Impulse Damping In Structural Materials

by

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Abstract

An experiment was devised and conducted to provide relative data on the impulse damping rates for a variety of materials selected for their utility in machine construction. Further, conventional wisdom indicates that there are substances which, when introduced into the core of a machine or tool, improve that tool's vibration damping characteristics. This experiment provides conclusive evidence to support this wisdom but does not yield any clear, general rule for its application—rather the opposite in fact. Cast iron damps vibrations more quickly than steel, but titanium damps vibrations faster than any other material tested. Filling the core of a sample with oil generally improves it's damping characteristics, but with copper the opposite occurs.

Thesis Supervisor: Professor Alexander H. Slocum

Title: Assistant Professor of Civil Engineering

Dedication

This thesis is dedicated to Alex Slocum, who has believed in my abilities and stood behind me throughout my MIT career. It was his confidence and enthusiasm that kept me both enrolled in, and interested in, MIT. I extend thanks to Hewlett Packard, which lent me a very nice oscilloscope that made my measurements possible, and to the Department of Physics, especially Gene Di Salvatore, for the use of an essential band-pass filter. I will be eternally grateful to Jennifer Hyman for making it all worthwhile. But mostly I thank my parents, who never failed to give the constant monetary support, and occasional emotional support, that has made my education possible.

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Chapter 1

Introduction to Vibration Damping

> The Danger of more or less perpetual vibration of significant magnitude is one of the bugbears of designers of accurate instruments, and research leading to some practical data on this subject for various types of members is urgently required.
>
> —T.N. Whitehead, *Instruments and Accurate Mechanism*

1.1 Background

If one considers the problem of threading a needle while sitting in car travelling quickly over an uneven road, the limitations on accuracy imposed by vibration are made quite clear. In more significant applications, such as machine tools or robotics, vibrational problems manifest themselves in poor surface quality and limitations on achievable accuracy. Further, vibration (particularly when manifested as “tool chatter”) is one of the primary causes of tool failure.

Sources of vibration may be clearly divided into two groups: environmentally sourced, and internally sourced. The control of the former source is most conveniently managed by isolation technology. Although the latter source might conceivably also be isolated from the point of interest, this is generally not possible; for example a cutting head cannot conceivably be isolated from the vibrations which it generates. It is, therefore, of primary concern to machine tool designers to maximize the dissipation of vibrational energy.

It has long been known that the addition of lead shot and or oil is an effective means to damp vibration. “Dead Blow” hammers use rubber coated brass ampules filled with lead shot and oil for their heads. The conventional wisdom behind such advances is that acoustically dead materials damp vibration well. It is also commonly believed that viscous fluids dissipate vibrational energy quickly (though this theory is somewhat undermined by the spring-like behavior of fresh “go-jo” hand cleaner).

There is a tremendous amount of literature on the subject of vibration in general, and even a significant volume on the subject of material damping in particular. There is, however, almost no tabulated data on the behavior of materials with respect to their damping characteristics†.

The data for the damping rates of materials which does exist [1] is of extremely limited scope and is further outdated by the fact that some of the few materials listed are no longer manufactured. Machine designers are given some limited theoretical basis for evaluating a given material's damping characteristics‡ most of which is well out of the scope of the present treatment of the subject. Further, in the most interesting regime of large scale motion, there is no quantitative understanding [2]. No reference what-so-ever could be found treating the subject of metal-fluid boundaries as they effect vibrational energy dissipation.

1.2 Scope of Experiment

It was proposed that an experiment be devised to quantitatively measure the relative damping performance of various materials chosen for their pertinence to machine tool designers. This experiment was undertaken with the understanding of it being preliminary in nature to a more exhaustive set of measurements. This preliminary study was meant to provide some quantitative basis for evaluating the common wisdom of machine tool designers and to provide some basis for the preparation of future experiments.

It was believed at the outset that the addition of viscous materials would significantly improve the damping characteristics of most materials. It was also believed that the addition of lead shot in the core of a sample would significantly improve its damping characteristics. Fol-

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† Most tabular data seems to have originated with *Energy Dissipation Mechanisms In Structures With Particular Reference To Material Damping* by B. Lazan. The paper was published in 1959 in the book Structural Damping edited by J. Ruzicka, © 1959, ASME.

‡ See, for example, Vibration Damping by A. Nashif, D. Jones, and J. Henderson, © 1985, John Wiley & Sons. Chapter three is particularly pertinent, as is chapter fourteen of Mechanical Behavior Of Materials by F. McClintock and A. Argon, ©1966, Addison-Wesley.

lowing the most straight-forward of logic, it was predicted that lead shot *and* oil would provide exceptional damping.

Further, from experience with machine tools and with day-to-day experience with different metals, a certain ranking was predicted without any deeper evaluation. It was predicted that cast iron would damp vibrations very well, and that brass would not (most machine tool bases are cast iron; many bells are made of brass). As crude as these estimates are, they are not uncharacteristic of the way a designer might select materials for non-critical applications (one would hope that for critical applications more care would be taken).

Interestingly enough, not all of the common sense predications turned out to be true, or even close to the measured results.

Chapter 2

Theory

2.1 Material Damping

Most solid materials exhibit some level of hysteresis when deformed mechanically, even over a small range. This is due to the dissipation of a certain amount of the elastic energy as heat or as plastic deformation. There are a number of mechanisms by which materials dissipate vibrational energy.

2.2 Damping Mechanisms

There are a tremendous number of mechanisms postulated to provide a degree of damping in a vibrating member. Only those most pertinent to the experiment at hand will be explored.

The two dominant modes of energy loss in our experiment would be acoustic excitation of the surrounding air, and mechanical loss to the table itself, which was not rigidly fixed. These modes of energy dissipation are not the subject of our current study, but cannot be ignored in the analysis.

Internally, a whole host of interactions might be taking place, which can be divided into two categories—linear and non-linear (rate independent and rate dependant) [3] [4]. It is thought that non-linear effects are dominant in most structural materials [5].

Most of the vibrational energy lost to damping ends up as heat in the end. Materials which are compressed tend to heat up. In the case of dynamic stress, the heat is not created in a homogenous fashion, which results in thermal potentials, and so in thermal currents. These currents represent a significant mode of loss.

Also significant, especially in the ferrous materials, is Snoek Damping [6]. When interstitial atoms are in solution in a crystalline solid, their position is determined by energy minimization. When such a solid undergoes strain, the balance of energy is disturbed and the solute atoms tend to migrate. The considerations for this migration tend to be purely physical: the interstitial atoms distort the crystal; if the crystal is physically deformed then the interstitial atoms will tend to collect where their presence causes a minimum additional distortion to the crystal lattice. This migration takes time, and can only be accomplished efficiently at a certain frequency, at which there will be a peak in the damping of the material. The amplitude of the peak is proportional to the number of mobile atoms and available sites. In certain crystal structures this process will tend to be anisotropic.

In polycrystalline materials, there is the possibility of grain slip where the crystal structure rearranges itself, effectively suffering plastic deformation.

Finally, there is the creation of magnetic eddy currents in a moving conductor. These effectively damp motion by creating current loops, and therefore heat, and therefore dissipation of energy.

Chapter 3

Apparatus

3.1 Mechanical Structure

A large number of mechanical elements were designed and fabricated by the author to allow convenient and accurate measurements of the samples to be tested. In the interest of accuracy, the stiffness of the mounting assembly was of paramount importance. Due to the tremendous number of test samples (fifty four) it was also critical that the samples be changed easily and without compromising the accuracy of the test.

3.1.1 Test Specimen

There was little flexibility in the design of the test specimens because of the interest in including data for Al_2O_3 and granite samples of which had already been purchased (at great expense). The specimens measure three by three by sixteen inches (see figure 3-1). A table of the specimen costs and suppliers is provided in Appendix B.3. A table of the materials properties is given in Appendix B.2.

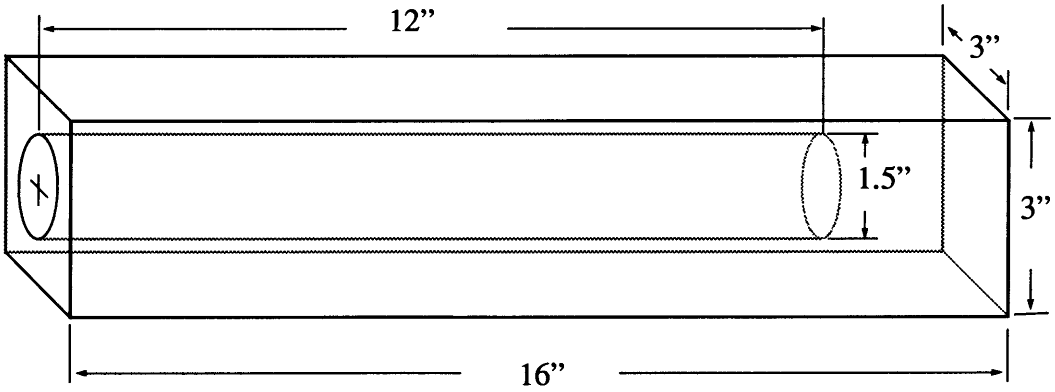

Figure 3-1: Test Specimen showing measurements. All tolerances were within approximately one sixteenth of an inch.

The specimens were designed as large as they are to more accurately simulate the conditions that they might be used in as applied to machine tool manufacture. Unfortunately, the size of the samples prohibited providing a true “built in” clamp, as would be required to produce pure first mode oscillations. The hole was bored to provide a cavity which was filled with various substances expected to alter the damping rate of the sample, and selected on the basis of the practical merit. The criterion include low cost, ease of handling, and potential for actual use. Figure 3-2 shows the specimens and cores tested. The particular alloys were chosen for each specimen as being the most commonly used or most applicable to machine tool design.

Specimen Materials
- Cast Iron, Class 40
- Steel, 1018
- Stainless Steel, 303
- Titanium, 6Al4V
- Aluminum, 6061
- Brass, C360
- Copper, 101
- Ceramic, 99.5% Al_2O_3
- Granite, Gray

Core Materials
- Air
- Sand, White Play Sand
- Lead Shot, #8
- Oil, 10W40
- Sand And Oil
- Lead Shot And Oil

Figure 3-2: List of specimen and core materials tested.

3.1.2 Sample Vise

A standard machine vise was used to fixture the samples, but with certain modifications to improve its stiffness. The base of the vise, which originally allowed rotational adjustment, was removed. A pair of mounting holes with three-quarter-inch clearance were drilled in the front of the vise, and a set of four half-inch clearance holes were drilled through the back flange of the vise. The gib of the vise was reinforced with a one-inch square steel bar which bridged the gib and was bolted down to the table at either end. The most significant alteration was the replacement of the vise faces (the originals were only one-quarter of an inch thick) with more substantial plates shown in figure 3-3. These plates were designed to utilize the original mounting holes drilled through the gib and base of the vise. The height of the faces were raised from one inch to three inches to improve the stability of the mounting system (the specimens were three inches square at the base). The faces were cut as thick as possible, the limiting factor being how wide the vise could be opened (five and half inches without any faces).

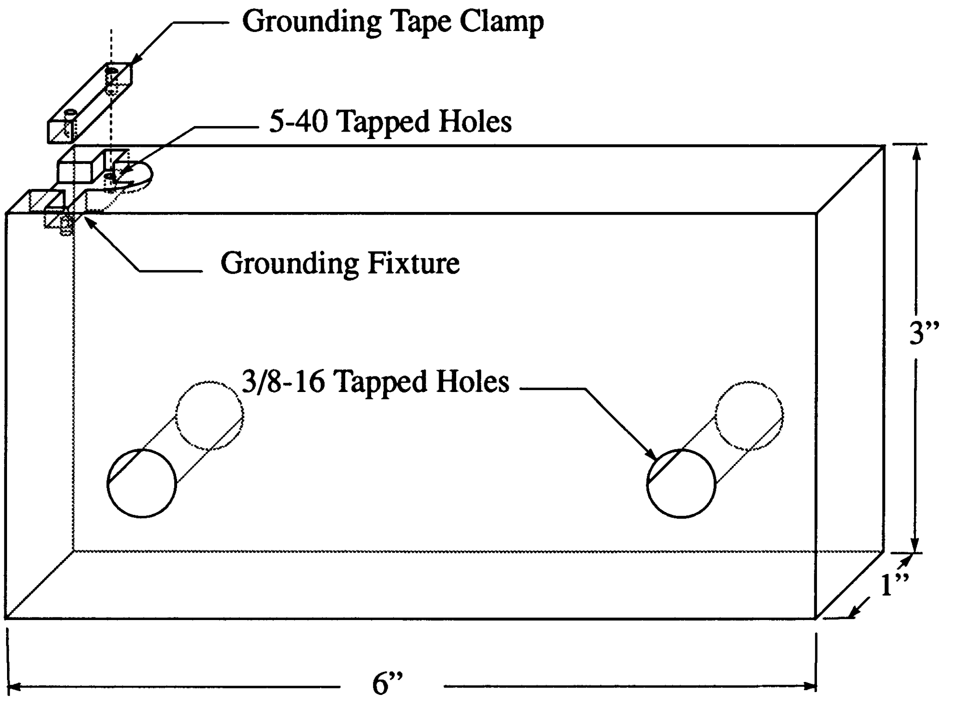

Figure 3-3: Vise Face, showing measurements and details. Two faces were manufactured; only one with a Grounding Fixture.

3.1.3 Test Bed

We were fortunate enough to find a surplus cyclic fatigue testing machine to use as our test bed. This machine was built with a cast iron table top approximately three feet square, three inches thick, and weighing about one ton.

The table's original purpose was to shake apart fatigue samples, and was still fitted with the necessary apparatus, consisting of a massive spring mounted motor assembly which protruded through the middle of the table. This assembly would freely oscillate at about ten hertz, and so it was fitted with an aluminum clamp to fix it to the table and then pre-loaded against the clamp to keep it steady.

The entire table assembly was suspended on springs yielding natural frequencies of approximately one hertz vertically and approximately five hertz horizontally. It was originally believed that the spring suspension of the table would isolate the experiment from environmental vibrations and thus improve the accuracy. In retrospect, environmental isolation was unnecessary. It is possible, moreover, that the effective stiffness of the mount could have been increased and the coupling between the sample and the probe mount reduced had the table been rigidly fixed.

A number of holes were drilled and tapped into the table to hold the vise. These consisted of two three-quarter inch by twelve pitch holes under the front of the vise and four one-half—thirteen pitch holes in the back. Helicoil® inserts were used for all threads to insure a good bite in the cast iron[†].

3.1.4 Probe Support Post

It was deemed critical that the probe be held steady for obvious reasons. To this end all of our pre-experimental wisdom was brought to bear on producing a post with great stiffness and a tremendously fast damping rate.

The body of the post was an eighteen inch long section of rectangular steel tubing, six inches by four inches, with three-eighths inch thick walls as shown in figure 3-4. To stiffen the tube, a quarter inch thick plate was welded across the bottom of the tube with a water-

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[†] Threads cut into cast iron have a habit of stripping at the least provocation. Helicoil® manufactures stainless steel helical thread repair inserts. To use them, one must drill an oversized hole, tap it with their tap, and then screw in the insert. Once inserted, the stainless threads have a nearly indefinite lifetime, which is particularly useful in softer materials (such as cast iron or even plastics) and when threads have been accidently stripped.

tight bead running around the entire perimeter. The top of the post was cross braced by welding three-sixteenth by one-half inch strips of steel across opposite corners.

In order to fixture the post to the table a pair of runners were welded to the bottom of the post along the six inch dimension. At one end both runners were drilled and tapped for one-half inch by thirteen pitch bolts. The bolts were used to adjust the verticality of the post. The

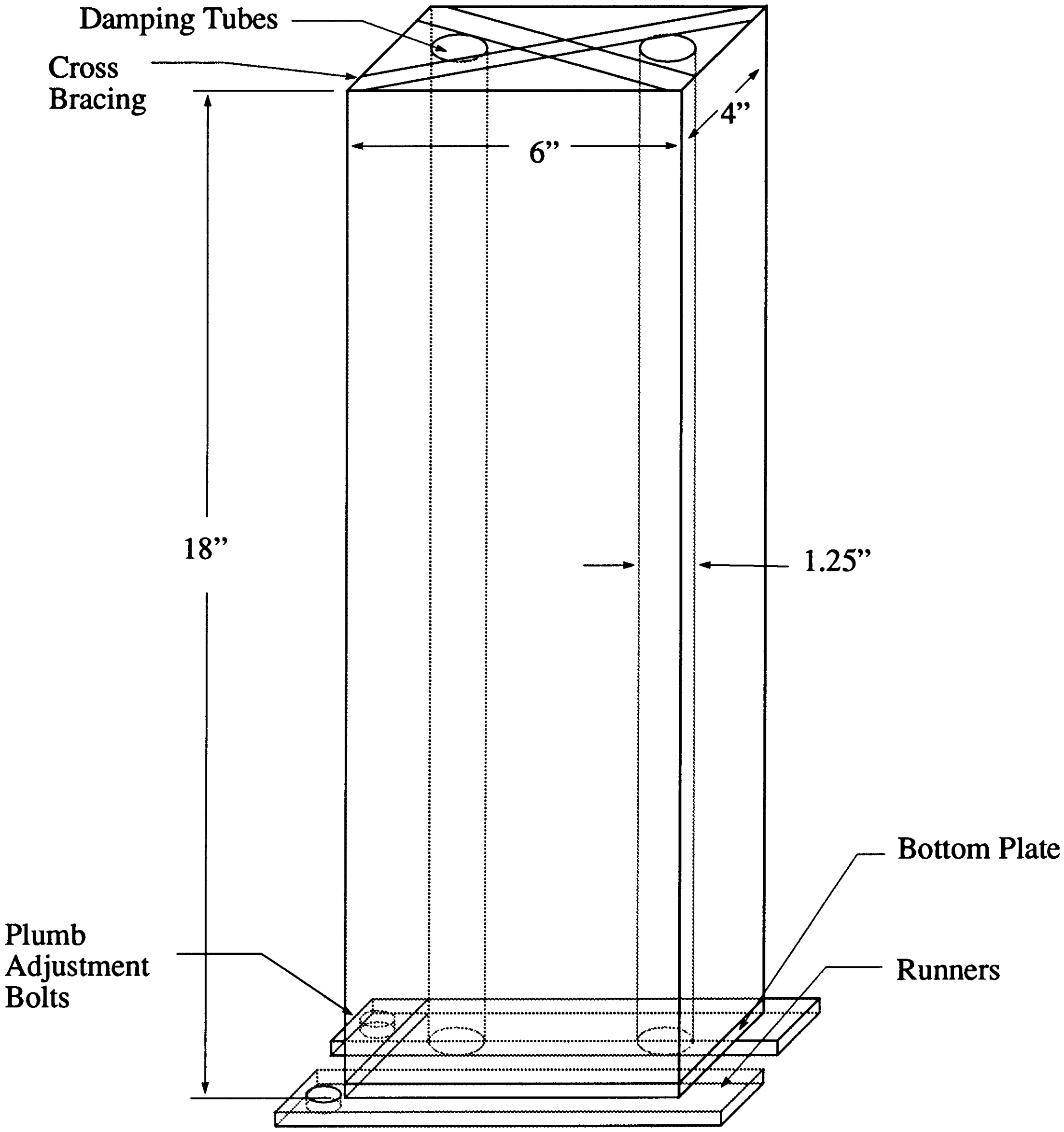

Figure 3-4: The Probe Support Post is made of heavy steel tubing with welded reinforcements. The post is filled with cast concrete and has two channels running the length filled with lead shot and oil to make the post "dead".

runners and bolts rode on inch thick precision ground parallels, which allowed three degrees of freedom to adjust the gap width and parallelize the face of the probe with the face of the sample.

In order to improve the stiffness yet further and to increase the damping capacity of the post, it was filled with concrete Before pouring the concrete, two steel pipes, one and a quarter inches in diameter, were greased and set into the post. Once the concrete hardened, the pipes were removed and the resulting channels were filled with lead shot and then oil to make the post "dead"—a construction technique used in optical bench posts. The result was very well damped, particularly at higher frequencies (above about 250 hertz).

3.1.5 Probe Clamp

The probe itself was held in a clamp (figure 3-5) made in two halves. with a half inch hole

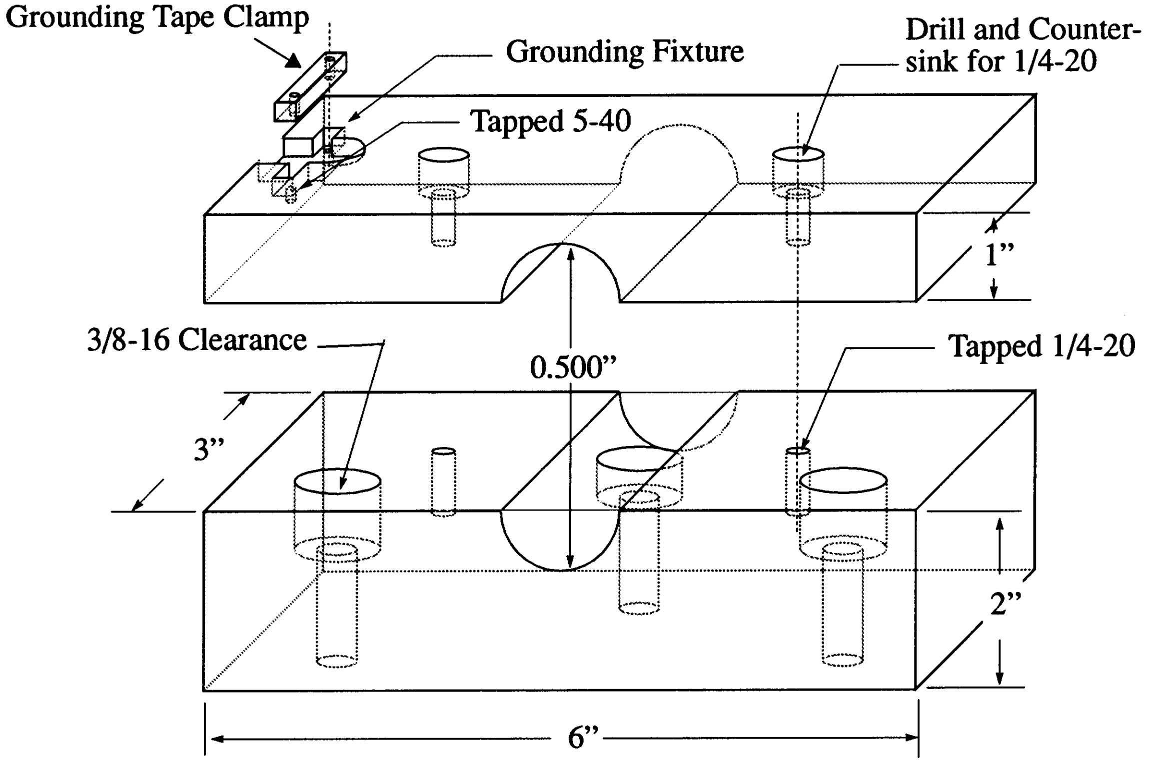

Figure 3-5: The Probe Clamp assembly. The 0.500" hole is bored to provide a slip fit with the probe.

reamed through the middle to fit the probe itself as closely as possible (in fact, a clearance of 0.002" was maintained). The clamp had machined into it a Grounding Fixture identical to the one in the Vise Face. Cast iron was selected for both the clamp and for an angle bracket used to mount the clamp to the Probe Support Post as it is known to have good dimensional stability and fairly good damping characteristics, as well as providing a stiff mounting point. All threads in both the clamp and the bracket were reinforced with Helicoil® inserts so that they could be reused if need be, and to allow higher bolt torque settings, which would have stripped cast iron threads.

The clamp was bolted to a cast iron angle bracket (figure 3-6) which was modified to allow

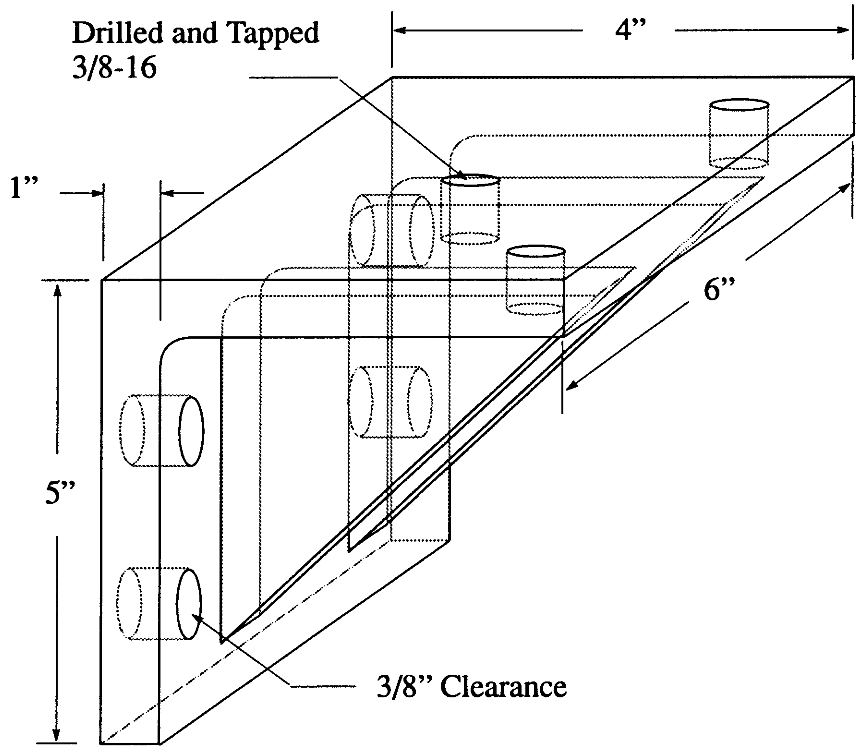

Figure 3-6: The Probe Clamp Mounting Bracket is an off-the-shelf flanged cast iron angle bracket with mounting holes drilled in it. The tapped holes are reinforced with Helicoil inserts.

it to be fixed to the post and to have the clamp bolted to it by drilling four holes through its five inch flange, and by tapping three holes in the four inch flange (with Helicoil® inserts).

3.1.6 Excitation Source

The mode of excitation was chosen to be an impulse as this was considered to be the most economical and feasible. A steel ball, approximately one inch in diameter was used as the "hammer". It was modified by welding a small stainless steel loop to the "top" from which the ball was suspended by means of a thin steel wire. In order to soften the blow, the ball was dipped in Plasticote®, thus enhancing the excitation of lower frequencies. The ball was hung from an aluminum frame shaped like an inverted "L" and bolted to the side of the test bed.

At the point where the arc of the ball's swing met the upright of the "L", an electromagnet made from a bolt and about twenty yards of magnet wire was mounted. The magnet was powered by 110 Volt AC wall current, rectified by a twelve amp bridge, and smoothed by a huge capacitor. The magnet was turned on by a momentary-on switch, and the ball was released when the magnet power was cut. The switch cut power before the variable transformer to reduce AC line noise during the measurement.

3.1.7 Assembly

Great care was taken during the assembly to insure that the entire structure was as stiff as possible and that there were no stray resonances which might throw off the measurement.

The vise and table were chemically cleaned and then epoxied together as well as being held by the six mounting bolts. Bolts in opposite corners of the vise were sequentially tightened to the maximum torque reasonably achieved with hand tools.

