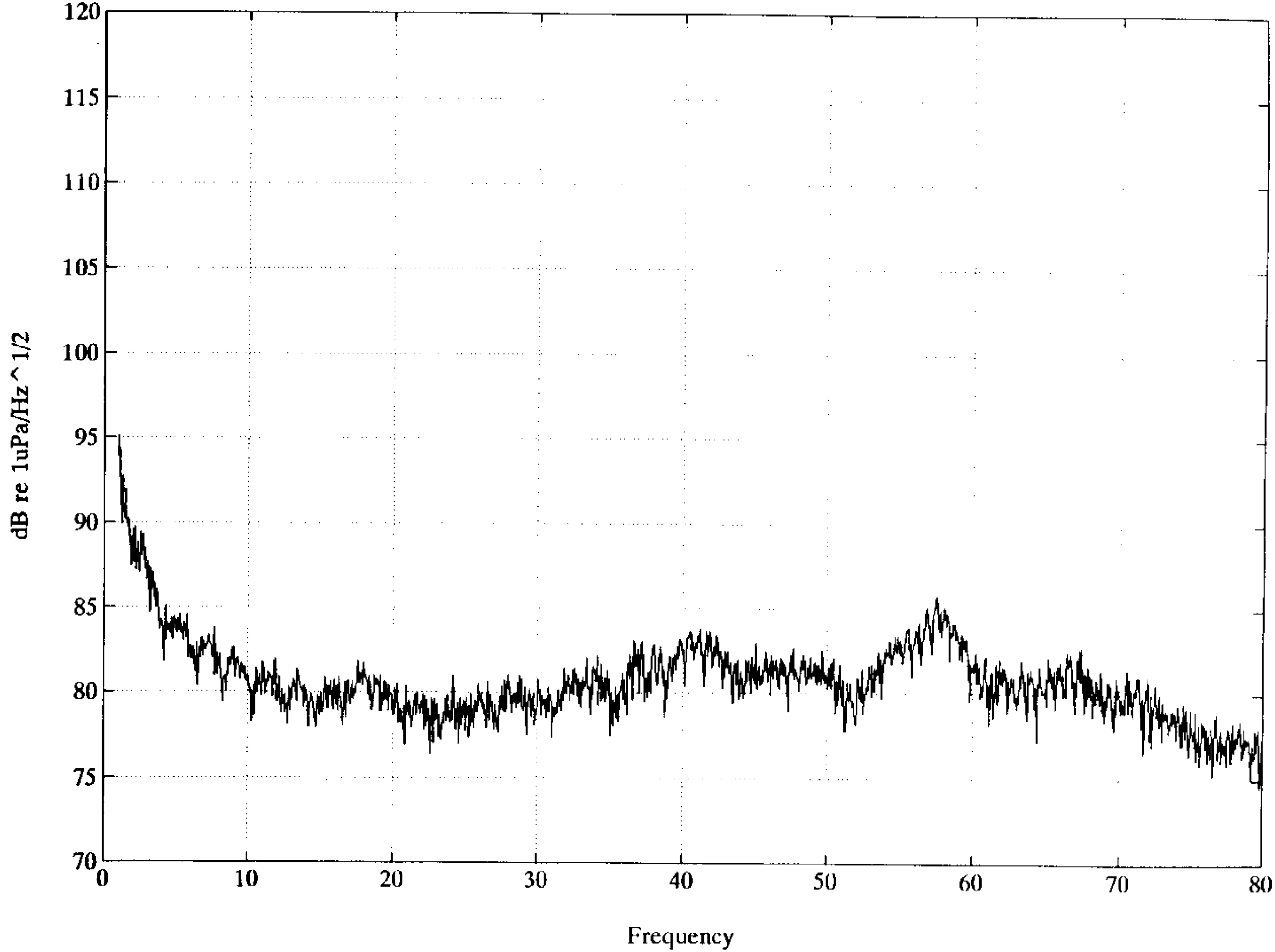
Ambient Noise Spectrum Level - 2/27/92 - Samples #2 to #16
dB re 1uPa/Hz ^ 1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)


Ambient Noise Spectrum Level - 2/28/92 - Samples #17 to #41
dB re 1uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

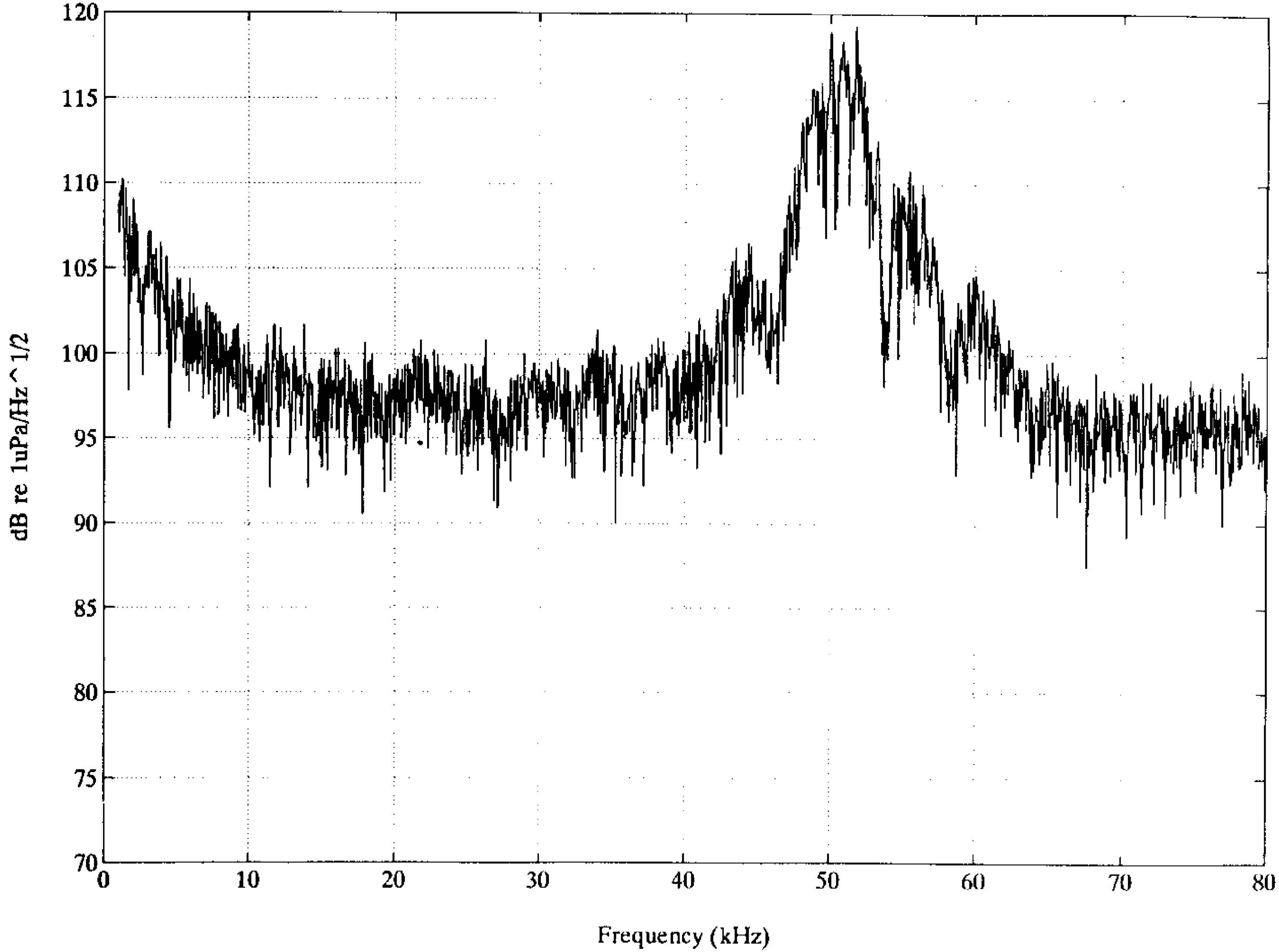

Ambient Noise Spectrum Level - 2/28/92 - Samples #42 to #65
dB re 1uPa/Hz ^ 1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency


Ambient Noise Spectrum Level - 2/28/92 - Samples #66 to #88
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
dB re 1 uPa/Hz ^ 1/2
Frequency (kHz)

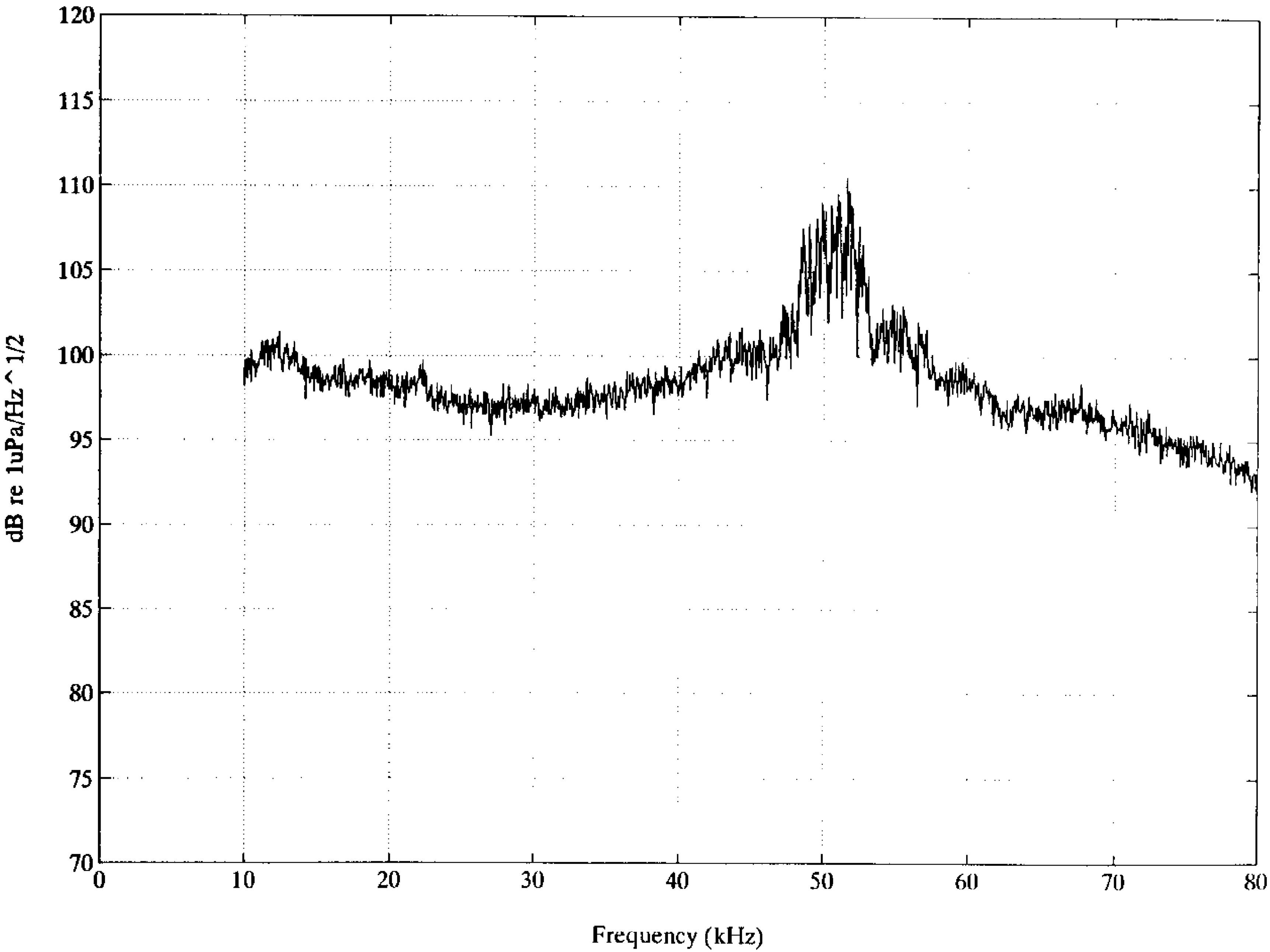
Ambient Noise Spectrum Level - 3/06/92 - Samples #115 to #122

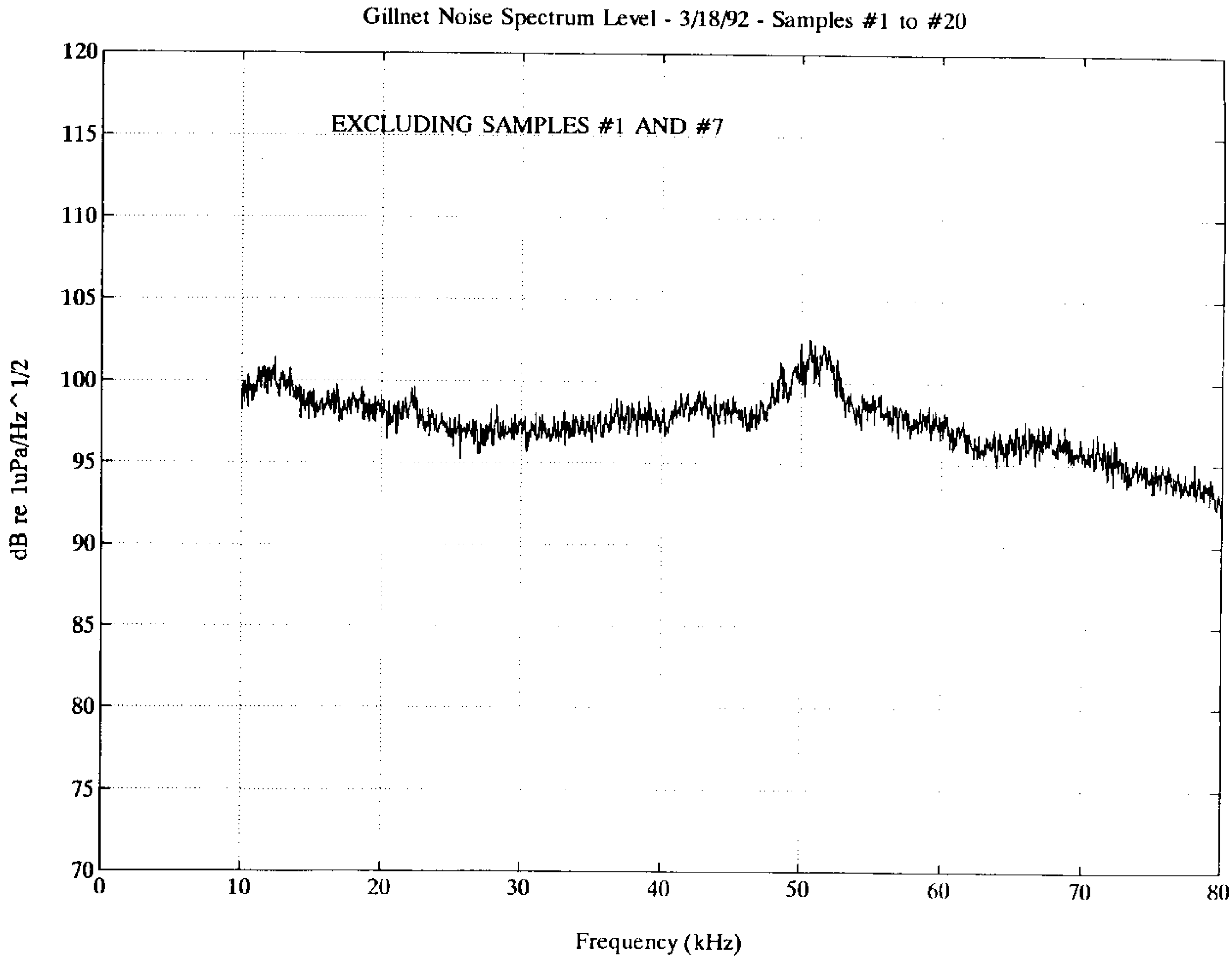


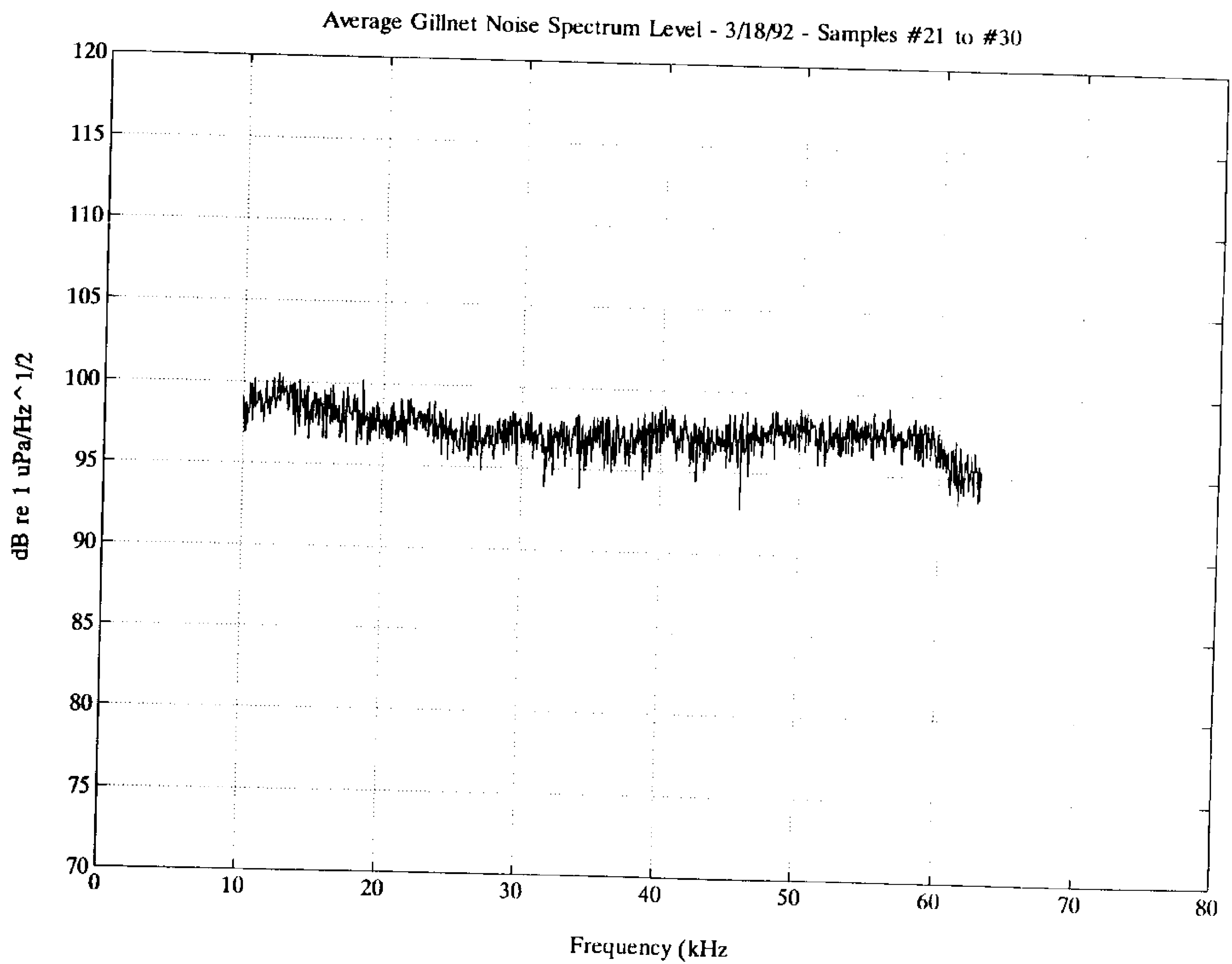
Gillnet Noise Spectrum Level - 3/18/92 - Samples #1 to #2



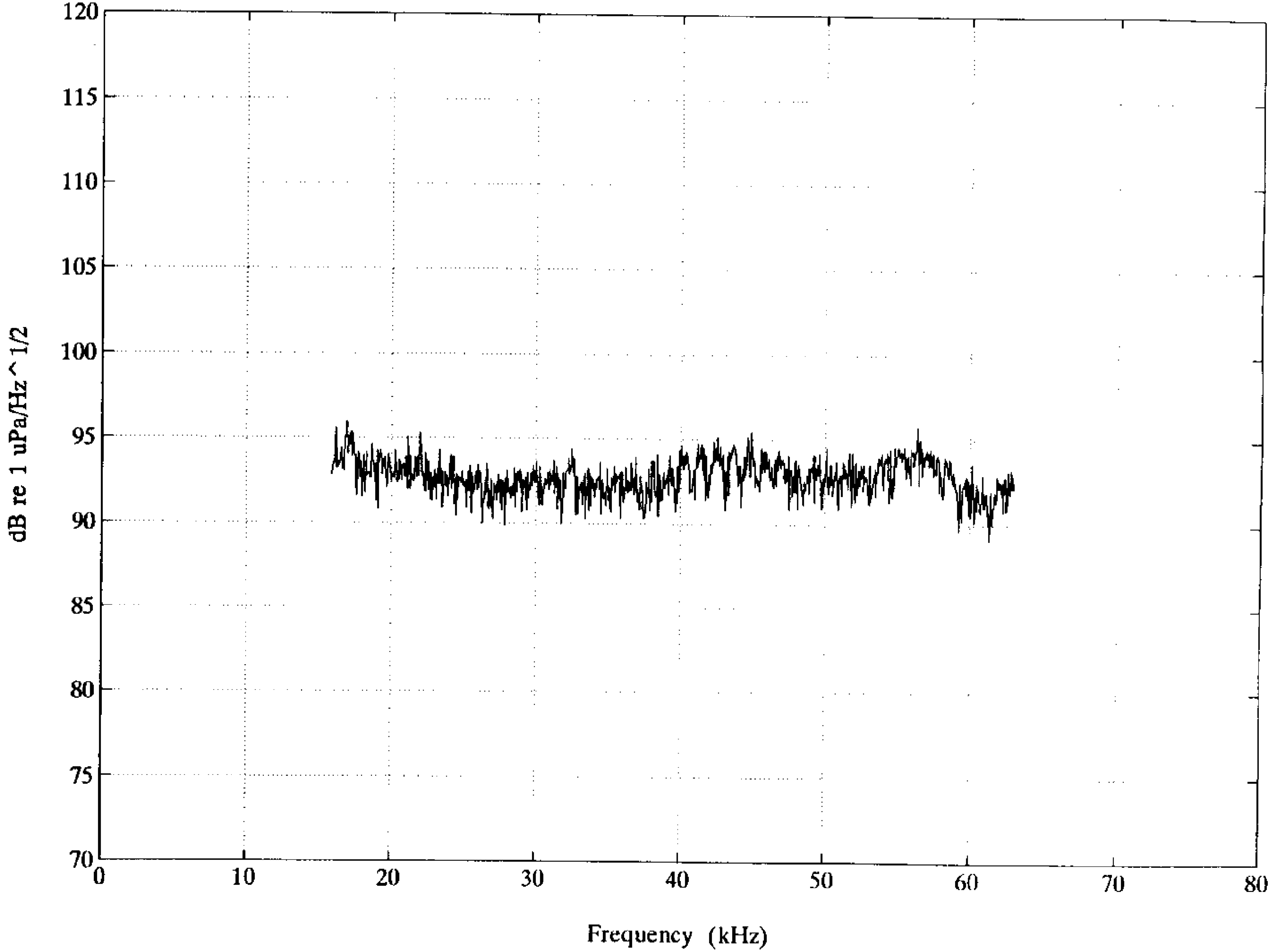
Gillnet Noise Spectrum Level - 3/18/92 - Samples #3 to #20



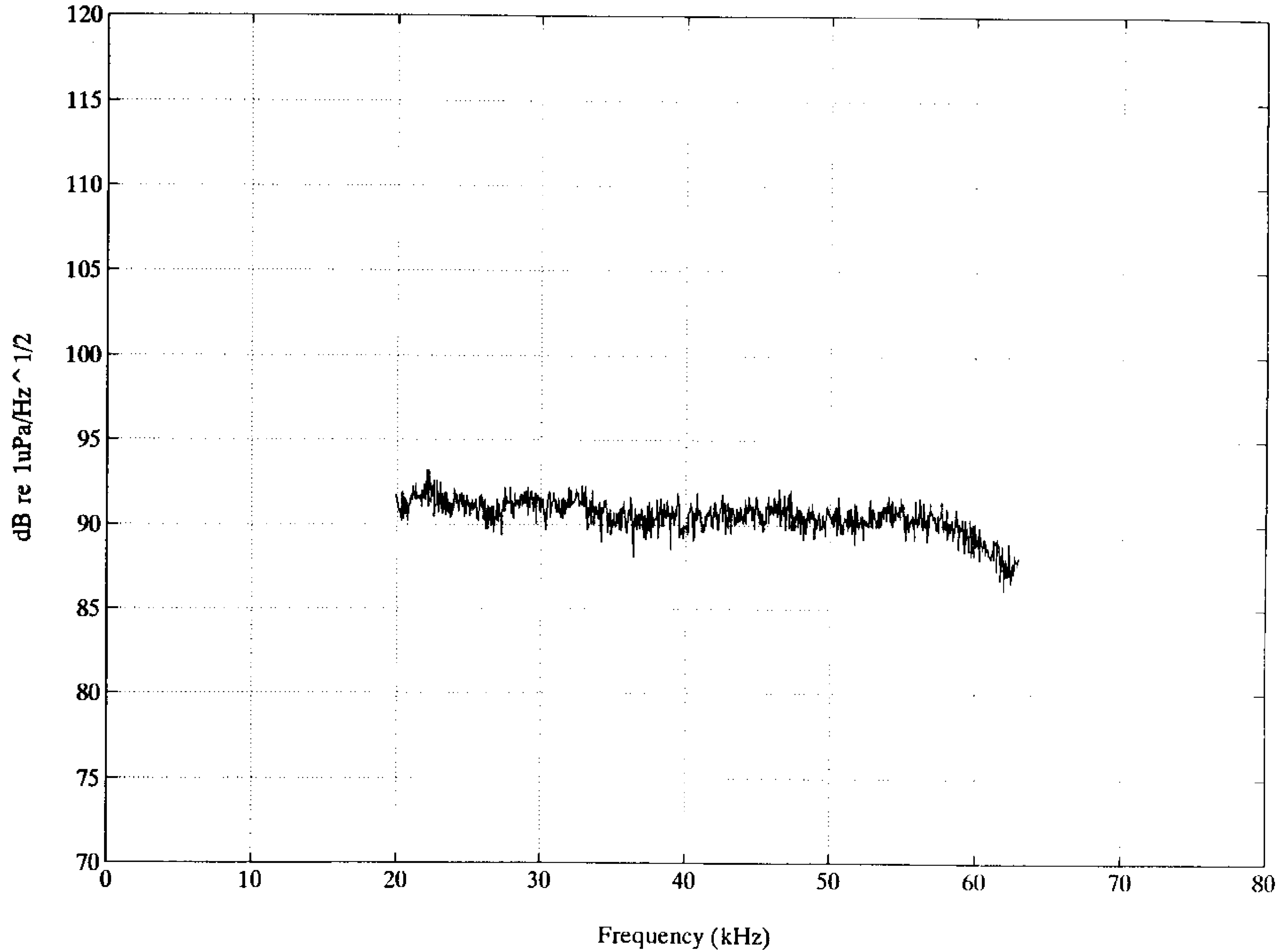

Gillnet Noise Spectrum Level - 3/18/92 - Samples #1 to #20
EXCLUDING SAMPLES #1 AND #7
dB re 1uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)


Average Gillnet Noise Spectrum Level - 3/18/92 - Samples #21 to #30
dB re 1 uPa/Hz ^ 1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz

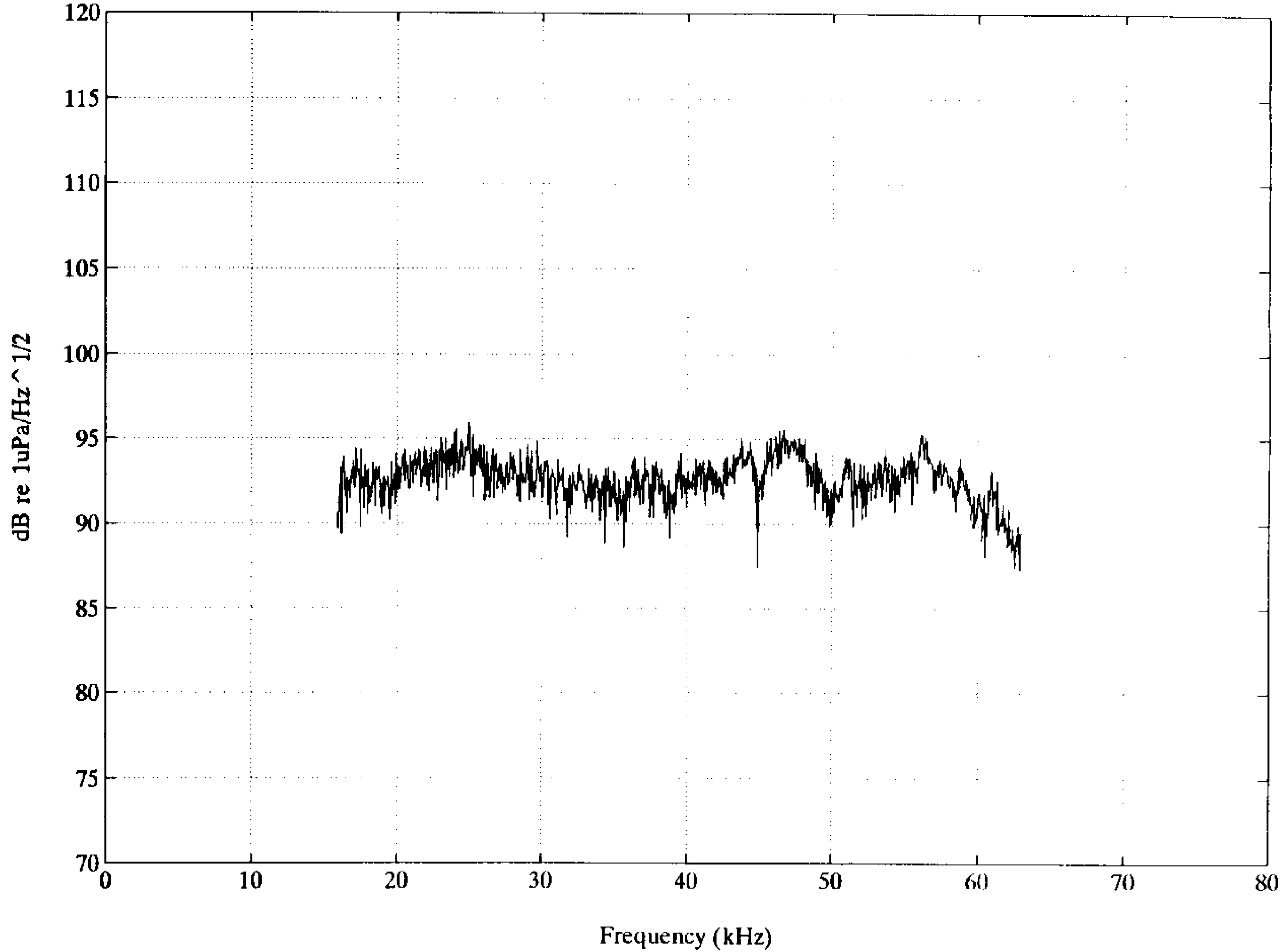
Average Gillnet Spectrum Level - 3/18/92 - Sample #31 to #40

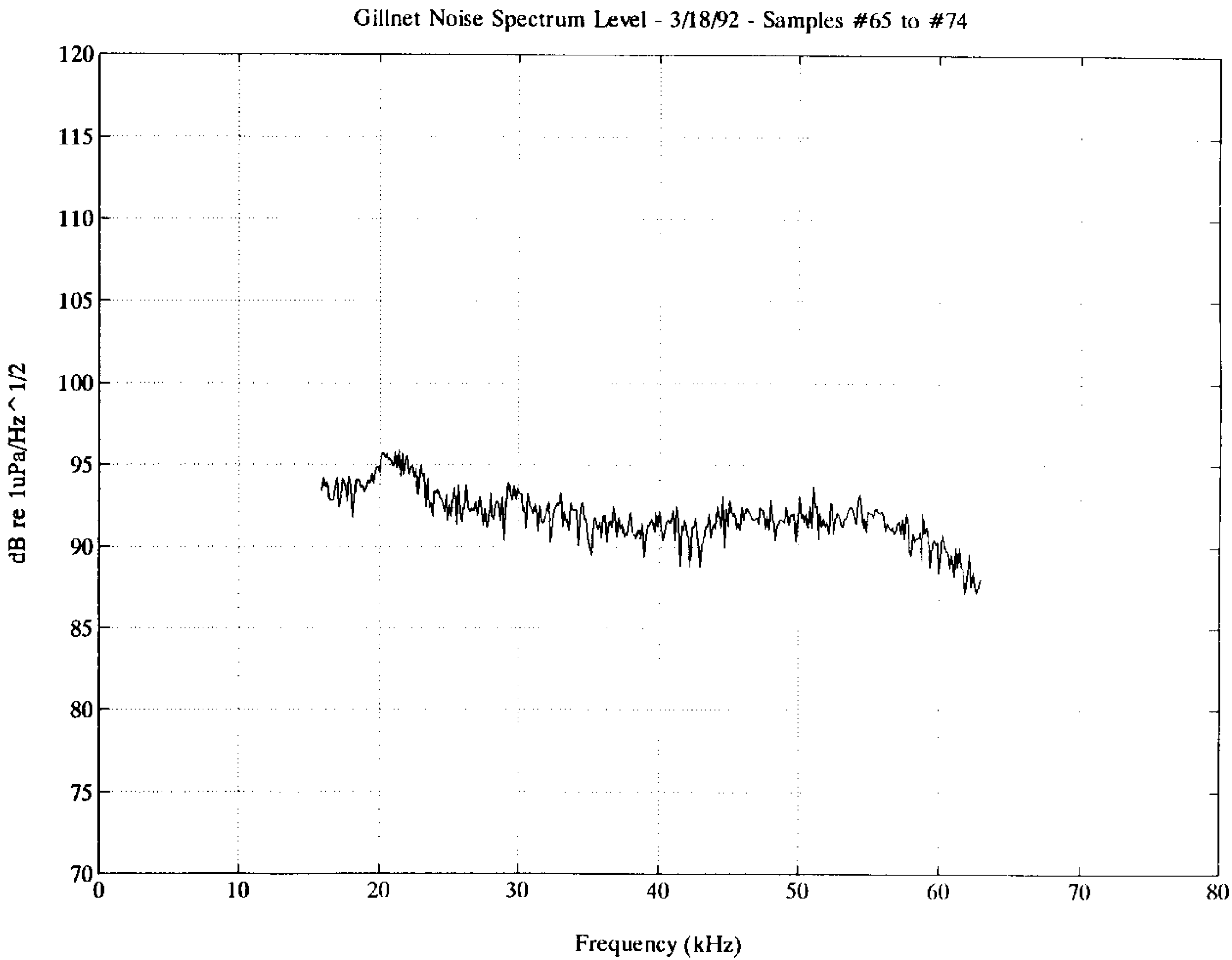


Gillnet Noise Spectrum Level - 3/18/92 - Samples #41 to #57

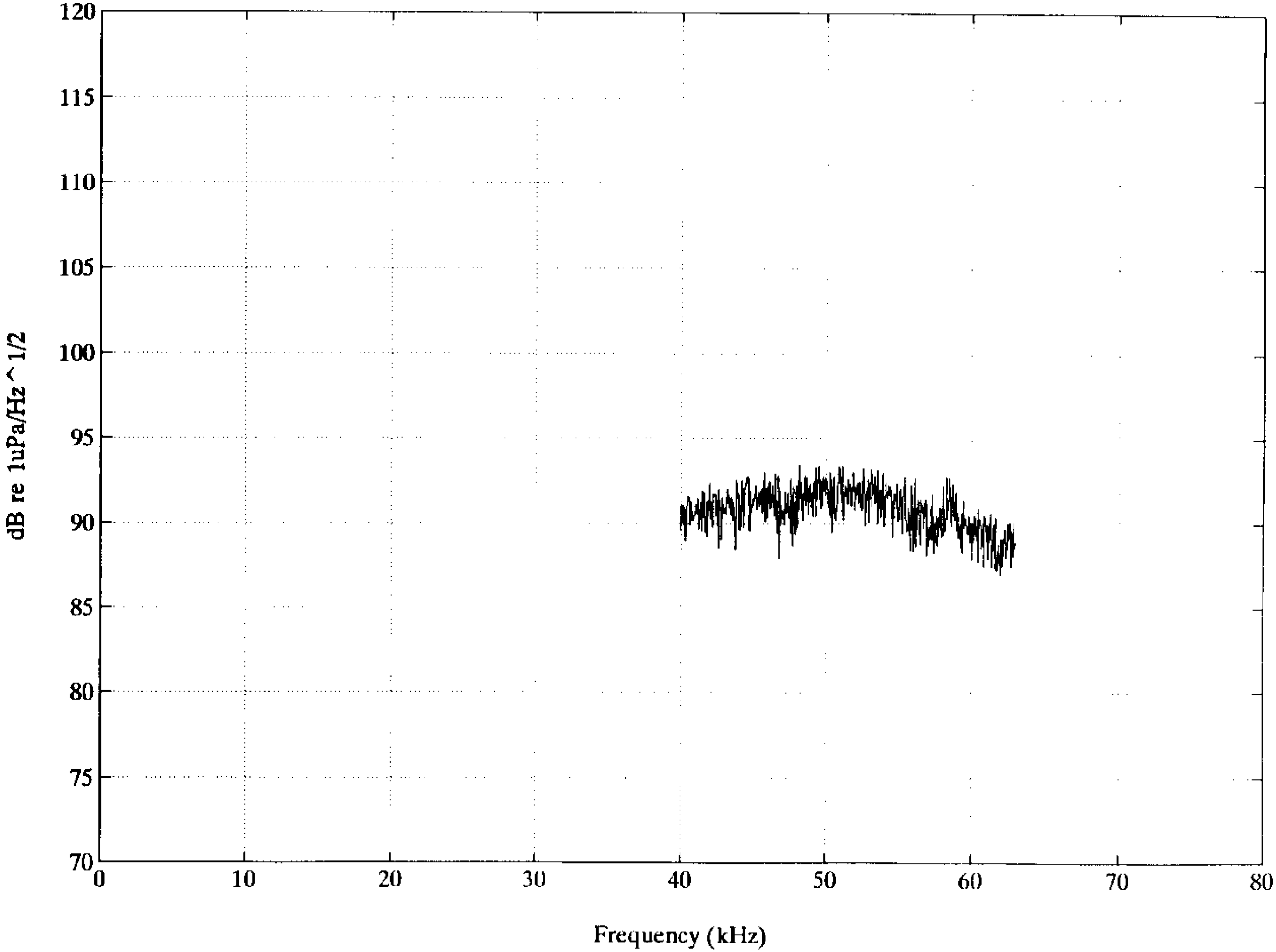


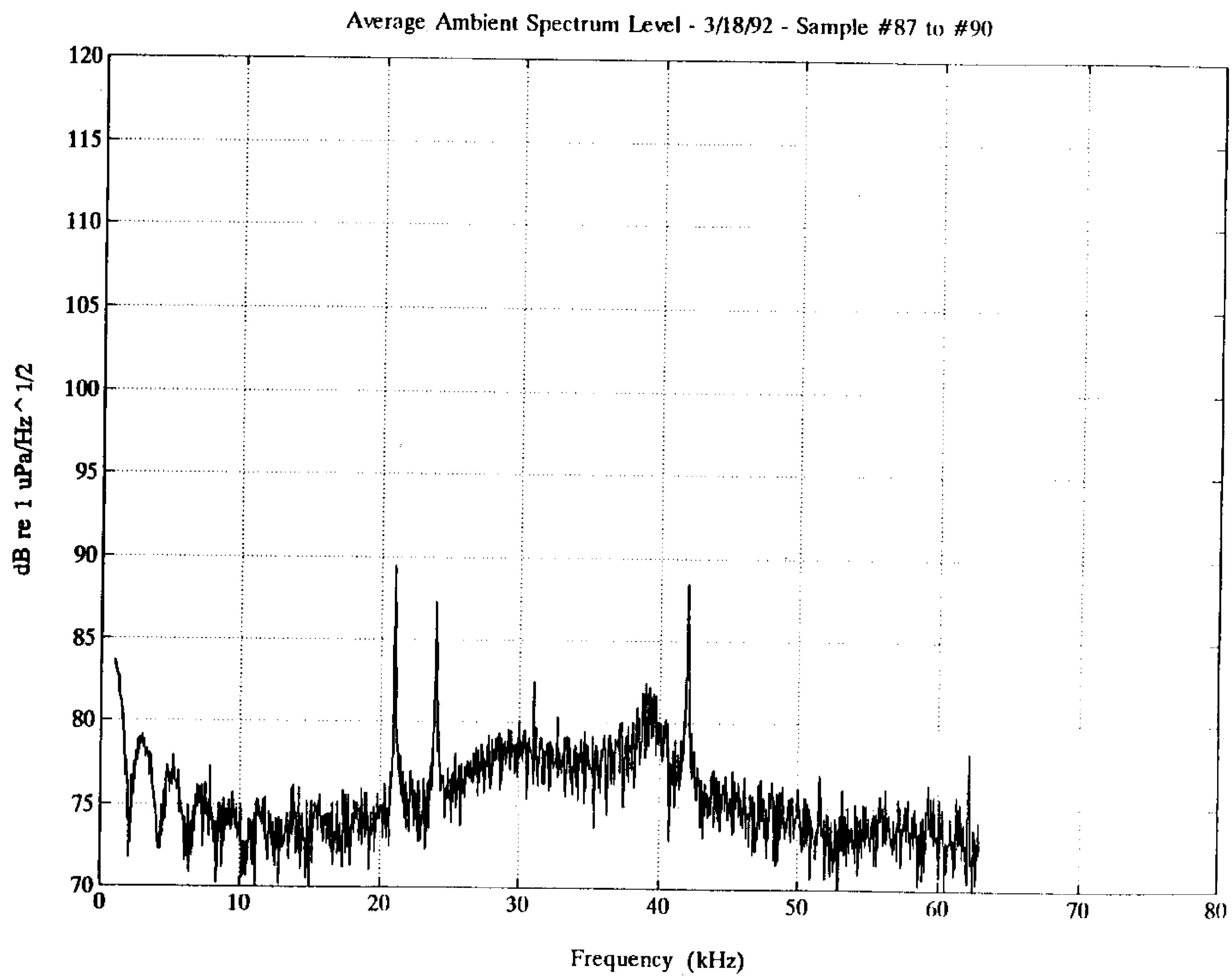
Gillnet Noise Spectrum Level - 3/18/92 - Samples #58 to #64



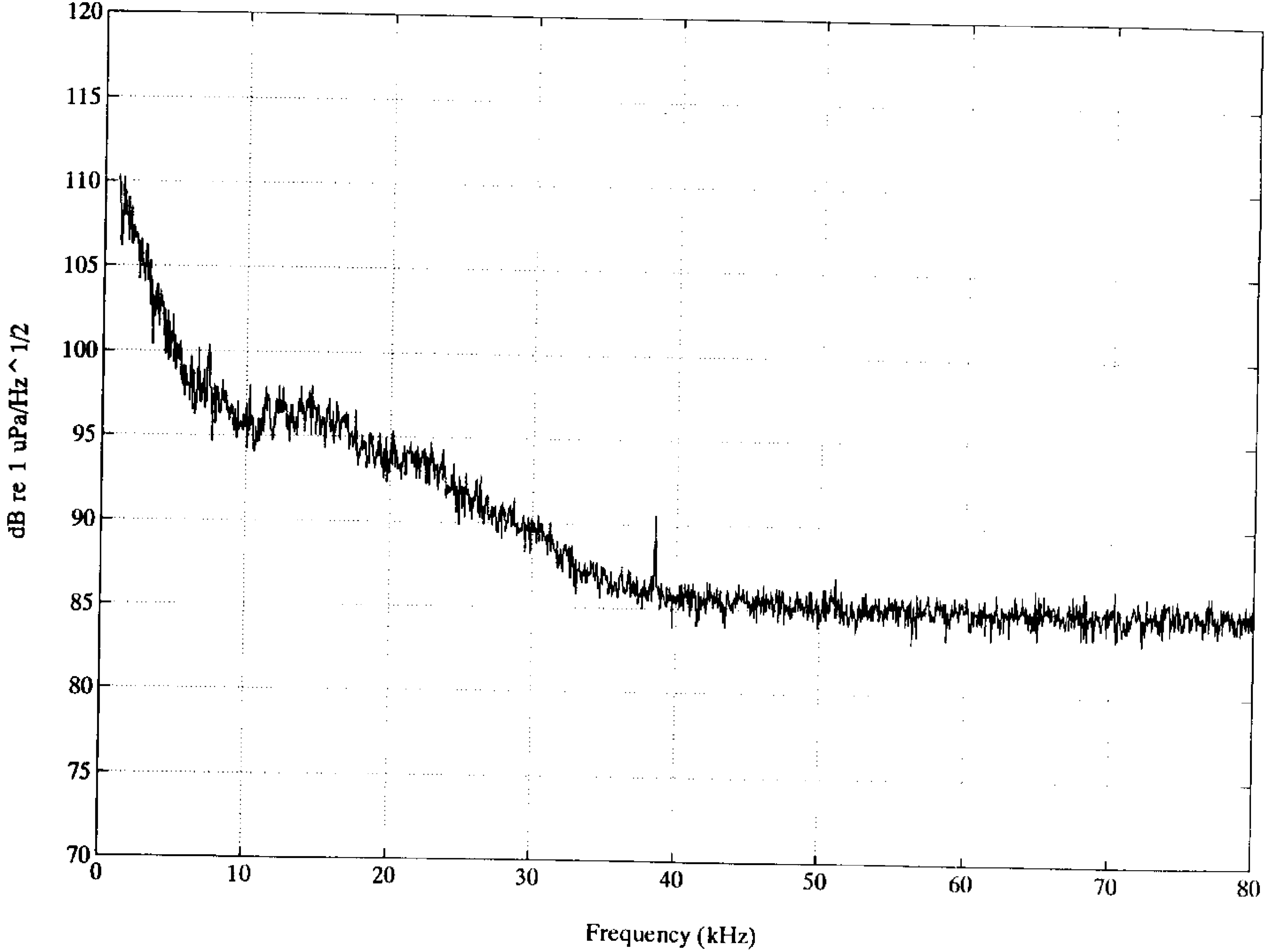

Gillnet Noise Spectrum Level - 3/18/92 - Samples #65 to #74
dB re 1uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

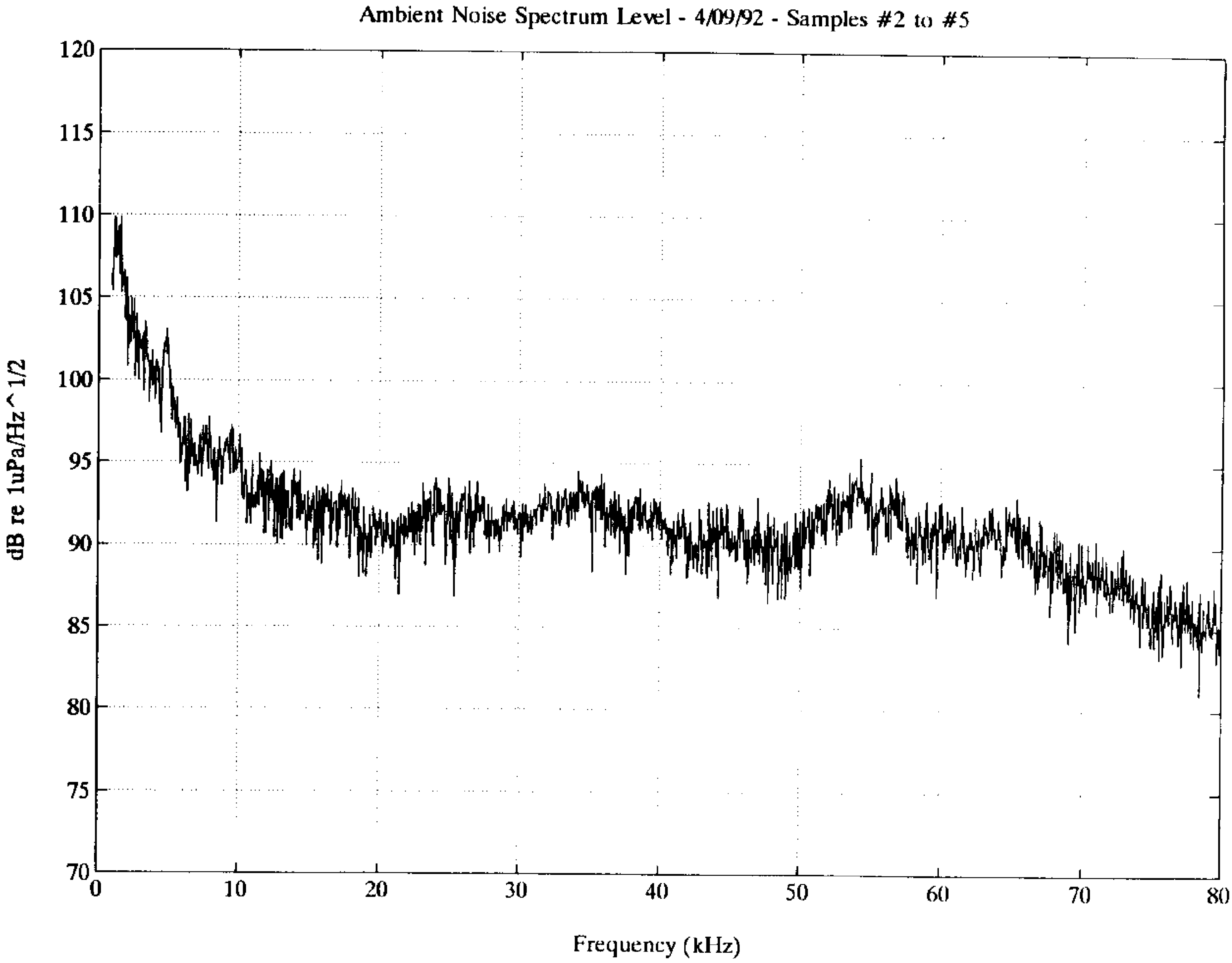
Gillnet Noise Spectrum Level - 3/18/92 - Samples #77 to #85

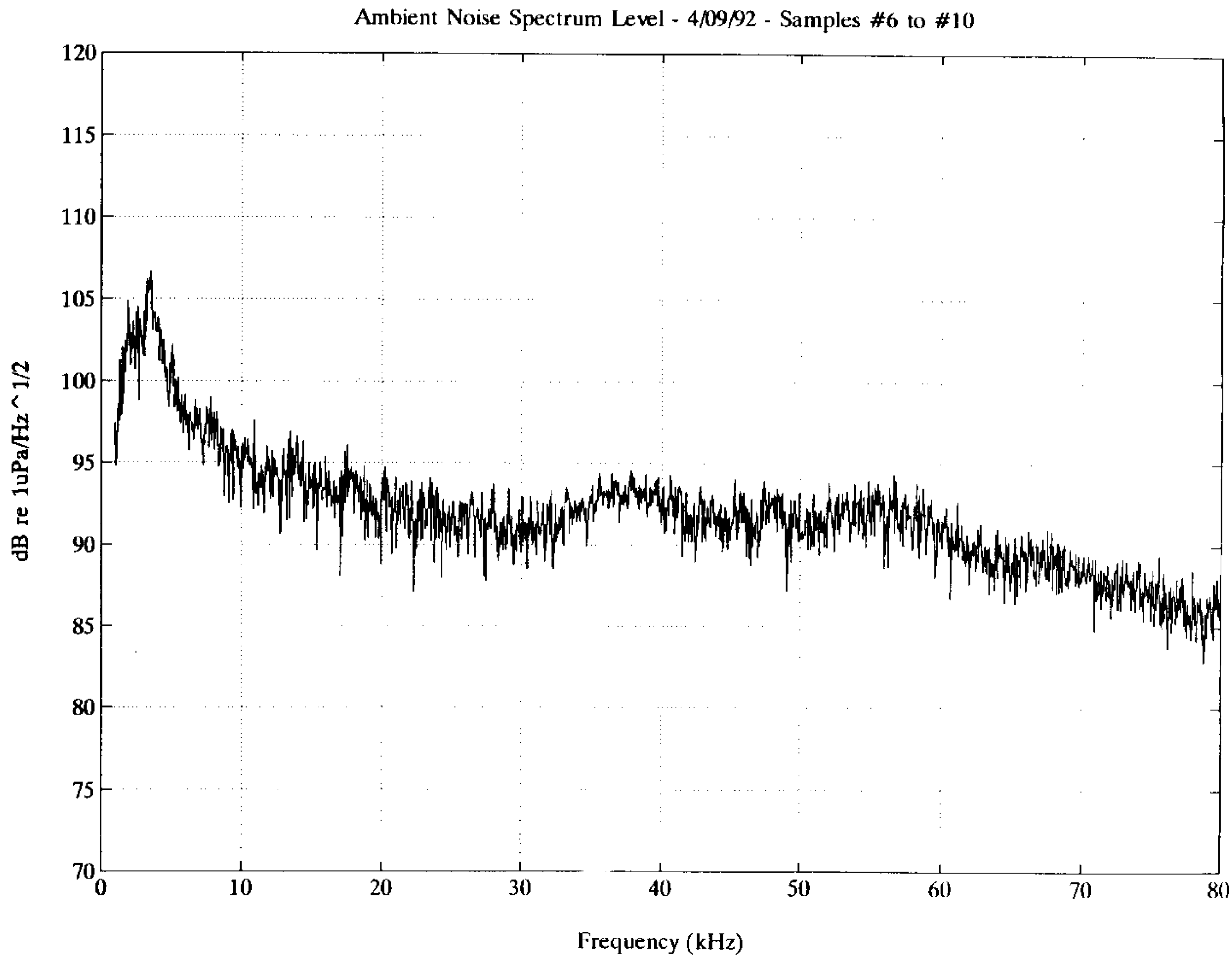



Average Ambient Spectrum Level - 3/18/92 - Sample #87 to #90
dB re 1 uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