The Probe Support Post was set on a pair of ground parallels to allow forward and backward motion without disturbing the height and pitch adjustments. The angle bracket was bolted to the post by means of a pair of long three-eighths inch fixturing rods which connected the four through-holes in the bracket to a pair of steel "C" channels on the opposite side of the post. The bracket was held by nuts on either end of the four fixturing rods.

The Probe Clamp was bolted to the bracket. Then the capacitance probe was laid into the bottom half of the clamp. It was adjusted to extend from the face of the clamp by a few hundredths of an inch. A drop of Duco Cement® was used to ensure that the probe would not drift in the clamp without risking damage when the time came to remove the probe. The top half of the clamp was bolted on.

Using the two plumb adjusting screws on the back of the post (and a lot of patient struggling), the probe face was made parallel to the surface of the sample. The post was then bolted to the table by means of fixturing clamps[†] for which a set of tapped holes was drilled in the table.

It was deduced that the table itself would be excited in resonance with the oscillating sample, so to minimize the energy of this oscillation transmitted to the post, a "sand box" was built around the post. Approximately one hundred pounds of sand was poured into a wooden box glued around the post. The edges of the box were sealed with caulking compound and five or six quarts of oil was poured over the sand to couple the table's vibrations through the entire mass of the sand.

In order to "settle in" the sample in the vise following each sample change, a long procedure was rigorously followed. First the sample was set into the vise and gib tightened to about ten foot· pounds of torque. Then the sample was struck fifty times with a soft mallet. Then the gib was tightened to about twenty foot· pounds of torque, and the clamping bar over the gib was tightened to about ten foot· pounds, following which another fifty blows were struck. The procedure was repeated until a torque of about 50 foot· pounds was reached on both the gib and the clamping bar.

[†] Fixturing clamps are blocks and threaded rods used to fixture parts for machining. They generally consists of a set of blocks with dozens of little steps cut into them, a set of bars with matching steps cut in them and a hole in the middle, and a set of threaded rods of various lengths which fit through the holes. Machine tools generally have "T" slots cut their ways, and "T" slot blocks are provided with threaded holes for the bottom ends of the rods. Nuts clamp down the bars, threaded onto the top ends of the rods.

This procedure, long as it might seem, was found to be necessary to prevent the sample from shifting closer to the probe after each blow (which the probe was sensitive to). The shift following an impact when the sample had simply been clamped into place was on the order

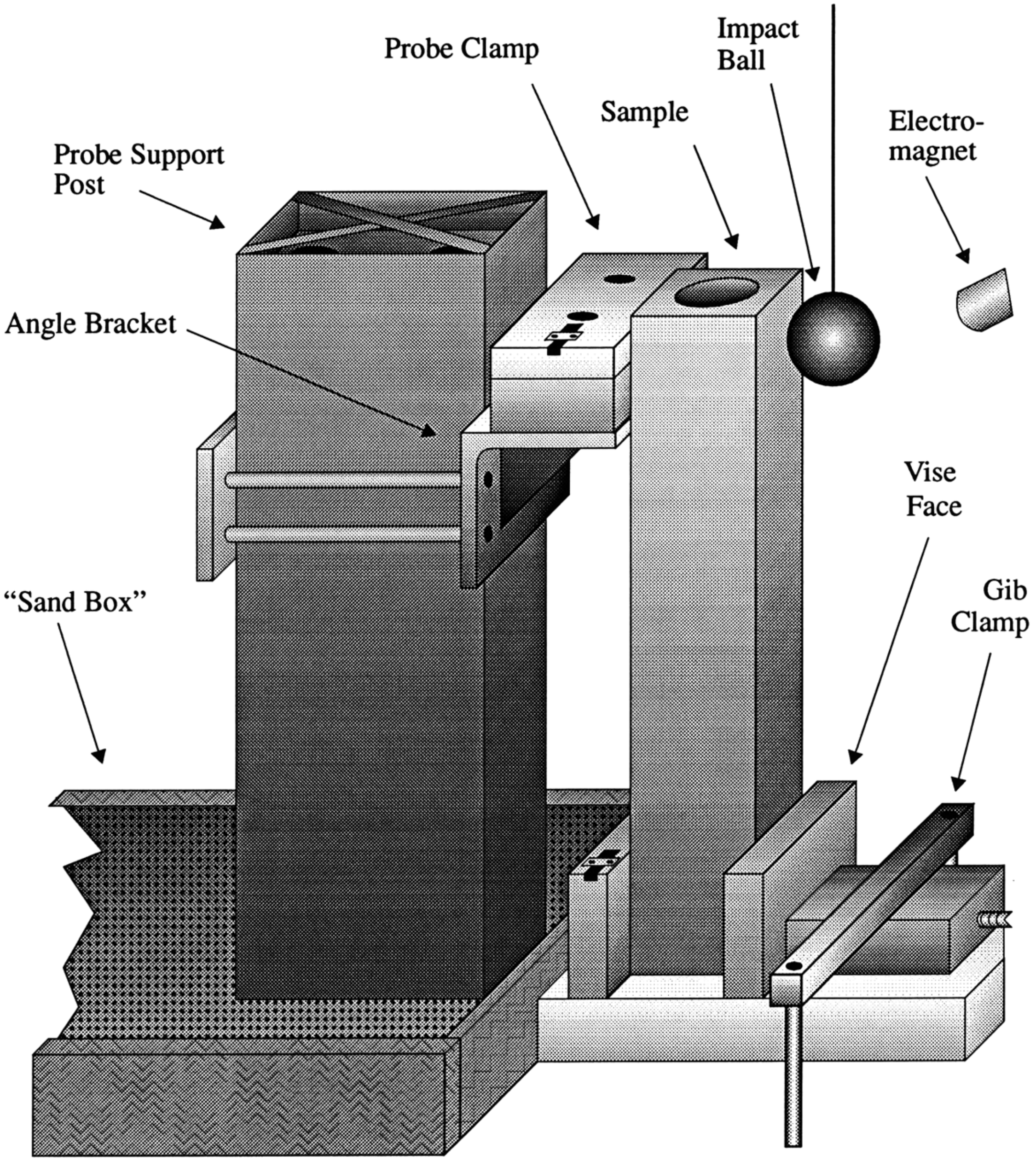

Figure 3-7: A stylized three dimensional view of the entire test assembly. Critical components are described carefully in the text.

of 0.001 - 0.005". Since the entire range of the probe is only 0.004", this level of shift was unacceptable. Following the settling-in procedure the shift was generally inconsequential.

Figure 3-7 shows a somewhat simplified view of the test assembly where non-essential details have been left out for the sake of clarity, and perspective has been ignored by necessity. Each of the labelled parts is described in function and dimension in the preceding text.

3.2 Instrument Chain

The instrument chain was required to perform three important tasks for each test run: first, facilitate proper calibration of the standoff for the capacitance probe (0.005"); second, allow easy assessment of problems with the test process; and third, record the necessary data.

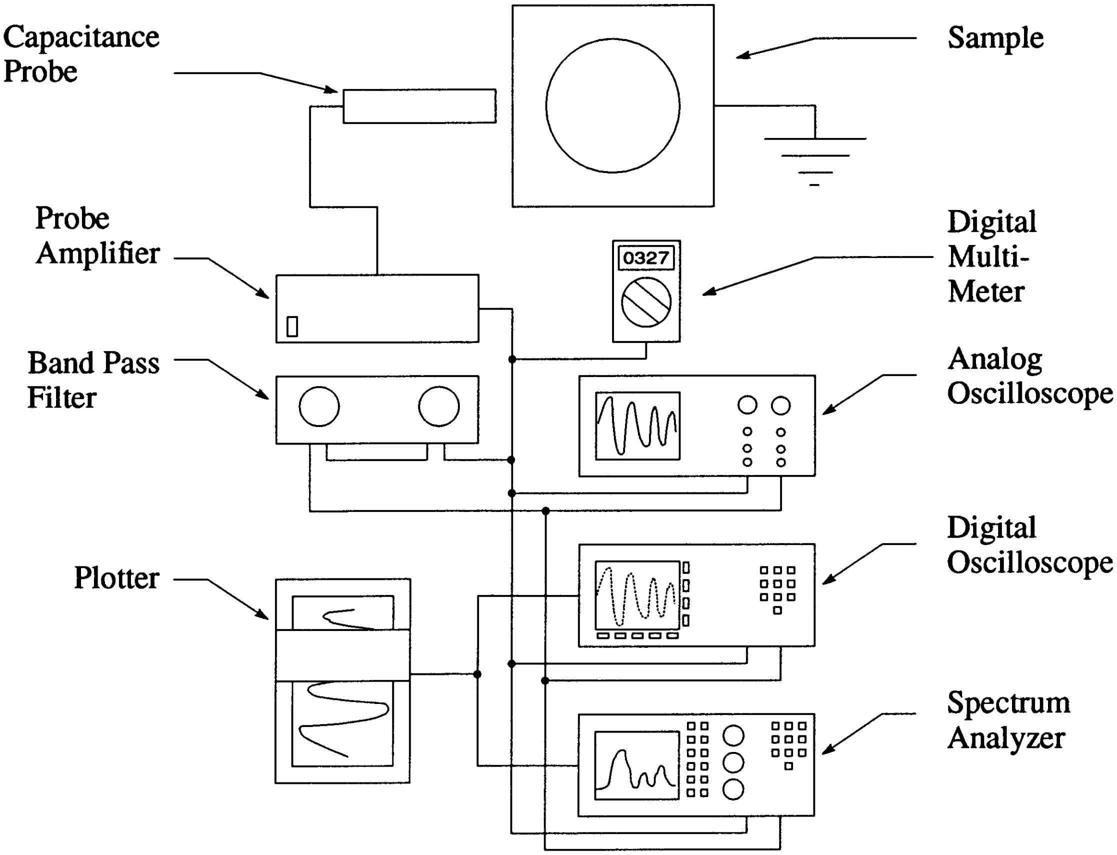

Figure 3-8: The instrument chain and wiring diagram.

3.2.1 Capacitance Probe

The transducer used in this experiment was a capacitance probe. The probe senses the slight variation in capacitance as a function of the distance between the probe face and a conductive surface. Our probe was manufactured by Pioneer Technology of San Jose, CA. The probe had an effective range of 0.003" - 0.007", which required fairly precise alignment between the probe and the sample.

Capacitance probes measure distance rather than velocity or acceleration, and so are fairly linear in their response from DC to their frequency limit of about five hundred hertz. Their limitations as transducers in vibration measurement come from the narrow gap in which they operate (0.004")[†] which limits dynamic range, and from their narrow frequency response.

The probe itself works in conjunction with an amplifier also manufactured by Pioneer Technology. The amplifier sends an high frequency AC signal and generates an output signal proportional to the current flow to ground across the effective capacitor between the parallel planes of the probe and the sample face. The amplifier/probe combination has a cumulative noise floor of about five millivolts, and generates about five volts per thousandth of an inch change in the gap. The effective noise floor is therefore at approximately one millionth of an inch relative displacement, or one part in four thousand.

3.2.2 Filter Network

In order to clean up the incoming signal, it was passed through a band pass filter which was set to maximize response around the primary harmonic. The response of the filter is graphed in appendix D.2 for each of the settings used. For the metallic samples a high pass setting of 90 hertz and a low pass setting of 750 hertz was selected to allow maximum response around the 200 to 350 hertz primary harmonic. The non-metallic samples both had

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[†] The granite sample actually struck the probe, breaking the glue which held it in place. In order to measure granite, the gap had to be adjusted to near the widest possible setting, which limited dynamic range severely.

primary harmonics centered at around half that figure, and so the filter settings were adjusted to approximately 15 hertz for the high pass, and 350 hertz for the low pass filters.

The filter was an analog type with two separate patches, each individually adjustable. Even with care taken insure that the minimum attenuation coincided with the primary harmonic, the signal still suffered a fifteen decibel loss passing though the filter.

3.2.4 Digital Oscilloscope

Hewlett Packard was nice enough to lend an HP 54110D Digitizing Oscilloscope with color display for this project. This oscilloscope is rated to one gigahertz, and claims an effective ten bits of resolution.

Two modes of capture and output were used. One allowed the capture of two channels simultaneously triggered, and then simultaneously displayed. This feature generated the paired time space graphs shown in appendix E. depicting filtered and un-filtered response for each sample. The second mode allowed the storage of four traces in memory, which were plotted overlaid. These also appear in appendix E., and generally indicate an absolutely incredible degree of repeatability.

Due to the magnification factor used to properly window the traces, the graphs only yield about seven bits of resolution. This limited the usefulness of the full time range of the data. The trace record length was chosen to be 250 milliseconds, but for all of the metallic samples only the first 100 milliseconds were significant.

3.2.5 Spectrum Analyzer

An Hewlett Packard HP 3562A Dynamic Signal Analyzer was used to analyze the power spectrum of the data. The spectrum analyzer was used in a mode similar to the dual trace mode of the oscilloscope, where two active channels grabbed the filtered and un-filtered signals at the same trigger. Both of these traces are plotted for each sample in appendix E., showing the effect of the filter on the power spectrum, and providing information on the relative amplitudes of the various frequency modes.

The analyzer was set up to provide a linear measurement of the power spectrum from one hertz to 500 hertz. An Hanning window was used to minimize the generation of spurious harmonics. The input was AC coupled to minimize the effects of DC drift and movement. The input range was 5.02 Volts peak to peak, with the record being triggered by a 303 millivolt threshold.

3.2.6 Additional Components

In order to facilitate easy calibration and quick analysis of problems, a digital multi-meter and a Tektronix 2465A oscilloscope were connected to the signal train. Since the output of the capacitance probe system was proportional to distance, it was an easy matter to set the gap between the probe face and the sample to within a few millionths of an inch by watching the output voltage on the multimeter.

The final output from both the digital scope and the spectrum analyzer was recorded on an Hewlett Packard ColorPro Plotter.

Chapter 4

Procedure

4.1 Experimental Procedure

A rigorous procedure was developed during the testing process in order to quickly and accurately collect the data from fifty four individual samples. Over the course of several days of testing, some one hundred and sixty two data graphs were drawn (which appear in their grand entirety in appendix E.).

Each test began with settling-in the sample[†]. Once that was achieved, the probe had to be aligned with the sample face. Although each of the samples had been sanded to provide a good surface to measure from, each sample was a little different in shape. Probe alignment required the use of the digital multi-meter which, being hand-held, could be set in a convenient place to watch the display while adjusting the gap distance. Parallelism was adjusted by eye, and rarely needed readjustment.

Once the sample and the probe were aligned and clamped down, the test instruments were armed. Under certain conditions the AC line current fluctuation caused by switching the electromagnet on would trip the instruments: on alternate test runs, the release pulse would trip them. Putting the instruments on an UPS[‡] only worsened matters as the UPS circuit was tripped by the line pulse, which, as often as not, completely shut down the instruments. An impromptu treaty was reached by running an extension cord across the room to a special power line installed for a sensitive computer system. It seems somewhat inappropriate that $55,000 worth of equipment would be incapacitated by a small line surge.

A trial run was recorded for each sample. The time space information (recorded by the digital oscilloscope) was used to determine proper scaling factors and to check how well set-

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[†] The settling-in procedure is described in detail in chapter 3.1.7.

[‡] Uninterruptable Power Supply—with a high level of surge suppression.

tled-in the sample was. The frequency space information was used to confirm the filter settings, and to check for surprise resonances (which might indicate a loose bolt or fitting).

If all went well, a full record was taken on both the analyzer and the ‘scope for both the filtered and un-filtered signals (which accounts for four of the five graphs for each sample). If the sample hadn't drifted too badly (which it generally didn't if the settling-in procedure was followed correctly), then four more records were captured in the memory of the ‘scope. These four separate records are plotted superimposed on the remaining graph given for each sample. For most of the samples the four traces line up nearly perfectly, indicating an extraordinary level of phase cohesiveness and repeatability.

4.2 Data Reduction

Collecting the data was actually a very small part of the overall analysis. It was not possible to fully automate the data reduction process[†]. The oscilloscope that Hewlett Packard lent us could not be interfaced to any of the computers in our lab, and so the process of taking the data from the fifty six graphs and entering it into a computer for analysis was done entirely by hand.

It was decided to grid the peaks of the decaying oscillations as being representative of the decay envelope. A transparency with a grid printed on it was used to find the coordinates of the oscillation peaks, which were entered one by one into a computer.

The overall envelope is defined by some combination of exponentially decaying, linearly decaying, and periodic envelopes. Since the goal of this project was to generate a ranking of the various decay rates, it was decided to try to pull out only the exponential term (which corresponds to a viscous decay function). A simple least squares curve fit to an exponential (as implemented in Cricket Graph®) was overwhelmingly biased by the amplitude of the early periodic beats in the envelope. The result was a $t = 0$ intercept at about half the original am-

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[†] See chapter 6, especially 6.1 for a description of what I would have liked to have done differently.

plitude.

A slightly modified version of the least squares fit algorithm was implemented as a Microsoft® BASIC program which clamped the amplitude at $t = 0$ at the amplitude of the first peak. This drastically improved the correspondence between the quantitative results and a qualitative comparison of the graphs, but was not fully satisfactory.

It was observed that the data had not been normalized (inconsequential) and had not been zeroed to the base line (quite significant). The curve fit program was modified to generate an error value as the absolute average of the differences between the curve fit and the original data. The linear displacement was then adjusted in small steps to minimize the error function. At the error minimum, the value of the exponent was returned. It was assumed that, since the variant term was linear, there would be no local minimums to confuse the program. The ranking as determined by the program is entirely in agreement with a qualitative visual assessment of the damping rates.

The program, named *Clamp Fit*, is listed in its entirety in appendix C. and was used to generate all final results. The process the author used to generate the data tables (not entirely recommended) was to enter the data into the Cricket Graph® which allowed easy visual inspection for erroneously entered datum, then to convert the data into a text file using Microsoft Word® where the proper format characters could be inserted. *Clamp Fit* then opened the text files and read the data.

Chapter 5

Results

5.1 Time-Space Interpretation

Clamp Fit used data entirely from the time domain. Unfortunately, the time domain is extremely chaotic due to the huge number of beating frequencies. This program implicitly assumed the equation of the envelope to be of the form

$$A(t) = A_0 \times e^{-\alpha t} + b \ , \tag{5.1}$$

where the data fit to this curve is taken from the peaks of the decaying sinusoidal equation defined by

$$A(t) = A_0 \sin(\omega t + b_1) \times e^{-\alpha t} + b_2 \ . \tag{5.2}$$

The result of this function (with arbitrary phase, frequency, amplitude and decay rate) is shown in figure 5-1. The circles in the figure represent the points that would have been entered into the computer as datum. The top left point would have been entered as A_0 at a time t_0. The remaining data would be normalized to fit these initial conditions. As one look at the

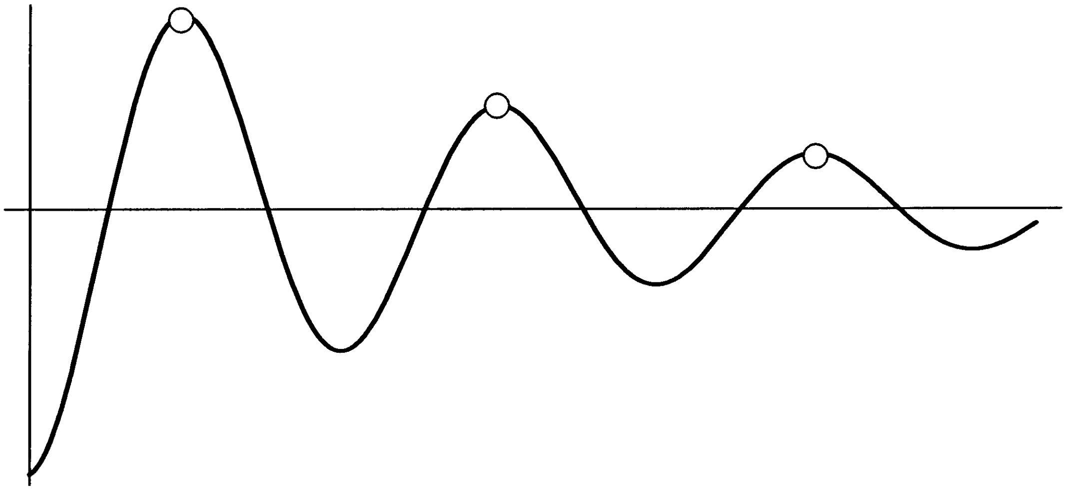


Figure 5-1: Idealized waveform which *Clamp Fit* is programmed to recognize and fit to. The circles represent datum that would be entered into the computer.

graphs in appendix E. will make apparent, the data entered shared little resemblance with this idealized version.

5.2 Calculated Relative Impulse Damping Rates

It is difficult to summarize fifty four data points in single graph and make it both intelligible and quantitatively useful. Numeric data are presented in appendix A. where the first column, in millihertz, is the exponent, α, from equation 5.1.

The data will be presented in two formats: a list of bar-graphs and a density plot.The bar graphs will probably be most useful for an engineer who is attempting to design a machine or tool. The density plot gives a quick qualitative overview of all the data collected.

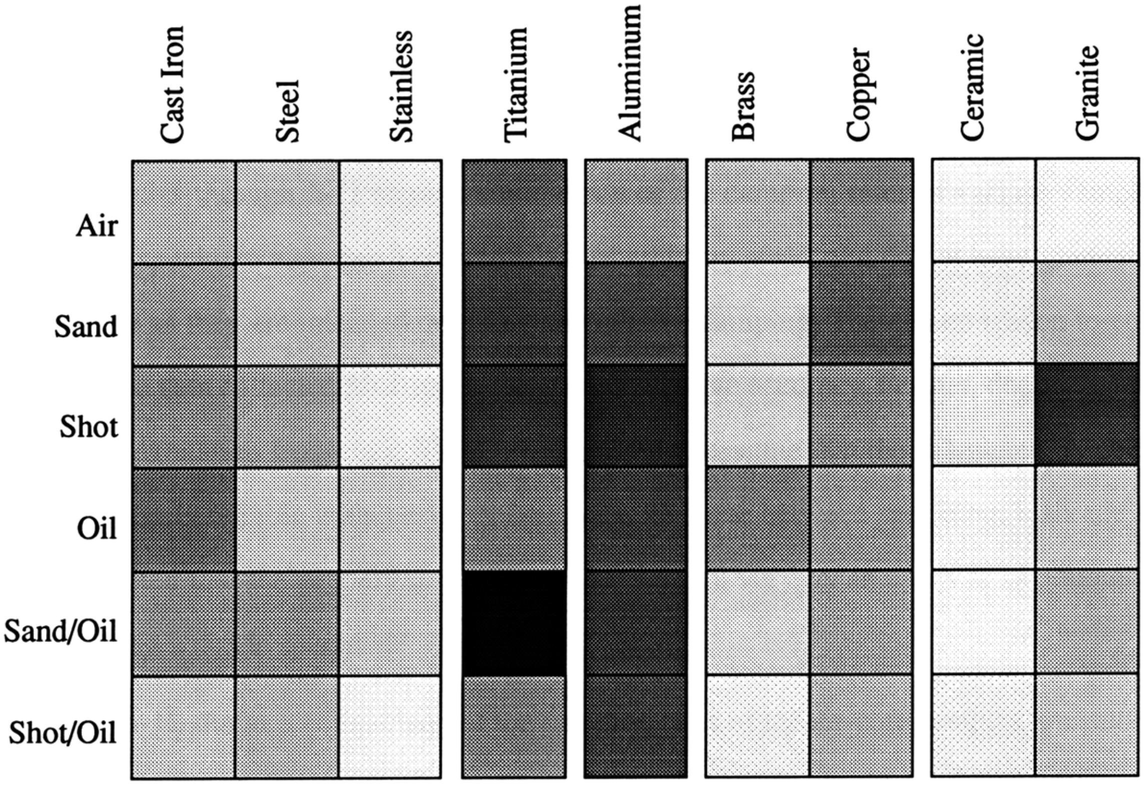


Figure 5-2: Density plot summary of data. Darker squares indicate faster damping rates. Blocks are grouped by material type.

It is clear from the density plot that no universal generalizations about the effects of core materials are universally valid, which is not surprising considering the complexity of large scale dislocation and movement across boundaries and into inhomogenous materials.

It is important to note that the frequency of the primary harmonic of aluminum was at approximately 400 hertz, which is right near the upper limit of the frequency response of the probe. It is also curious that as the frequency of the primary harmonic decreases (444 Hz with air, 330 Hz with lead shot and oil), the initial displacement measured increases (310 mV with air, 390 mV with lead shot and oil), indicating that the aluminum-air sample oscillates at a rate above the functional ceiling of the test. It is also important to consider that since the damping coefficient that is being solved out of the equation is velocity dependant, that the damping rate would necessarily be faster for higher frequencies at the same range of displacement.

Titanium, notably, damps about twice as well as any other material measured.

Figures 5-3 through 5-11 show a comparison of the damping rates of various samples grouped by specimen material. The graphs are of arbitrary scale, and do not have graduated vertical axis as they are intended only to show relative damping. There is no reason to consider that the data collected is of any better than qualitative accuracy. Further, due to the differences in excitation frequency, it is not really valid to assume that the calculated damping rates are entirely reliable within a given specimen, let alone between specimen. It should be carefully noted that the primary excitation frequency can vary by as much as two hundred hertz—within a single specimen[†].

Figure 5-12 shows a comparison of the damping rates of the air-core samples, indicating the range of values between materials. The damping rate of the Probe Support Post is also included. It is interesting to note that the post, with all the effort expended in making it as dead as possible, is still only slightly better damped than an empty titanium bar, and not near-

---

[†] The granite-air sample's primary harmonic was measured at 70.8 Hz, while the granite-sand/oil sample oscillated primarily at 268 Hz, a difference of 197 Hz.

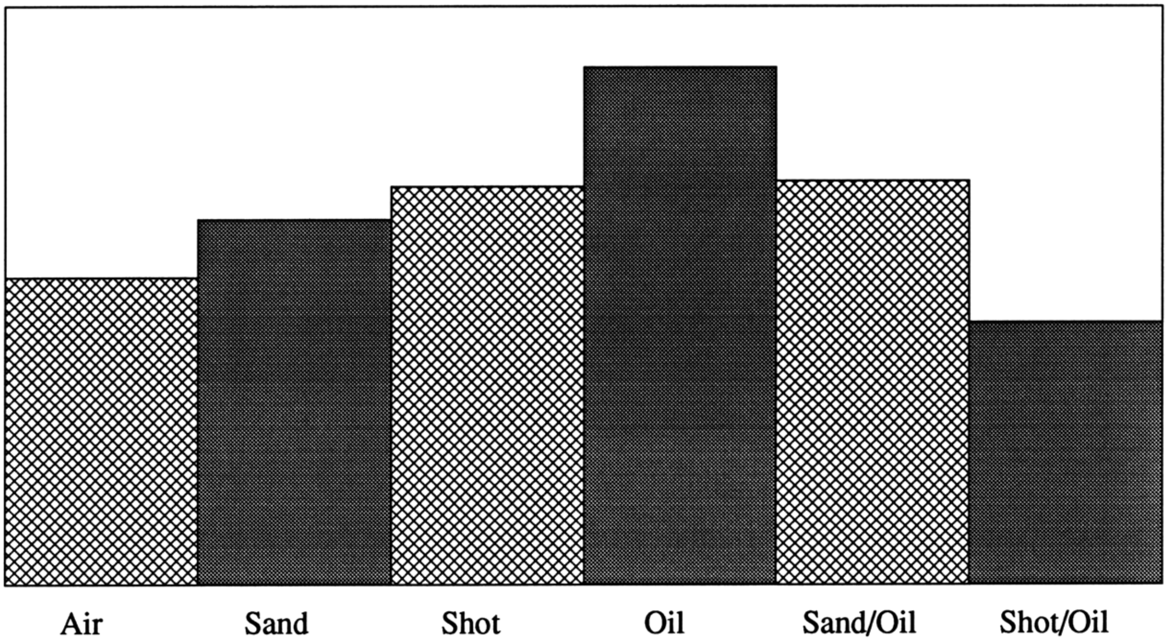


Figure 5-3: Bar graph comparison of the damping rates for cast iron.