Average Gillnet Spectrum Level - 3/26/92 - Samples #1 to #15

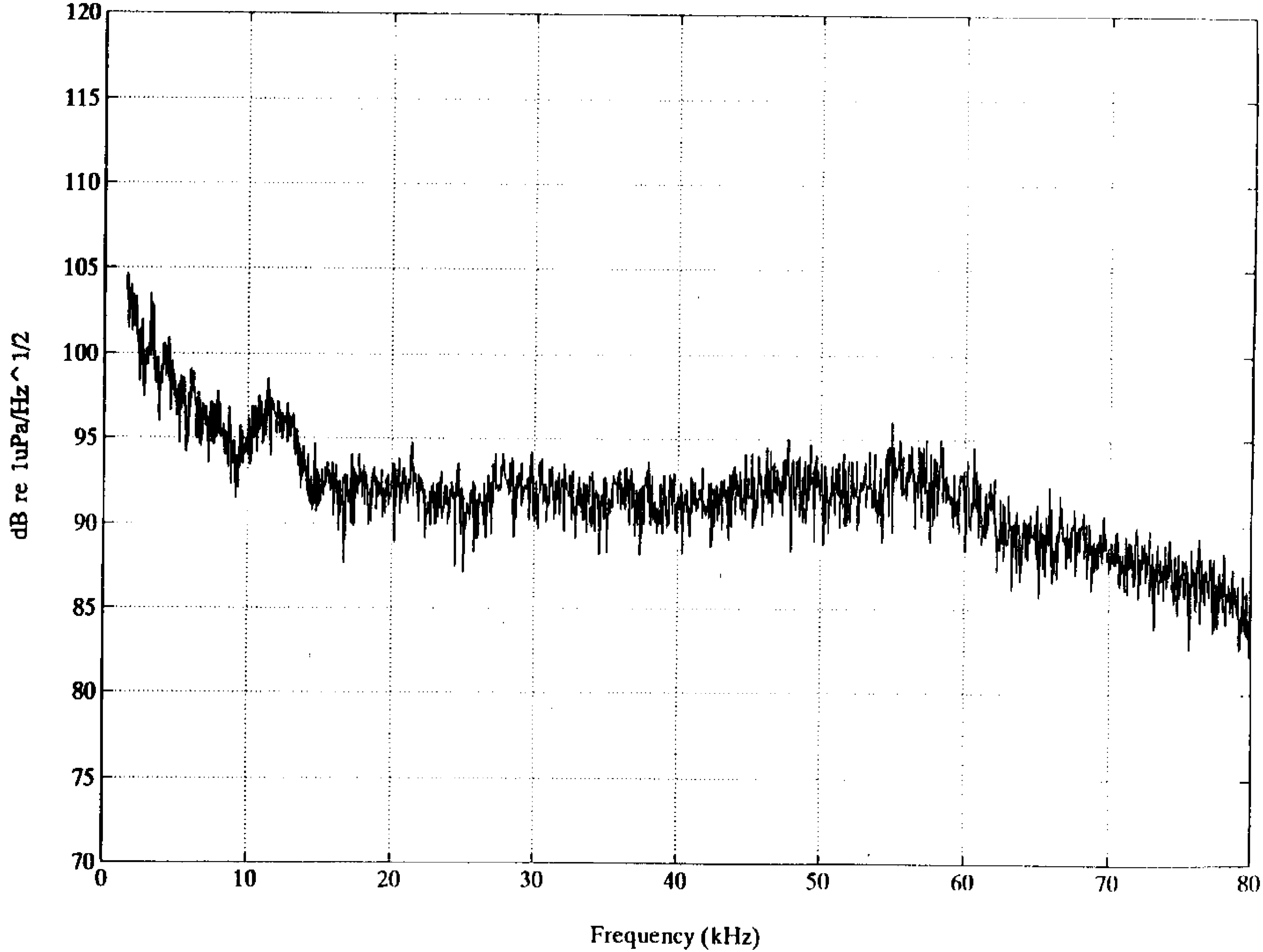



Ambient Noise Spectrum Level - 4/09/92 - Samples #2 to #5
dB re 1uPa/Hz^1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

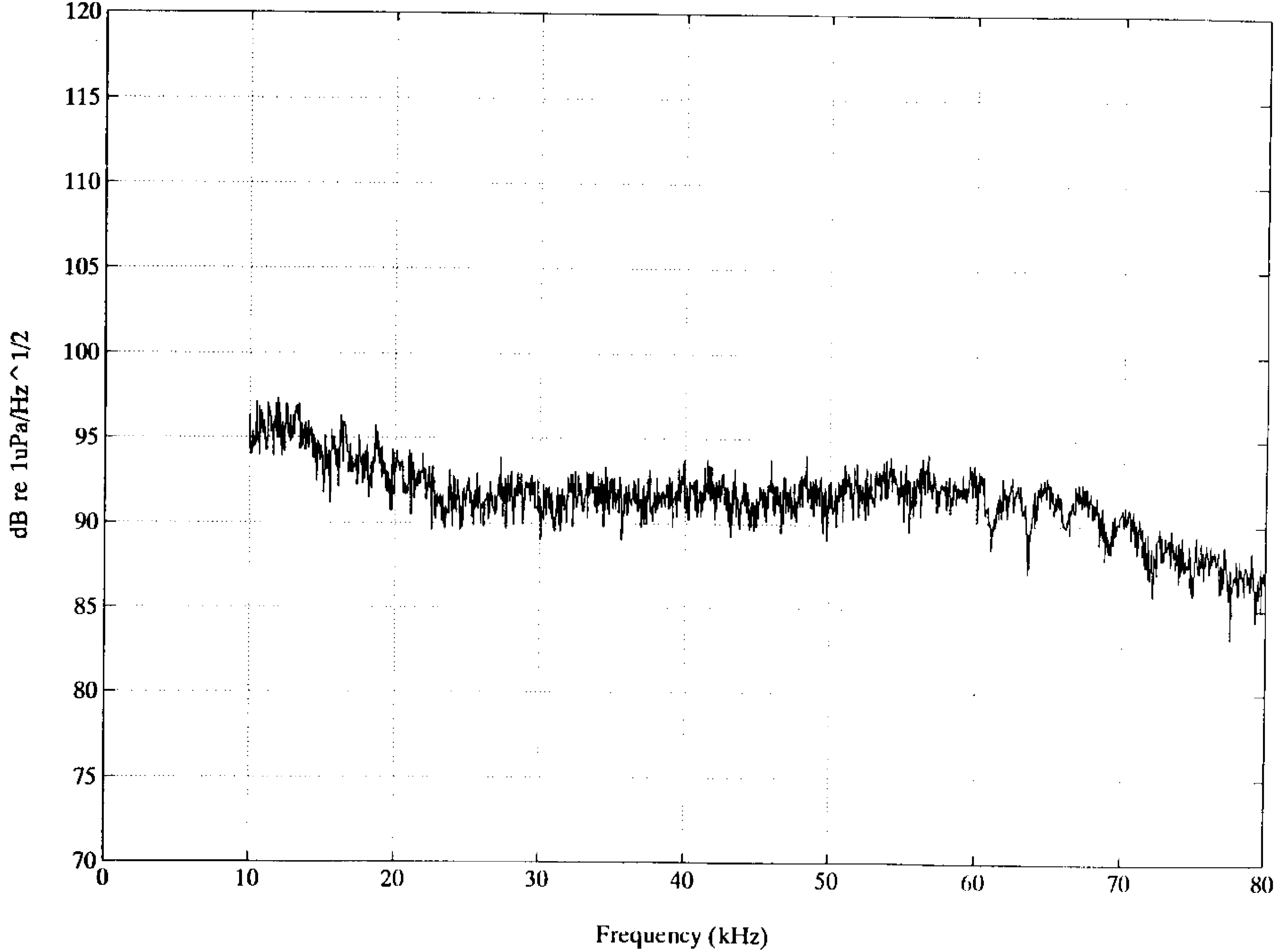


Ambient Noise Spectrum Level - 4/09/92 - Samples #6 to #10
dB re 1uPa/Hz ^ 1/2
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80
Frequency (kHz)

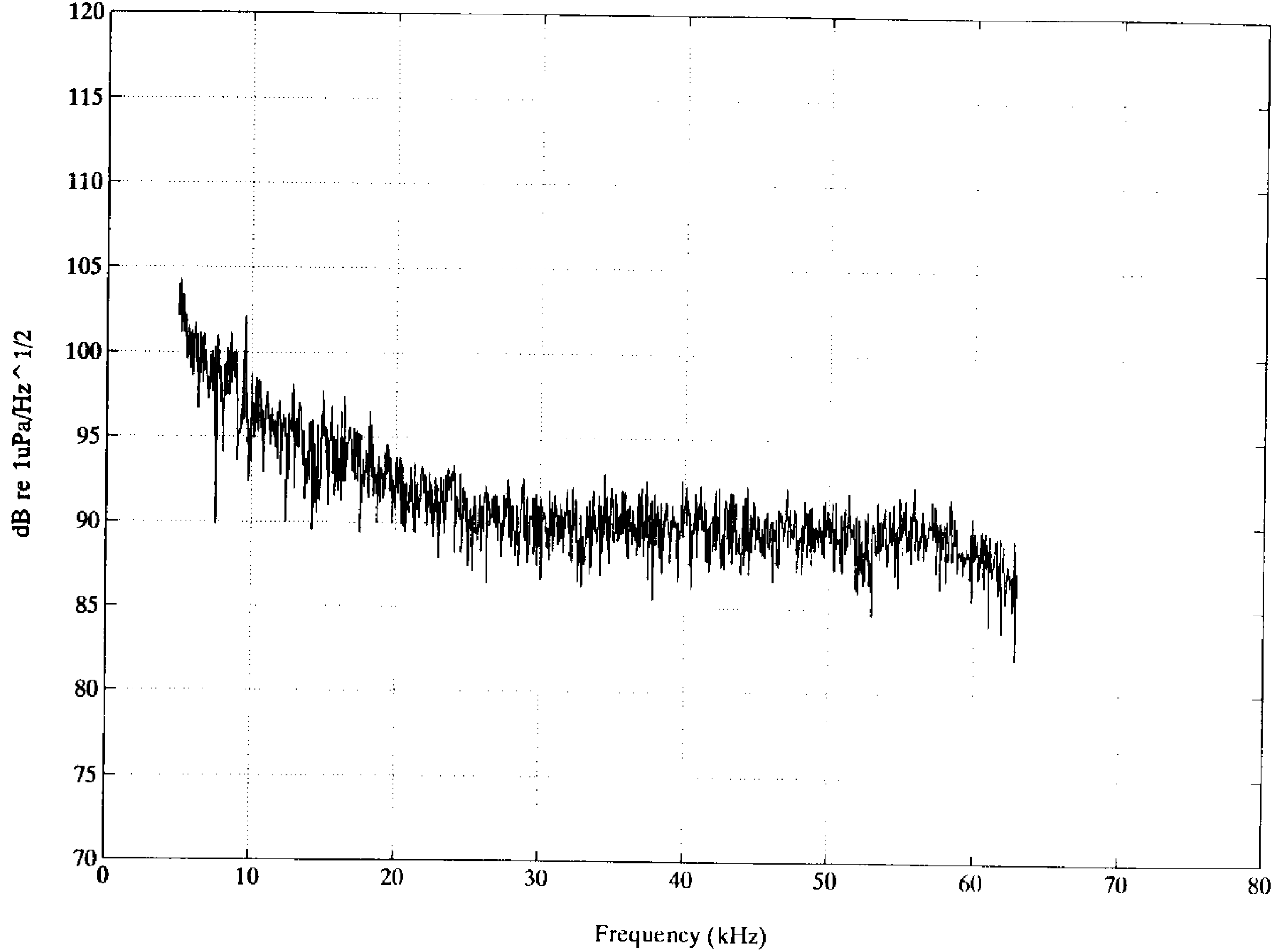
Ambient Noise Spectrum Level - 4/09/92 - Samples #11 to #14



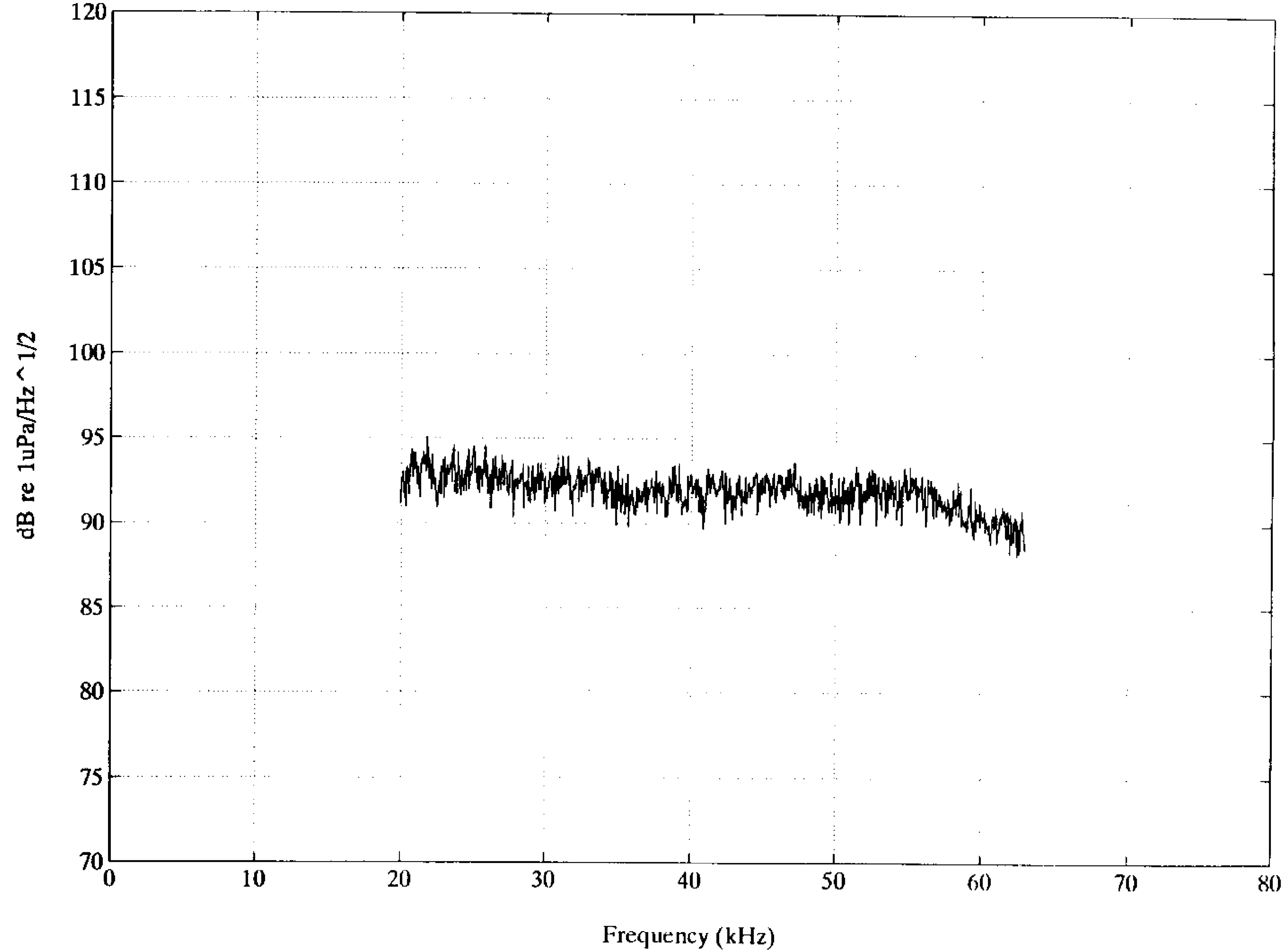
Ambient Noise Spectrum Level - 4/09/92 - Samples #16 to #25



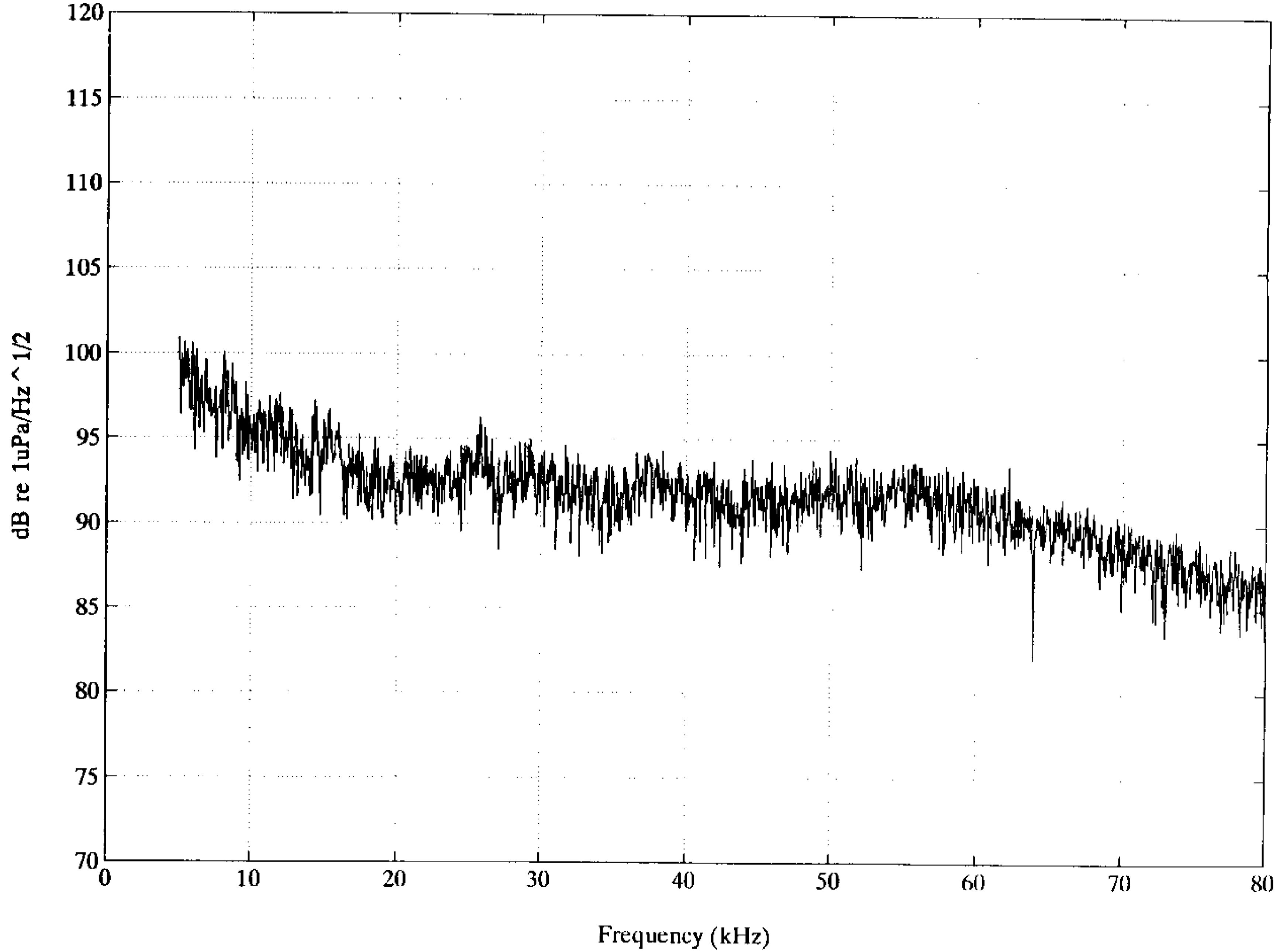
Average Ambient Noise Spectrum Level - 4/9/92 - Samples #26 to #30



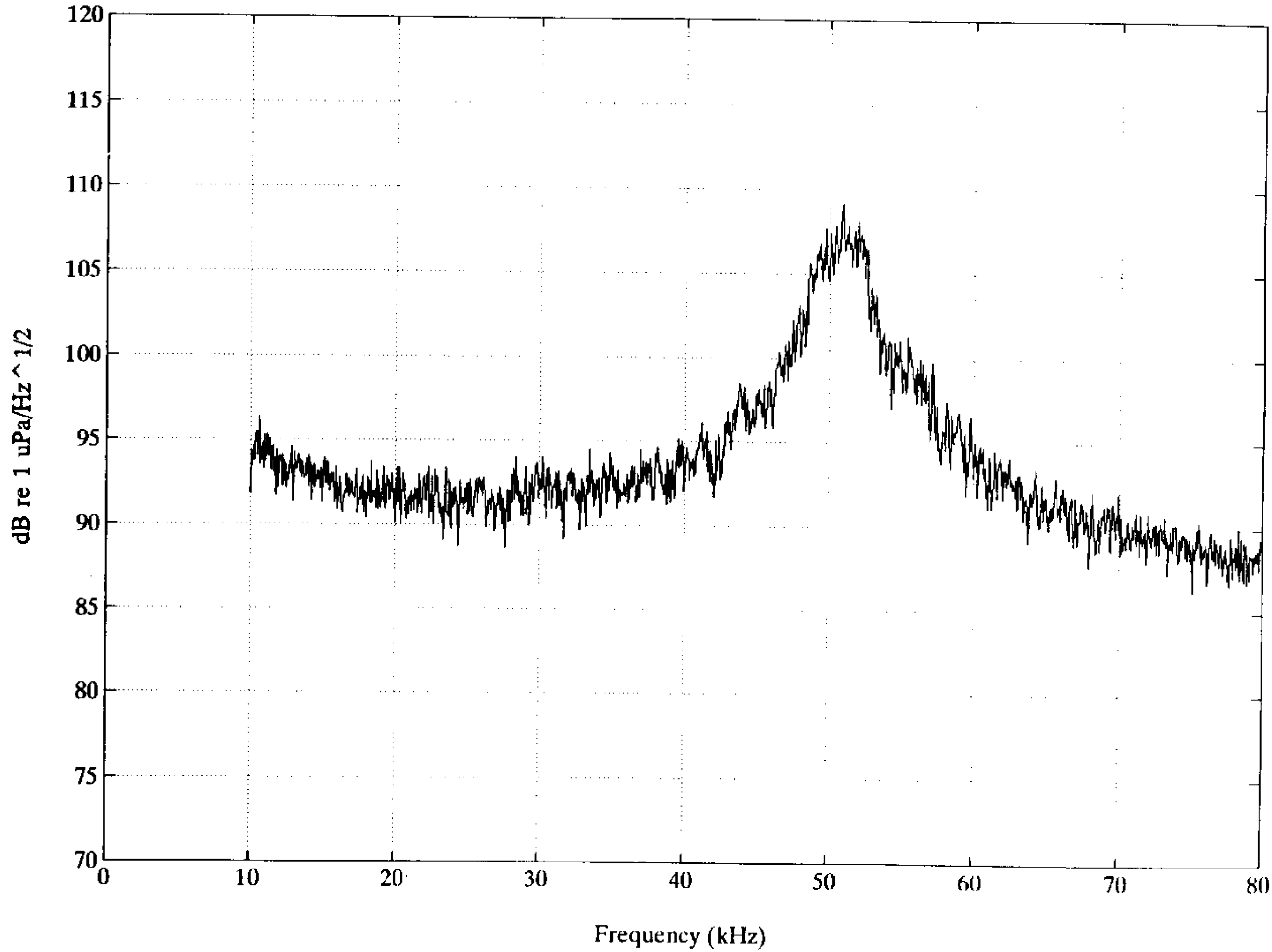
Average Ambient Noise Spectrum Level - 4/9/92 - Samples #31 to #40



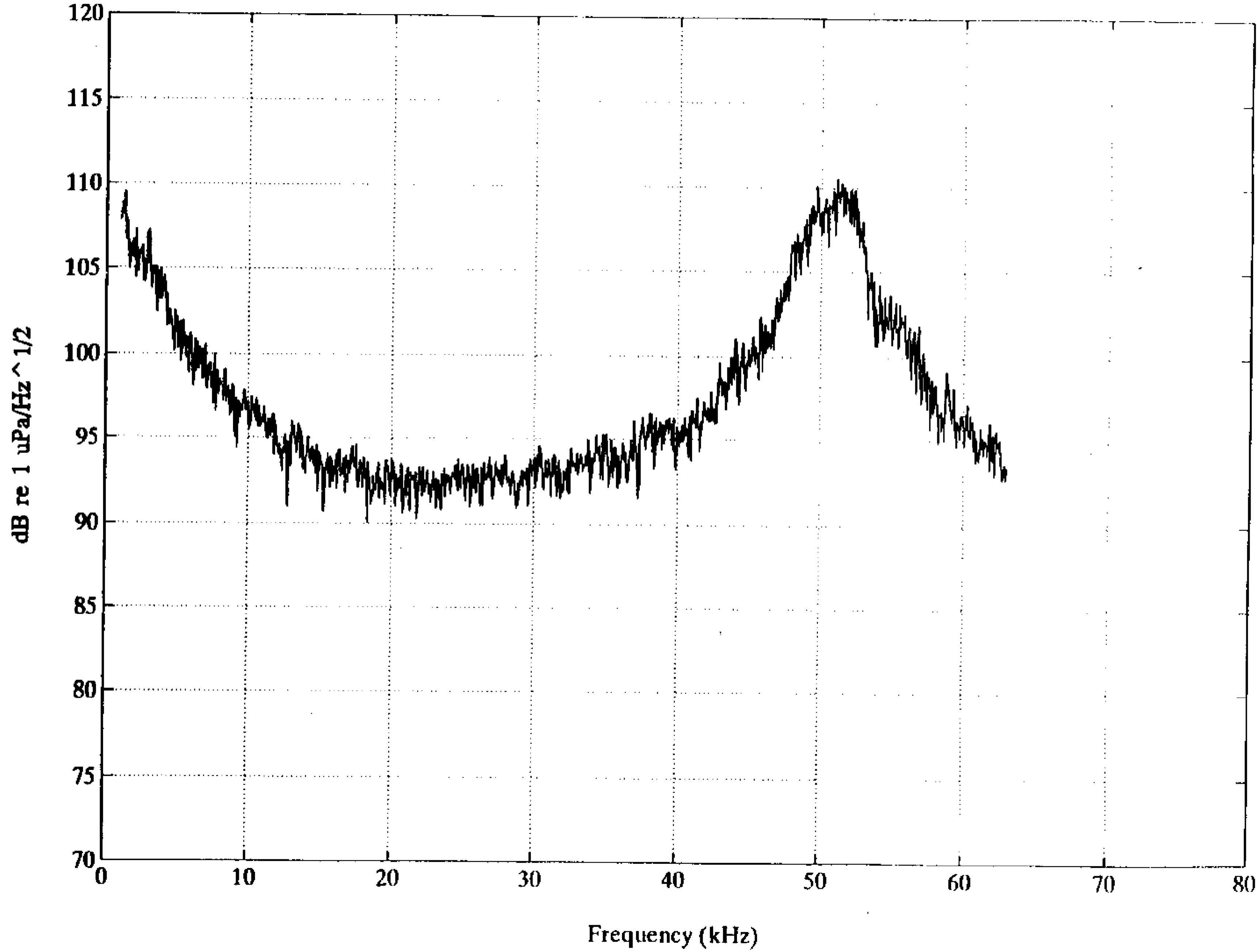
Average Ambient Noise Spectrum Level - 4/9/92 - Samples #41 to #45

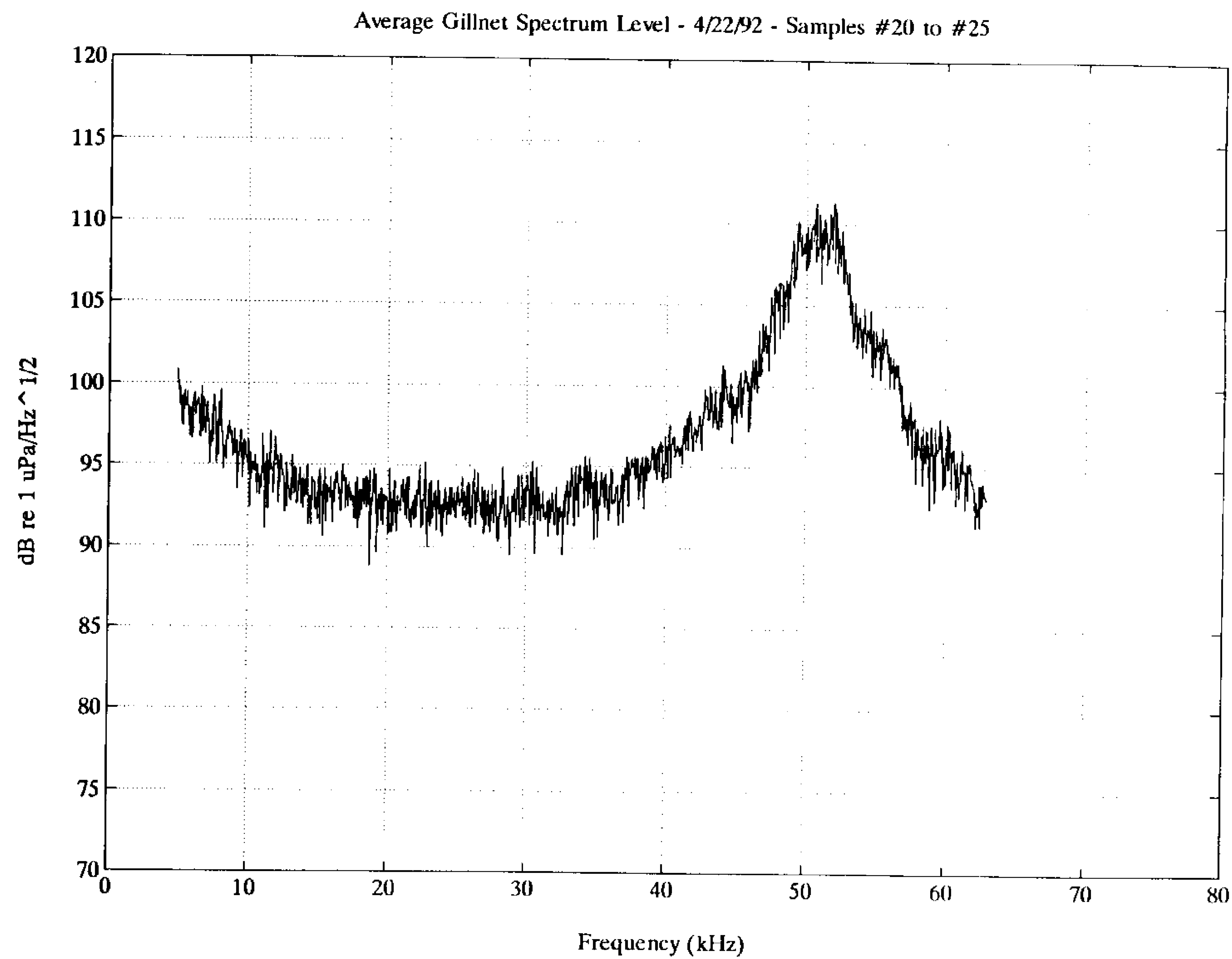


Average Gillnet Spectrum Level - 4/22/92 - Samples #01 to #09

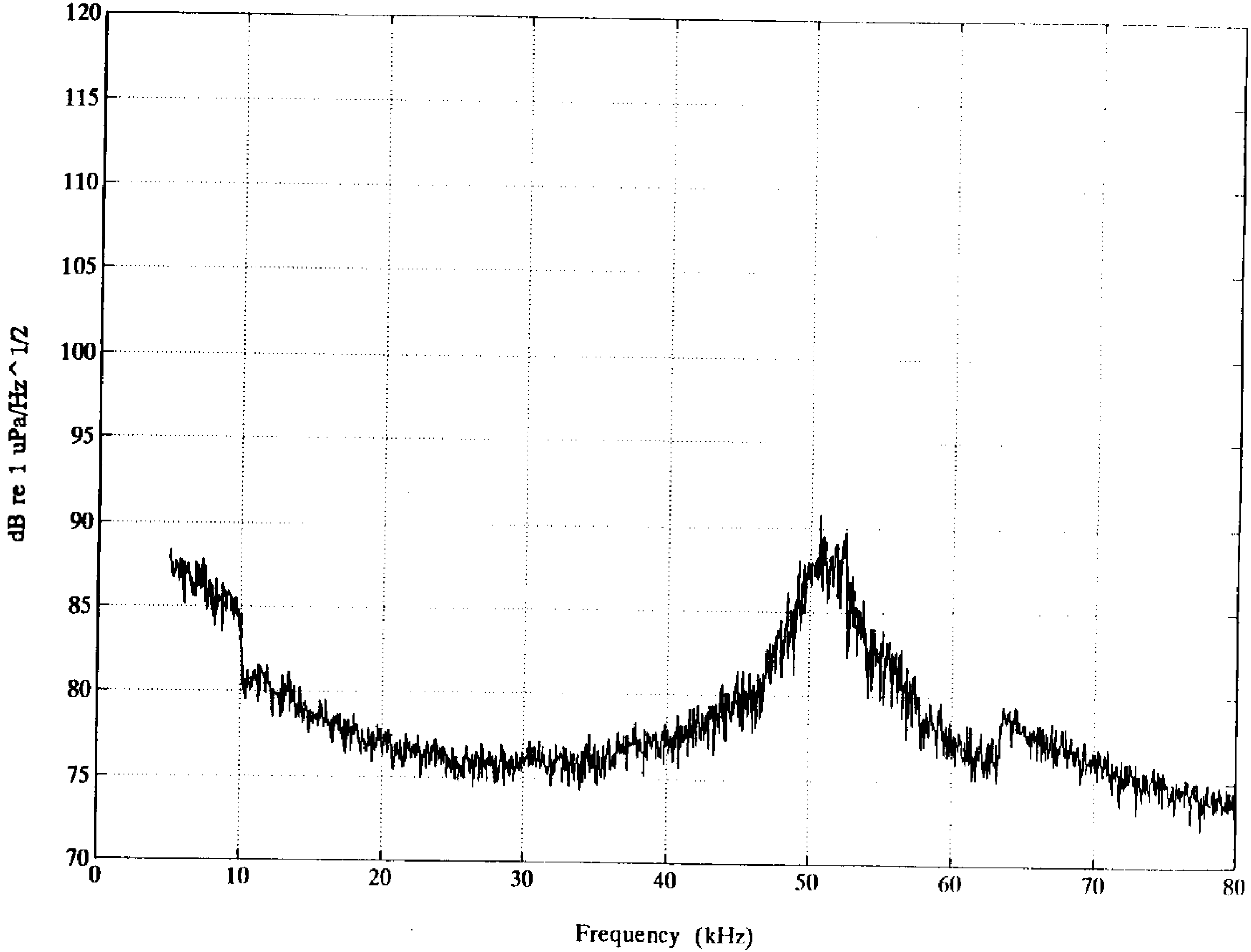


Average Gillnet Spectrum Level - 4/22/92 - Samples #10 to #19



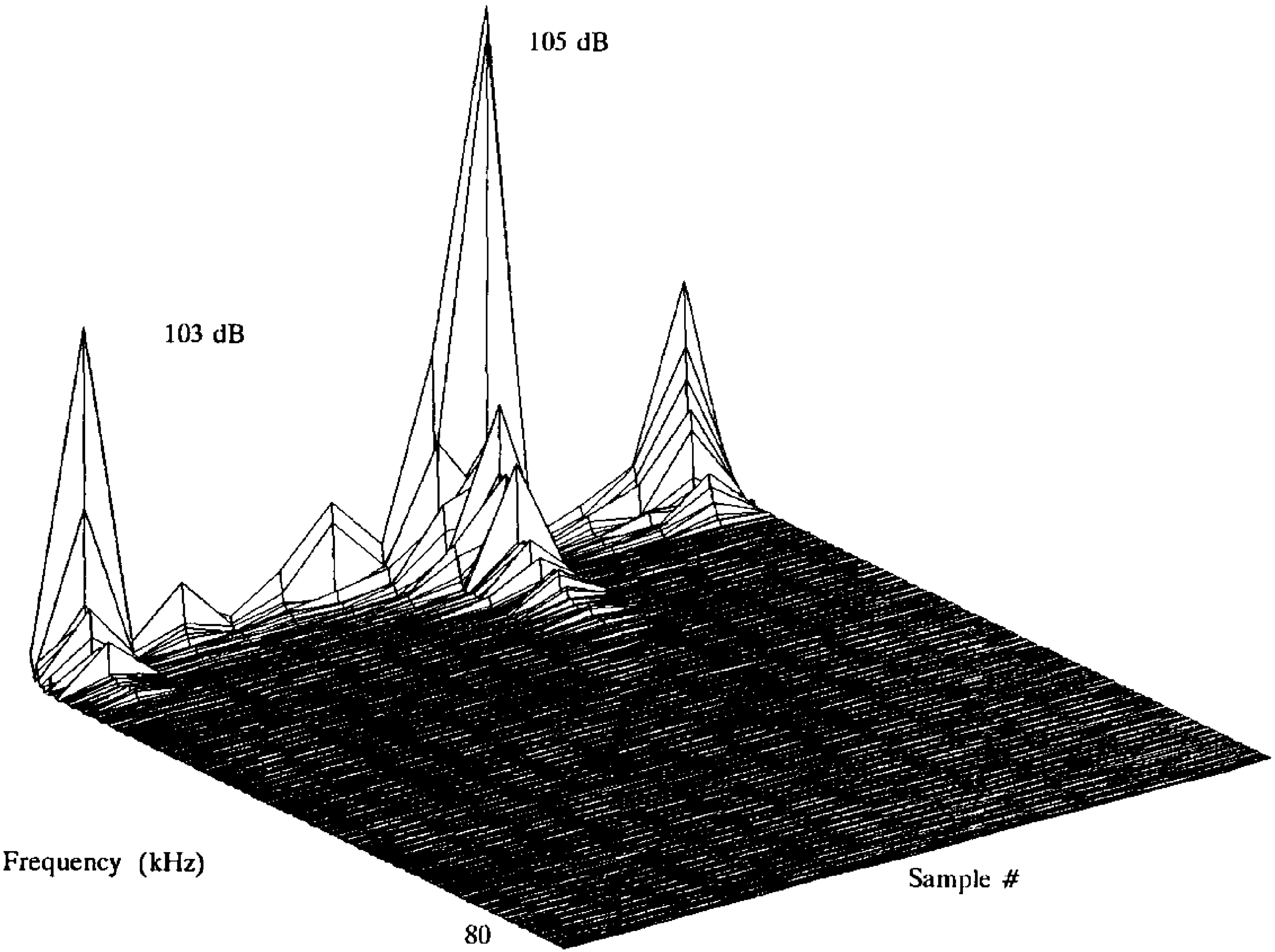

Average Gillnet Spectrum Level - 4/22/92 - Samples #20 to #25
dB re 1 uPa/Hz ^ 1/2
Frequency (kHz)
120
115
110
105
100
95
90
85
80
75
70
0
10
20
30
40
50
60
70
80

Ambient Noise Spectrum Level - 4/22/92 - Samples #26 to #44

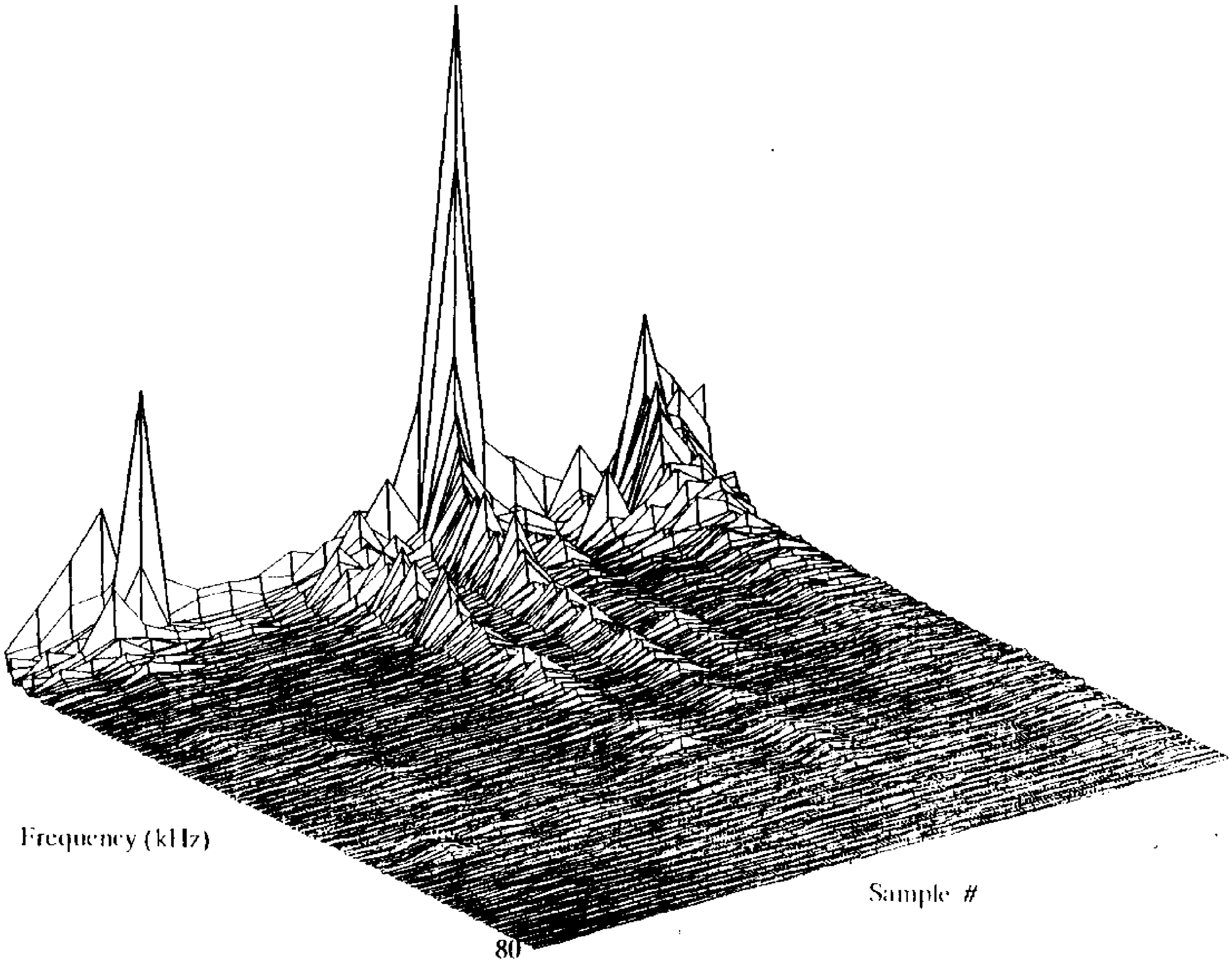


APPENDIX C

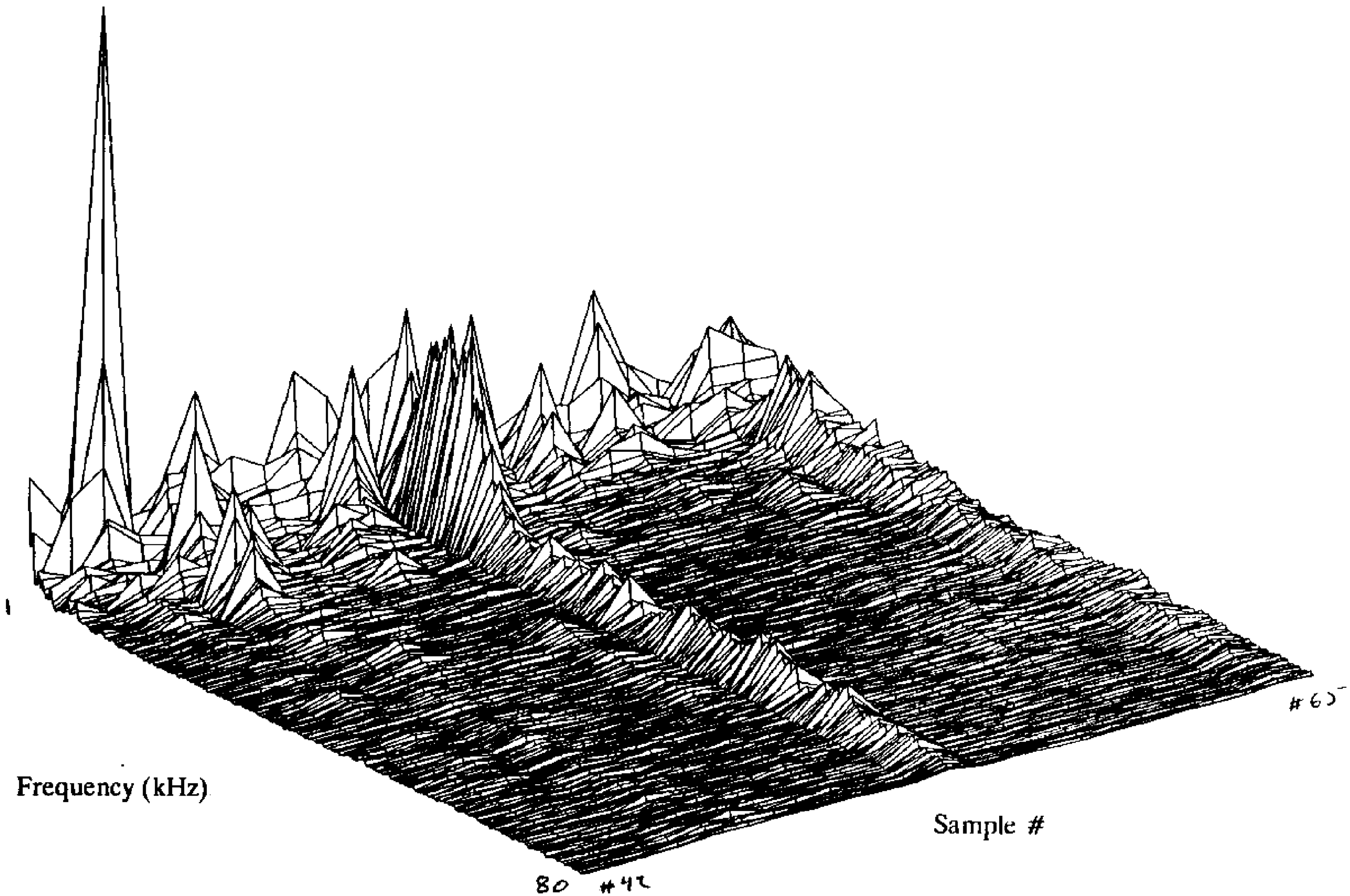
Ambient Noise Spectrum Level - /27/92 - Samples #02 to #16



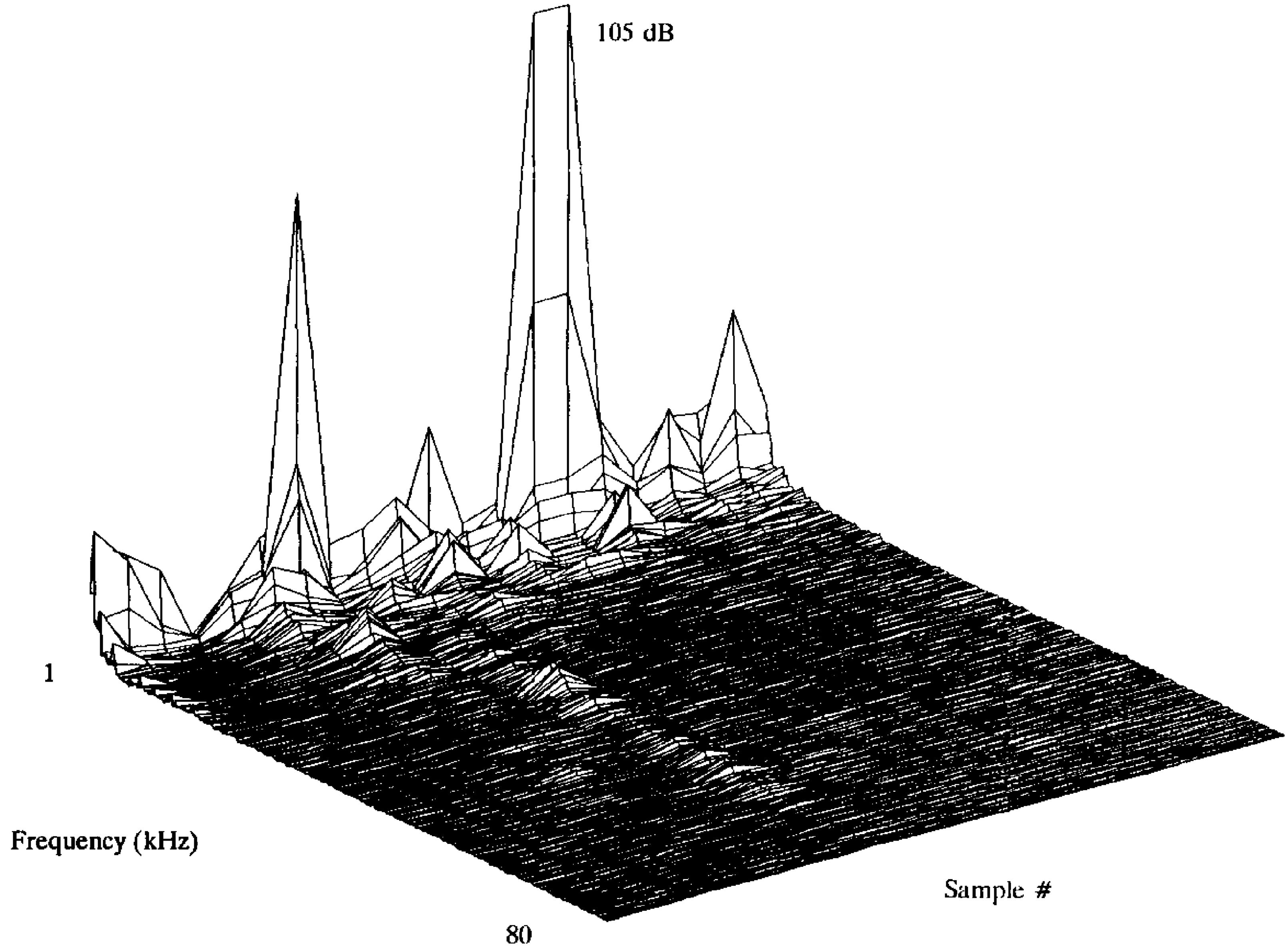
Ambient Noise Spectrum Level - 2/28/92 - Samples #17 to #41



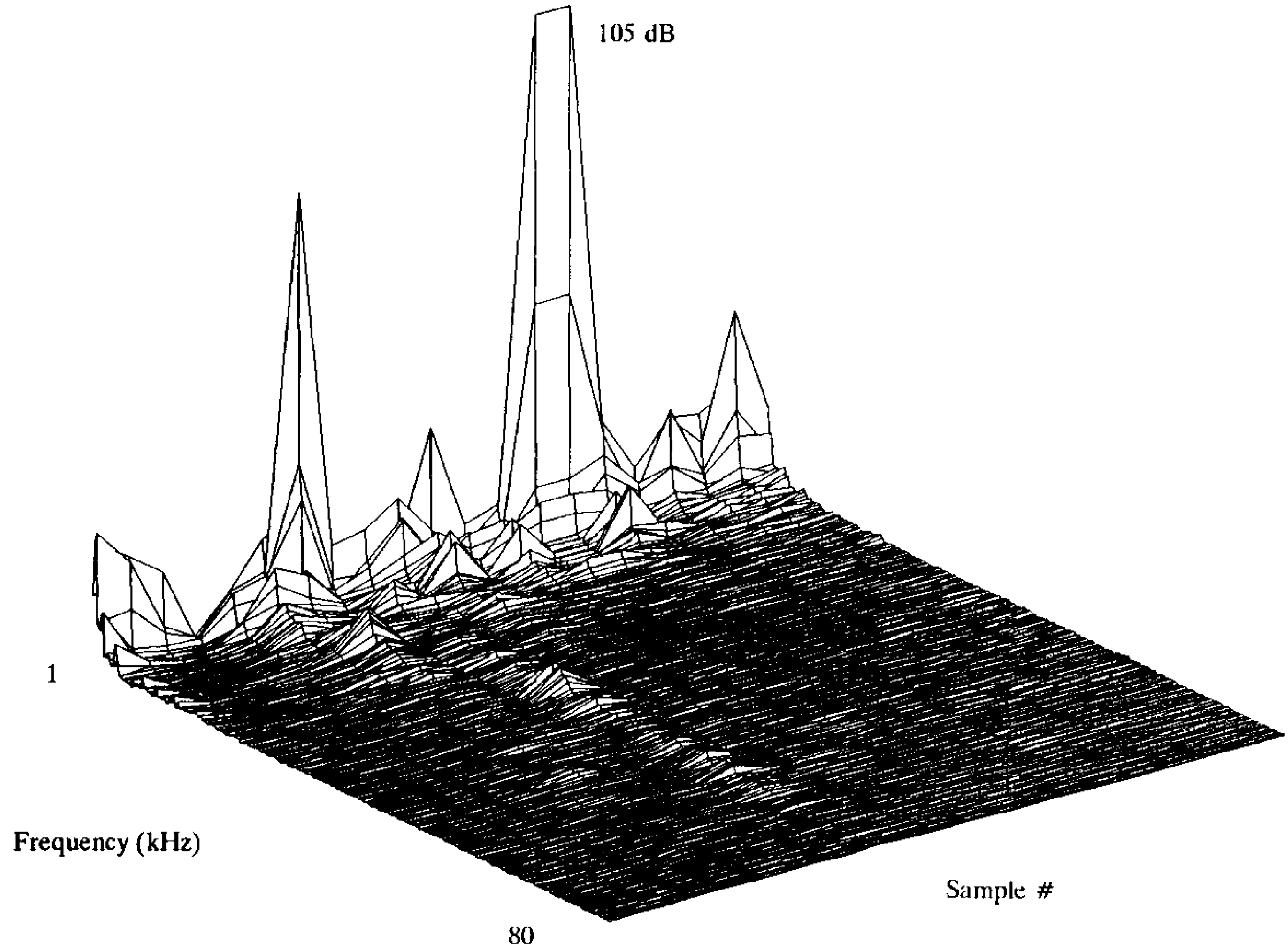
Ambient Noise Spectrum Level - 3/18/92 - Sample #42 to #65



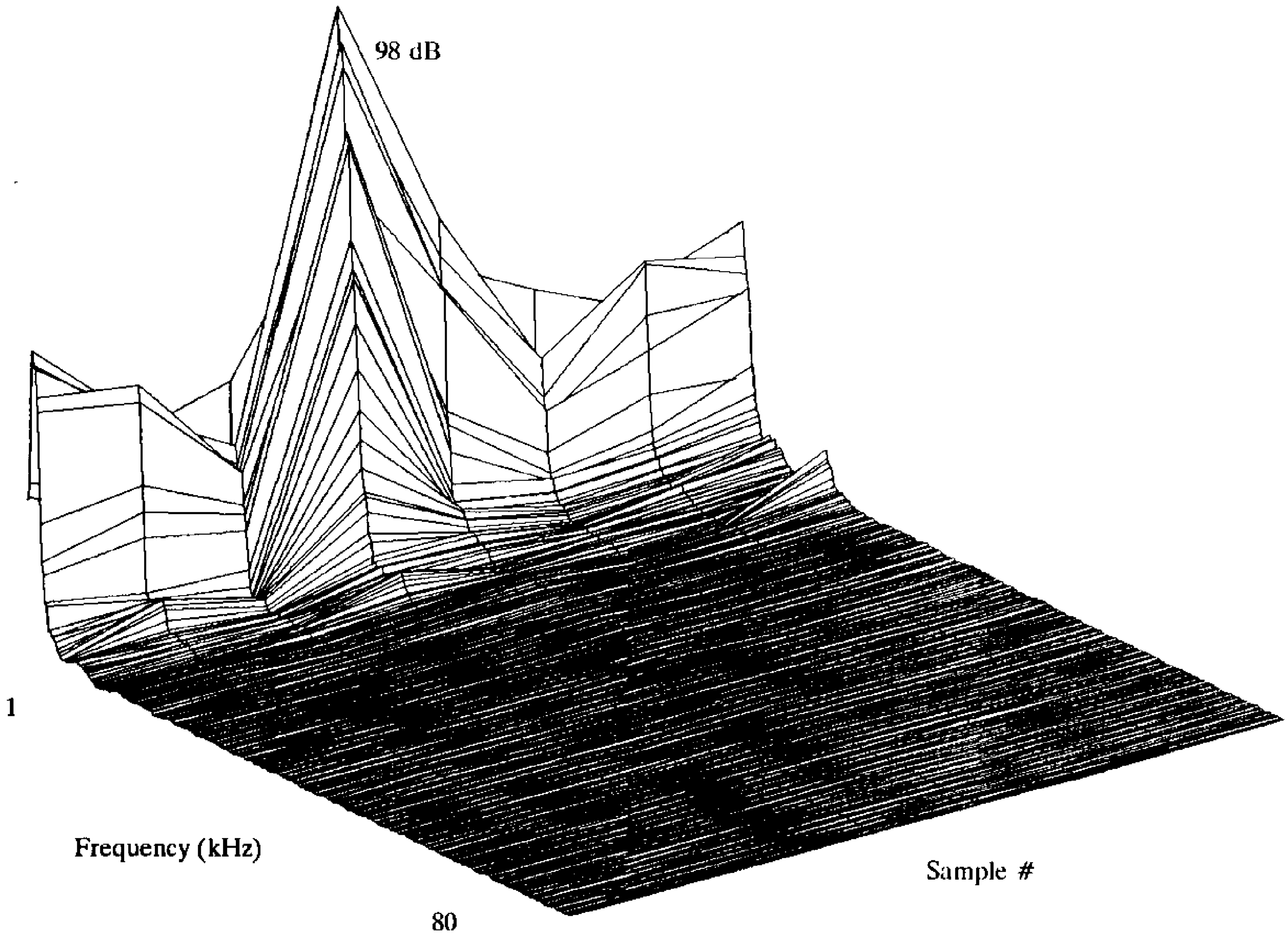
Ambient Noise Spectrum Level - 2/28/92 - Samples #89 to #110