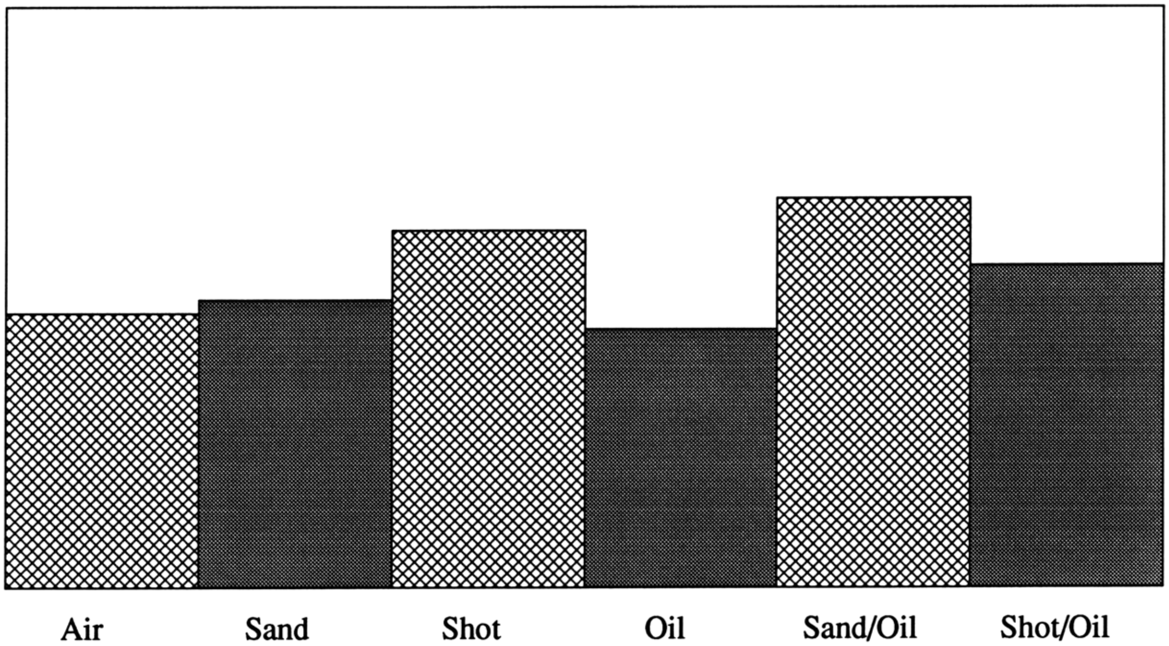


Figure 5-4: Bar graph comparison of the damping rates for steel.

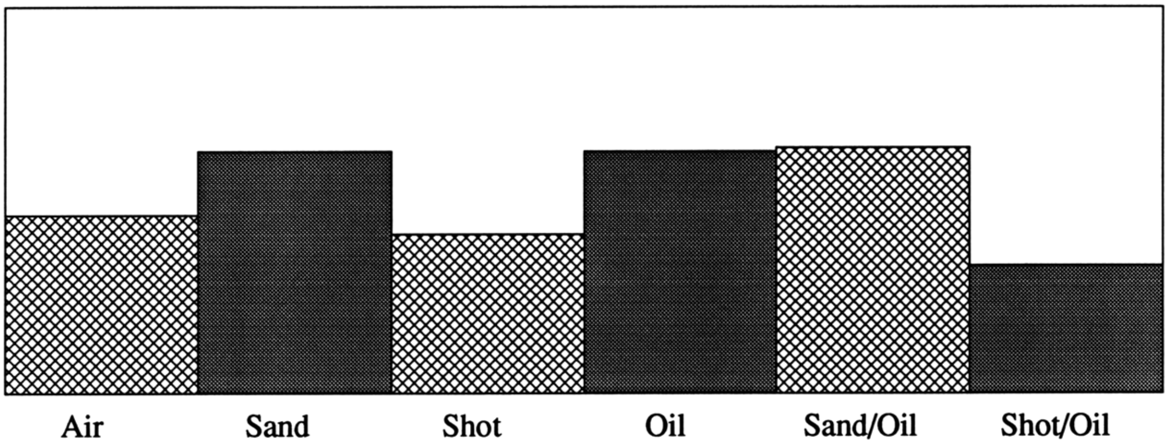


Figure 5-5: Bar graph comparison of the damping rates for stainless steel.

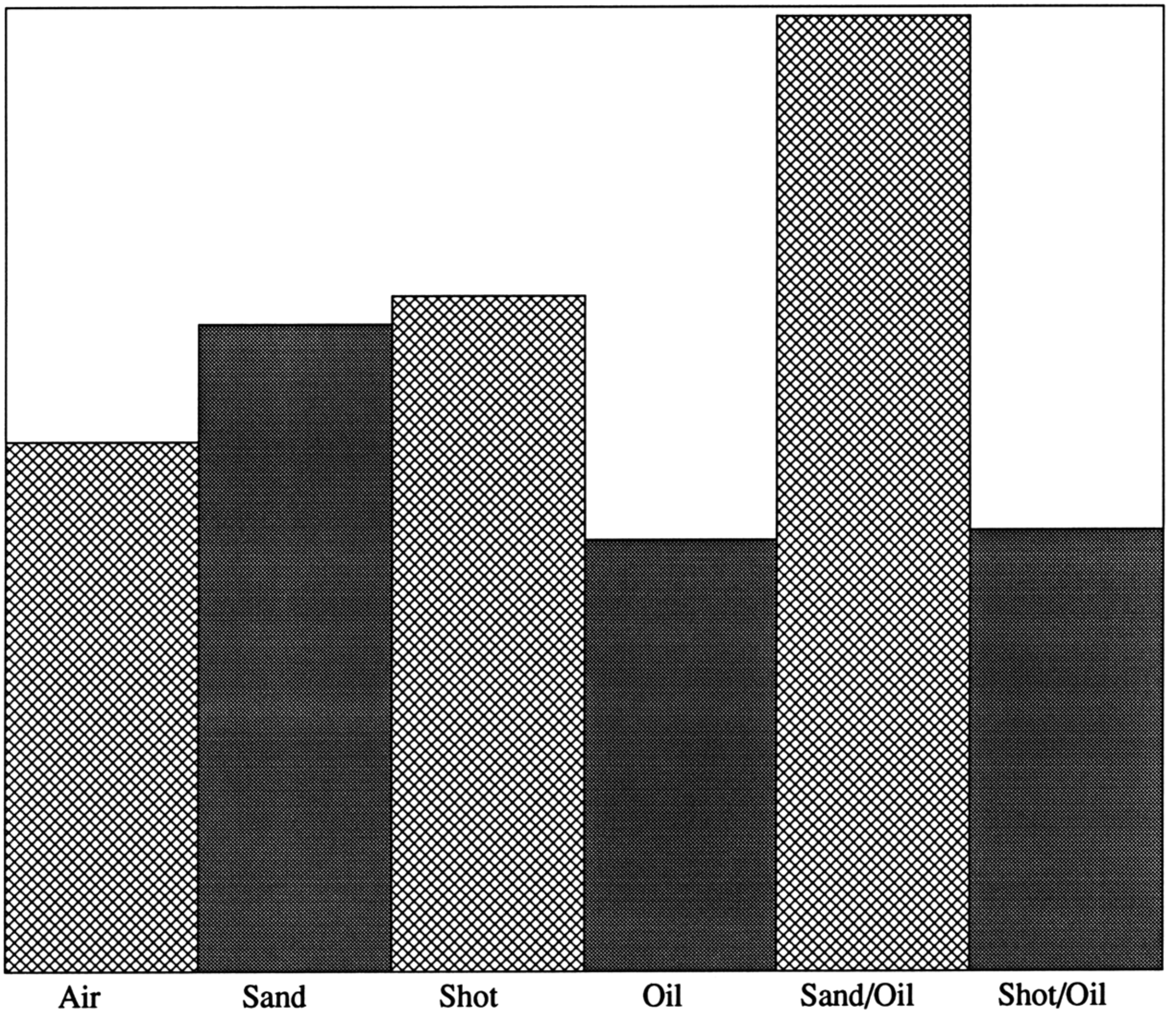


Figure 5-6: Bar graph comparison of the damping rates for titanium.

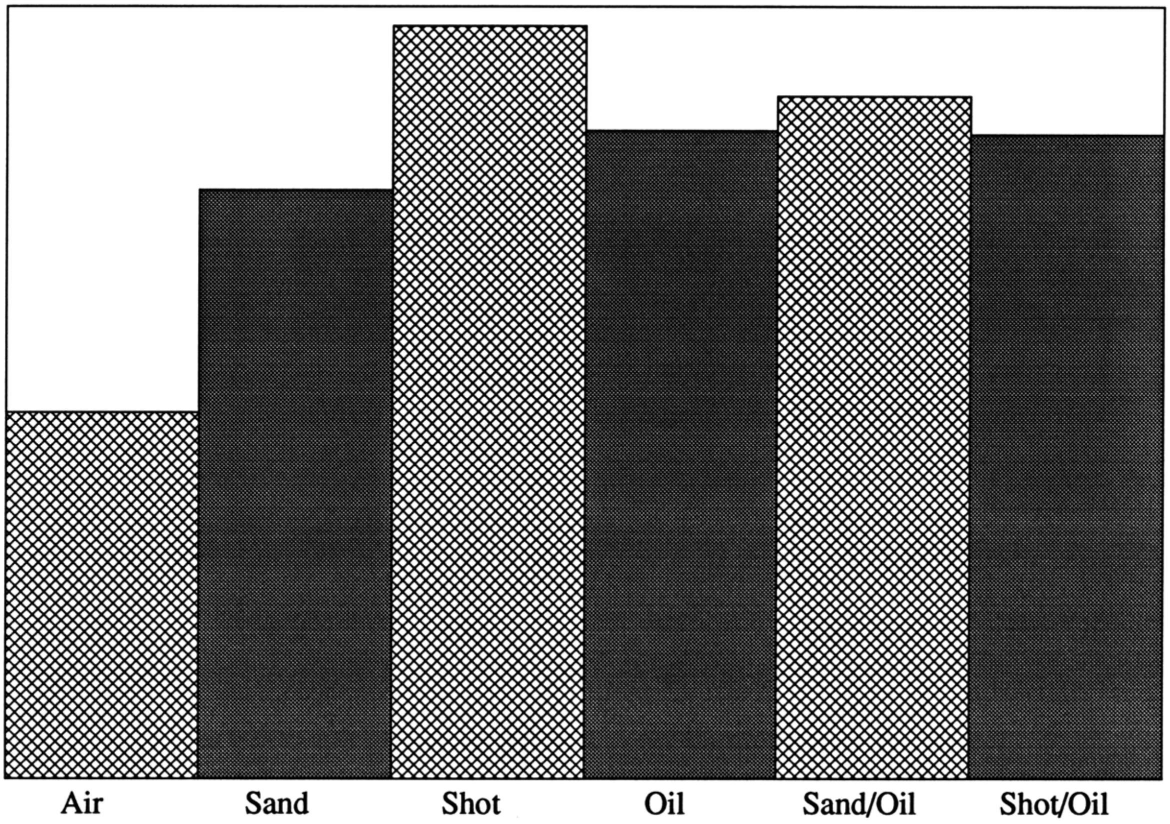


Figure 5-7: Bar graph comparison of the damping rates for aluminum.

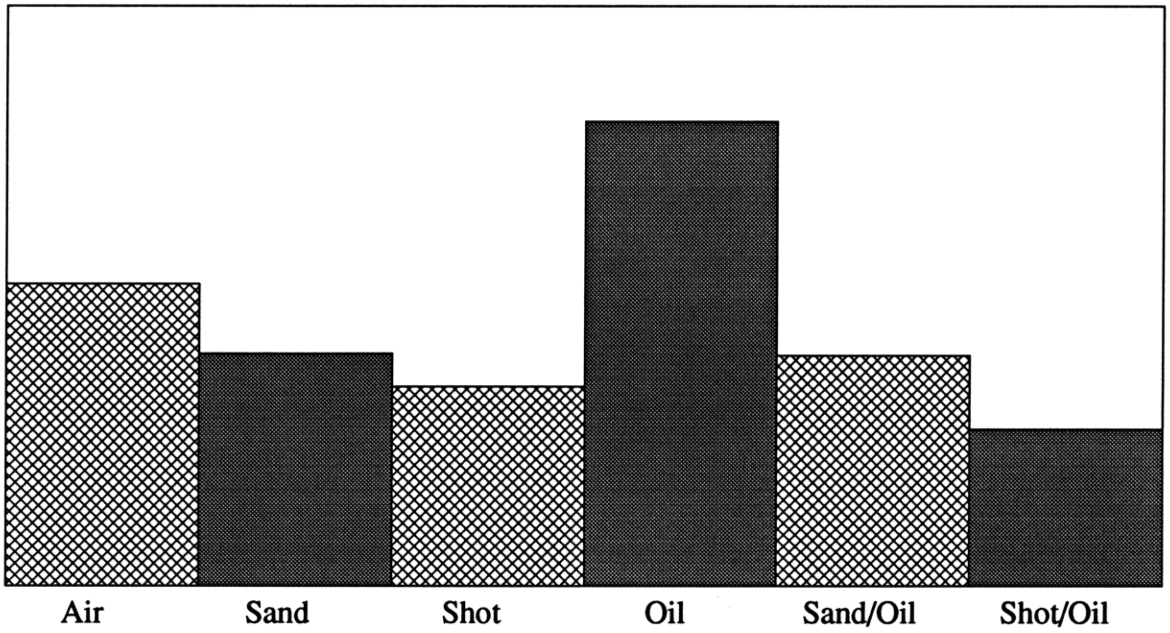


Figure 5-8: Bar graph comparison of the damping rates for brass.

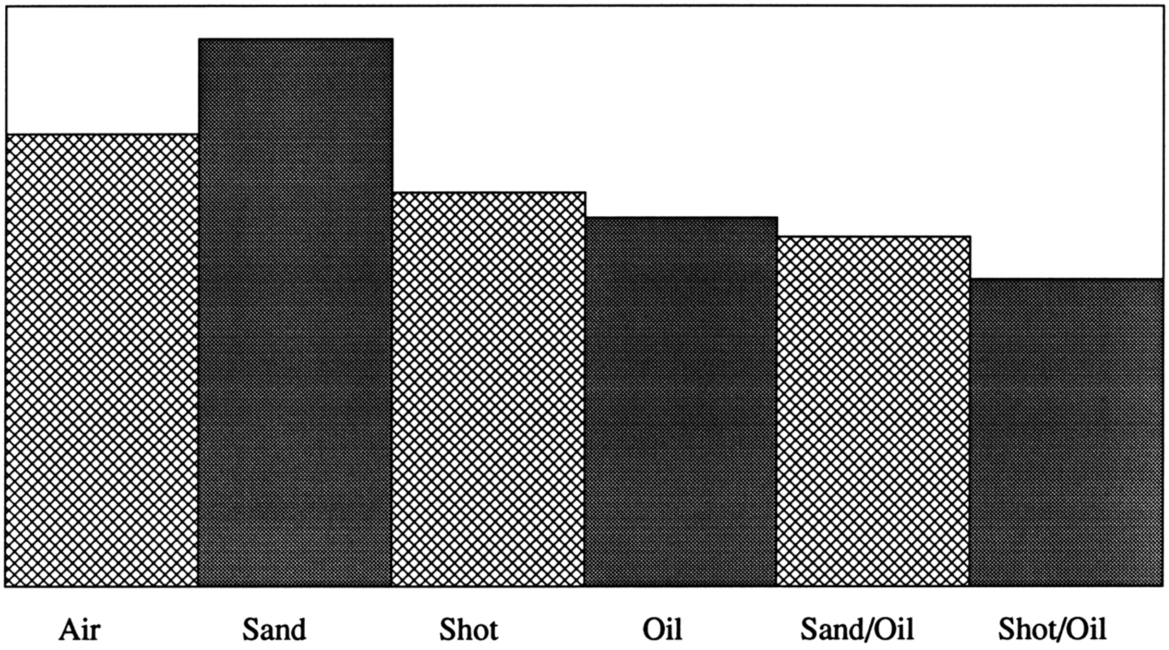


Figure 5-9: Bar graph comparison of the damping rates for copper.

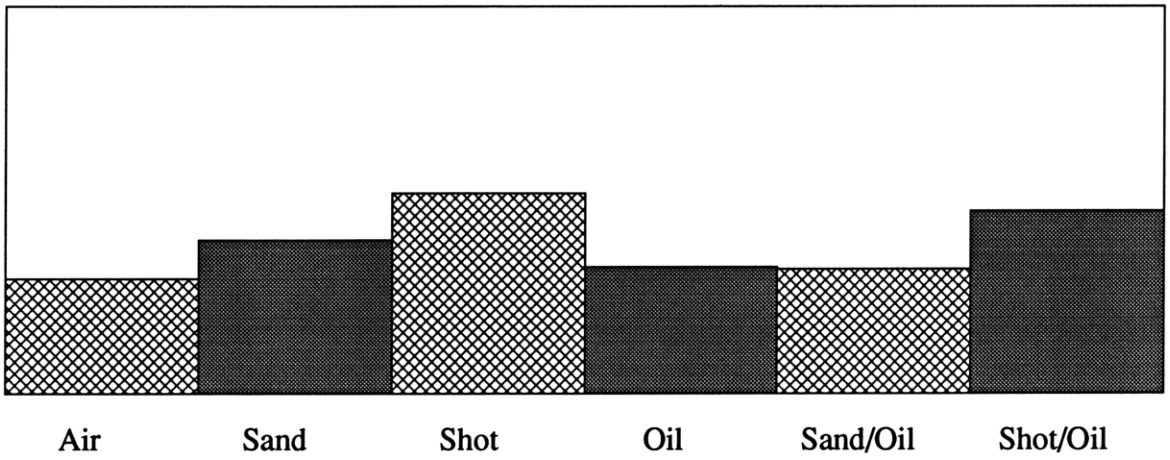


Figure 5-10: Bar graph comparison of the damping rates for ceramic.

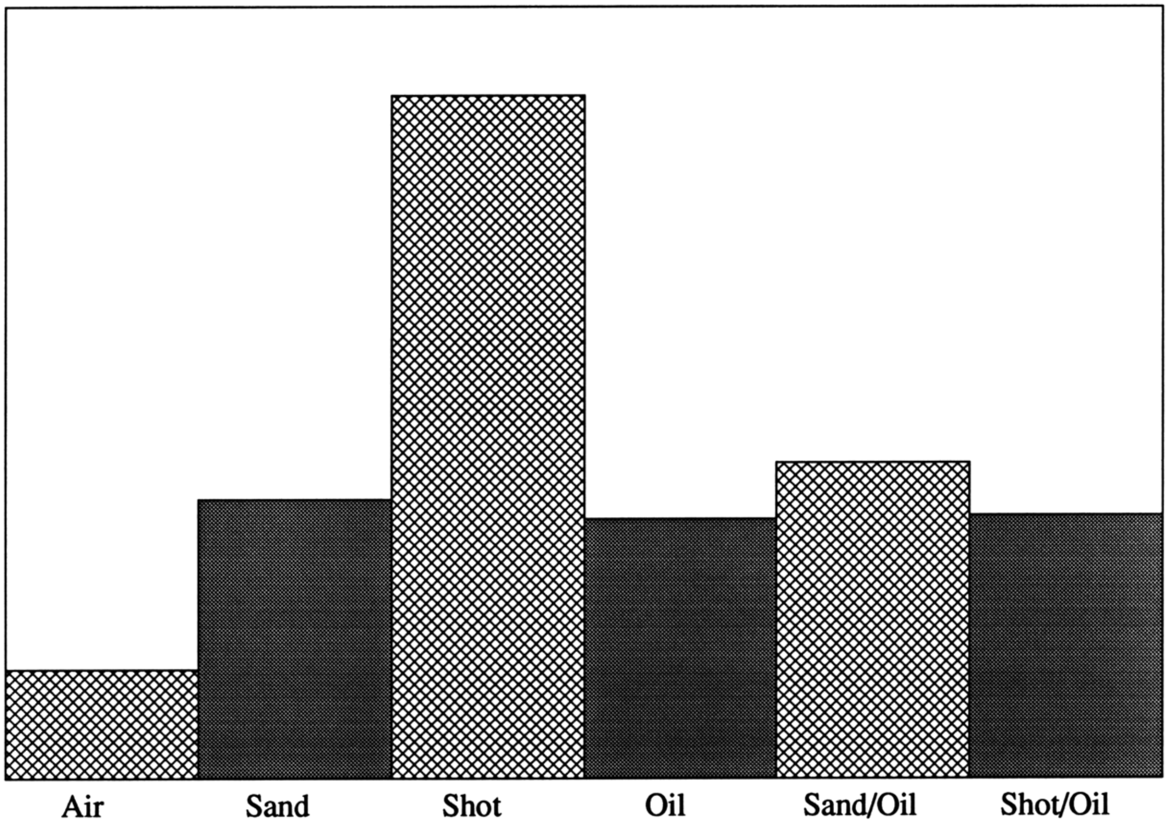


Figure 5-11: Bar graph comparison of the damping rates for granite.

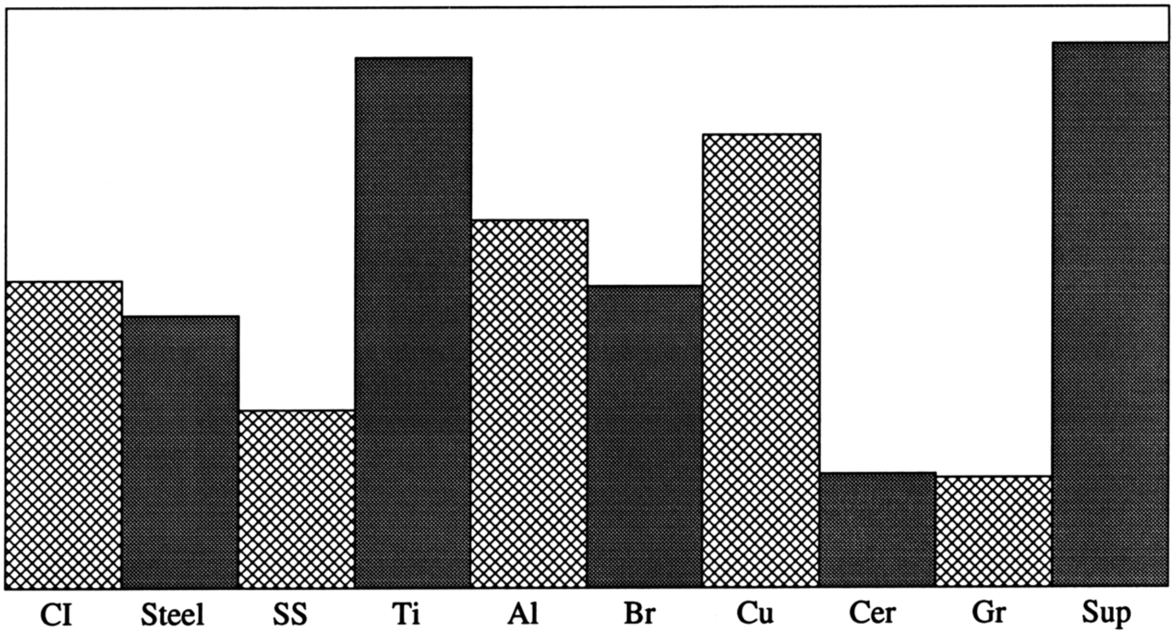


Figure 5-12: Comparison of damping rates of all samples with air cores and support.

ly so well damped as titanium and sand. On the other hand, the post is significantly better damped than any of the steel samples, even though its shape would tend to allow bell-like vibrations (as in tubular bells).

5.3 Frequency-Space Interpretation

A great deal of information about the damping characteristics of the samples was encrypted into the frequency-space graphs. Remembering that the frequency width of an impulse is proportional to the inverse of its lifetime, one can, with surprising success, measure directly from the frequency space graphs the lifetime, frequency, and amplitude of each excited resonance.

The exact relationship, assuming a gaussian distribution around the center frequency, is that the full width of the frequency-space peak at 1/e of its maximum is the inverse of the time it would take for the pulse to decay to 1/e of its initial amplitude in time-space. Unfortunately, there is a significant amount of noise in the frequency-space, which would preclude using this measurement system with any hope of significant accuracy. Another problem would be in determining a useful system of comparing the values so determined.

As a simple example, take the ceramic-air sample. At the beginning of the pulse the amplitude on the graph measures 3.3 centimeters[†] at 72 Hz. A measurement of the frequency width yields approximately 9.2 Hz[‡]. If we fit these numbers into equation 5.2, but rewritten as

$$A(t) = \mathrm{Hgt} \times \cos(2\pi f t) \times e^{-\mathrm{width} \times t} \quad , \tag{5.3}$$

where "Hgt" is the height of the pulse, "f" is the frequency and "width" is the width of the pulse in frequency space and graph A(t) we get Figure 5-13. Excitingly enough, though these numbers were actually measured right off the frequency space graph, the overall decay time of even this simple pulse is fairly close to the actual pulse decay in appendix E.

[†] We might as well use centimeters as millivolts since we are only interested in the relative amplitude.

[‡] For the frequency we will stick to exact units so our result will come out in seconds.

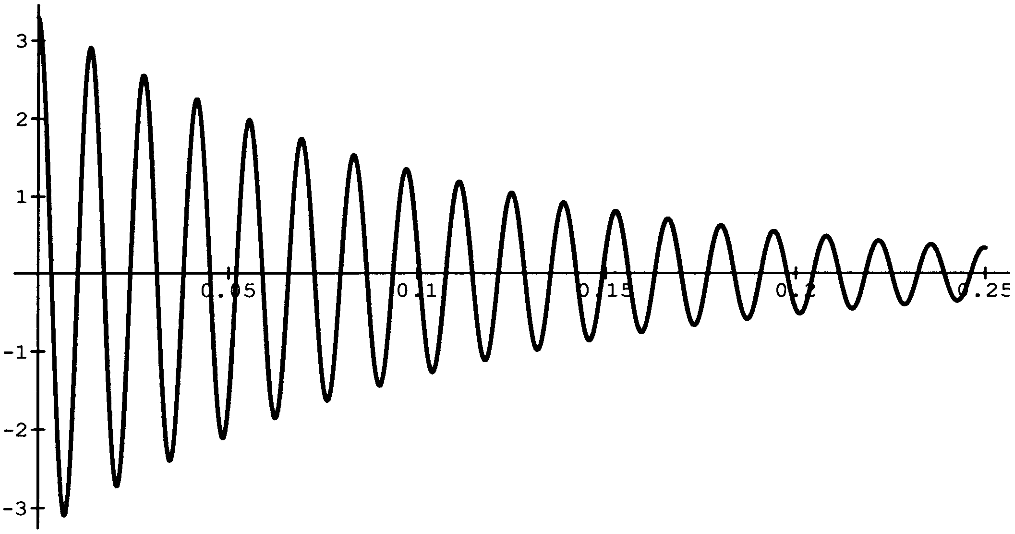


Figure 5-13: Plot of equation 5.3, representing the primary harmonic of the ceramic-air sample.

Clearly, looking at the frequency space graph, the primary harmonic is only slightly dominant over a tremendous number of frequencies all working together. If we fit the measured values of the biggest peaks into

$$A(t) = \frac{H_1}{\omega_1^2}(\cos(\omega_1 t)e^{-W_1 t}) + \frac{H_2}{\omega_2^2}(\cos(\omega_2 t)e^{-W_2 t}) + \text{et...}, \qquad (5.4)$$

where H_1 and H_2 are the measured heights of the peaks, the ω's are the center frequencies of the peaks, and the W's are the widths in hertz for, say, the six dominant peaks in the ceramic-air sample, the plot would look like figure 5-14[†].

Figure 5-14 is especially interesting when one considers that the horizontal axis, the time axis, is scaled in seconds, and that the calculated wave form is surprisingly similar to the wave form of the real time-space graph in appendix E., even from an extremely limited six term equation. It was assumed that all phases are at a maximum at t = 0, which is not unreasonable.

[†] The graph in figure 5-14 (and 5-13) was generated using Mathematica®. The command line used was: Plot[((3.3/453^2) Cos[453 t] Exp[-11.5 t]) + ((2.2/758^2) Cos[758 t] Exp[-4.6 t]) + ((1.4/937^2) Cos[937 t] Exp[-2.3 t]) + ((2.2/1130^2) Cos[1130 t] Exp[-3.46 t]) + ((2/1173^2) Cos[1173 t] Exp[-4.38 t]) + ((2.5/2471^2) Cos[2471 t] Exp[-5.77 t]), {t, 0,.25}, PlotPoints -> 2400, PlotRange -> All]

Clearly there is a great deal of promise in the frequency space evaluation of the damping characteristics, in fact, frequency space is often the space of choice for certain evaluations of periodic and impulse related behavior [7].

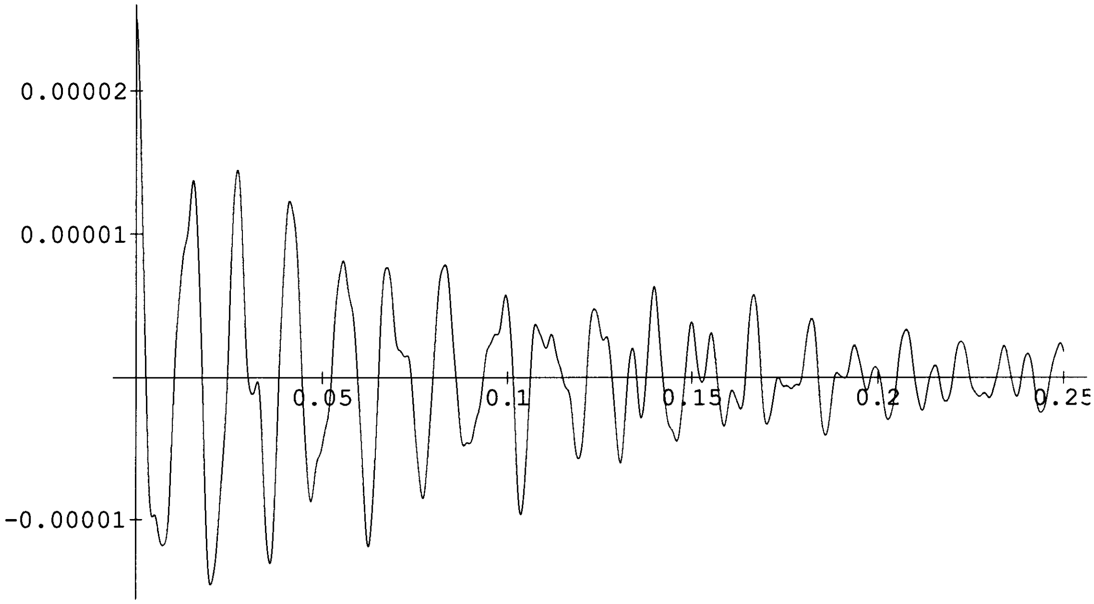


Figure 5-14: Superposition of the six dominant frequency terms from frequency space plot of ceramic-air sample.

Chapter 6

Lessons

This chapter is comprised of a collected list of improvements to the measurement process as determined by hard experience and clear hindsight.

6.1 Improved Data Collection

The primary alteration to the method of collecting the data would be to automate it. Once the data has been stored digitally, it should stay that way until it is fully reduced and readable. It is recommended that either a analog to digital interface be used with a personal computer right off, or a complete HPIB system or its equivalent be set up for numeric processing.

If this particular experiment is repeated, or another similar one, I would suggest that the data be rectified (or squared) and a large number of runs be averaged. An alternative is to break the record down into equal time length segments, then integrate the absolute value over the segment length, average a number of runs, and then fit the runs to a curve.

6.2 Improved Experimental Set Up

Of primary importance in measuring the oscillations of any sample is that the sample oscillate. Massive steel members tend not to move significantly and are therefore somewhat impractical for dynamic testing. Furthermore, it is next to impossible to devise a fixture strong enough to hold a three inch square bar of stainless steel steady whilst it whips around. Reducing the thickness of the samples by a factor of three, and replacing the one large cavity with a row of smaller cavities would result in large, more easily measurable deflections. Further, making the sample significantly rectangular would reduce inter-modal coupling.

The base of the system must be made as absolutely massive as possible to simplify the motion of the beam. In the same vein, the instrument post should be as stable as possible, even to the point of mounting it on the floor if need be, to eliminate coupling between the sample and the post. Random vibrations from other equipment are not nearly so difficult to unravel as two pseudo-cantilever beams oscillating synchronously. It is almost certain that the coupling between the sample and the post was responsible for the overall sinusoidal envelope that made the data so difficult to fit to an exponential curve.

The capacitance probe was not optimal for vibration testing either. A voice coil would have worked quite well, or a microphone and acoustically coupled tube. Either of these would provide an extremely low noise floor (potentially), broad frequency response, and good dynamic range as well as being simpler and less expensive than the probe.

6.3 Improved Excitation Sources

There is significant merit to a simple impact test, especially when evaluating the rate at which a given object will damp out vibrations caused by an impact. The harmonic content of an impact test is controlled to a great degree by the geometry of the object, and the damping rate of the material is a function of frequency. It is therefore difficult to compare data generated in such an uncontrolled experiment.

A very elegant and expensive way to improve the control of the experiment is to use a high force voice coil to drive the sample. Using, say, the HP 3562A, one could set it to sweep a sine wave into a 10kw amplifier which could drive a large coil and flex the sample in an extremely controlled manner. Voice coils are manufactured with up to five hundred pounds of force continuous, and up to ten times that if actively cooled.

Far less expensive would be to couple an AC servo motor through a spring to the sample. The speed of the motor (and hence frequency of excitation) could be regulated by a control system easily. The only detraction would be that the driving force becomes irrevocably a function of frequency.

Chapter 7

Conclusion

7.1 Value Of This Experiment

The data collected in this experiment reveals some rather interesting trends, and reinforces a great deal that was believed without proof. Probably most pertinent is the rather gratifying data indicating that cast iron is significantly damped by the addition of oil, which could have an immediate effect on the design of machine tools. Most machine tools are manufactured from cast iron already, and generally have oil channels already designed into them for lubrication. It would be a fairly straight forward matter to enlarge some of the channels to provide an oil reservoir where vibrations are a problem.

It has been known for some time that certain alloys of titanium damp very well, and this study provides a bench mark for further exploration into “superalloys” such as Type 403 which might have twice the damping capacity of even titanium.

This experiment also provided a significant body of practical knowledge on how to conduct a test like this one.

7.2 Areas Of Future Research

The preliminary data generated in this study indicates just how much more needs to be learned. Damping is of significant concern to designers in fields ranging from precision machinery to aerospace. It is clear that more research needs to be done if a significantly useful body of data is to be built up.

Further, the process by which the damping itself is occurring need to be studied. There is, as of yet, no theory good enough to predict damping rates for materials under large scale oscillations.

I would recommend that an experiment be set up using the practical knowledge gained in this experiment to test a much larger number of samples, with emphasis on measuring various alloys of the same basic material. I would also recommend that this experiment be set up to allow data to be gathered as a function of frequency which should yield interesting information about the dominant modes of loss in various materials.

Appendix A

Summary of Calculable Properties

Sample Specimen - Core	Damping Rate (mHz)	Time to $1/e \cdot A_0$ (msec)	Primary Frequency (Hz)	Initial Displacement (mV)	Sample Mass (Kg)
Cast Iron - Air	0.0159	62.9	237	405	14.37
Cast Iron - Sand	0.0189	52.9	237	400	14.93
Cast Iron - Shot	0.0206	48.5	234	405	16.48
Cast Iron - Oil	0.0268	37.3	218	407	14.68
Cast Iron - Sand/Oil	0.0209	47.8	237	360	15.08
Cast Iron - Shot/Oil	0.0136	73.5	232	400	16.64
Steel - Air	0.0141	70.9	214	395	15.70
Steel - Sand	0.0148	67.6	214	390	16.26
Steel - Shot	0.0184	54.3	206	455	17.81
Steel - Oil	0.0133	75.2	206	445	16.11
Steel - Sand/Oil	0.0201	49.8	229	390	16.41
Steel - Shot/Oil	0.0166	60.2	194	437	17.97
Stainless - Air	0.00919	109	202	375	15.68
Stainless - Sand	0.0125	80.0	202	390	16.24
Stainless - Shot	0.00822	122	202	350	17.79
Stainless - Oil	0.0125	80.0	214	390	16.09
Stainless - Sand/Oil	0.0127	78.7	214	405	16.39
Stainless - Shot/Oil	0.00660	152	214	400	17.95
Titanium - Air	0.0274	36.5	247	430	9.07
Titanium - Sand	0.0335	29.9	224	410	9.63
Titanium - Shot	0.0350	28.6	202	440	11.18
Titanium - Oil	0.0223	44.8	232	430	9.48
Titanium - Sand/Oil	0.0495	20.2	253	437	9.78
Titanium - Shot/Oil	0.0228	43.9	229	437	11.34
Aluminum - Air	0.0190	52.6	444	310	5.57
Aluminum - Sand	0.0305	32.8	414	290	6.13
Aluminum - Shot	0.0390	25.6	340	360	7.68
Aluminum - Oil	0.0336	29.8	384	375	5.98
Aluminum - Sand/Oil	0.0354	28.2	327	390	6.28
Aluminum - Shot/Oil	0.0334	29.9	330	390	7.84

Sample Specimen - Core	Damping Rate (mHz)	Time to 1/e·A_0 (msec)	Primary Frequency (Hz)	Initial Displacement (mV)	Sample Mass (Kg)
Brass - Air	0.0156	64.1	202	400	16.90
Brass - Sand	0.0120	83.3	186	400	17.46
Brass - Shot	0.0103	97.1	202	390	19.01
Brass - Oil	0.0240	41.7	214	410	17.31
Brass - Sand/Oil	0.0119	84.0	206	400	17.61
Brass - Shot/Oil	0.00805	124	202	375	19.17
Copper - Air	0.0234	42.7	212	400	18.00
Copper - Sand	0.0283	35.3	214	400	18.56
Copper - Shot	0.0204	49.0	237	375	20.11
Copper - Oil	0.0191	52.4	216	400	18.41
Copper - Sand/Oil	0.0181	55.2	216	400	18.71
Copper - Shot/Oil	0.0159	62.9	232	340	20.27
Ceramic - Air	0.00587	170	99.6	310	7.97
Ceramic - Sand	0.00789	126	69.4	330	8.53
Ceramic - Shot	0.0103	97.1	67.8	400	10.08
Ceramic - Oil	0.00650	154	54.1	187	8.38
Ceramic - Sand/Oil	0.00635	157	97.6	165	8.68
Ceramic - Shot/Oil	0.00942	106	76.2	180	10.24
Granite - Air	0.00567	176	70.8	225	5.41
Granite - Sand	0.0145	69.0	202	225	5.97
Granite - Shot	0.0354	28.2	188	250	7.52
Granite - Oil	0.0135	74.1	258	215	5.82
Granite - Sand/Oil	0.0164	61.0	268	200	6.12
Granite - Shot/Oil	0.0137	73.0	217	230	7.68
Probe Support	0.0281	35.6	90	235[1]	

[1] Non-calibrated impact.

Appendix B

Materials Data

B.1 Volumes and Masses of Components

Volume of Standard Test Specimen	$2.01 \times 10^{-3}\ m^3$
Volume of Test Specimen Bore	$3.48 \times 10^{-4}\ m^3$

Mass of Sand Core	0.557 Kg
Mass of Lead Shot Core	2.11 Kg
Mass of Oil Core	0.331 Kg
Mass of Sand and Oil Core	0.714 Kg
Mass of Lead Shot and Oil Core	2.27 Kg

B.2 Material Properties [1]

Material	Modulus GN/m^2	Poisson's Ratio ν	Shear Modulus GN/m^2	Coefficient of Expansion α (10^{-6}/°C)	Density $10^3 kg/m^3$
Cast Iron	110	0.25	45	10.4	7.15
Steel	205	0.27	79	11.4	7.79
Stainless Steel, 303	200	0.30	73.1	17.3 [2]	7.80
Titanium	110	0.34	41.4	8.82	4.51
Aluminum, 6061	73	0.33	26	22	2.77
Brass	105	0.35	38	20.4	8.43
Copper	117	0.35	64	16.7	8.95
Ceramic Al_2O_3 99.5%	372 [4]	0.22 [4]	152 [4]	8.0 [4]	3.89 [4]
Granite (Rock of Ages)	20 [3]	0.01 [3]		6.2 [3]	2.64 [3]

Sand (Play Sand, White, Dry, as packaged)	1.6 [6]
Lead Shot (#8, aggregate density)	6.07 [5]
Oil (10w-40 Motor Oil)	0.9 [2]

---

[1] S. H. Crandall, N.C. Dahl, and T.J. Lardner, An Introduction to the Mechanics of Solids. McGraw-Hill Book Co., NY 1978 except as otherwise noted.

[2] Scientific, and Engineering Formulas, Tables, Functions, Graphs, Transforms, Research and Education Association, Piscataway NJ, 1984.

[3] Phone Conversation, "John" of Rock of Ages Corp. (802) 476-3115, 3 May 1990.

[4] Phone Conversation, "Cathy" of Coors Ceramics, (303) 277-4082; 20 March 1990.

[5] Measured by Arnold H. Gessel, 19 March 1990.

[6] Phone Conversation, "Jim" of Sommerville Lumber, (617) 623-2800; 19 March 1990.

B.3 Specimen Costs And Suppliers

Material	Price	Source
Class 40 Cast Iron rounded corner	50.46	Peterson
1018 Steel, cold ground	46.18	Peterson
303 Stainless Steel	380.00	Royce
6AL4V Titanium	246.25	President
Aluminum, 6061-T6511	44.55	Admiral
C360 Cartridge Brass	120.45	Admiral
Copper (oxy free) 101	306.00	Kelco
Al_2O_3 99.5% pure	2500.00[1]	Coors
Granite	1000.00[1]	Rock Of Ages

Supplier	Location	Phone Number
Admiral Metals	Woburn, MA	(617) 933-8300
Peterson Metals	Wocster, MA	(800) 325-3245
Kelco Metals	Rockland, MA	(617) 773-5711
President Steel and Titanium	Hanson, MA	(617) 294-0991
Royce Aerospace Metals	NY	(800) 645-9530
Coors Ceramics Division	Golden, CO	(303) 277-4082
Rock Of Ages	Barre, VT	(802) 476-3115

[1] The exact prices of the ceramic and granite samples are unknown due to circumstances beyond my control.

Appendix C

Clamp Fit, A Recursive Error Minimization Program For The Macintosh Computer In Microsoft® Basic

This is a complete listing of the Microsoft® Basic program *Clamp Fit* which was written by the author to analyze the data. In the following listing explanatory comments are identified by a "⇒" character.

⇒ The following commands set up the Macintosh window environment and a pleasing text face, the basic operational instructions are then displayed.

```
CALL TEXTFONT(2)
CALL TEXTSIZE(12)
CALL MOVETO(10,15)
PRINT “This program will fit the data point by point to an exponential curve,”
CALL MOVETO(10,30)
PRINT “holding the first point fixed. The number the program outputs is the”
CALL MOVETO(10,45)
PRINT “average value of the resultant exponential amplitude.”
CALL MOVETO(10,60)
PRINT “The data must be arranged ‘time, amplitude’.”
DIM tme(200),amp(200),tmeamp(200),tmesqr(200)
```

⇒ The following section calls up a standard window interface to the New File System which allows the user to interactively scroll through the file system tree.

```
start:
```

```
CALL MOVETO(10,75)

PRINT “You will be asked to select a data file. Press any key to continue”

dummy$ = INPUT$(1)

CLS

flnme$ = FILES$(1,"")
```

⇒ Once the proper data file has been selected, the program opens it and fills an array with the data contained therein.

```
OPEN flnme$ FOR INPUT AS #1

x = 0 : tmesum = 0 : ampsum = 0 : tmeampsum = 0 : tmesqrsum = 0

WHILE NOT EOF(1)

INPUT #1,tme(x),amp(x)

IF tme(x) = 0! THEN x = x - 1 : GOTO 20

x = x + 1

WEND
```

⇒ Following the initialization of the data array, the program initializes some variables that it will need reset for each pass of the recursion. The top of the recursion loop is labeled “20”. The recursion attempts to minimize the error, labelled “epsilon” by adjusting the linear displacement “beta”.

```
20 nmb = x

beta = 0

delta = .0001

itr$ = "one"
```

⇒ The time axis is zeroed for each element of the array.

```
 FOR x = 0 TO nmb
  tme(x) = tme(x)-tme(0)
 NEXT x
```

⇒ The following loop, labelled “loop:”, calculates the average value of the exponent, α, in the equation defining the amplitude of the decay envelope at any positive time:

$$A(t) = A_0 e^{-\alpha t} + \beta,$$

for each element of the array “amp(x)” by “tme(x)”.

```
loop:
epsilon = 0
alpha = 0
 FOR x = 1 TO nmb
  tmpa = (LOG((amp(x) / (amp(0) - beta)) - beta) / tme(x))
  alpha = alpha + tmpa
 NEXT x
 alpha = alpha / nmb
```

⇒ The following “FOR - NEXT” loop calculates the average error, “epsilon”. The virtue of each recursion is measured by the minimization of epsilon by incrementing beta by an amount delta. The step size (delta) is fixed so that the variation in alpha between steps is less than 1‰.

```
 FOR x = 0 TO nmb
  tmpd = amp(x) - ((amp(0) - beta) * EXP(alpha * tme(x)) + beta)
  epsilon = epsilon + ABS(tmpd)
 NEXT x
```

```
epsilon = epsilon / (nmb +1)
```

⇒ The following block provides a status report for the curious user.

```
CALL MOVETO(10,25)

PRINT "alpha:  ";alpha

CALL MOVETO(10,40)

PRINT "beta:  ";beta

CALL MOVETO(10,55)

PRINT “epsilon:  ";epsilon

CALL MOVETO(10,70) : PRINT “previous epsilon:  ";eps
```

⇒ The following block checks the improvement in epsilon. If the improvement is initially negative, delta is negated so that the direction of the search is reversed. If the improvement becomes negative at some later time, the value of alpha is called optimized and the program quits out of the recursion loop.

```
IF itr$ = “one” THEN beta = delta : itr$ = “two” : eps = epsilon : GOTO loop

IF itr$ = “two” AND eps < epsilon THEN delta = -1 * delta : beta = delta : itr$ = “more” : GOTO loop

itr$ = “more”

IF eps < epsilon THEN GOTO done

eps = epsilon

beta = beta + delta

GOTO loop
```

⇒ Since the value of beta must be incremented one delta past it’s optimum value, the displayed values of alpha and beta are recomputed at the value beta held one step earlier in the recursion.

```
done:
beta = beta - delta
epsilon = 0
alpha = 0

 FOR x = 1 TO nmb
  tmpa = (LOG((amp(x) / (amp(0) - beta)) - beta) / tme(x))
  alpha = alpha + tmpa
 NEXT x
 alpha = alpha / nmb

 FOR x = 0 TO nmb
  tmpd = amp(x) - ((amp(0) - beta) * EXP(alpha * tme(x)) + beta)
  epsilon = epsilon + ABS(tmpd)
 NEXT x
 epsilon = epsilon / (nmb +1)
```

⇒ Finally, the optimized values are displayed, along with a message reminding the user just which file has been optimized.

```
CALL MOVETO(5,130)
PRINT "Data for file: ";flnme$
CALL TEXTFACE(1)
```

```
CALL MOVETO(25,160)

PRINT "The calculated damping rate (alpha) is: ";alpha

CALL MOVETO(25,190)

PRINT "The linear displacement is: ";beta

CALL MOVETO(25,220)

PRINT "The average error is: "; epsilon


 CLOSE

closingbits:

CALL MOVETO(20,260)

CALL TEXTFACE(0)

PRINT "Wanna do another (y or n)? " :  overag$ = INPUT$(1)

IF overag$ = "y" THEN CLS : GOTO start

IF overag$ = "n" THEN END

BEEP : GOTO closingbits
```

Appendix D.

Apparatus Data

The following pages contain the original data as it was plotted. The graphs are, excepting the addition of an identifying legend, exactly photo-reproduced from the originals. It was impossible to alter the layout of the graphs to match the orientation of the thesis without losing significant data and/or clarity. In the interest of preserving the full value of the original data, no compromise was made to aesthetic unity.

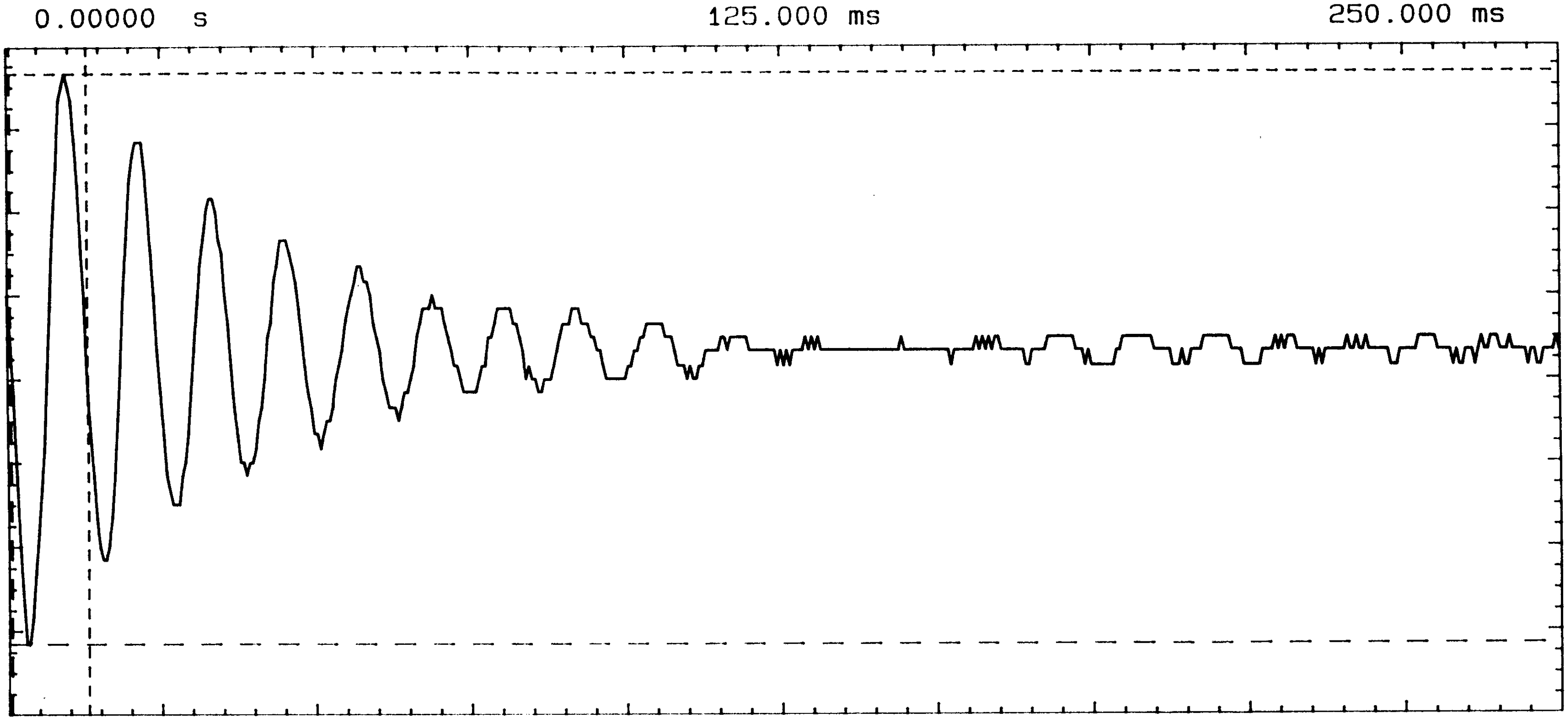
Appendix D.1 Probe Support Post Behavior 56

Appendix D.1 shows graphs of the behavior of the probe support post as measured using the same instrumentation in the same configuration as for the measurement of the samples. The post was excited by a hammer blow, and so a comparison of the initial displacement amplitudes is meaningless.

Appendix D.2 Filter Response 59

Appendix D.2 shows the response of the two band pass filter configurations used to improve the clarity of the data. The graphs were recorded using the Hewlett Packard spectrum analyzer's "swept sine" mode. The analyzer generates a sine wave output and sweeps it through a given frequency simultaneously measuring the filter's response to that frequency.

The first plot is of the filter response used with the metallic samples. The second plot shows the response of the filter configuration used with the non-metallic samples.