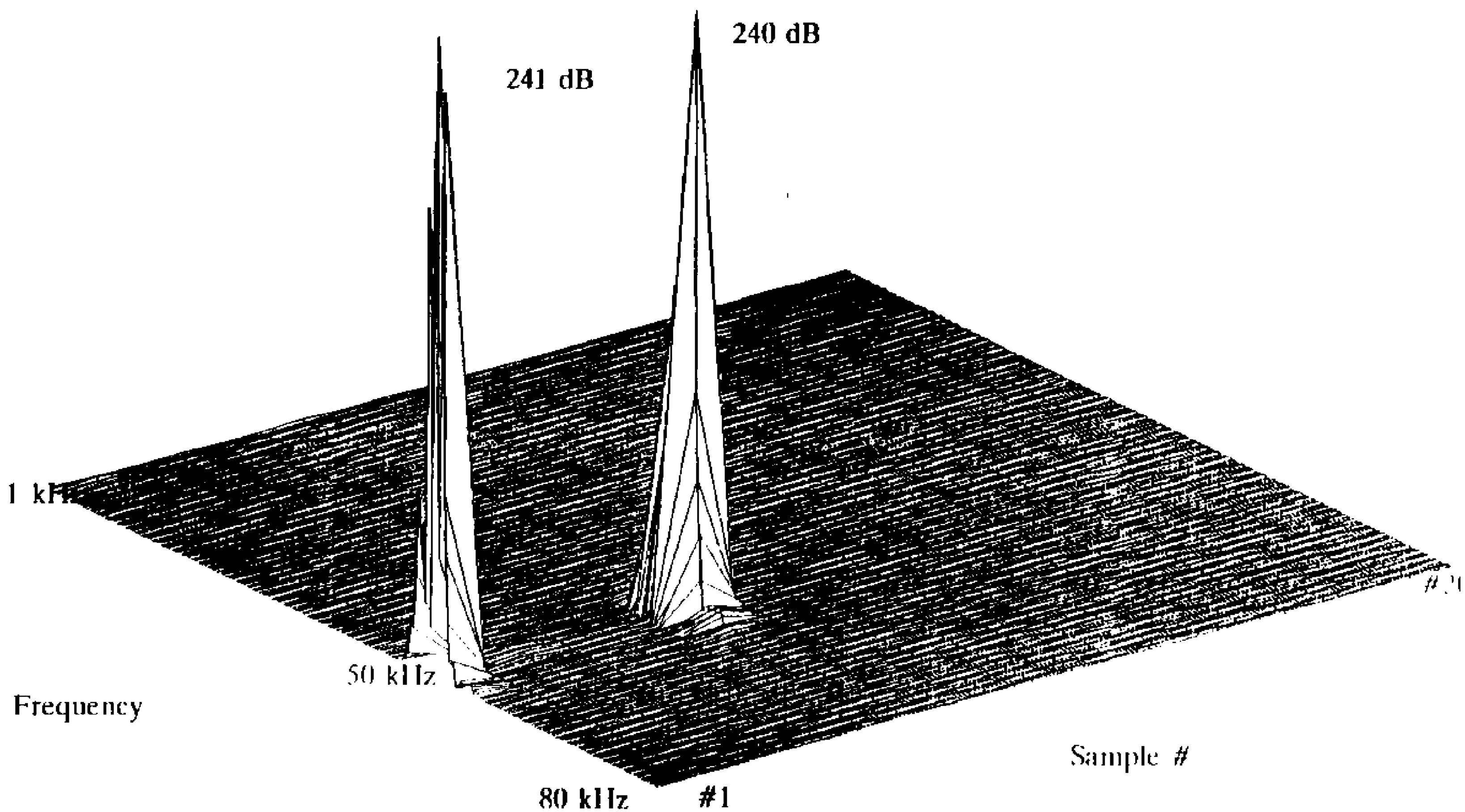
Ambient Noise Spectrum Level - 2/28/92 - Samples #89 to #110



Ambient Noise Spectrum Level - 3/06/92 - Samples #115 to #122

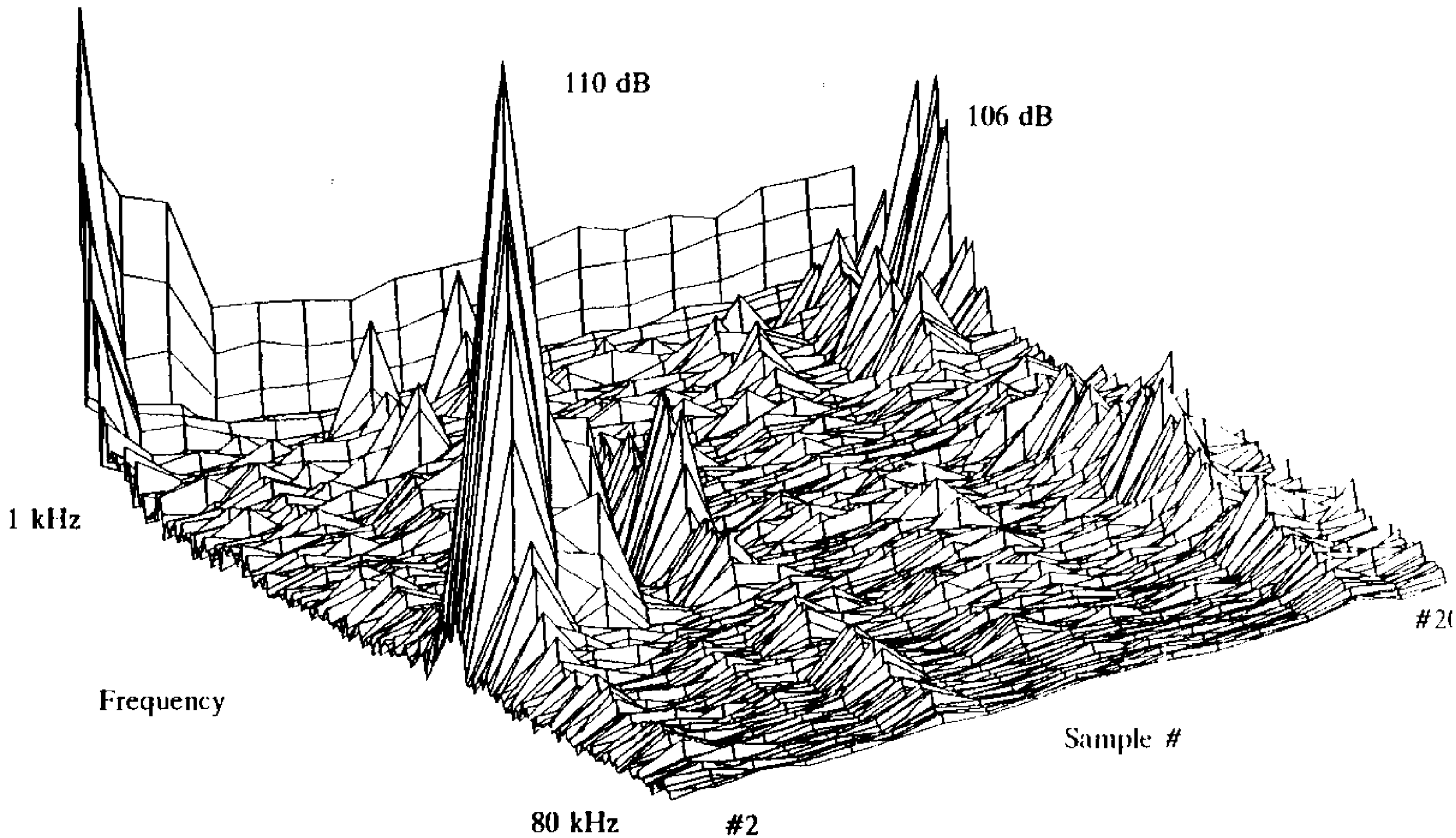


Gillnet Noise Spectrum Level - 3/18/92 - Samples #1 to #20

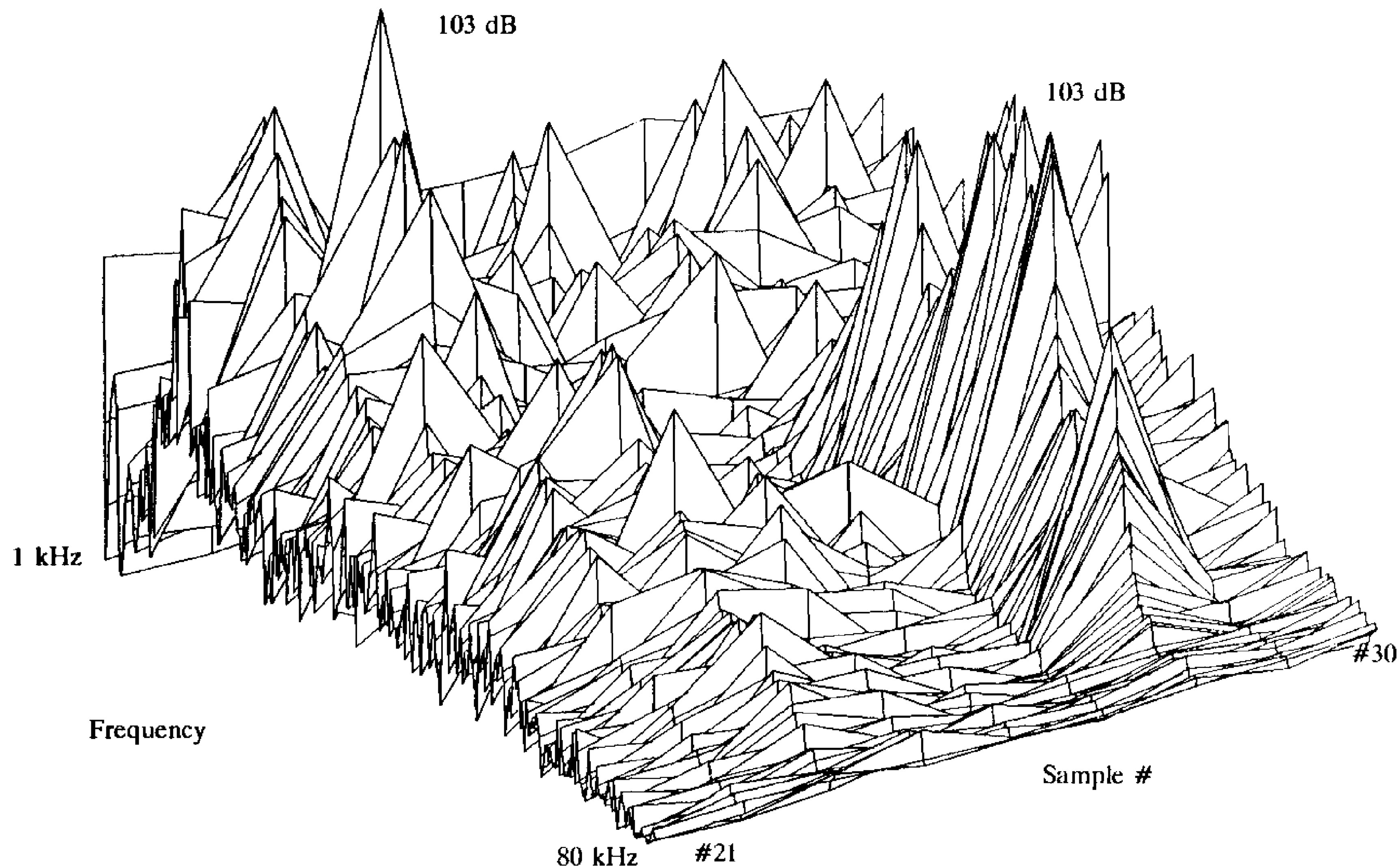


Gillnet Noise Spectrum Level - 3/18/92 -Sample #1 to #20

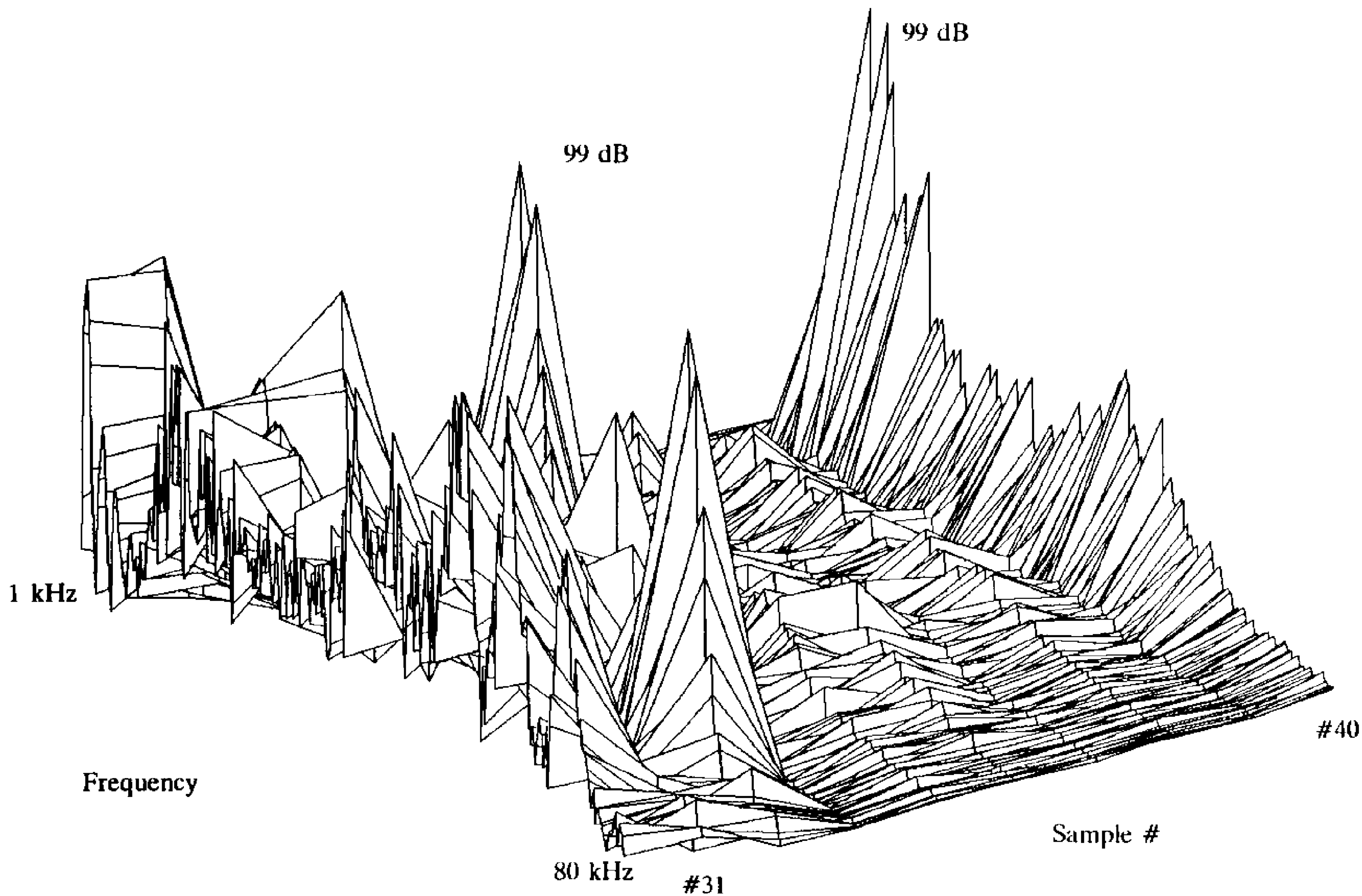
NOTE: EXCLUDES SAMPLES #1 AND #7



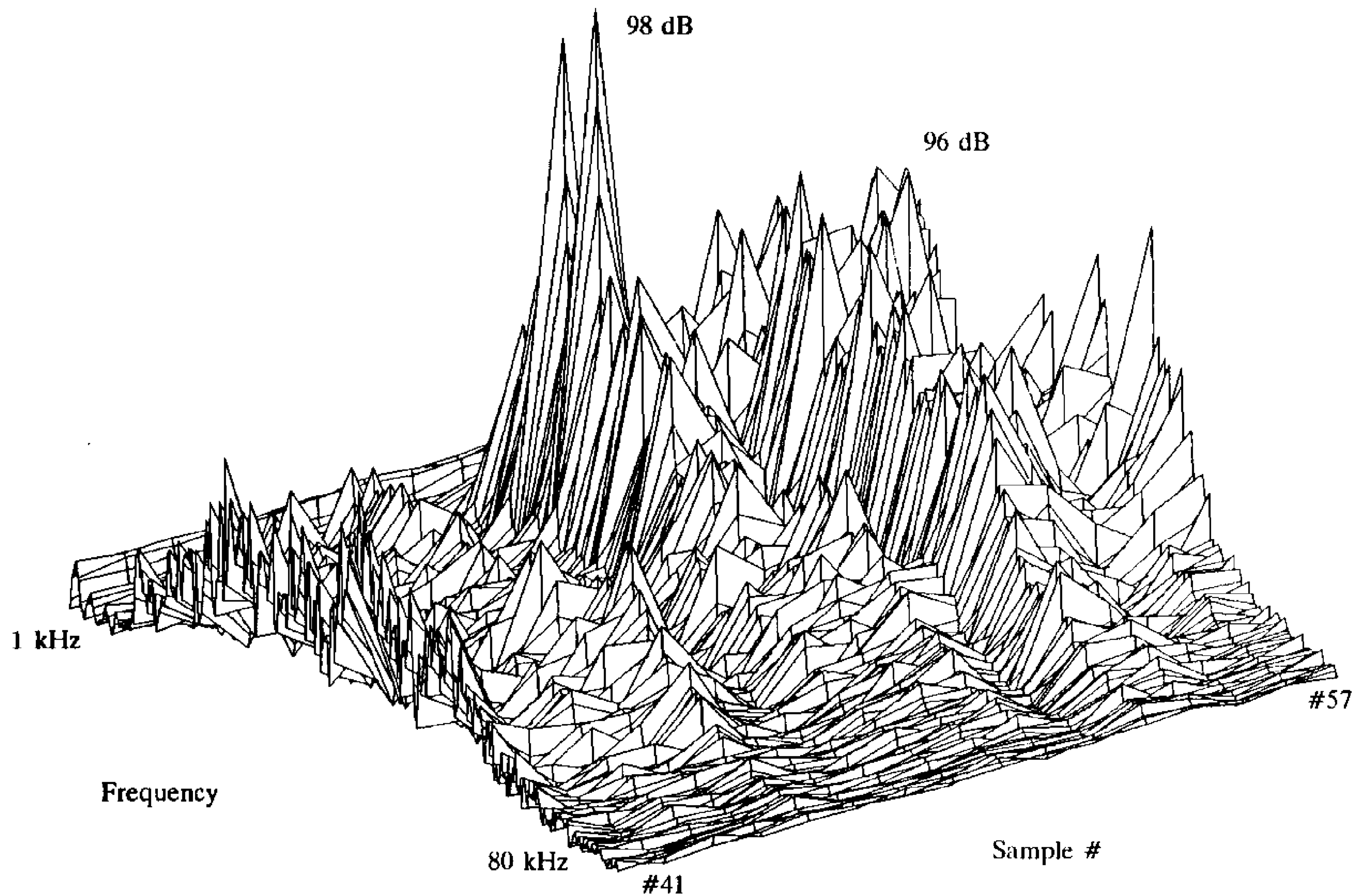
Gillnet Noise Spectrum Level - 3/18/92 - Sample #21 to #30



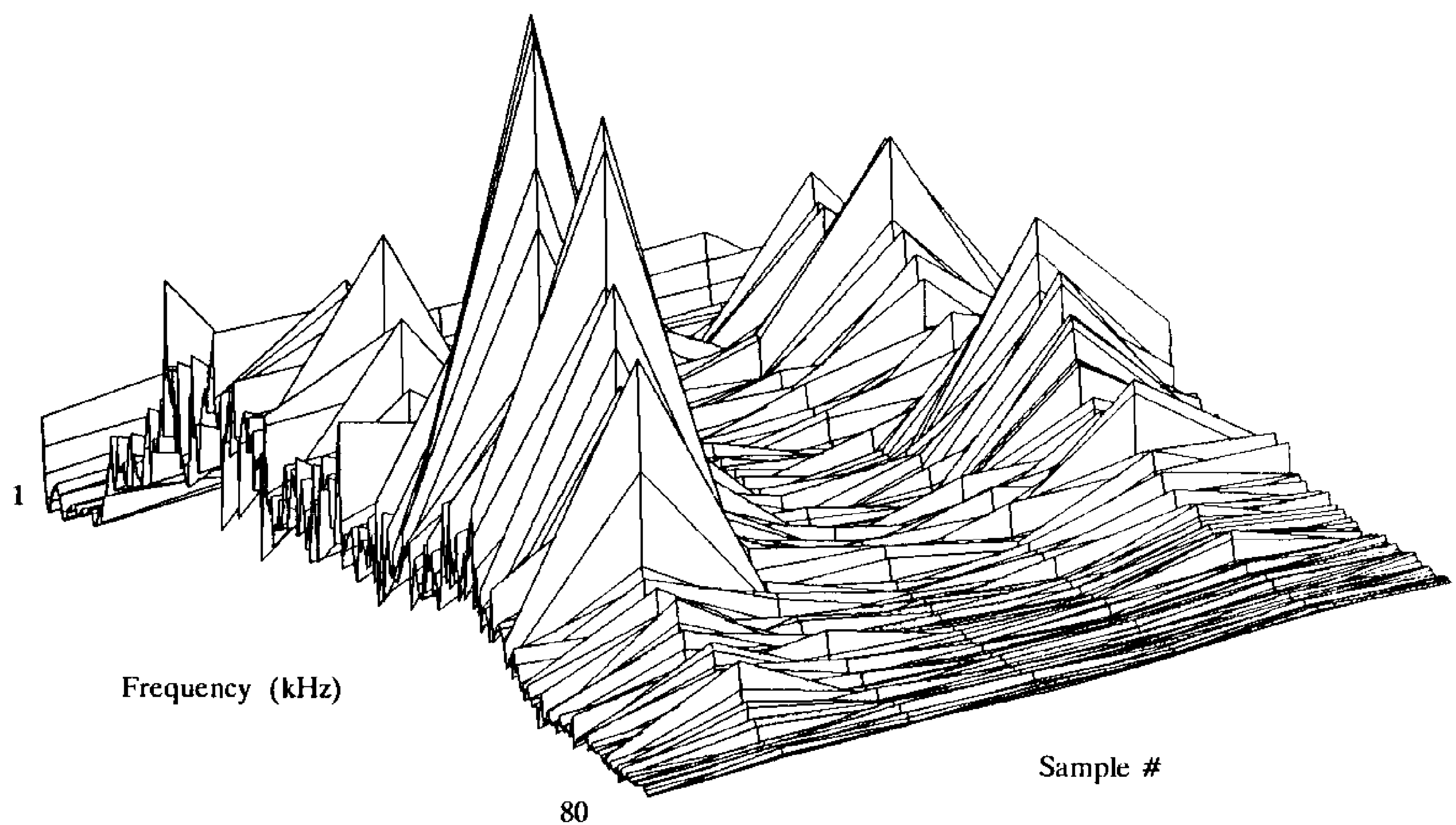
Gillnet Noise Spectrum Level - 3/18/92 - Samples #31 to #40



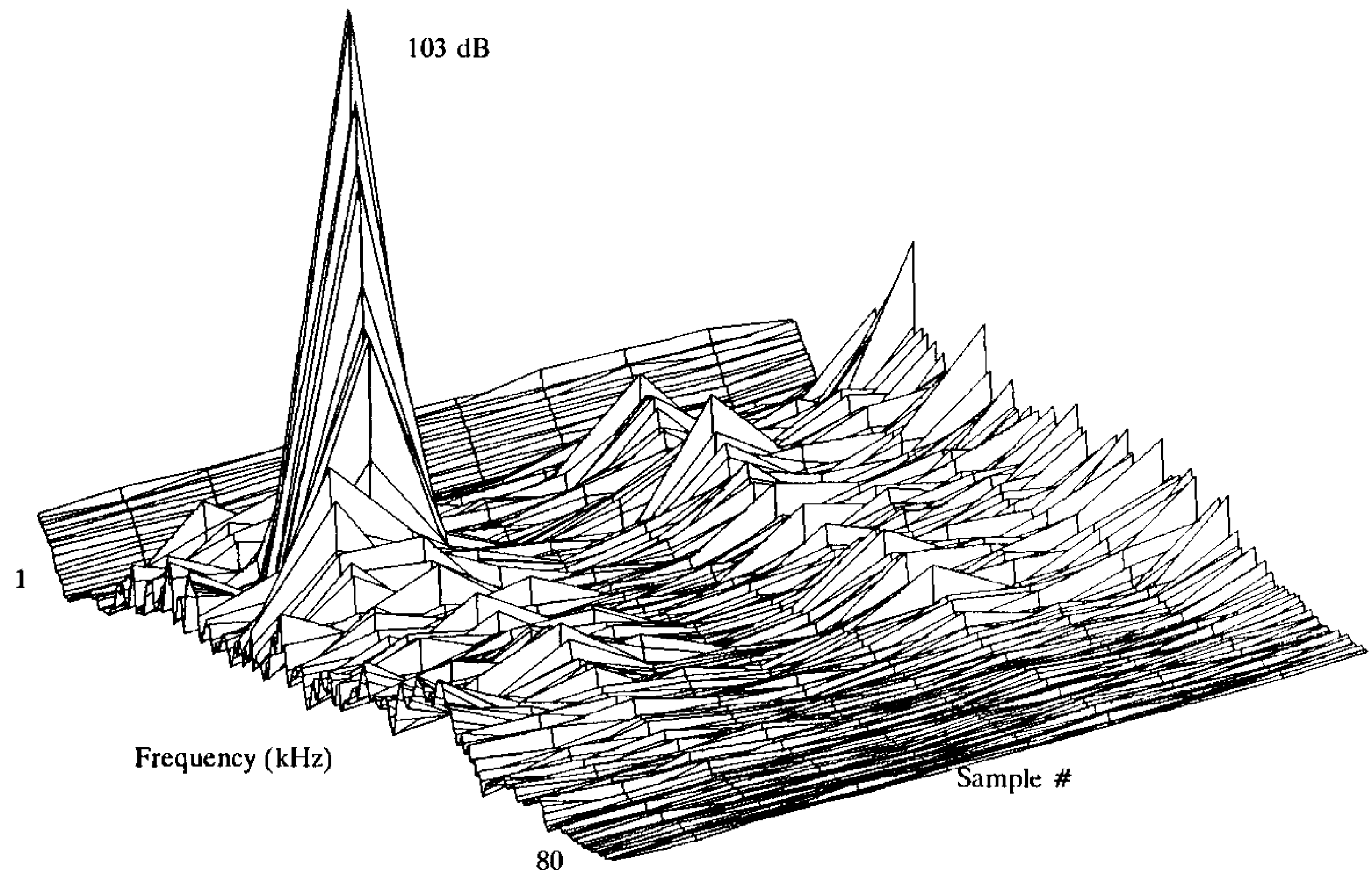
Gillnet Noise Spectrum Level - 3/18/92 - Samples #41 to #57