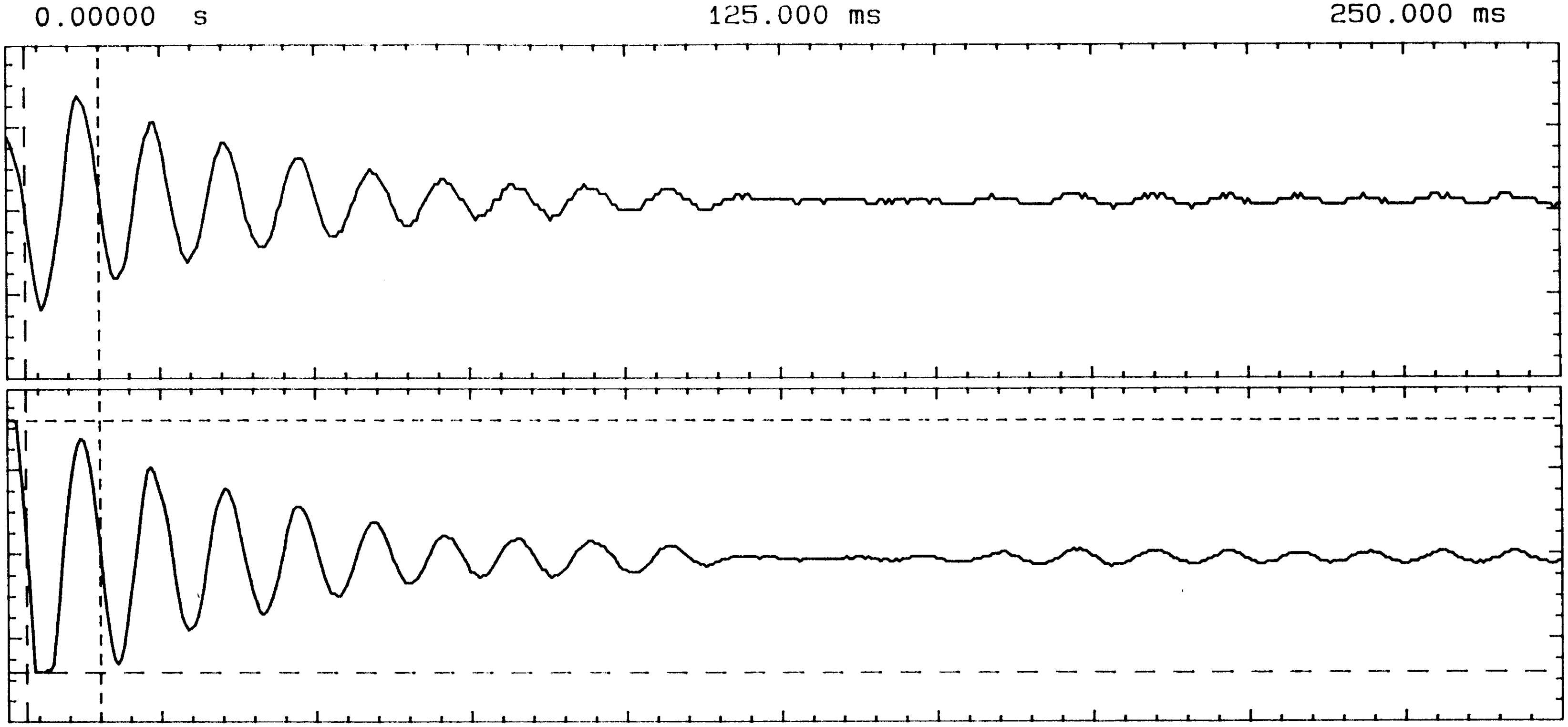


Ch. 1 = 75.00 mvolts/div
Timebase = 25.0 ms/div
Ch. 1 Parameters
Rise Time = 3.92708 ms
Preshoot = 0.000 volts
RMS Volts = 174.0 mvolts

Freq. = 81.6326 Hz
+ Width = 6.26667 ms
Overshoot = 0.000 volts
Dutycycle = 51.15 %

Offset = 0.000 volts
Delay = 0.00000 s
Period = 12.2500 ms
- Width = 5.98333 ms
P-P Volts = 510.9 mvolts

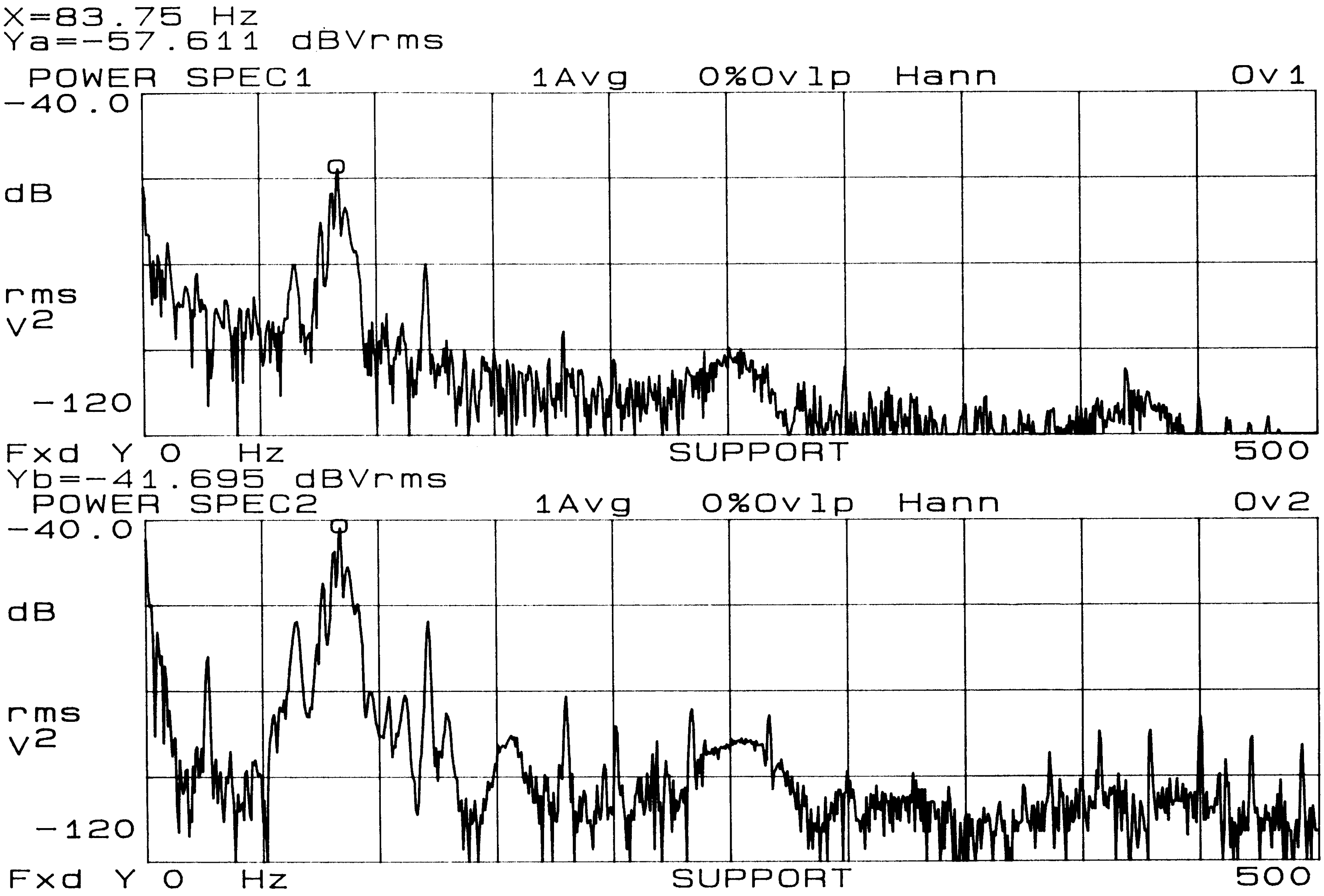
Trace: Probe Support: Uncalibrated Impact Filtrered Input



```
Ch. 1      =  200.0 mvolts/div                                   Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.      =  84.0764  Hz      Period     =  11.8939 ms
Rise Time =  3.78186 ms           + Width    =  5.85227 ms        - Width   =  6.04167 ms
Fall Time =  2.35920 ms           Preshoot   =  0.000   volts    Overshoot =  0.000  volts
P-P Volts =  3.000  volts         RMS Volts  =  1.040   volts    Dutycycle =  49.20 %
```

Top Trace: Probe Support: Uncalibrated Impact Filtrered Input Time-Space

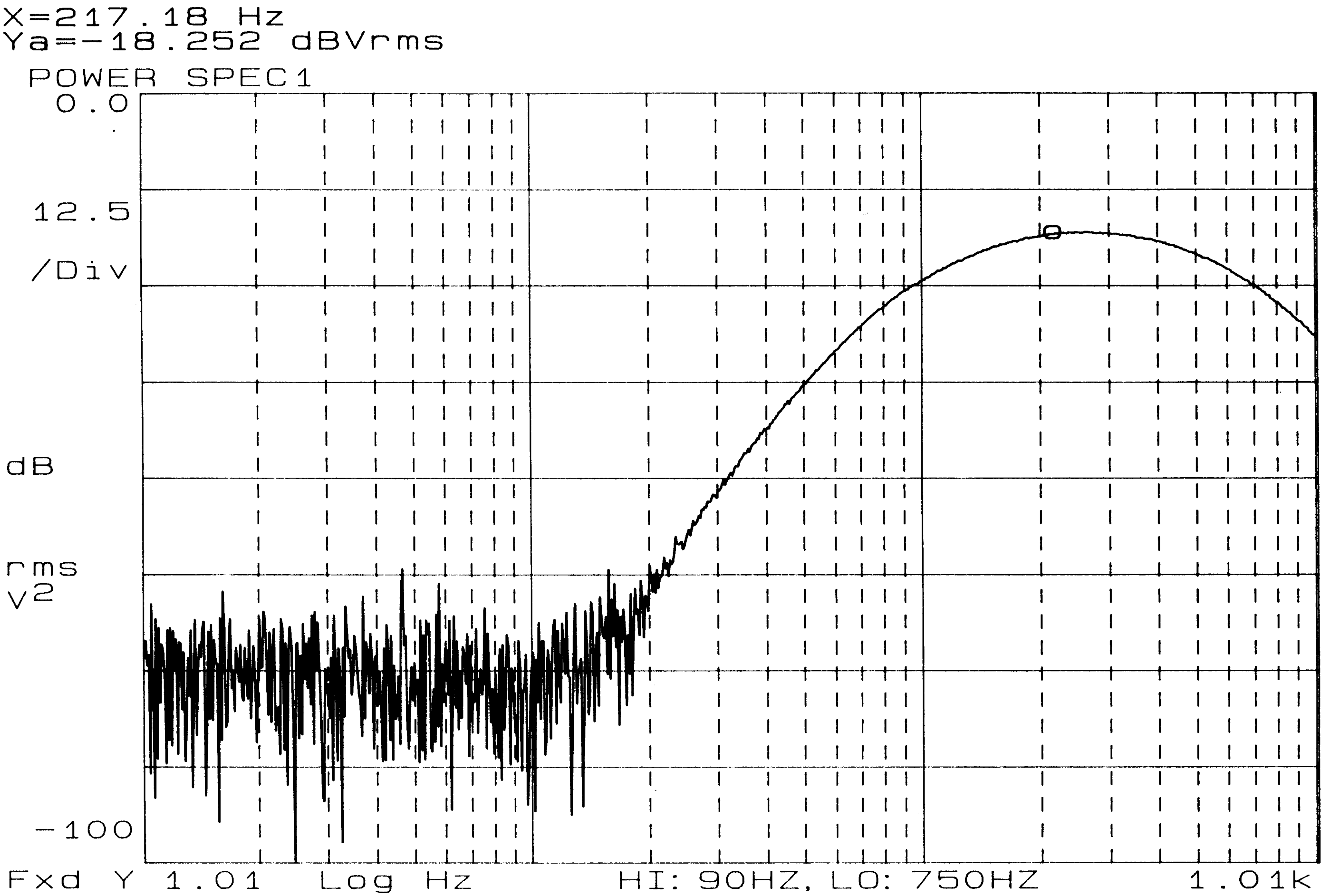
Bottom Trace: Probe Support: Uncalibrated Impact Un-filtered Input



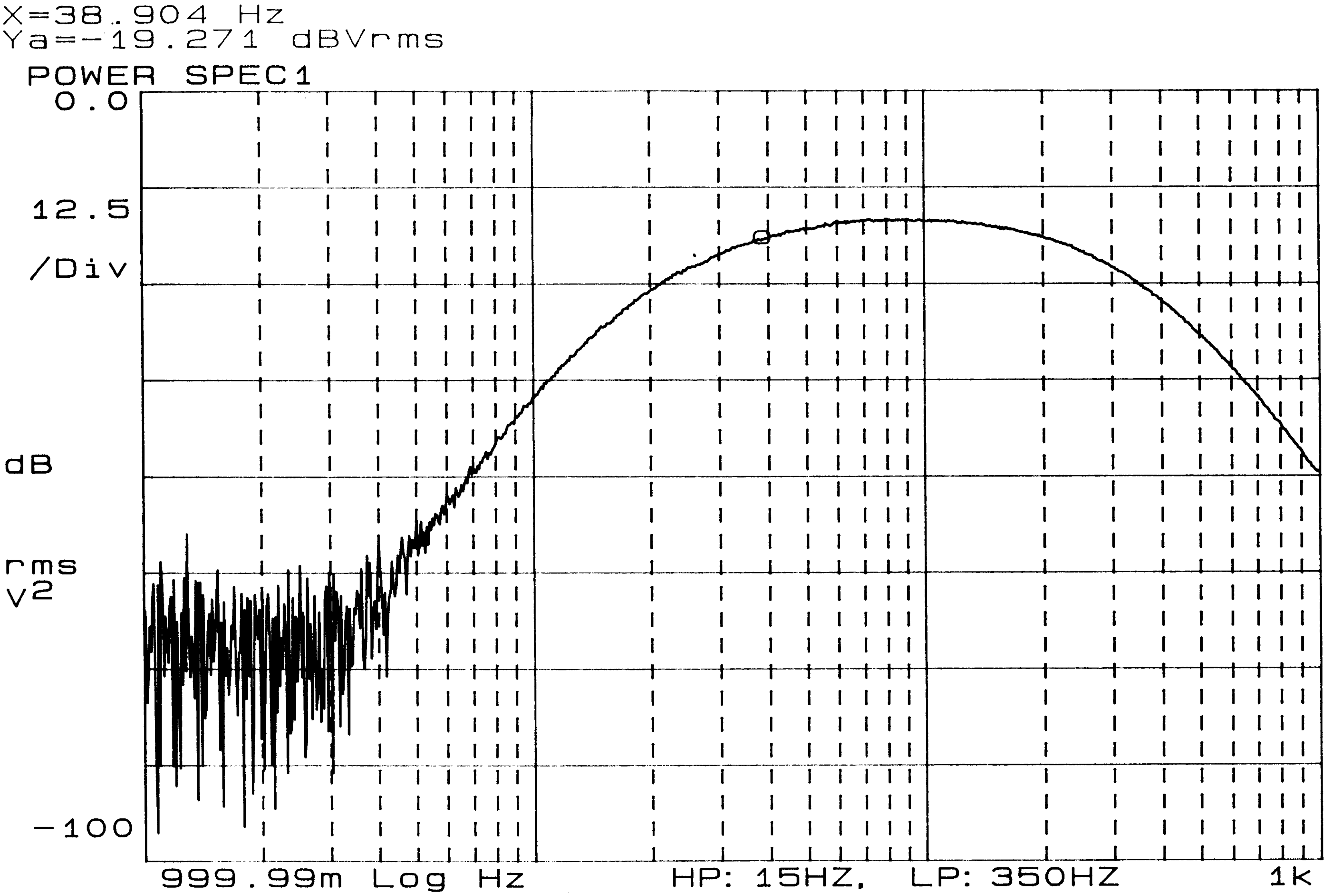
Top Trace: Probe Support: Uncalibrated Impact Filtrered Input

Frequency-Space

Bottom Trace: Probe Support: Uncalibrated Impact Un-filtered Input



Band Pass Filter Response: High Pass Cutoff: 90 Hz, Low Pass Cutoff: 750 Hz.



Band Pass Filter Response: High Pass Cutoff: 15 Hz, Low Pass Cutoff: 350 Hz

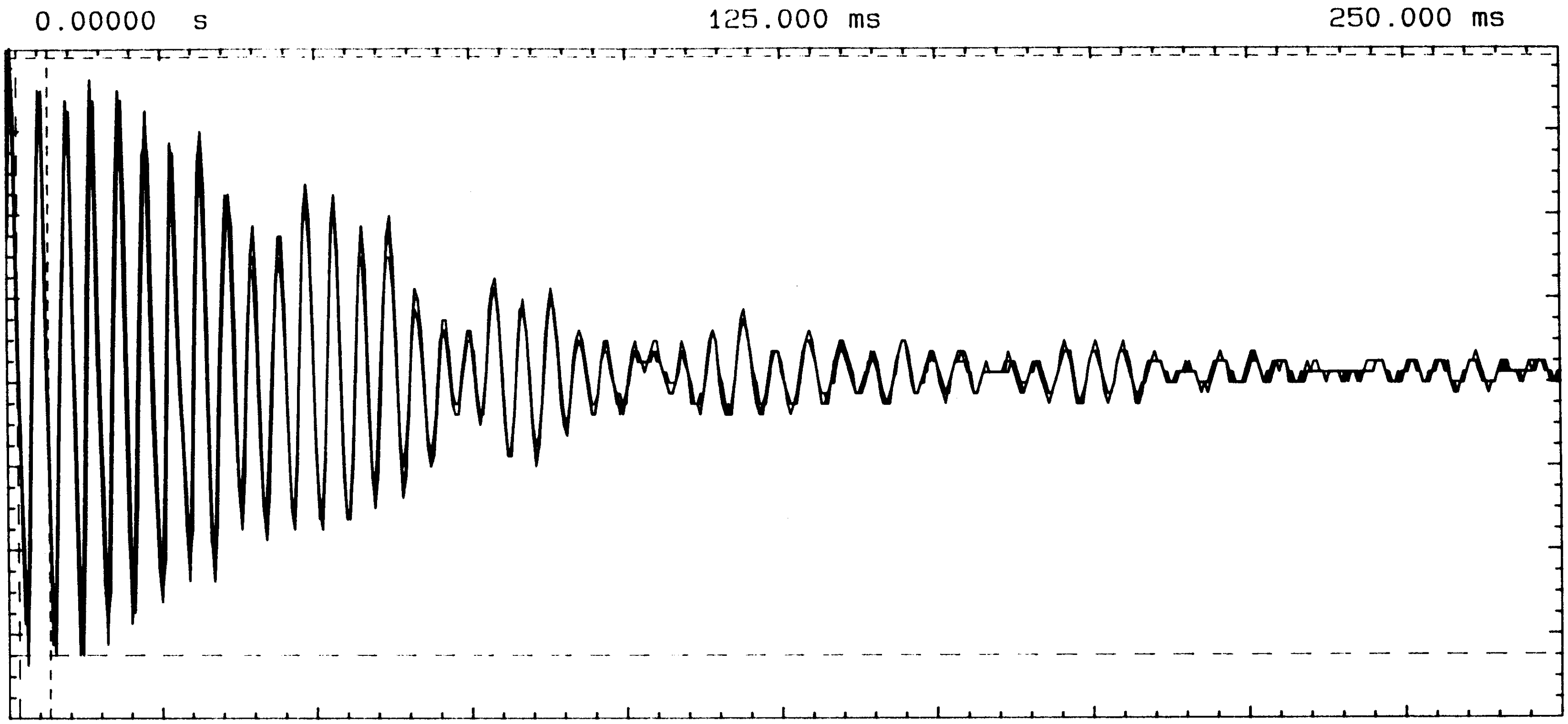
Appendix E.

Original Data

The following pages contain the original data as it was plotted. The graphs are, excepting the addition of an identifying legend, exactly photo-reproduced from the originals. It was impossible to alter the layout of the graphs to match the orientation of the thesis without losing significant data and/or clarity. In the interest of preserving the full value of the original data, no compromise was made to aesthetic unity.

In the following appendix, there are three pages devoted to each sample. The first page shows the four trace overlay from which data was taken and analyzed using *Curve Fit.* The second page shows a typical time-space record and a trace of the un-filtered time-space record. The third page shows the frequency-space record for each sample both filtered and un-filtered. All four graphs were recorded simultaneously. The temperature of the samples was between twenty one and twenty three degrees Celsius.

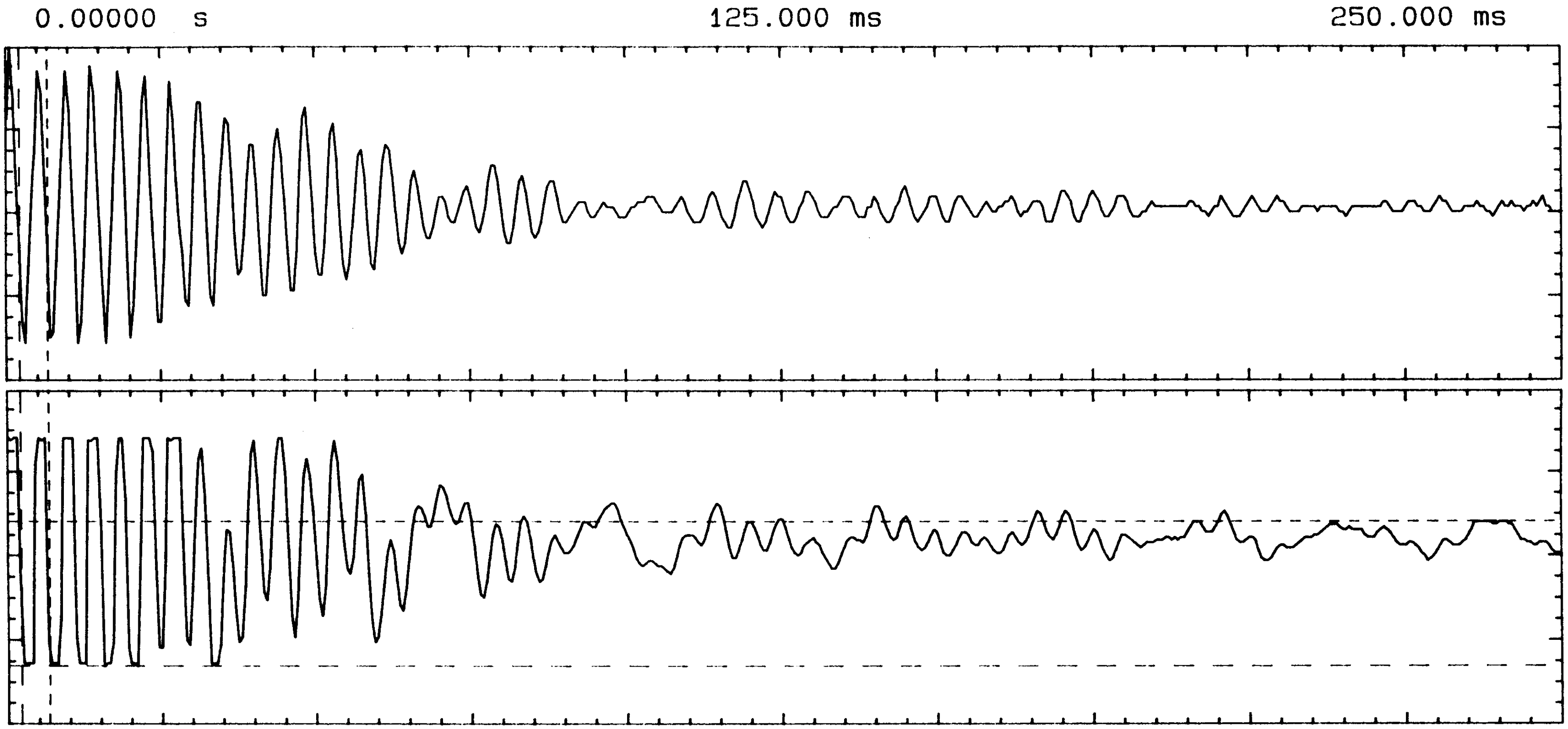
The graphs are presented in the same order as the list of samples in appendix A.



```
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 1   =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 2   =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 3   =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 4   =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Mem 4 Parameters                 Freq.       =  218.976  Hz        Period    =  4.56671 ms
Rise Time =  1.98830 ms          + Width     =  2.19117 ms         - Width   =  2.37554 ms
Fall Time =  1.86560 ms          Preshoot    =  0.000  volts       Overshoot =  0.000  volts
P-P Volts =  712.6 mvolts        RMS Volts   =  202.7 mvolts       Dutycycle =  47.98 %
```

Trace: Cast Iron Specimen Air Core Filtrered Input

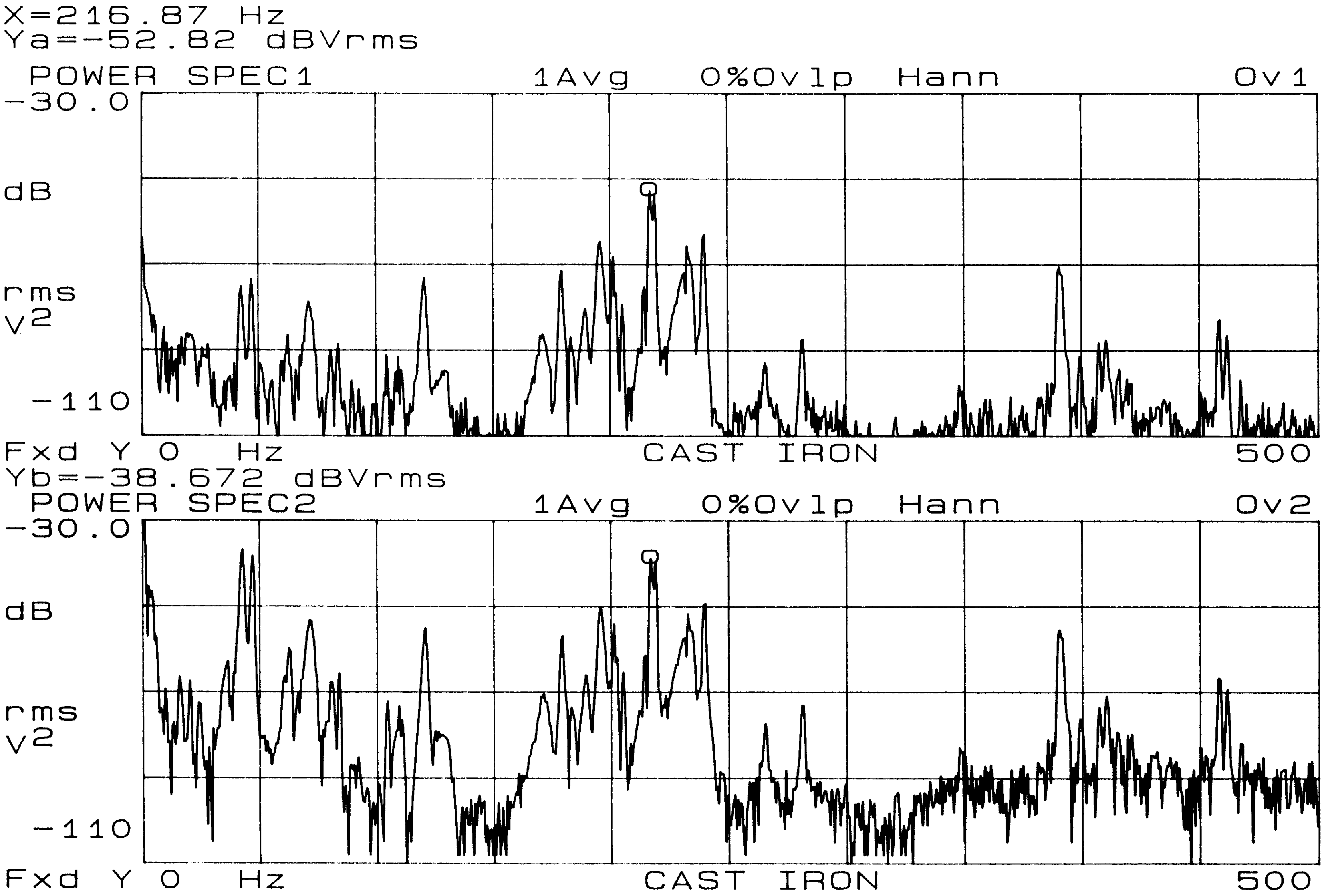
Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                               Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                               Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  233.065  Hz                 Period     =  4.29065 ms
Rise Time  =  289.473 us          + Width     =  2.20224 ms                  - Width    =  2.08841 ms
Fall Time  =  582.465 us          Preshoot    =  1.000   volts               Overshoot  =  0.000   volts
P-P Volts  =  2.718  volts        RMS Volts   =  1.217   volts               Dutycycle  =  51.32 %
```

Top Trace: Cast Iron Specimen Air Core Filtrered Input Time-Space

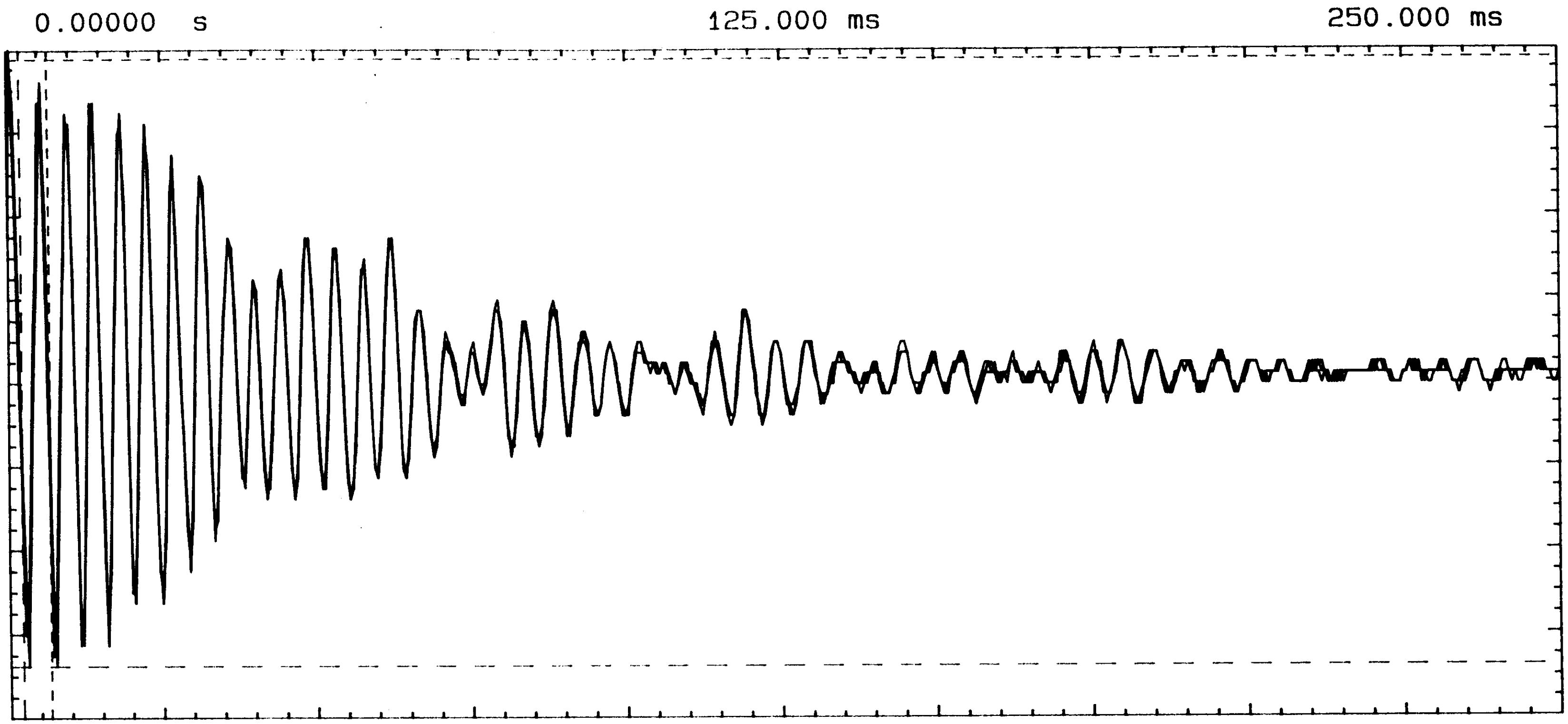
Bottom Trace: Cast Iron Specimen Air Core Un-filtered Input



Top Trace: Cast Iron Specimen Air Core Filtrered Input

Bottom Trace: Cast Iron Specimen Air Core Un-filtered Input

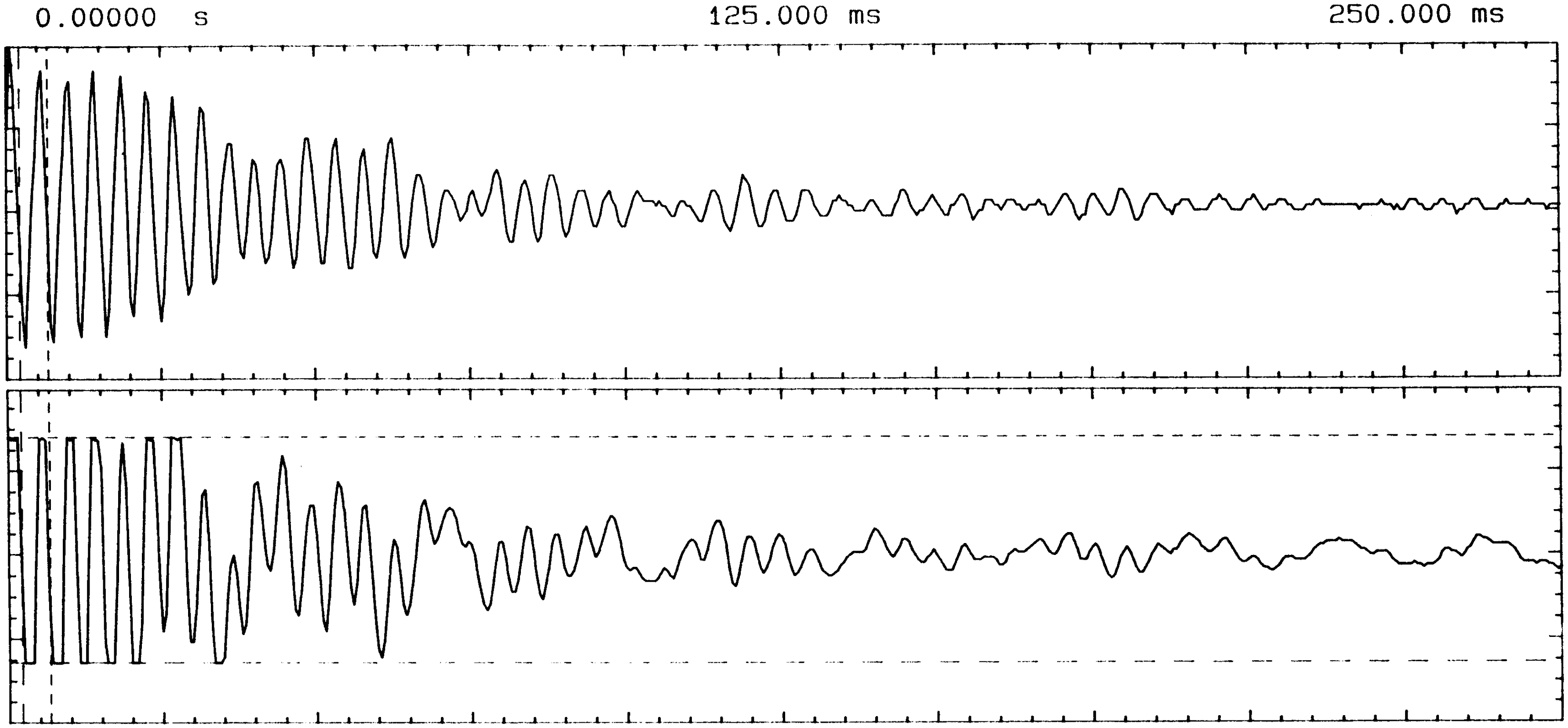
Frequency-Space



```
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Mem 1 Parameters                 Freq.      =  214.801  Hz             Period     =  4.65548 ms
Rise Time =  2.02577 ms          + Width    =  2.29067 ms              - Width    =  2.36481 ms
Fall Time =  1.68369 ms          Preshoot   =  0.000  volts            Overshoot  =  0.000  volts
P-P Volts =  725.1 mvolts        RMS Volts  =  211.7 mvolts            Dutycycle  =  49.20 %
```

Trace: Cast Iron Specimen Sand Core Filtrered Input

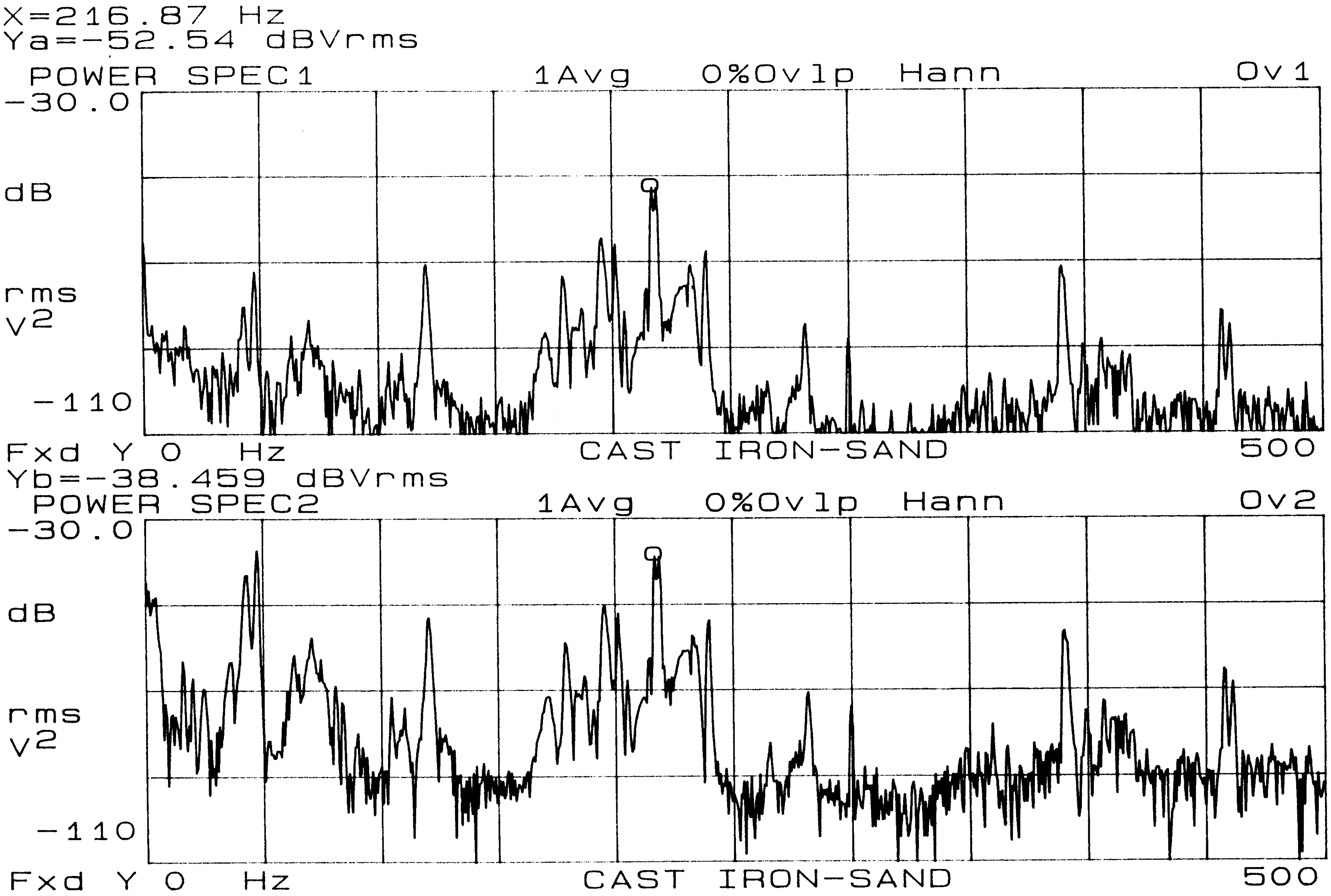
Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                        Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                        Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Ch. 2 Parameters                     Freq.       =  229.885  Hz       Period     =  4.35000 ms
Rise Time =  809.408 us              + Width     =  1.85392 ms        - Width    =  2.49608 ms
Fall Time =  809.553 us              Preshoot    =  0.000   volts     Overshoot =  0.000   volts
P-P Volts =  2.687   volts           RMS Volts =  1.122   volts       Dutycycle =  42.61 %
```

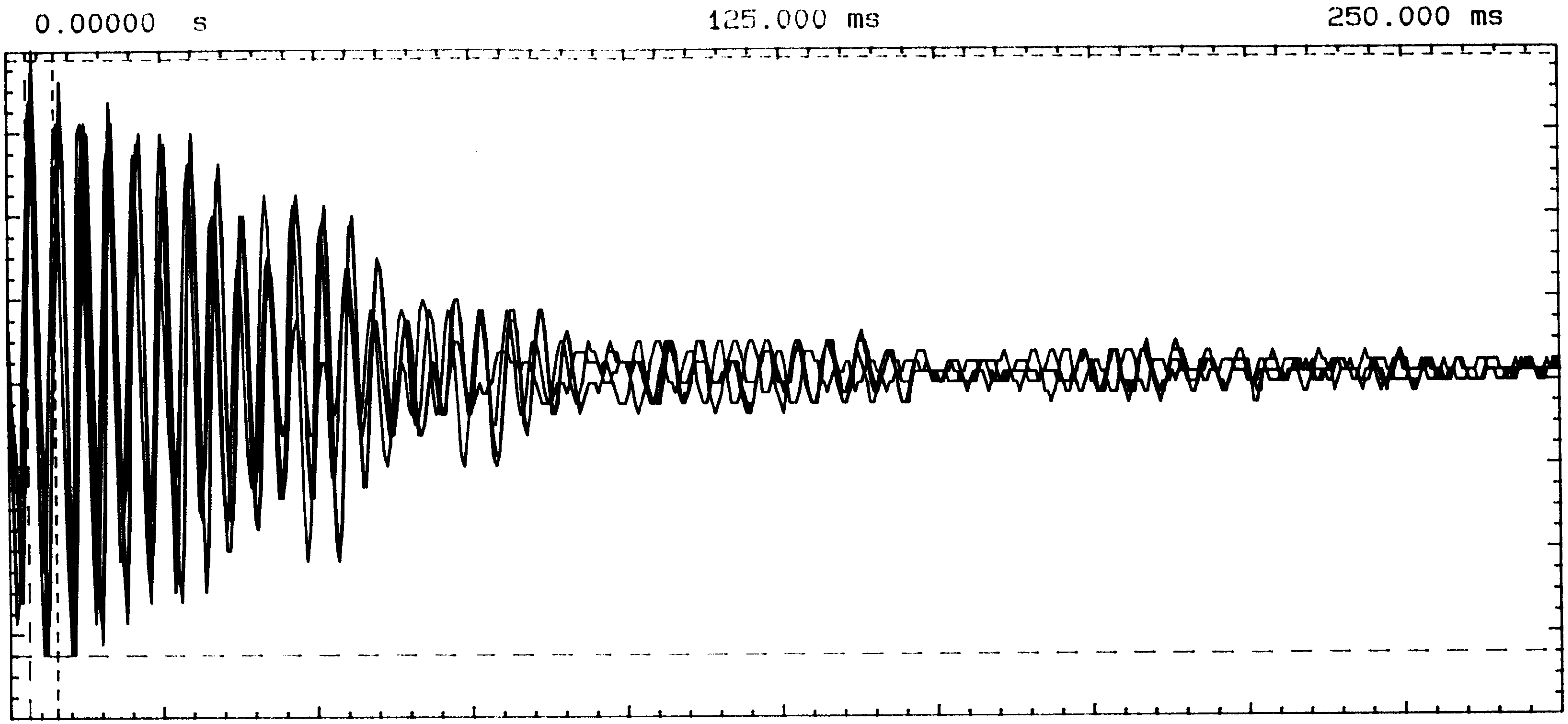
Top Trace:	Cast Iron Specimen	Sand Core	Filtrered Input
Bottom Trace:	Cast Iron Specimen	Sand Core	Un-filtered Input

Time-Space



Top Trace:	Cast Iron Specimen	Sand Core	Filtrered Input
Bottom Trace:	Cast Iron Specimen	Sand Core	Un-filtered Input

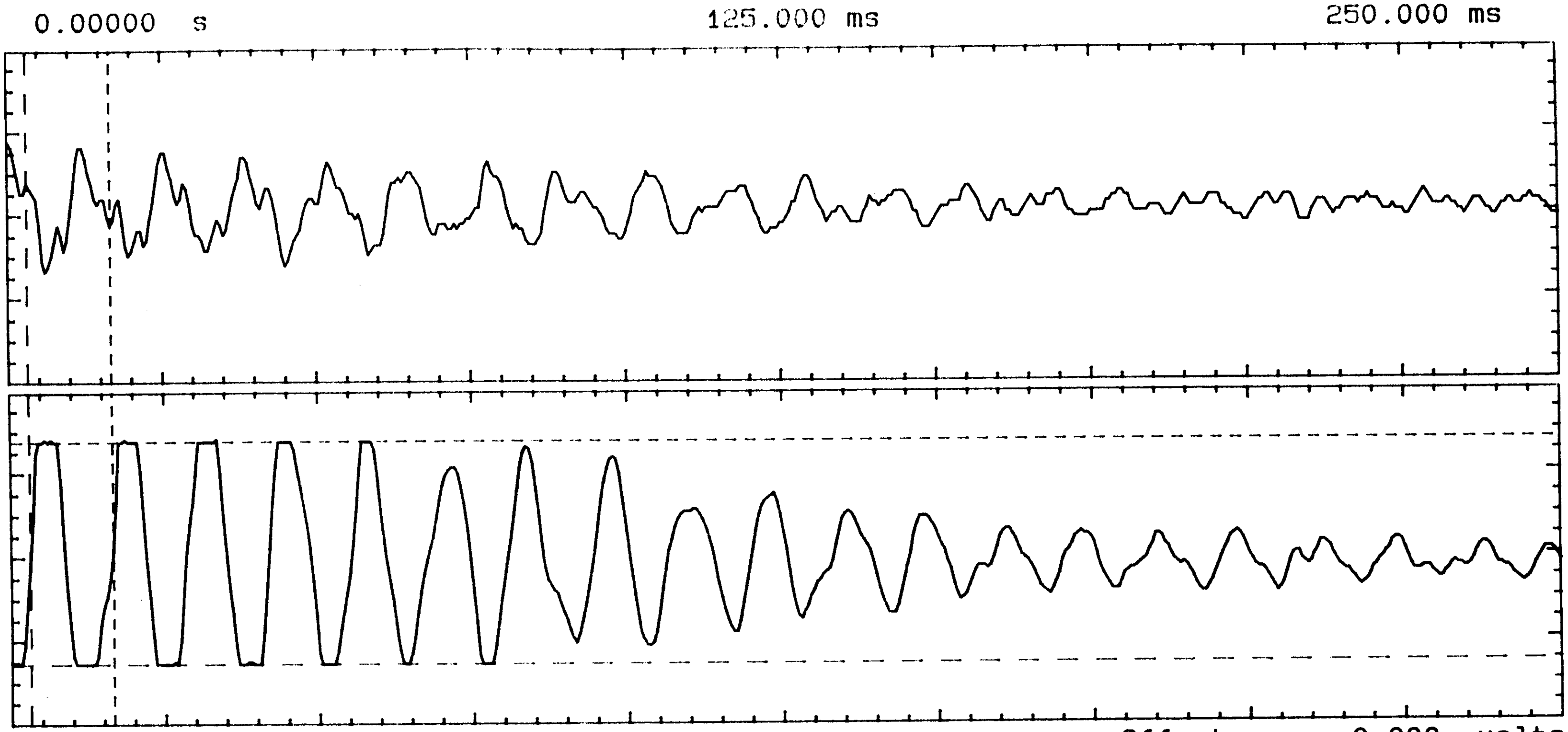
Frequency-Space



```
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 1  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 2  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 3  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 4  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Mem 4 Parameters               Freq.      =  226.719  Hz          Period    =  4.41075 ms
Rise Time =  2.02960 ms        + Width    =  2.16623 ms           - Width   =  2.24452 ms
Fall Time =  1.60693 ms        Preshoot   =  0.000  volts         Overshoot =  0.000  volts
P-P Volts =  712.6 mvolts      RMS Volts  =  217.9 mvolts         Dutycycle =  49.11 %
```

Trace: Cast Iron Specimen Lead Shot Core Filtrered Input

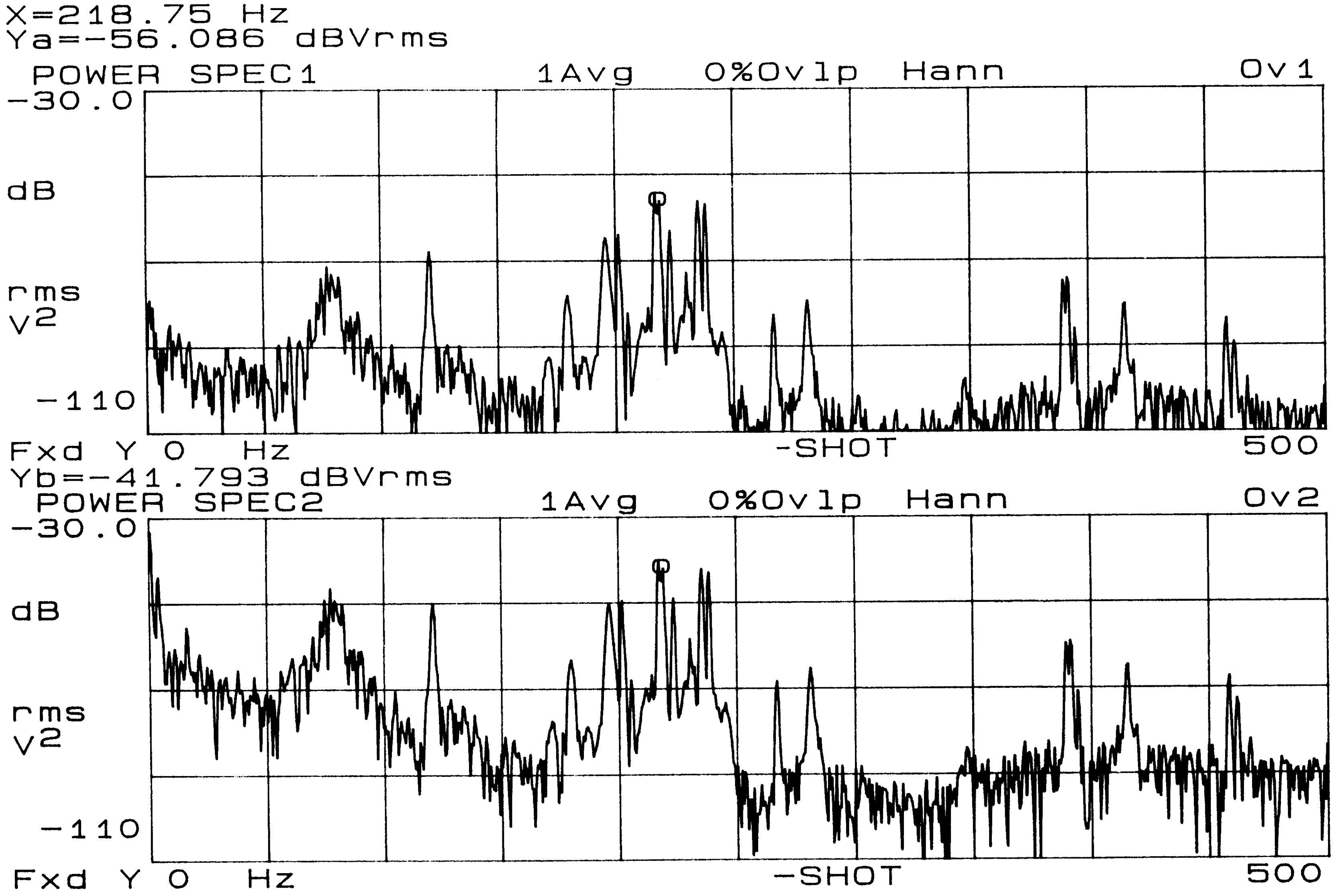
Four Trace Overlay in Time-Space



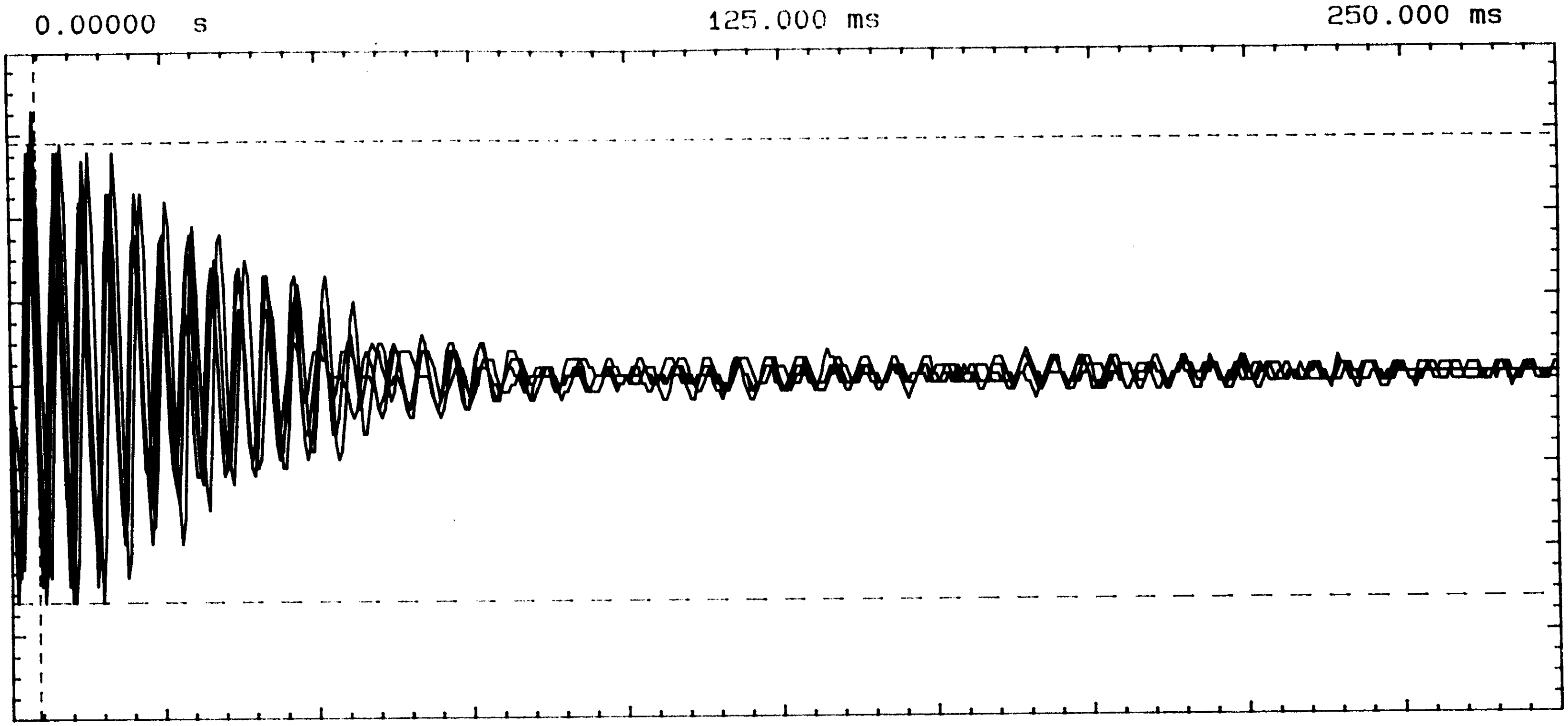
```
Ch. 1      =  200.0 mvolts/div                                    Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                    Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                         Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  75.2930  Hz      Period     =  13.2814 ms
Rise Time =  1.85647 ms           + Width     =  5.49265 ms       - Width    =  7.78879 ms
Fall Time =  2.00513 ms           Preshoot    =  0.000   volts    Overshoot  =  31.25 mvolts
P-P Volts =  2.687   volts        RMS Volts   =  1.074   volts    Dutycycle  =  41.35 %
```