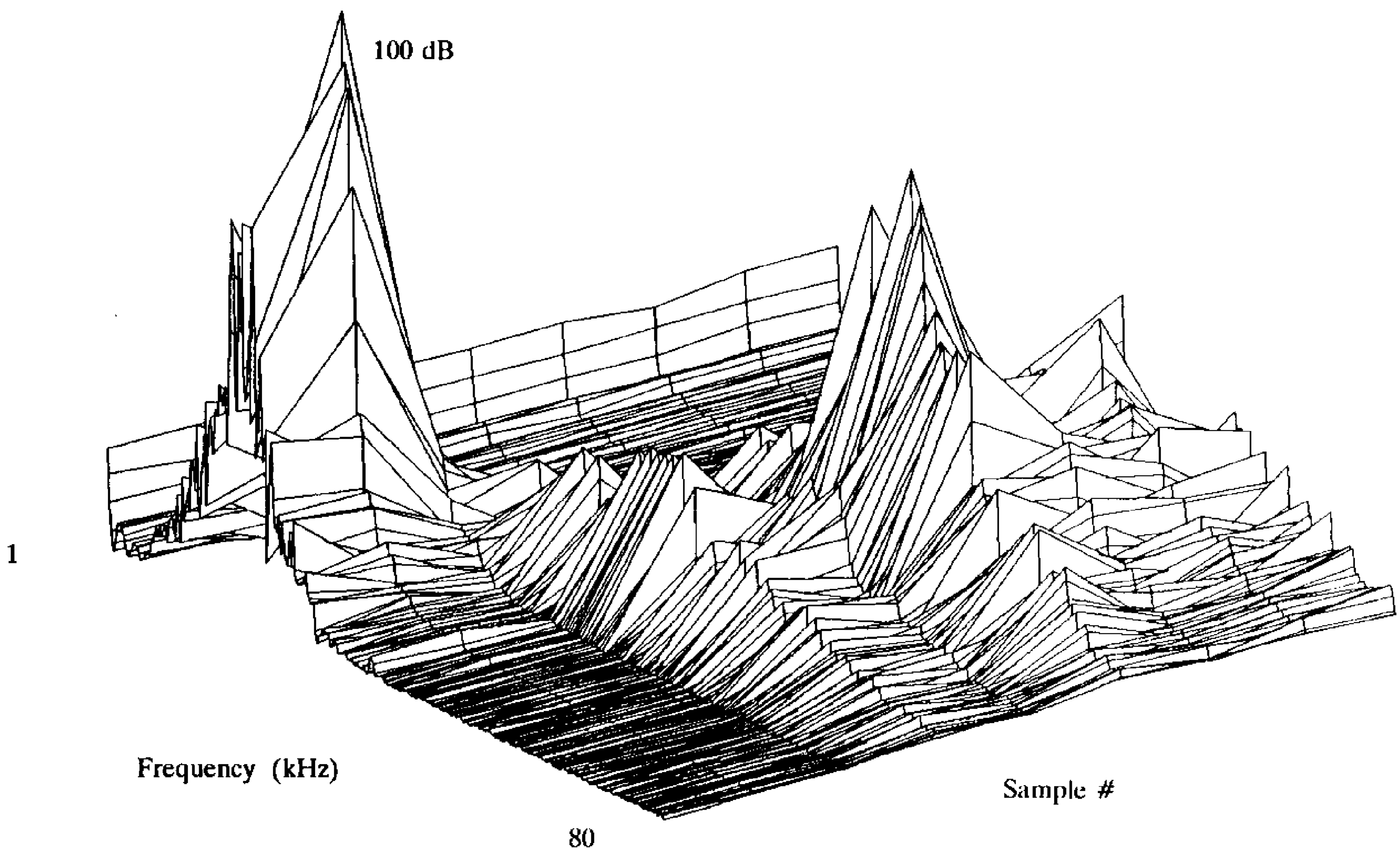
Gillnet Noise Spectrum Level - 3/18/92 - Samples #58 to #64



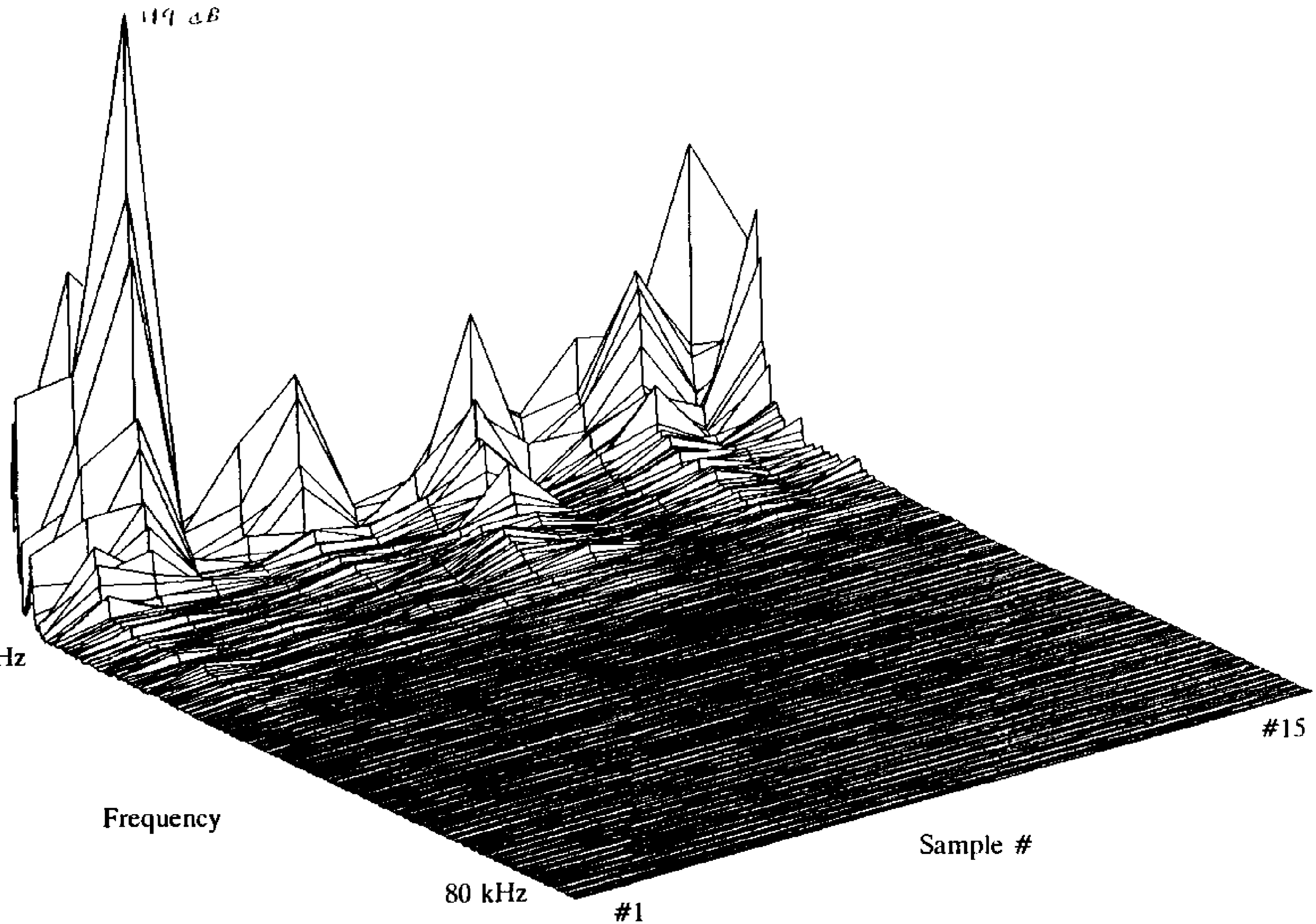
Gillnet Noise Spectrum Level - 3/18/92 - Samples #65 to #74



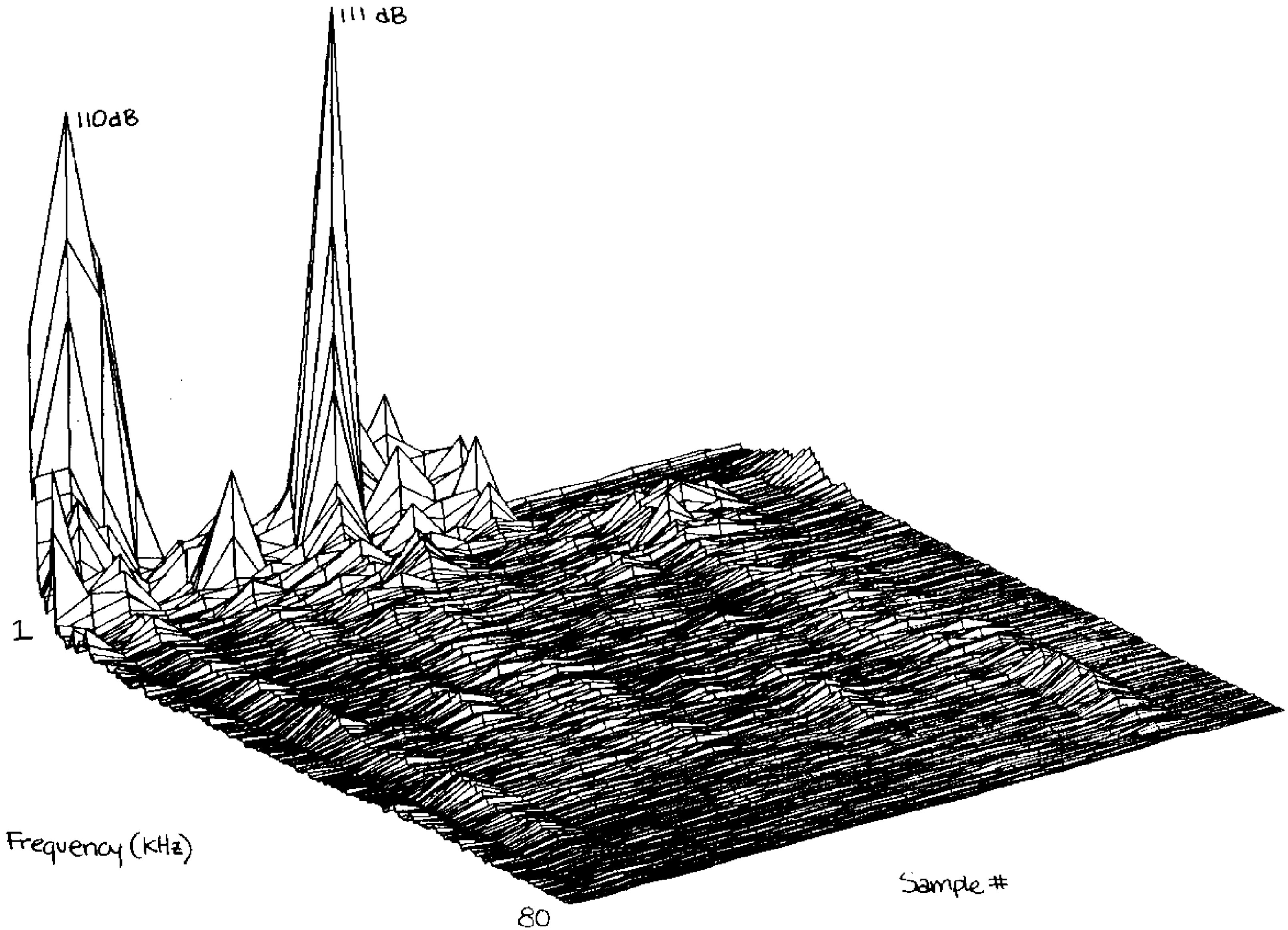
Gillnet Noise Spectrum Level - 3/18/92 - Samples #77 to #85



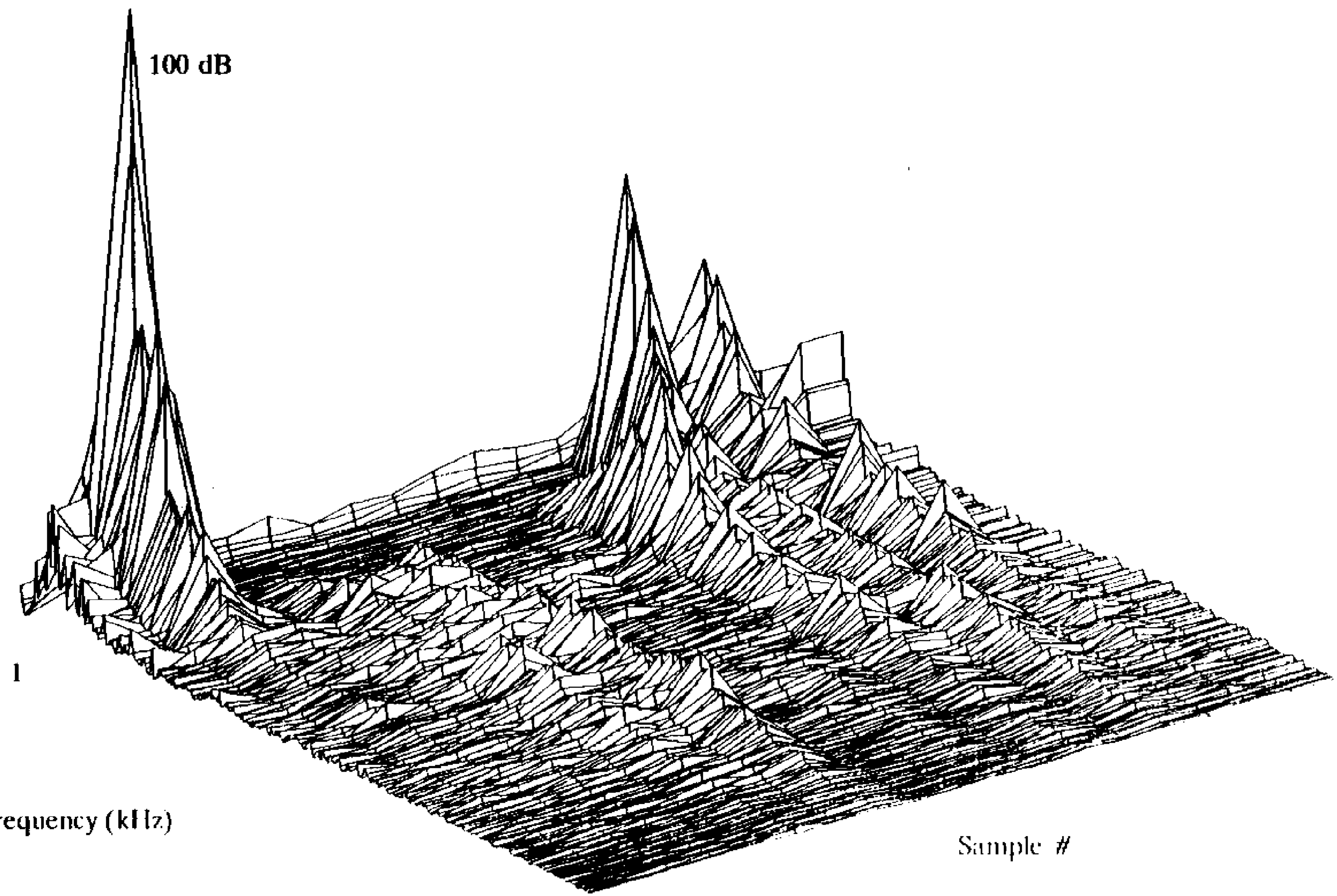
Gillnet Noise Spectrum Level - 3/26/92 - Samples #1 to #15



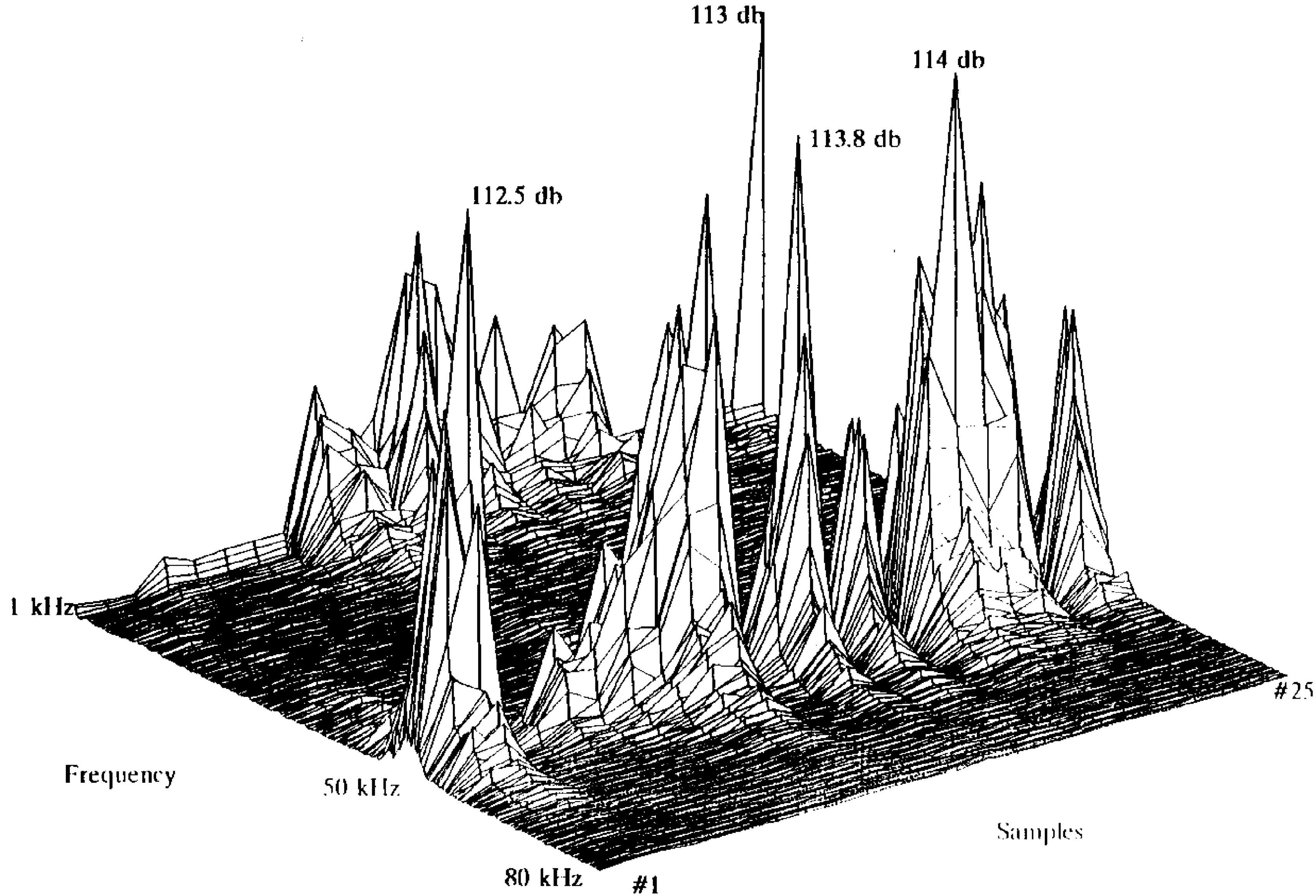
1
Ambient Noise Spectrum Level - 4/09/92 - Samples #2 to #25



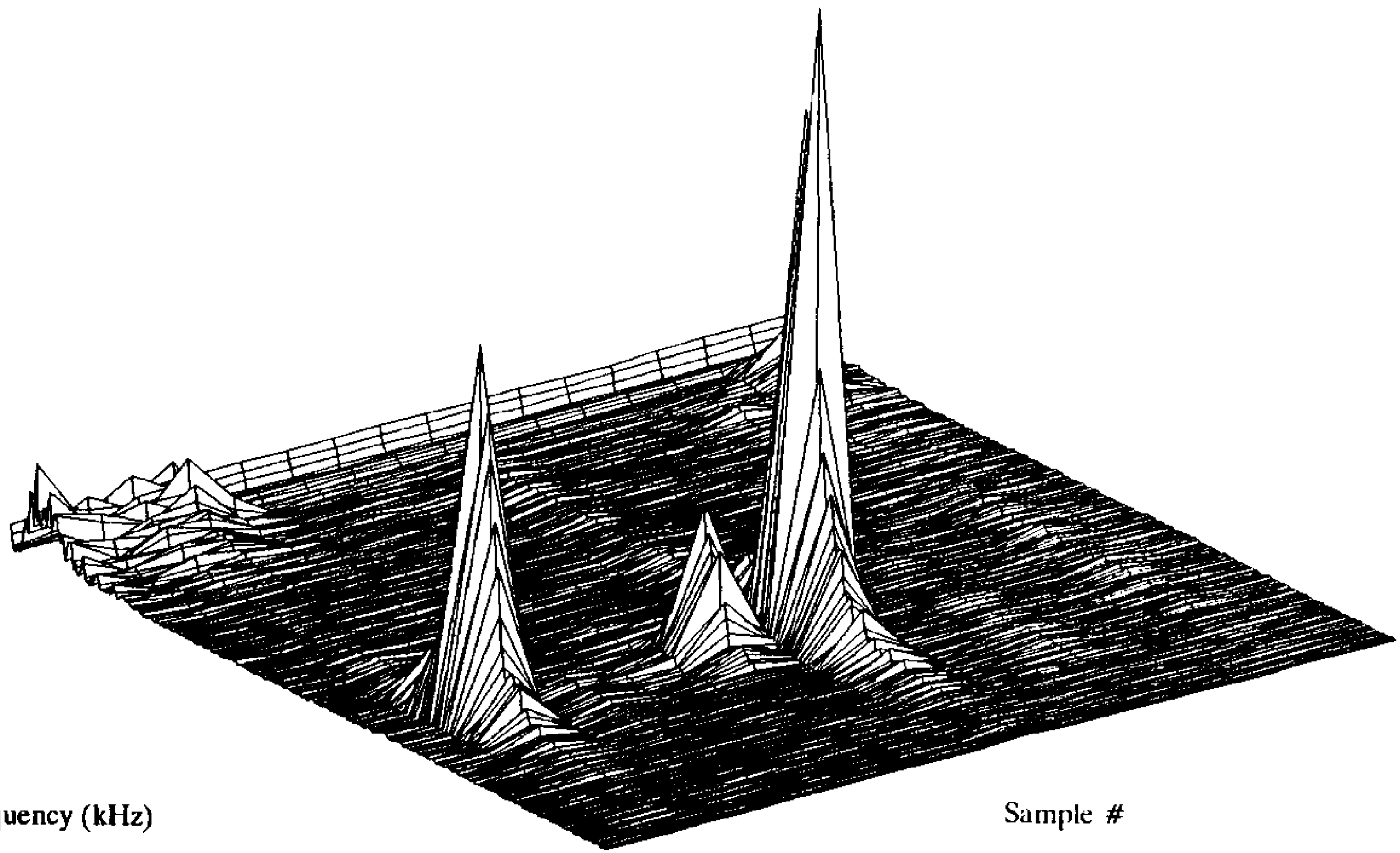
Ambient Noise Spectrum Level - 4/09/92 - Samples #26 to #45



Modified Gillnet Noise Spectrum Level - Samples #1 to #25

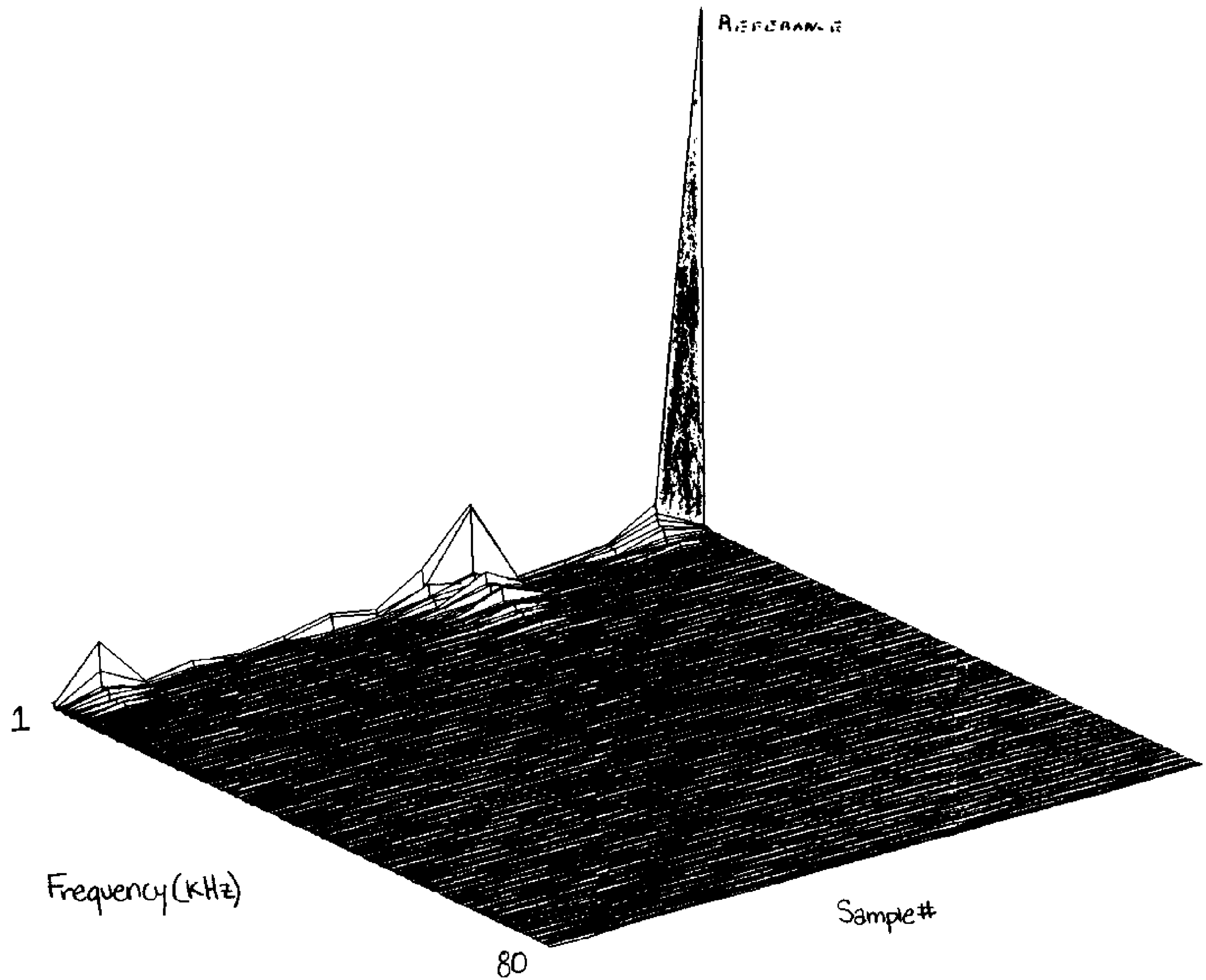


Ambient Spectrum Level - 4/22/92 - Samples #26 to #44

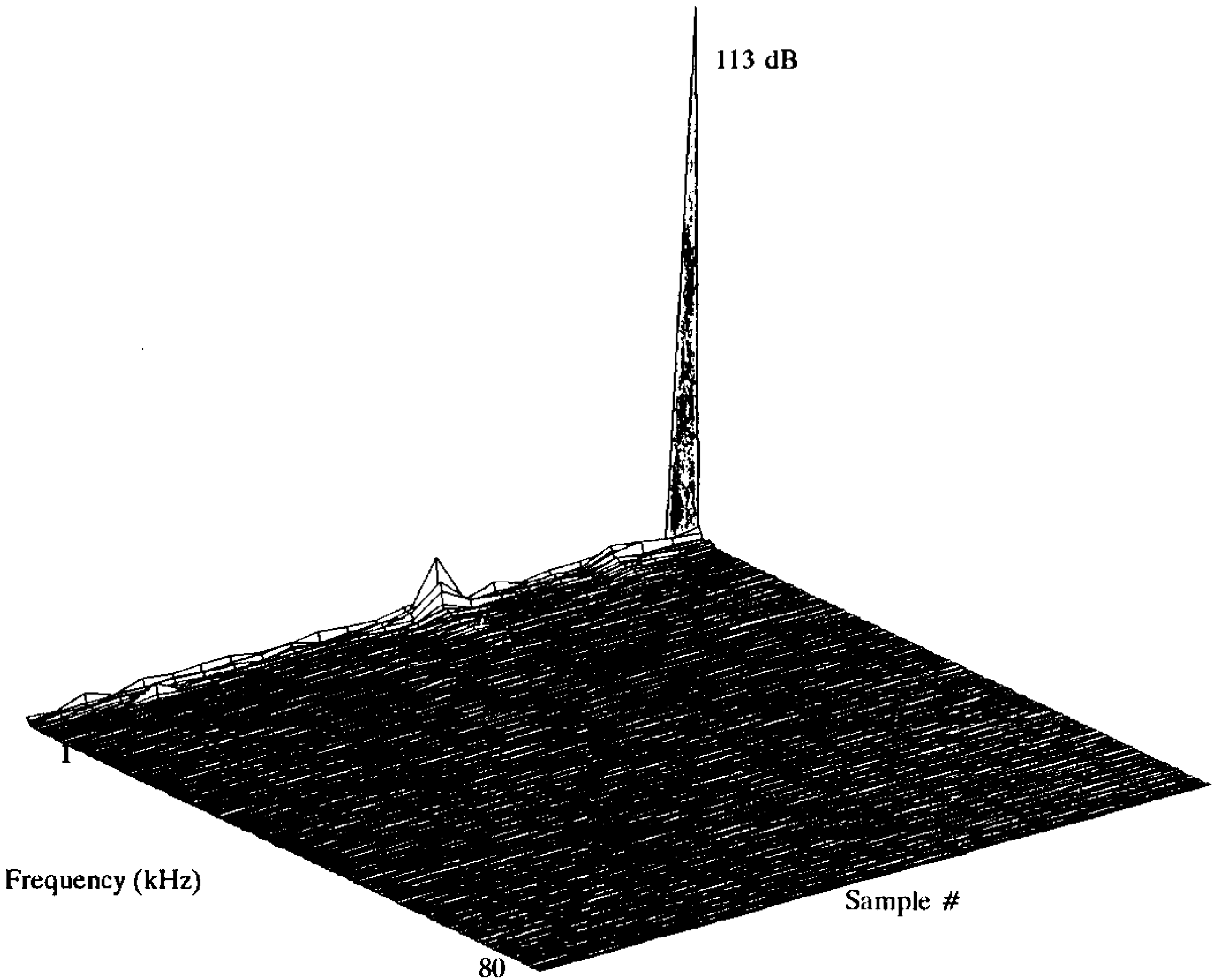


APPENDIX D

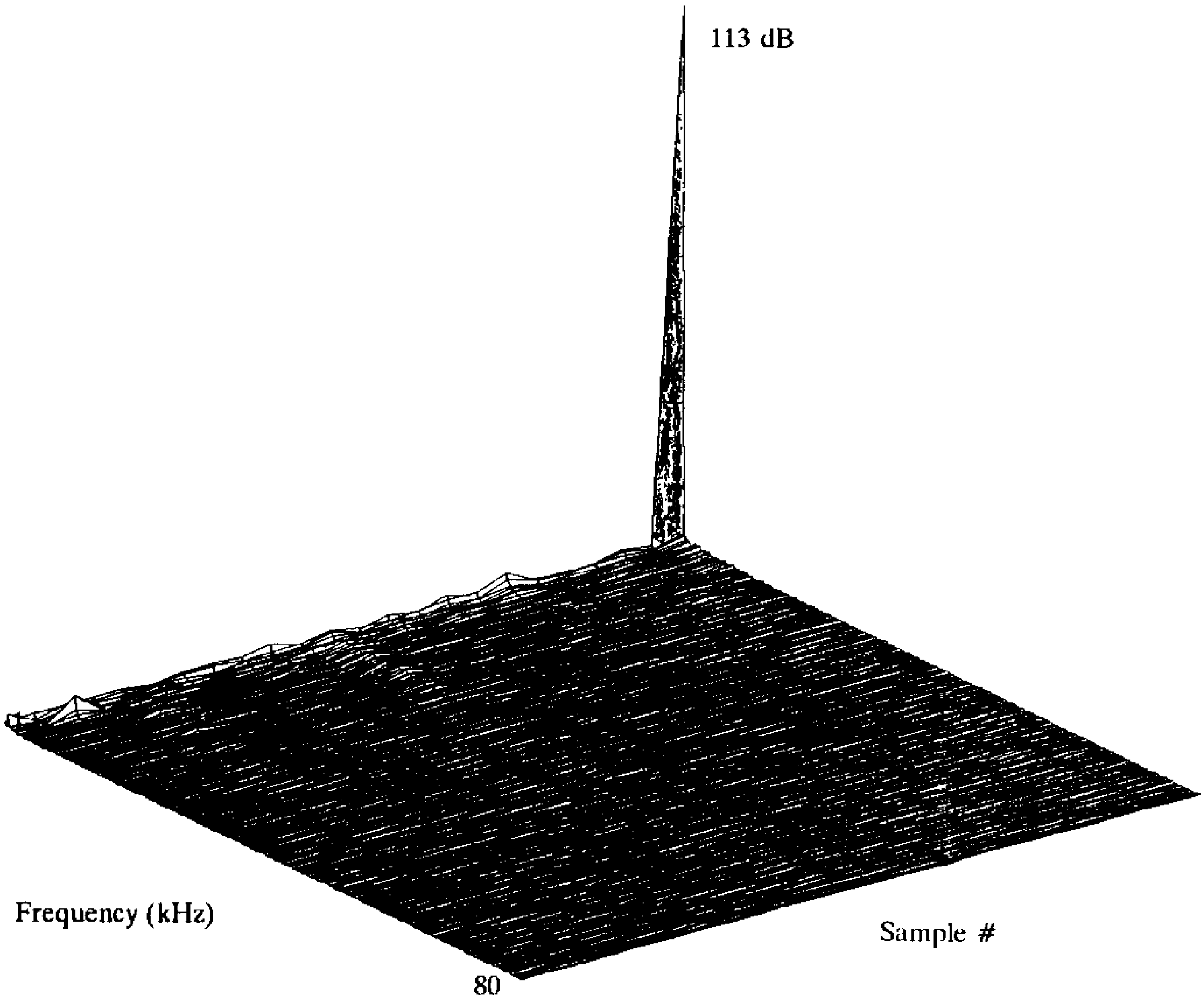
Ambient Noise Spectrum Level - 2/27/92 - Samples #2 to #16



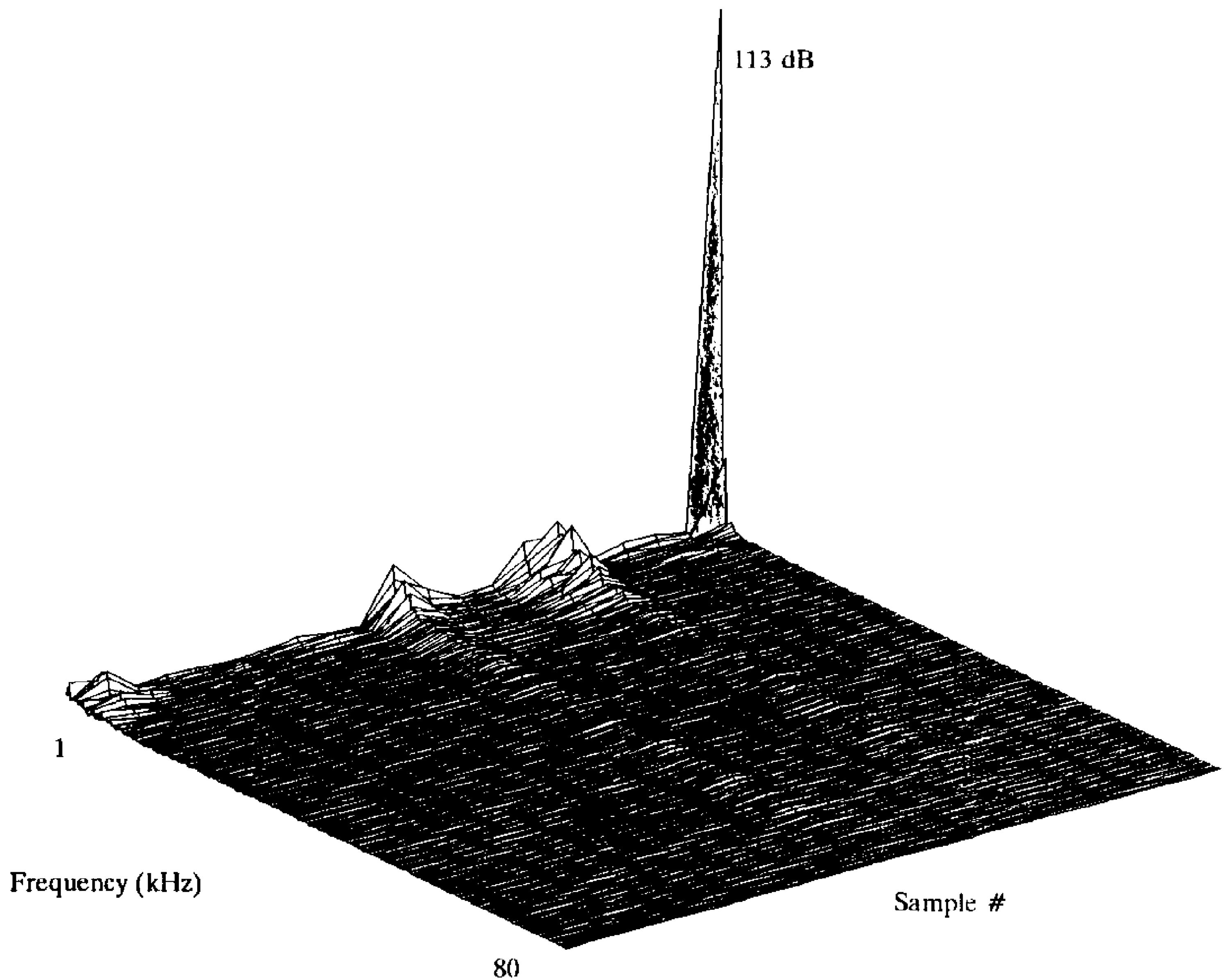
Ambient Noise Spectrum Level - 2/28/92 - Samples #17 to #41



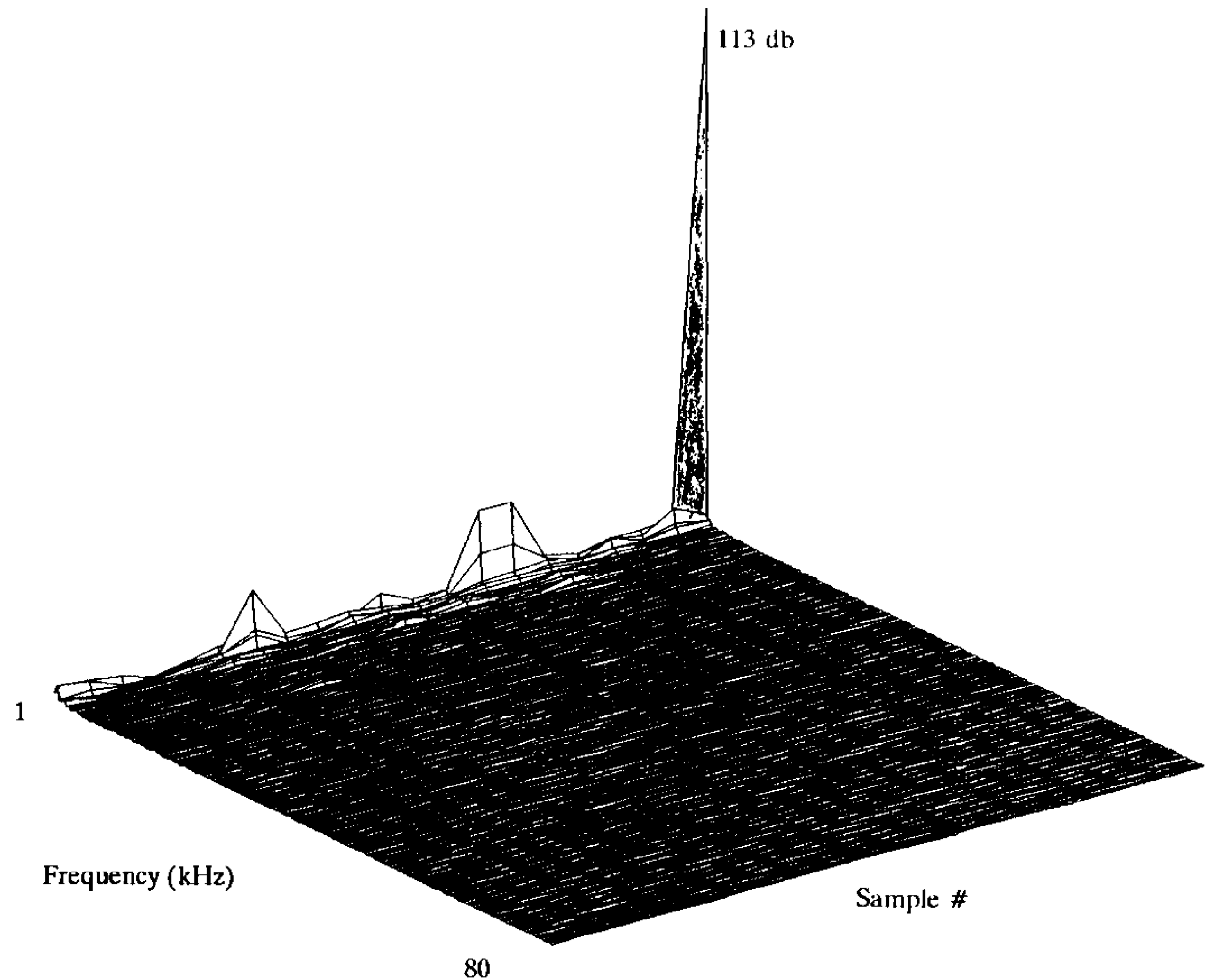
Ambient Noise Spectrum Level - 2/28/92 - Samples #42 to #65



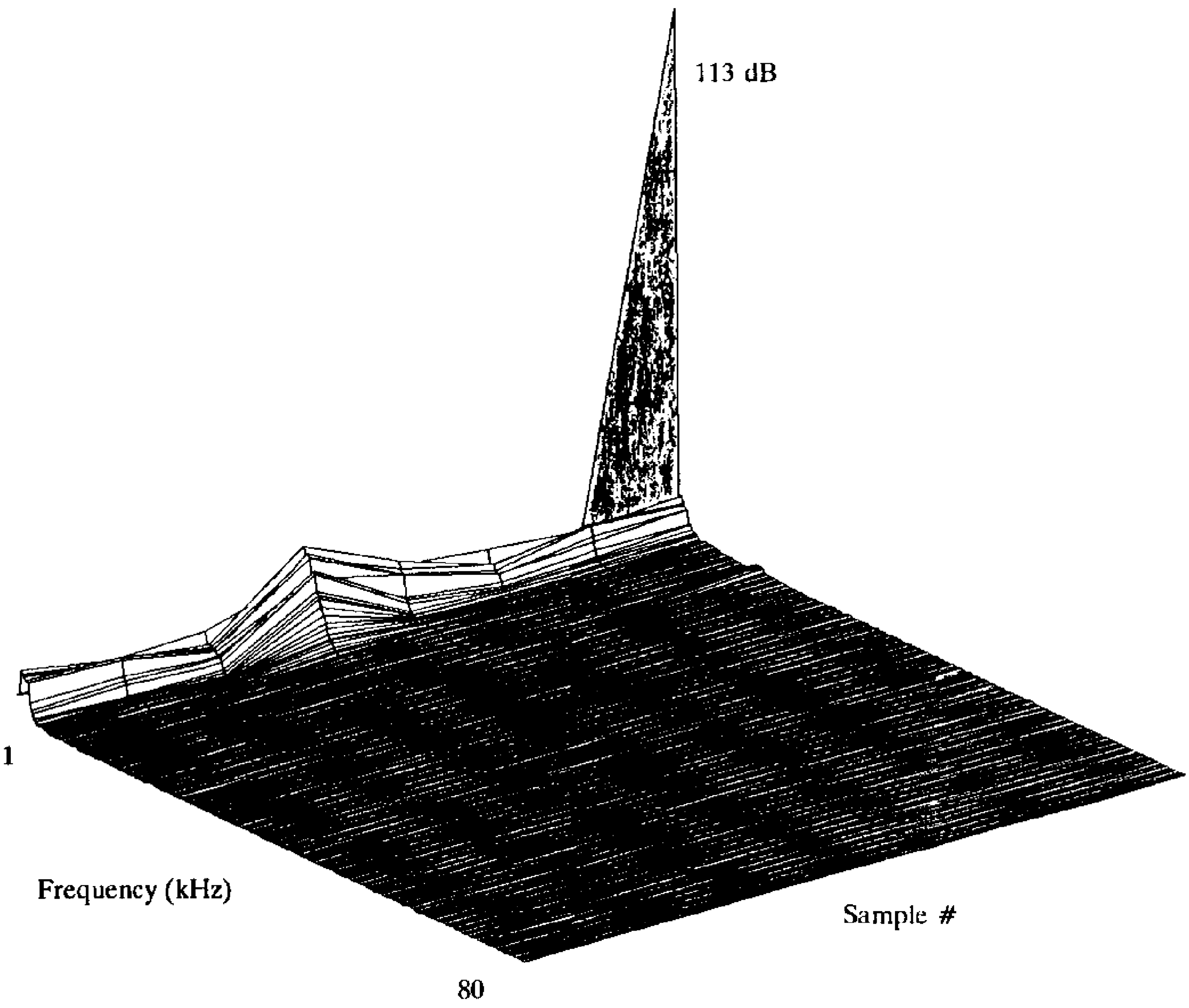
Ambient Noise Spectrum Level - 2/28/92 - Samples #66 to #88



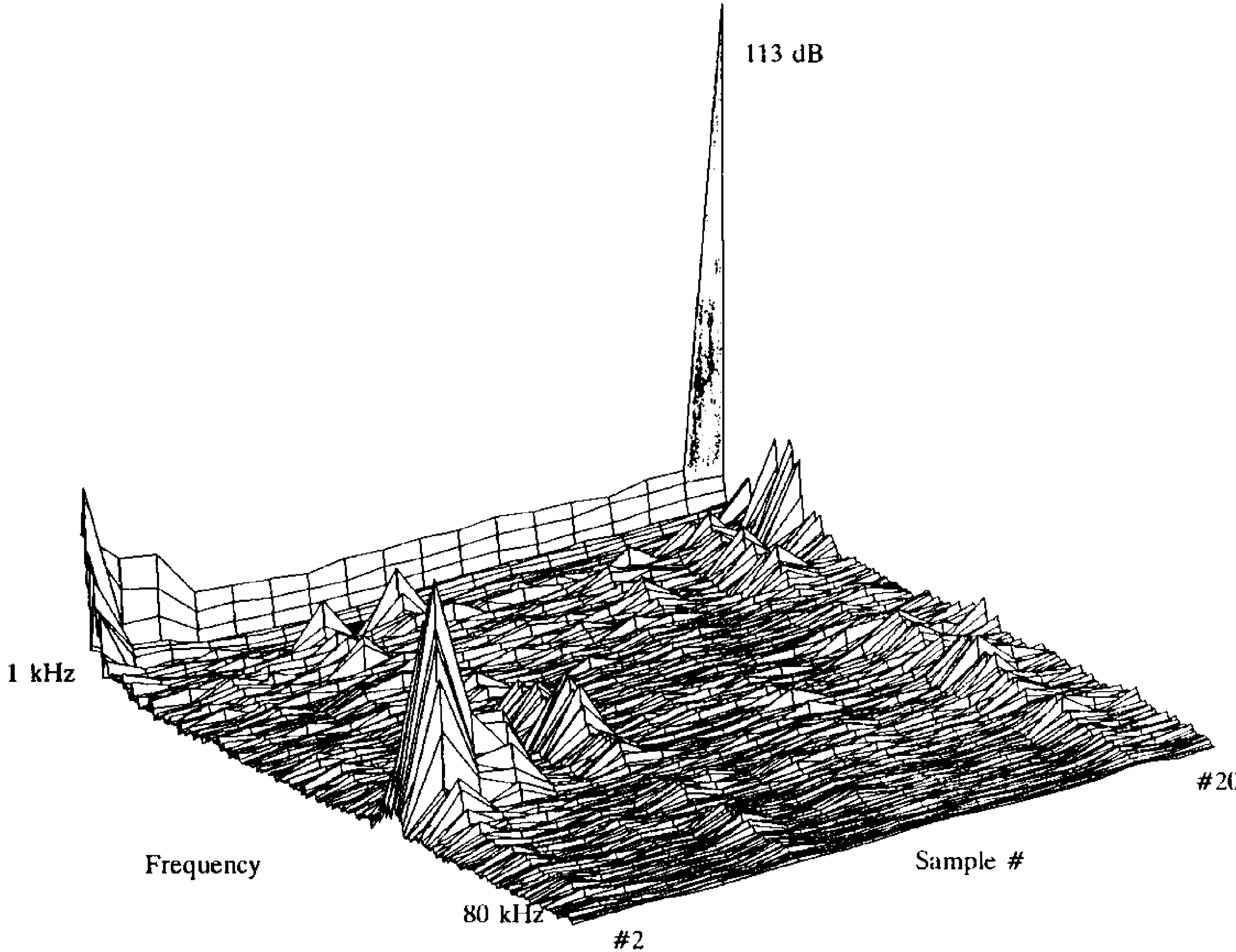
Ambient Noise Spectrum Level - 2/28/92 - Samples #89 to #110



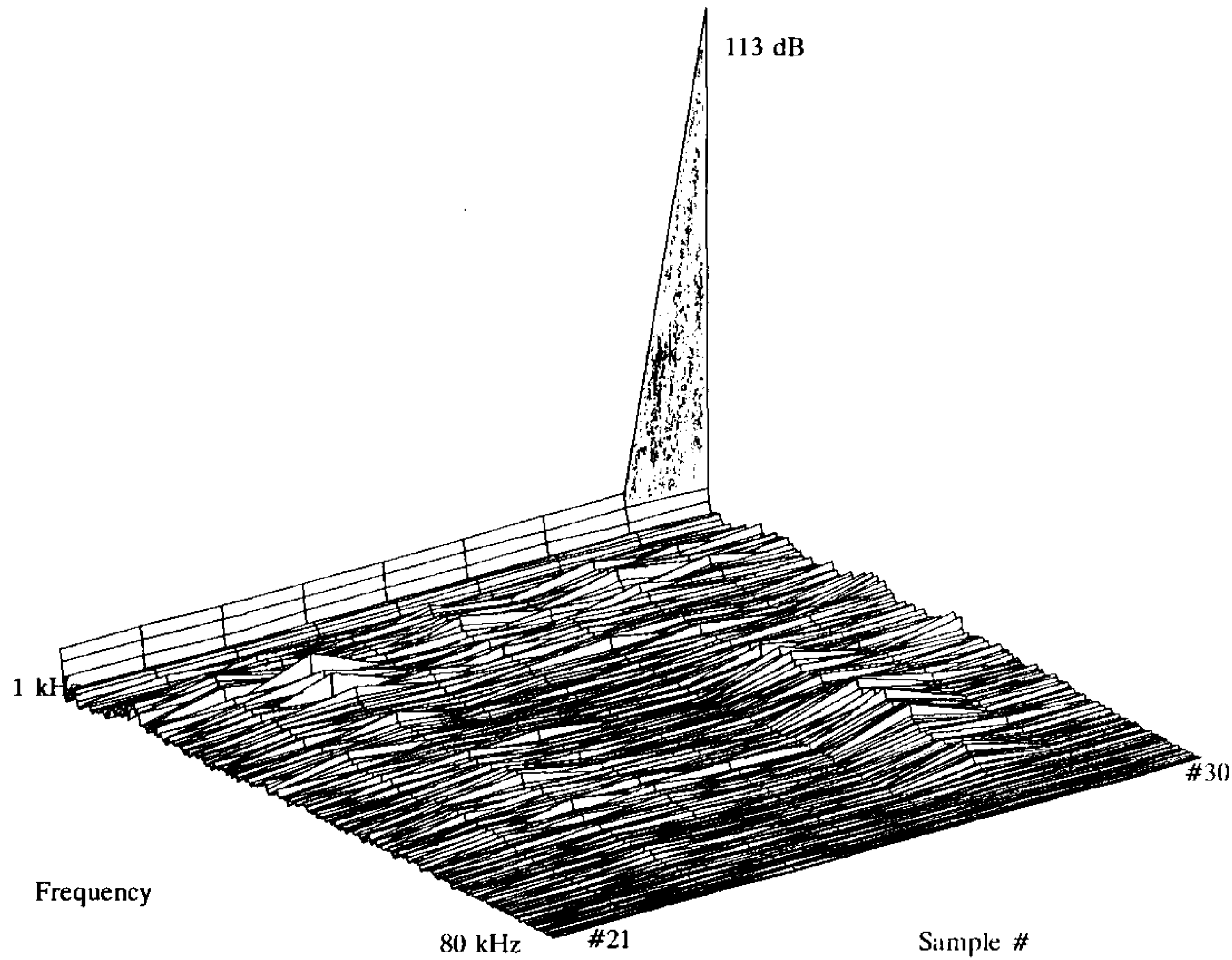
Ambient Noise Spectrum Level - 3/06/92 - Samples #115 to #122



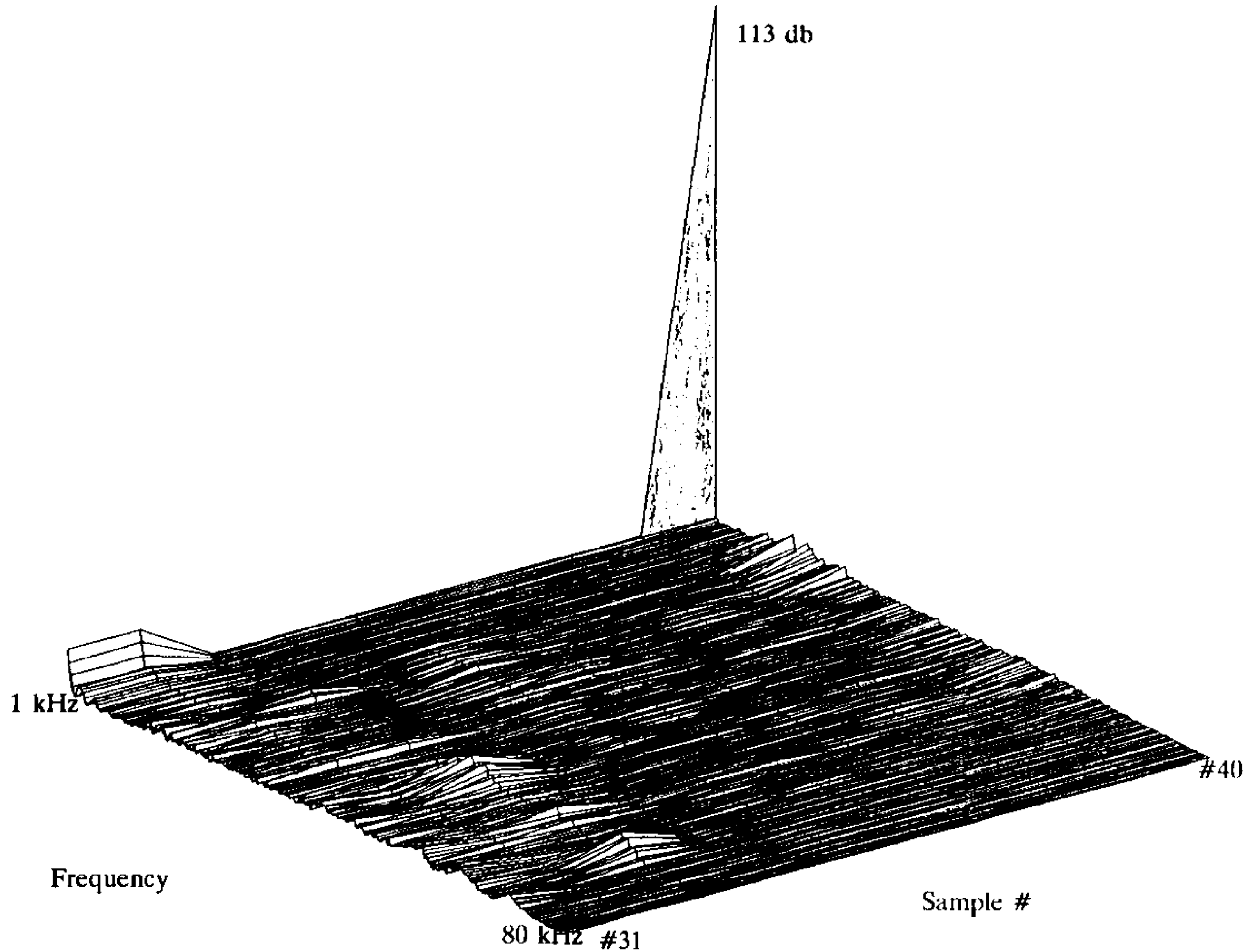
Gillnet Noise Spectrum Level - 3/18/92 -Sample #1 to #20