Top Trace: Cast Iron Specimen Lead Shot Core Filtrered Input Time-Space

Bottom Trace: Cast Iron Specimen Lead Shot Core Un-filtered Input



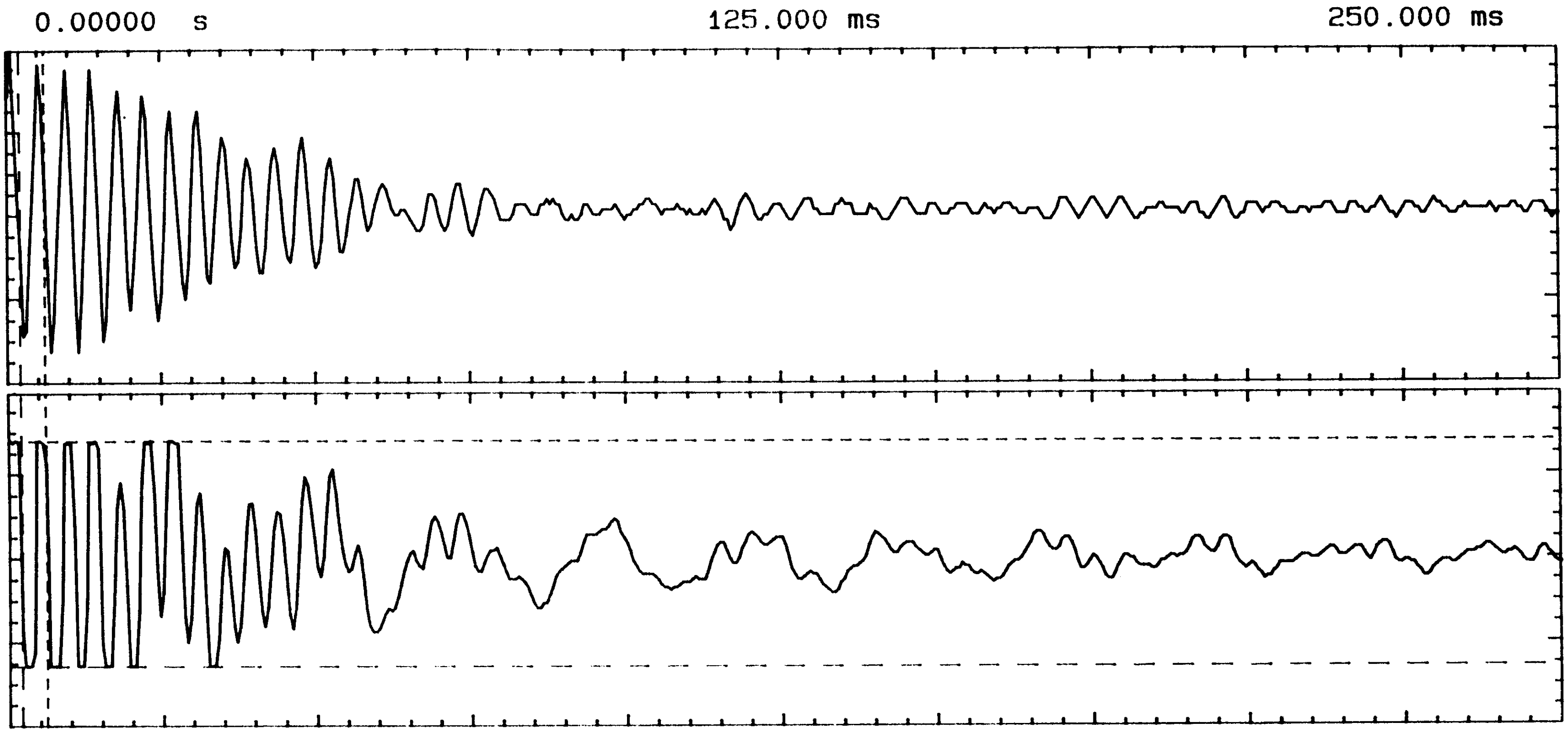
Top Trace:	Cast Iron Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Cast Iron Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Mem 1 Parameters                    Freq.     =  220.127  Hz            Period     =  4.54283 ms
Rise Time =  1.69971 ms             + Width   =  2.23691 ms             - Width    =  2.30591 ms
Fall Time =  1.48703 ms             Preshoot  =  0.000  volts           Overshoot =  0.000  volts
P-P Volts =  687.6 mvolts           RMS Volts =  206.9 mvolts           Dutycycle =  49.24 %
```

Trace: Cast Iron Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space

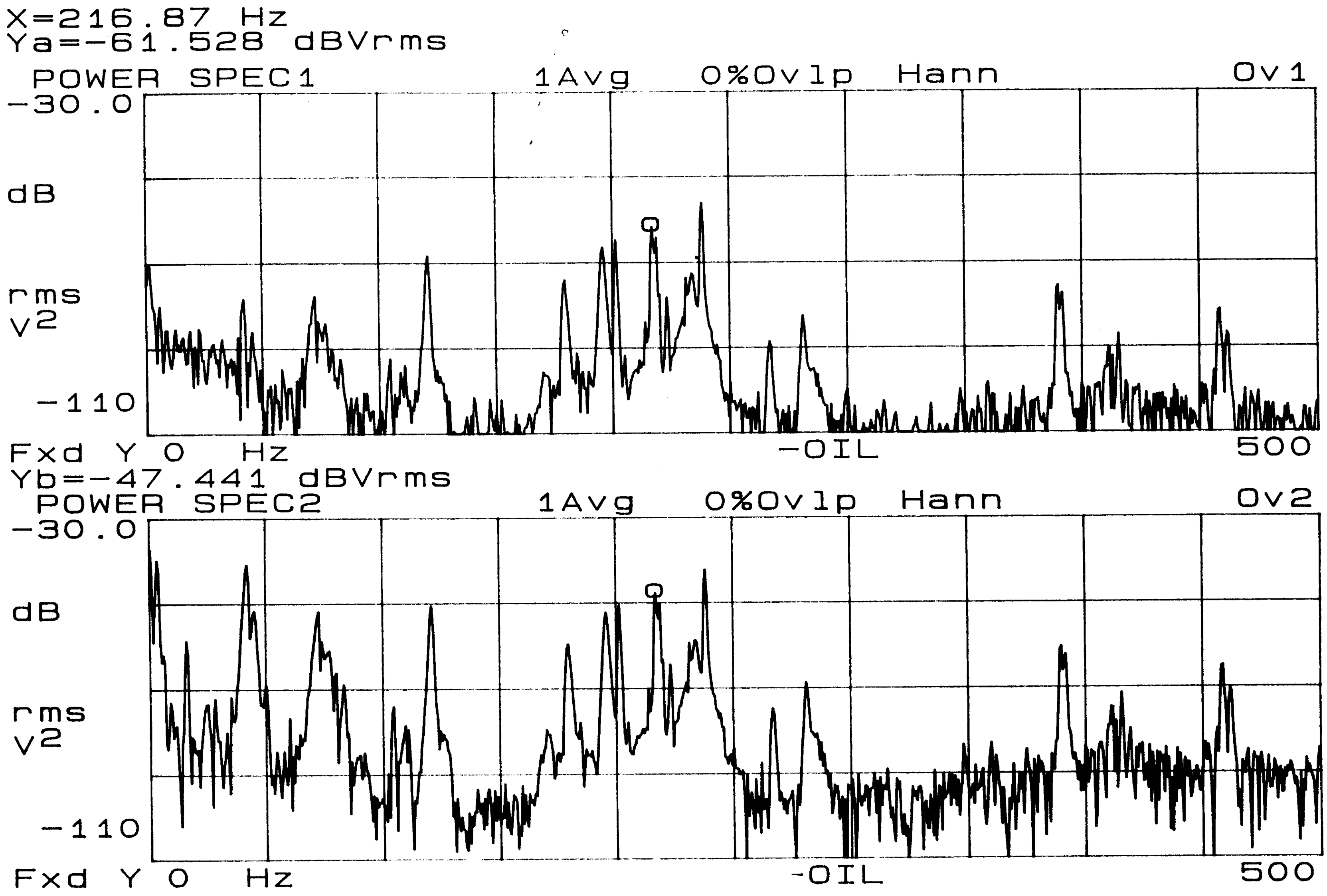


Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Rise Time = 424.671 us
Fall Time = 639.269 us
P-P Volts = 2.687 volts

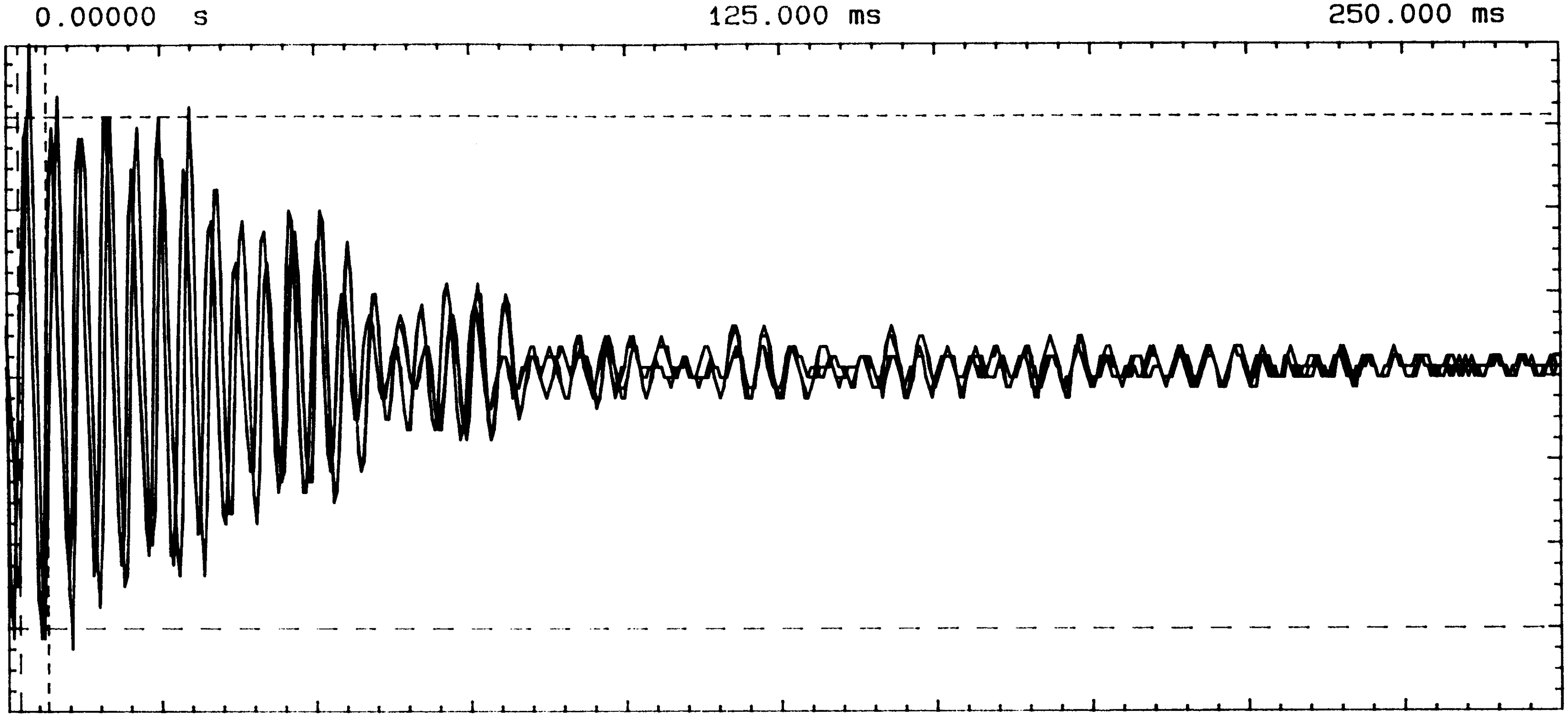
Freq. = 225.988 Hz
+ Width = 1.98621 ms
Preshoot = 0.000 volts
RMS Volts = 1.247 volts

Offset = 0.000 volts
Offset = 0.000 volts
Delay = 0.00000 s
Period = 4.42500 ms
- Width = 2.43879 ms
Overshoot = 0.000 volts
Dutycycle = 44.88 %

Top Trace:	Cast Iron Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Cast Iron Specimen	Oil Core	Un-filtered Input	



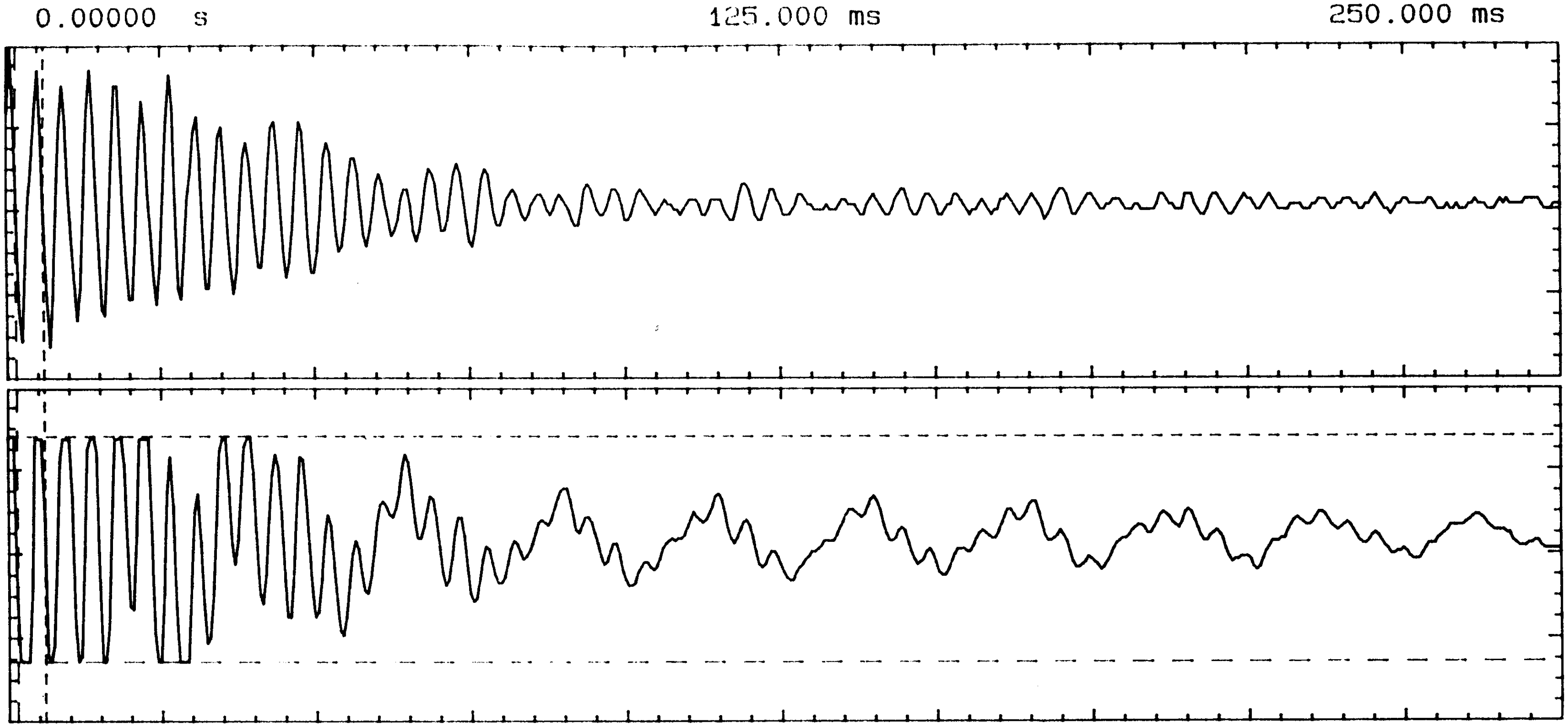
Top Trace:	Cast Iron Specimen	Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Cast Iron Specimen	Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Mem 1 Parameters                Freq.      =  225.357  Hz       Period     =  4.43741 ms
Rise Time =  1.71383 ms         + Width    =  2.36565 ms        - Width    =  2.07176 ms
Fall Time =  1.31094 ms         Preshoot   =  0.000  volts      Overshoot =  0.000  volts
P-P Volts =  612.6 mvolts       RMS Volts  =  198.7 mvolts      Dutycycle =  53.31 %
```

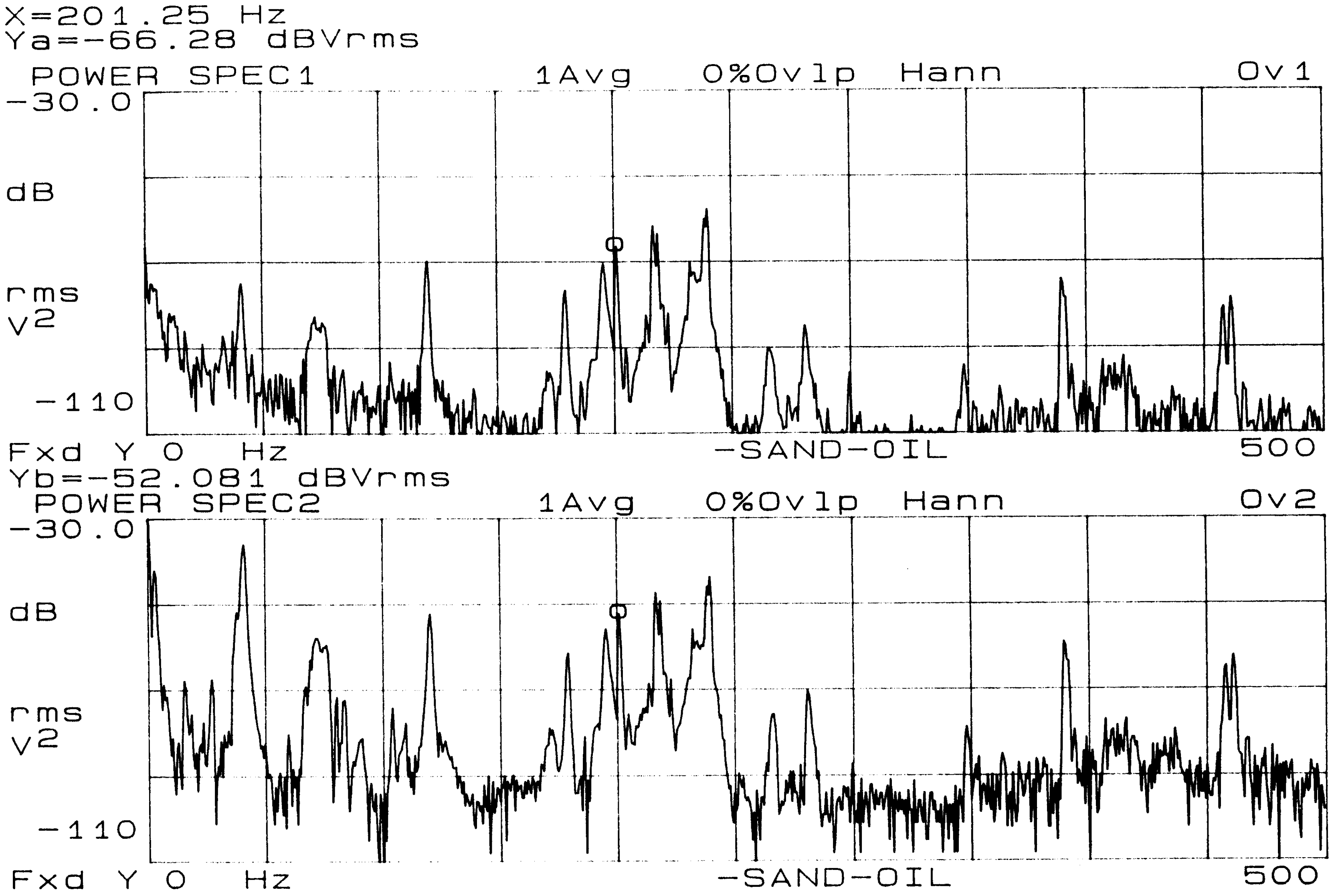
Trace: Cast Iron Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

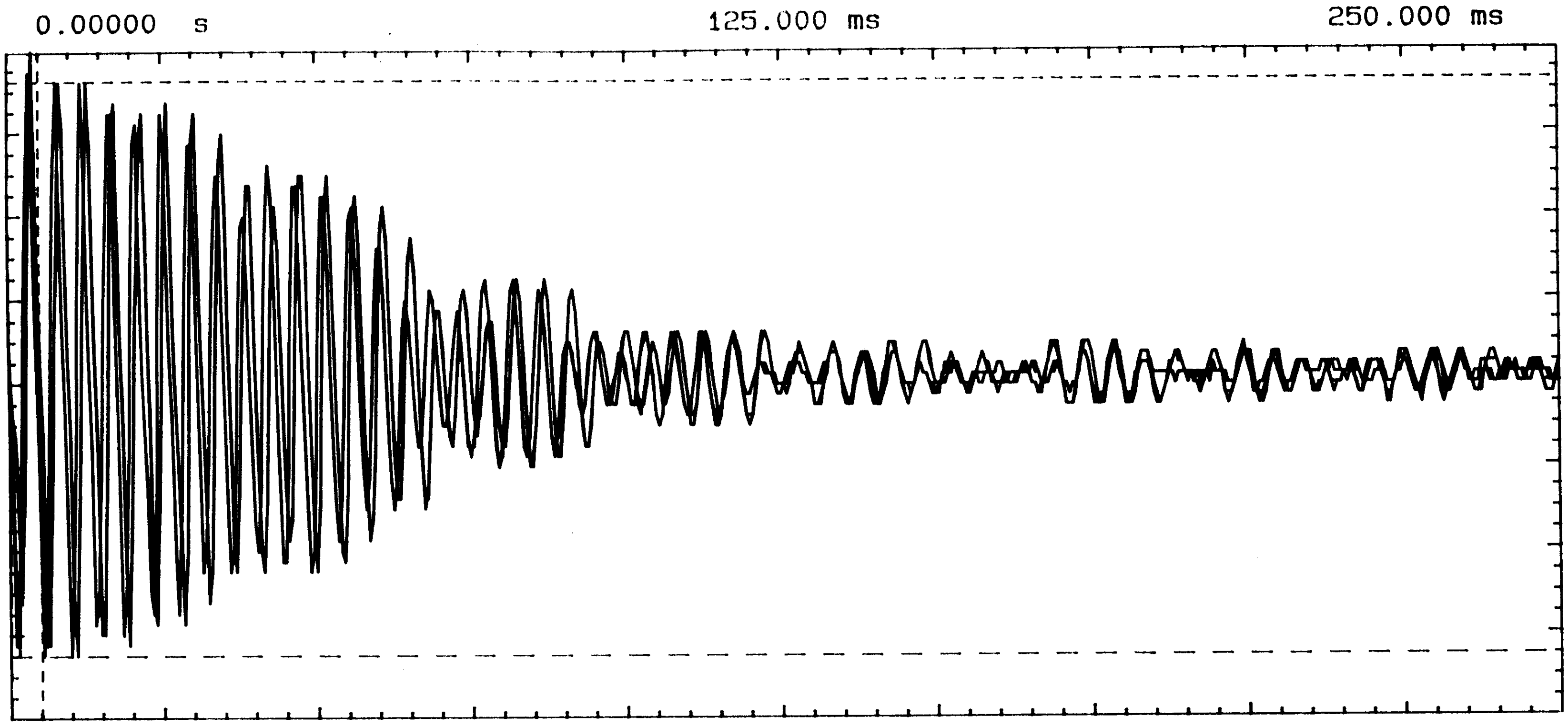


```
Ch. 1      =  200.0 mvolts/div                                     Offset    =  0.000  volts
Ch. 2      =  1.000  volts/div                                     Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay     =  0.00000  s
Ch. 2 Parameters                  Freq.      =  209.183  Hz        Period    =  4.78050 ms
Rise Time =  779.721 us           + Width    =  1.99569 ms         - Width   =  2.78480 ms
Fall Time =  765.381 us           Preshoot   =  0.000  volts       Overshoot =  0.000  volts
P-P Volts =  2.687  volts         RMS Volts  =  1.133  volts       Dutycycle =  41.74 %
```

Top Trace:	Cast Iron Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Cast Iron Specimen	Sand/Oil Core	Un-filtered Input	