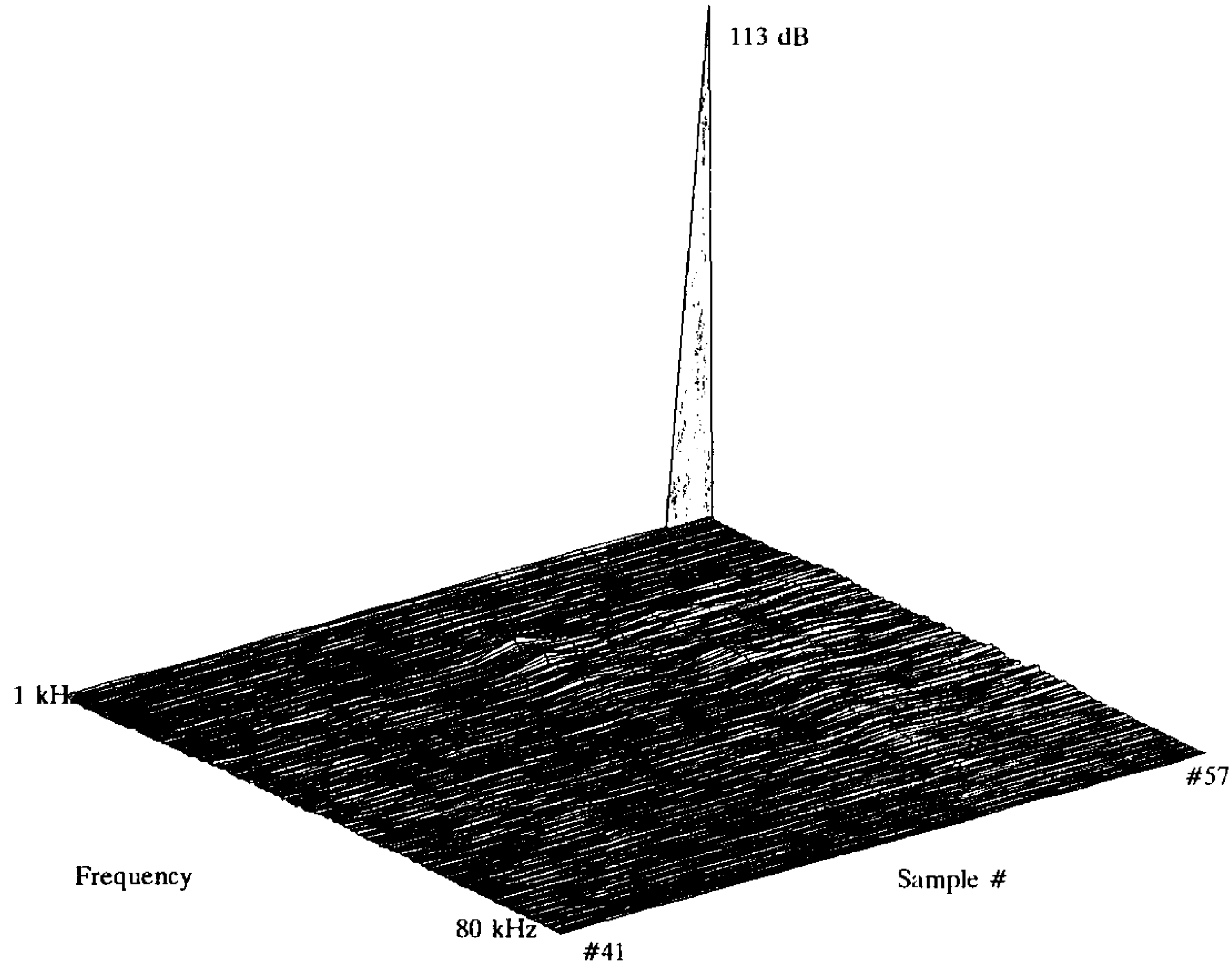
Gillnet Noise Spectrum Level - 3/18/92 - Sample2 #21 to #30



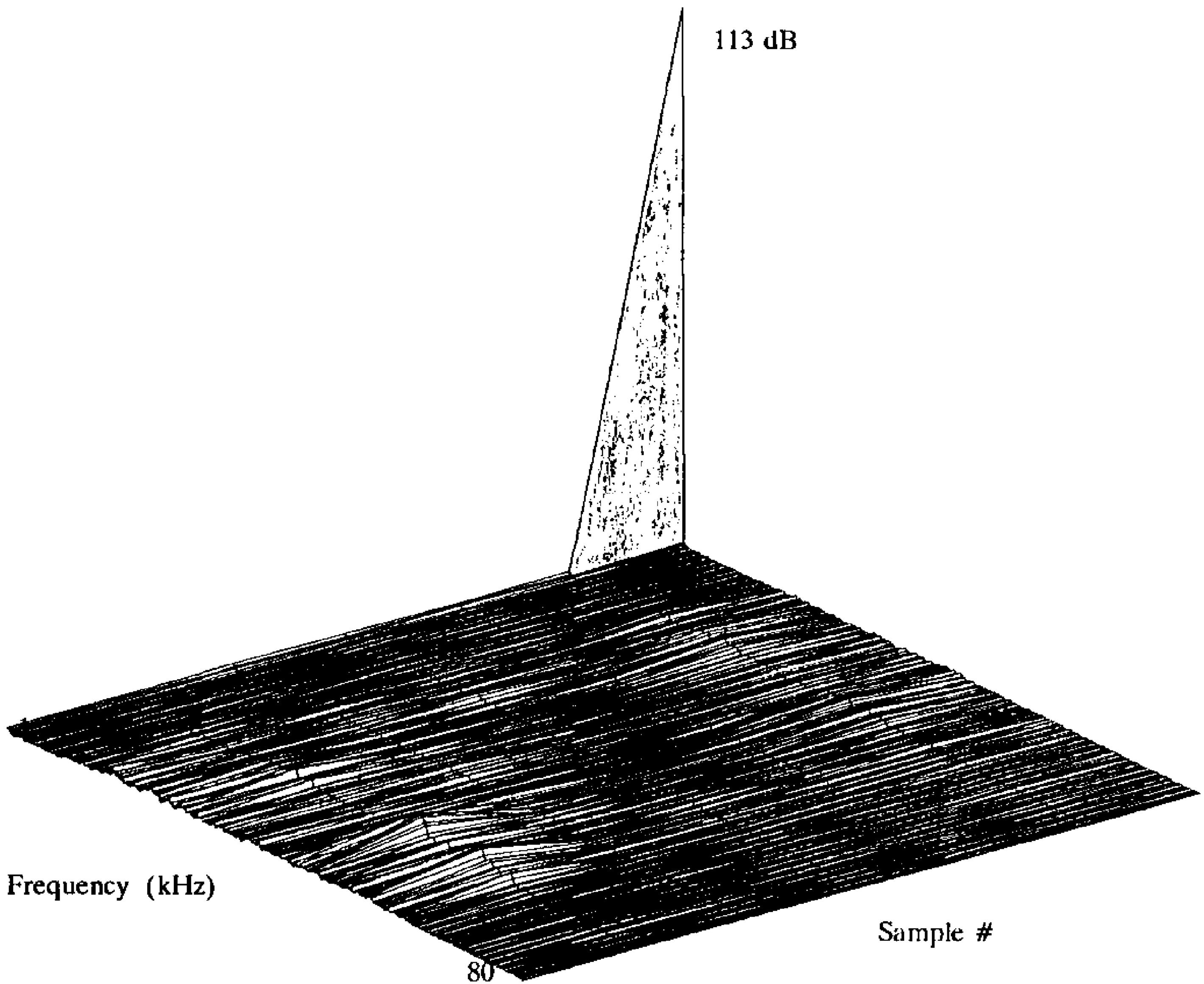
Gillnet Noise Spectrum Level - 3/18/92 - Samples #31 to #40



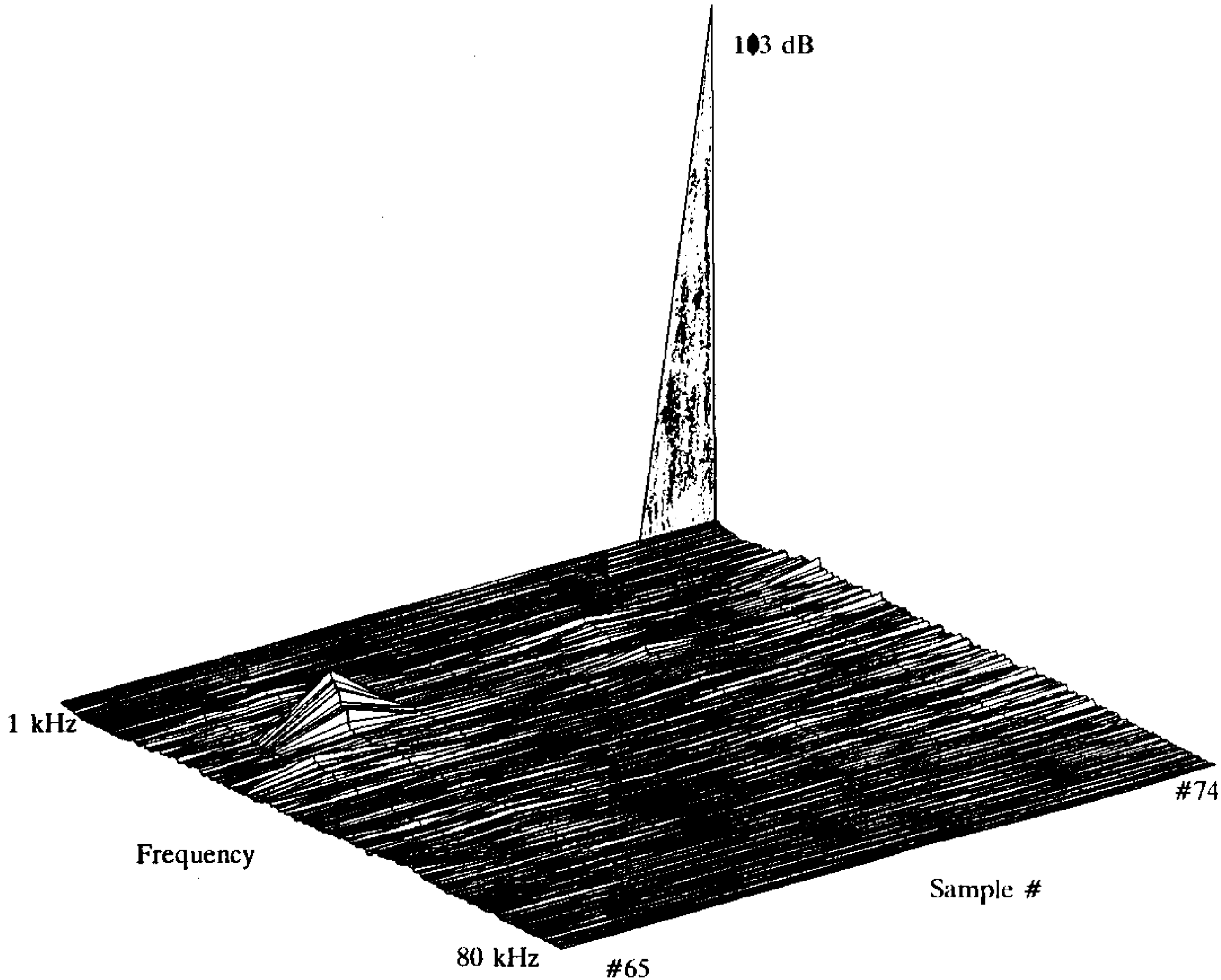
Gillnet Noise Spectrum Level - 3/18/92 - Samples #41 to #57



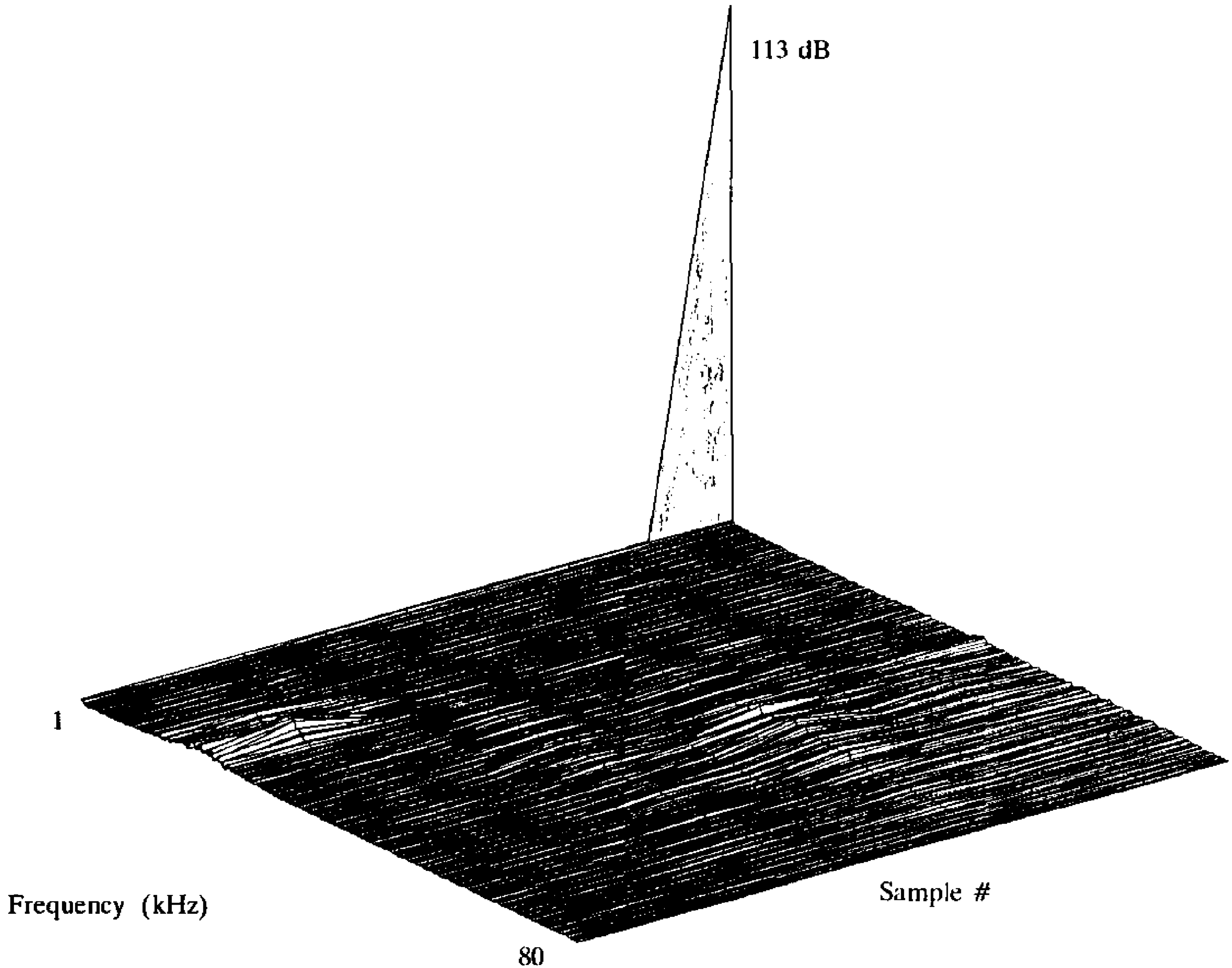
Gillnet Noise Spectrum Level - 3/18/92 - Samples #58 to #64



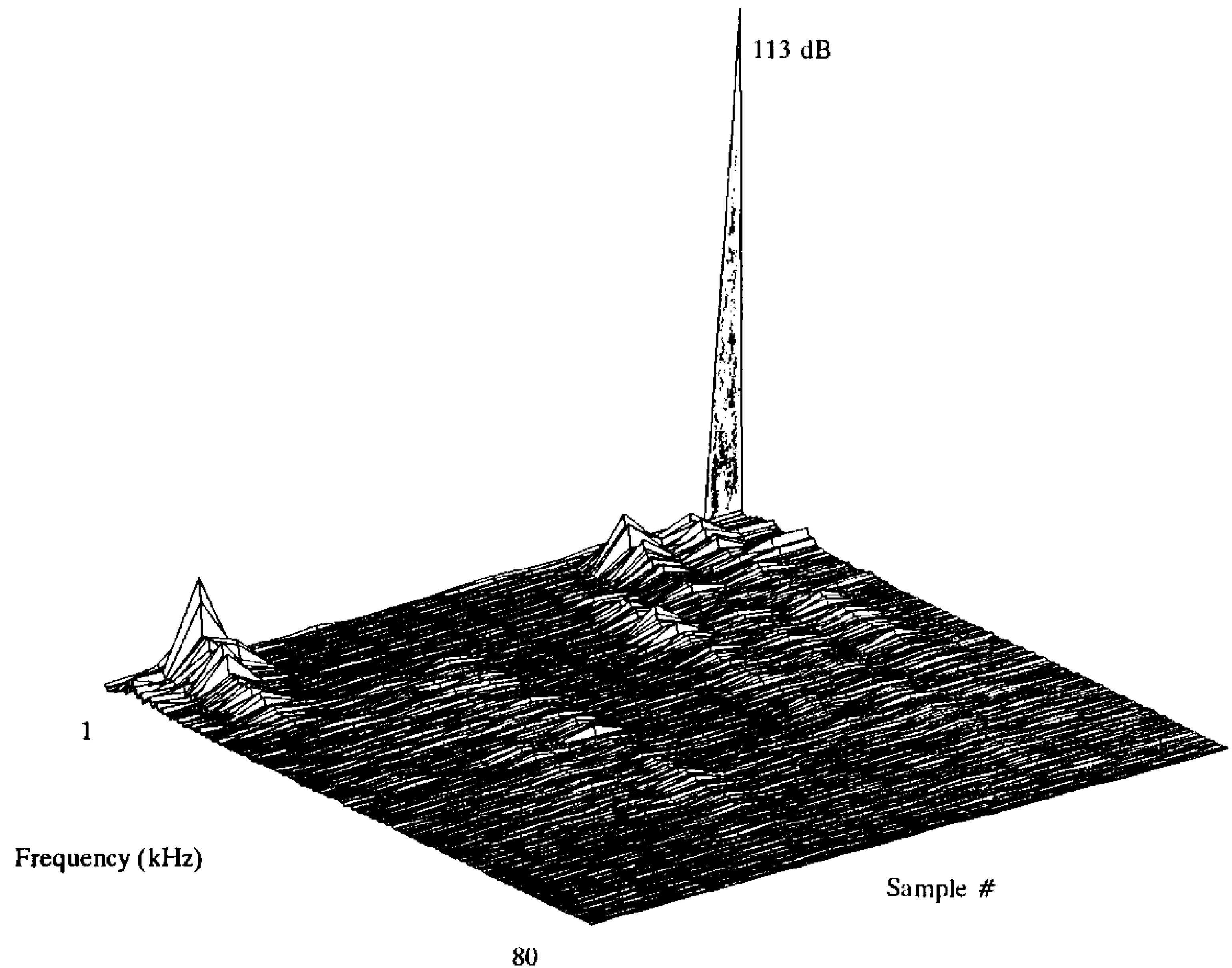
Gillnet noise Spectrum Level - 3/18/92 - Samples #65 to #74



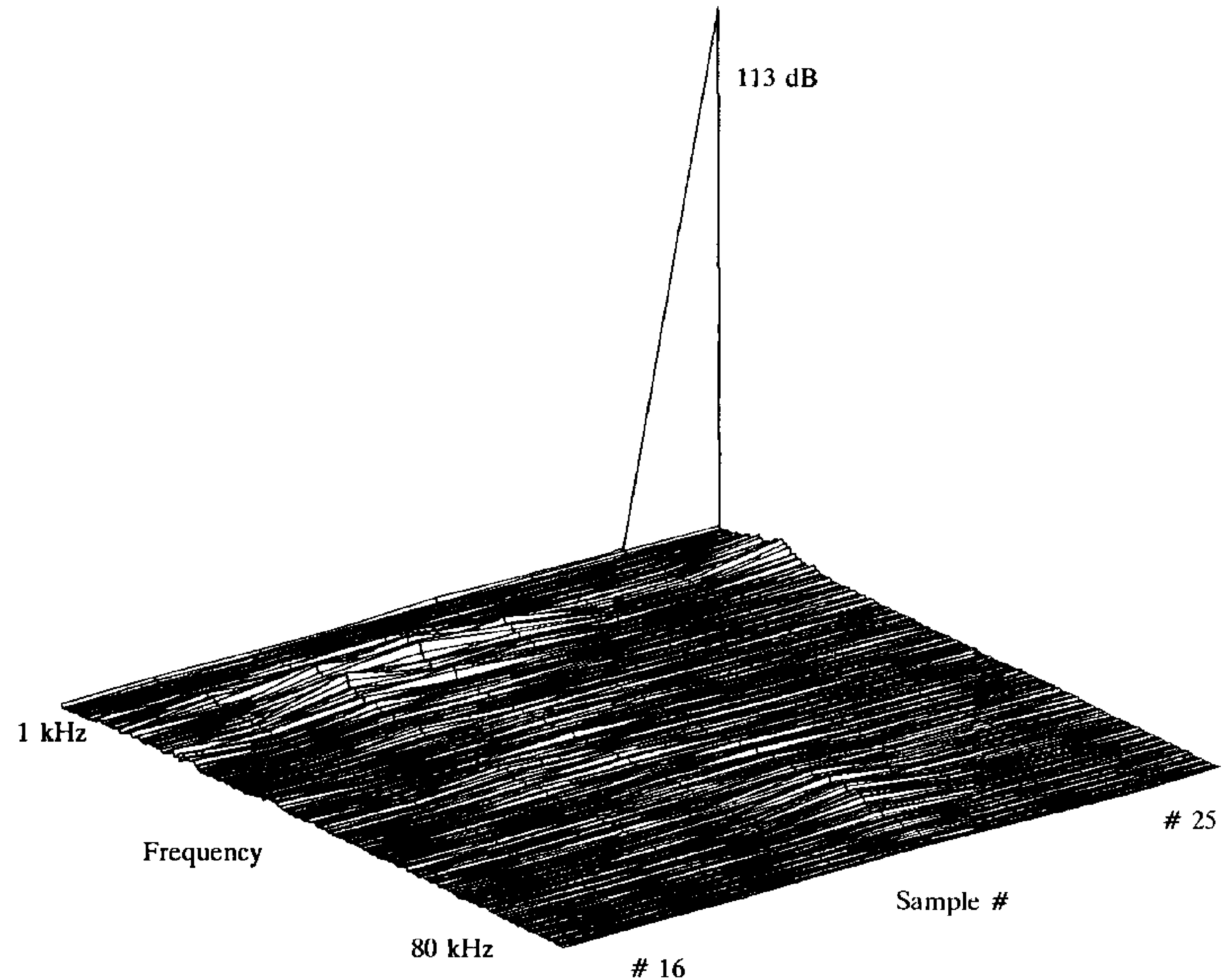
Gillnet Noise Spectrum Level - 3/18/92 - Samples #77 to #85



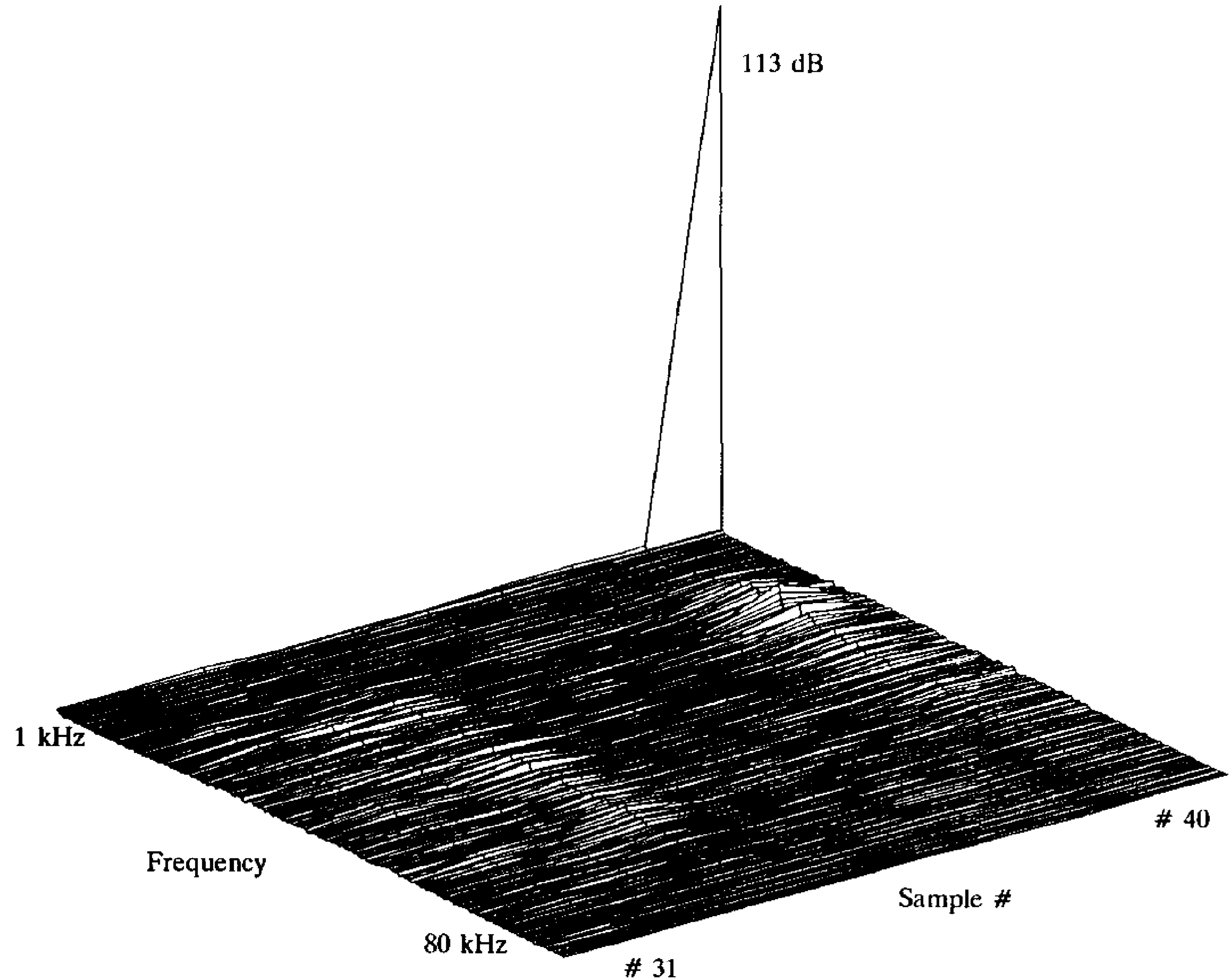
Ambient Noise Spectrum Level - 4/09/92 - Samples #26 to #45



Ambient Noise Spectrum Level - 4/09/92 - Samples #16 to #25



Ambient Noise Spectrum Level - 4/09/92 - Samples #31 to #41



Ambient Spectrum Level - 4/22/92 - Samples #26 to #44