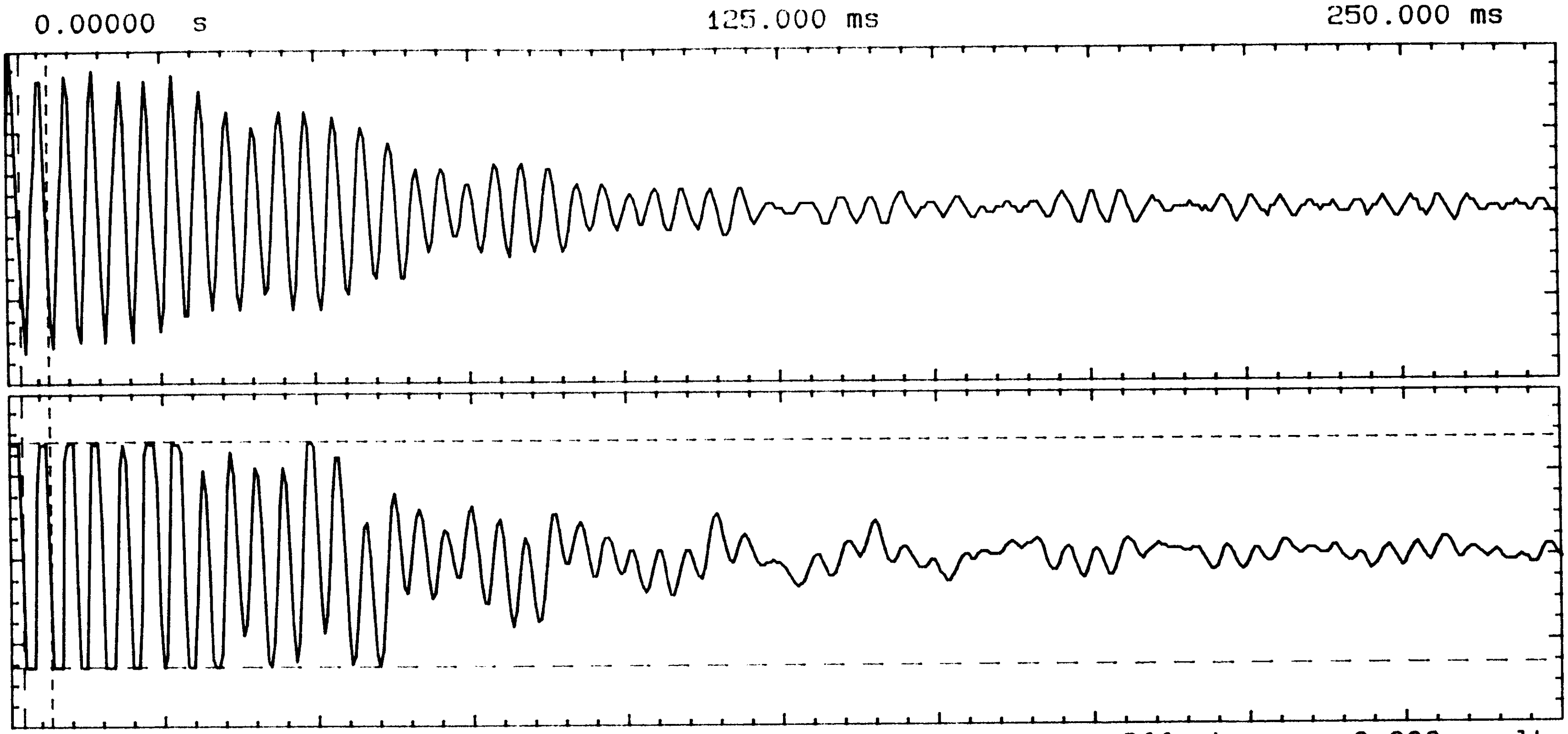
Top Trace:	Cast Iron Specimen	Sand/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Cast Iron Specimen	Sand/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Mem 1 Parameters                   Freq.      =  216.818  Hz             Period     =  4.61217  ms
Rise Time =  1.67944 ms            + Width    =  2.23986 ms              - Width    =  2.37231  ms
Fall Time =  1.61542 ms            Preshoot   =  0.000  volts            Overshoot =  0.000  volts
P-P Volts =  687.6 mvolts          RMS Volts =  202.7 mvolts             Dutycycle =  48.56 %
```

Trace: Cast Iron Specimen Lead Shot/Oil Core Filtrered Input

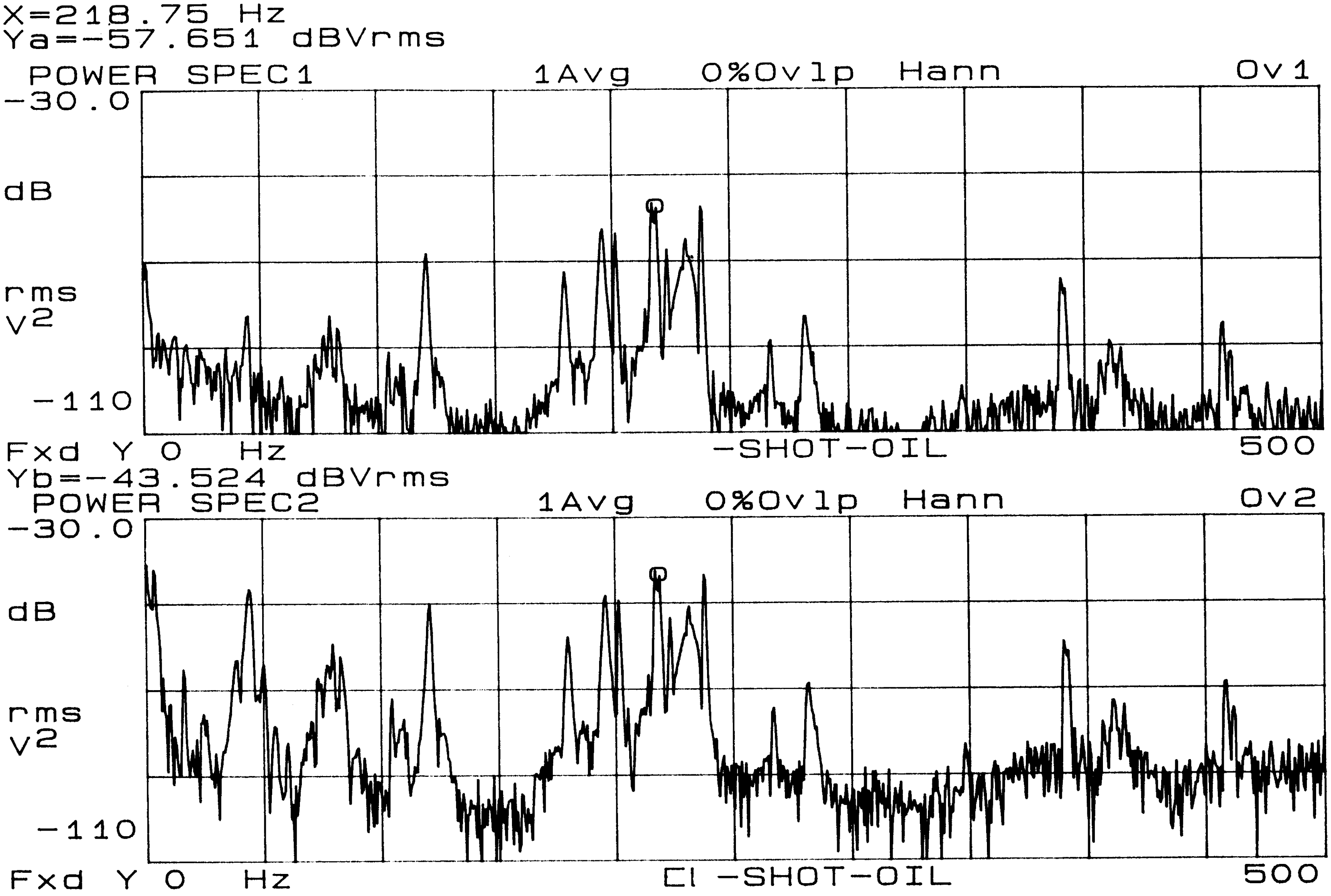
Four Trace Overlay in Time-Space



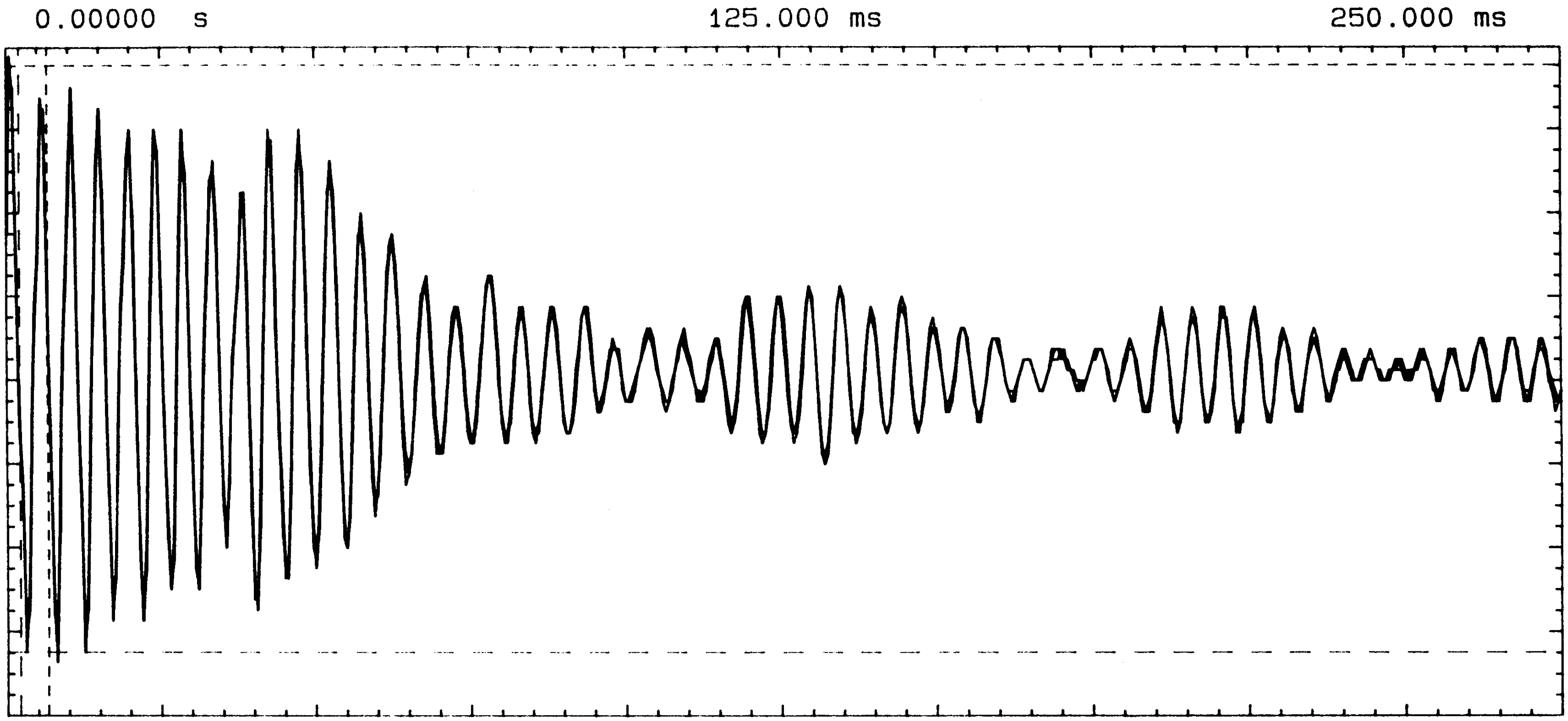
```
Ch. 1     =  200.0 mvolts/div                                          Offset     =  0.000   volts
Ch. 2     =  1.000  volts/div                                          Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                               Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.      =  227.844  Hz          Period     =  4.38896 ms
Rise Time =  724.655 us             + Width    =  2.14650 ms           - Width    =  2.24246 ms
Fall Time =  803.883 us             Preshoot   =  0.000   volts        Overshoot  =  0.000   volts
P-P Volts =  2.687   volts          RMS Volts  =  1.143   volts        Dutycycle  =  48.90 %
```

Top Trace: Cast Iron Specimen Lead Shot/Oil Core Filtrered Input Time-Space

Bottom Trace: Cast Iron Specimen Lead Shot/Oil Core Un-filtered Input



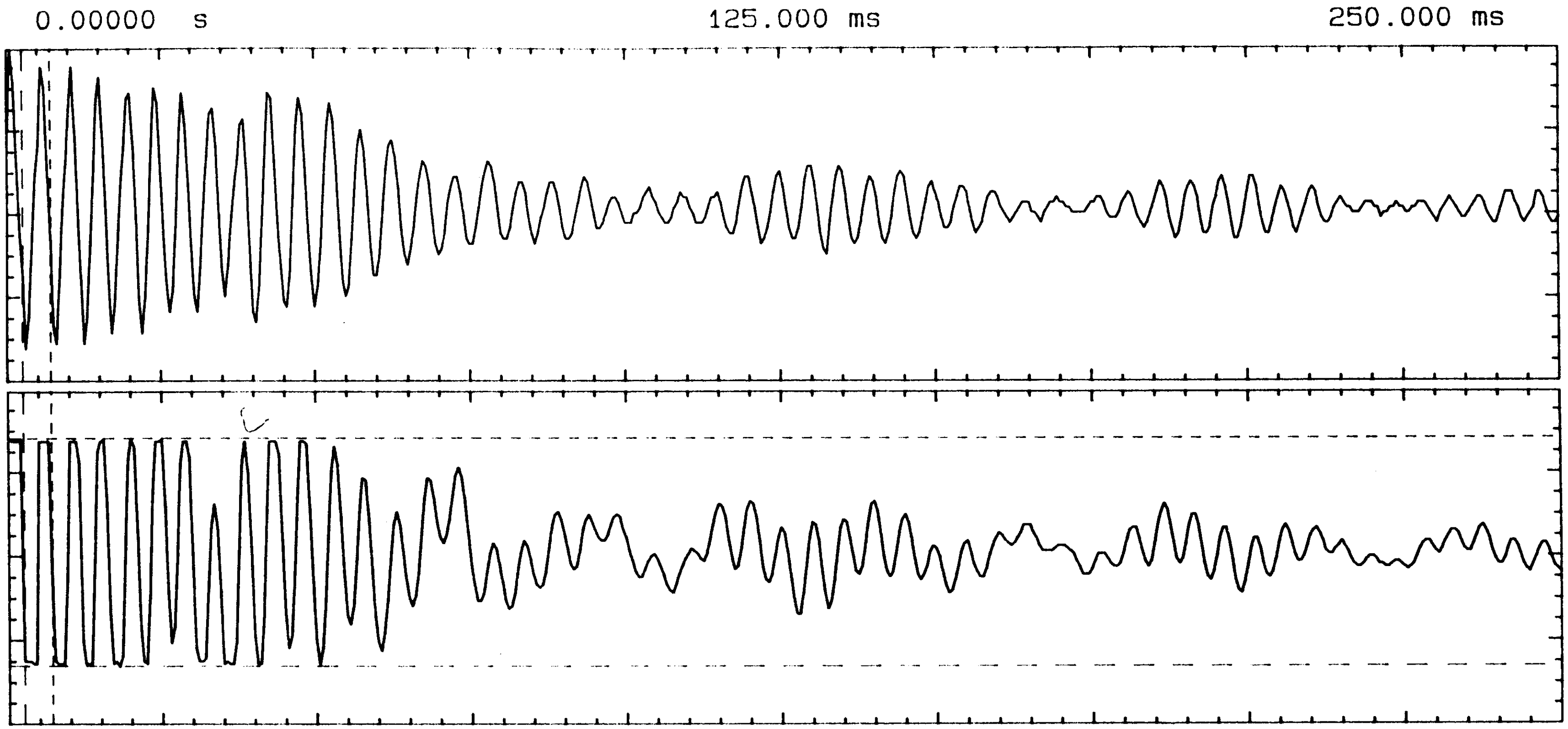
Top Trace:	Cast Iron Specimen	Lead Shot/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Cast Iron Specimen	Lead Shot/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Mem 1 Parameters                 Freq.       =  202.899  Hz            Period     =  4.92855 ms
Rise Time =  2.07754 ms          + Width     =  2.43137 ms              - Width    =  2.49718 ms
Fall Time =  1.75481 ms          Preshoot    =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  700.1 mvolts        RMS Volts   =  211.4 mvolts           Dutycycle  =  49.33 %
```

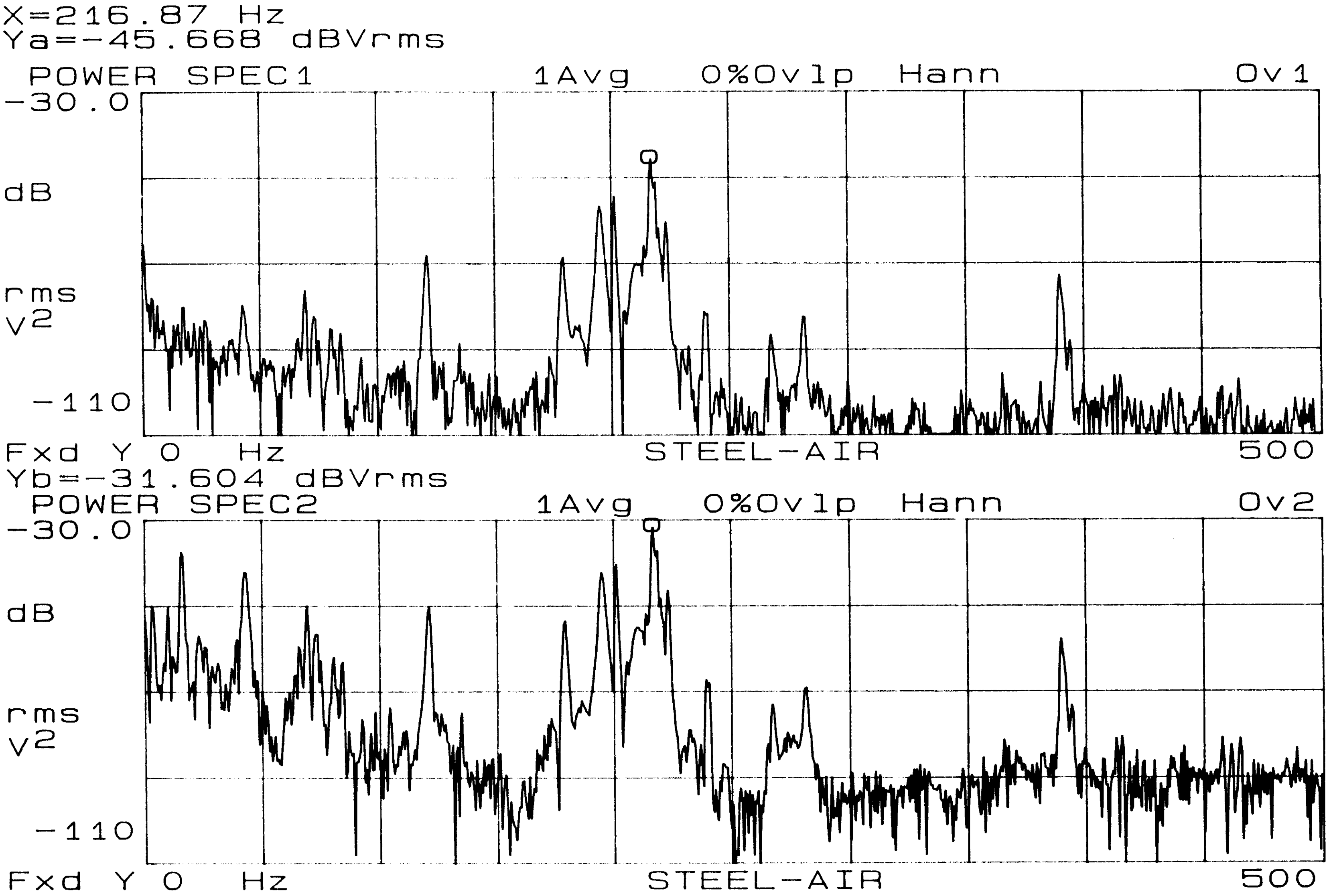
Trace: Steel Specimen Air Core Filtrered Input

Four Trace Overlay in Time-Space



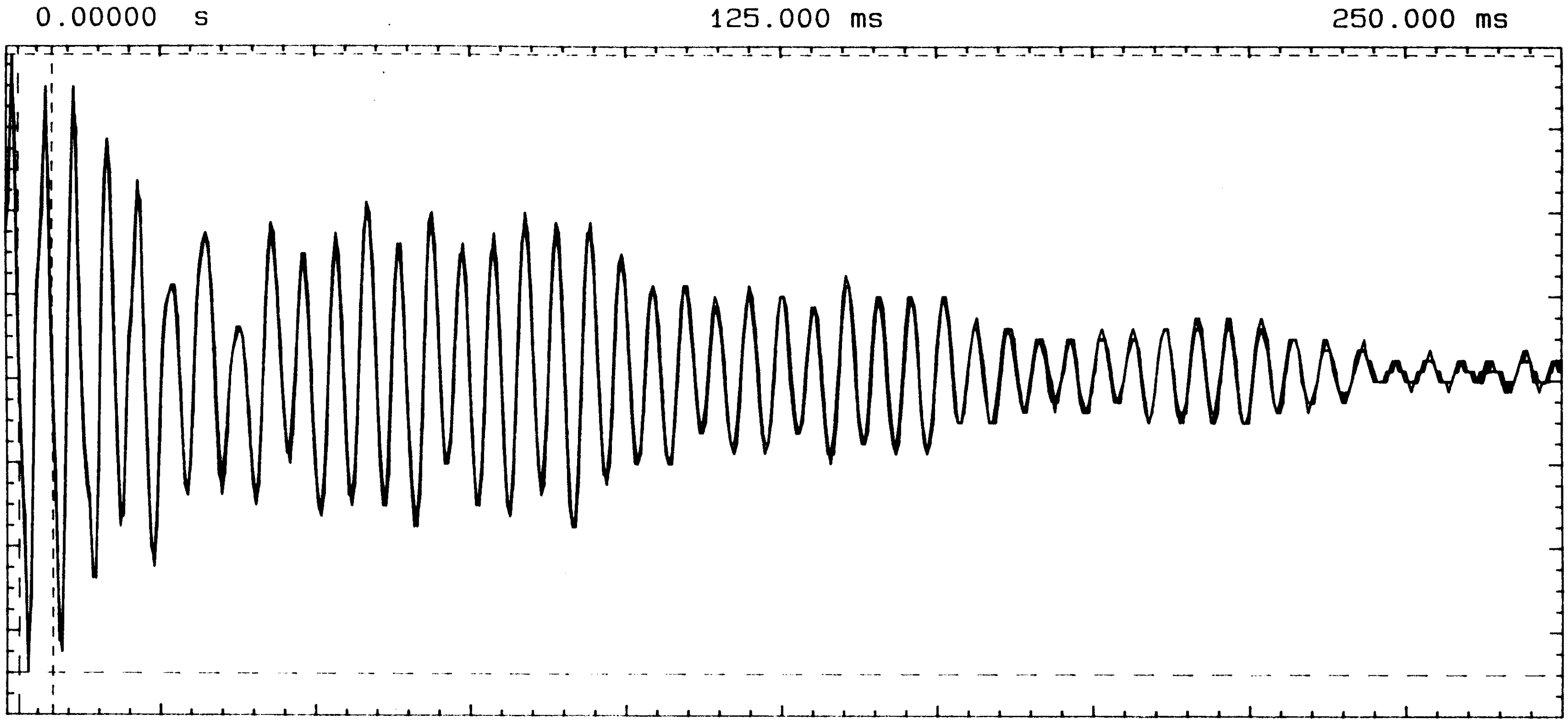
```
Ch. 1      =  200.0 mvolts/div                                      Offset    =  0.000  volts
Ch. 2      =  1.000  volts/div                                      Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                           Delay     =  0.00000  s
Ch. 2 Parameters                     Freq.       =  215.960  Hz     Period    =  4.63048 ms
Rise Time =  409.421 us              + Width     =  2.13636 ms      - Width   =  2.49412 ms
Fall Time =  409.421 us              Preshoot    =  0.000  volts    Overshoot =  0.000  volts
P-P Volts =  2.718  volts            RMS Volts   =  1.251  volts    Dutycycle =  46.13 %
```

Top Trace:	Steel Specimen	Air Core	Filtrered Input	Time-Space
Bottom Trace:	Steel Specimen	Air Core	Un-filtered Input	



Top Trace: Steel Specimen Air Core Filtrered Input Frequency-Space

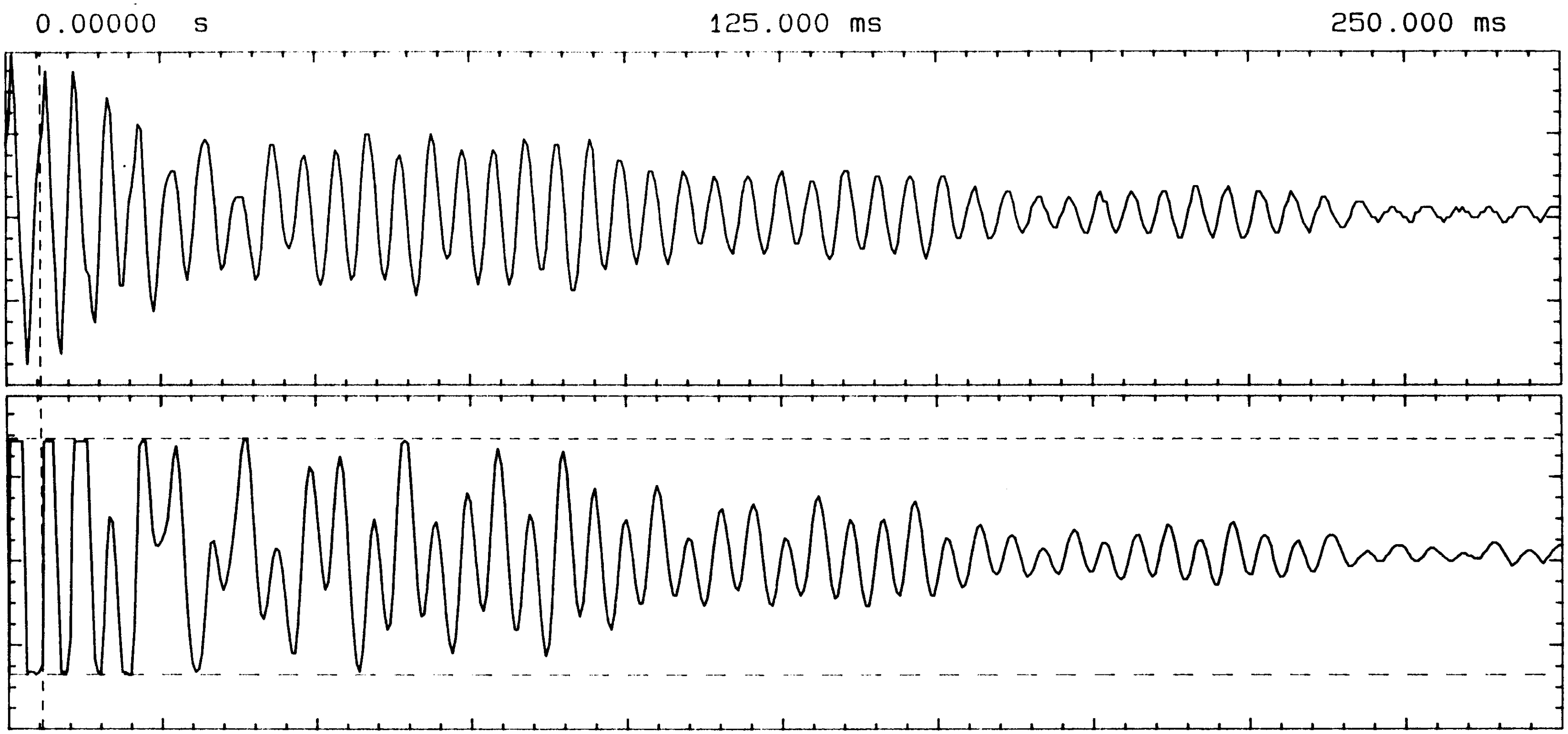
Bottom Trace: Steel Specimen Air Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                      Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                      Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                      Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                      Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Mem 2 Parameters                    Freq.      =  187.524  Hz       Period     =  5.33266 ms
Rise Time =  2.52431 ms             + Width    =  2.76241 ms        - Width    =  2.57025 ms
Fall Time =  1.98643 ms             Preshoot   =  0.000   volts     Overshoot  =  0.000   volts
P-P Volts =  737.6 mvolts           RMS Volts  =  202.4 mvolts      Dutycycle  =  51.80 %
```

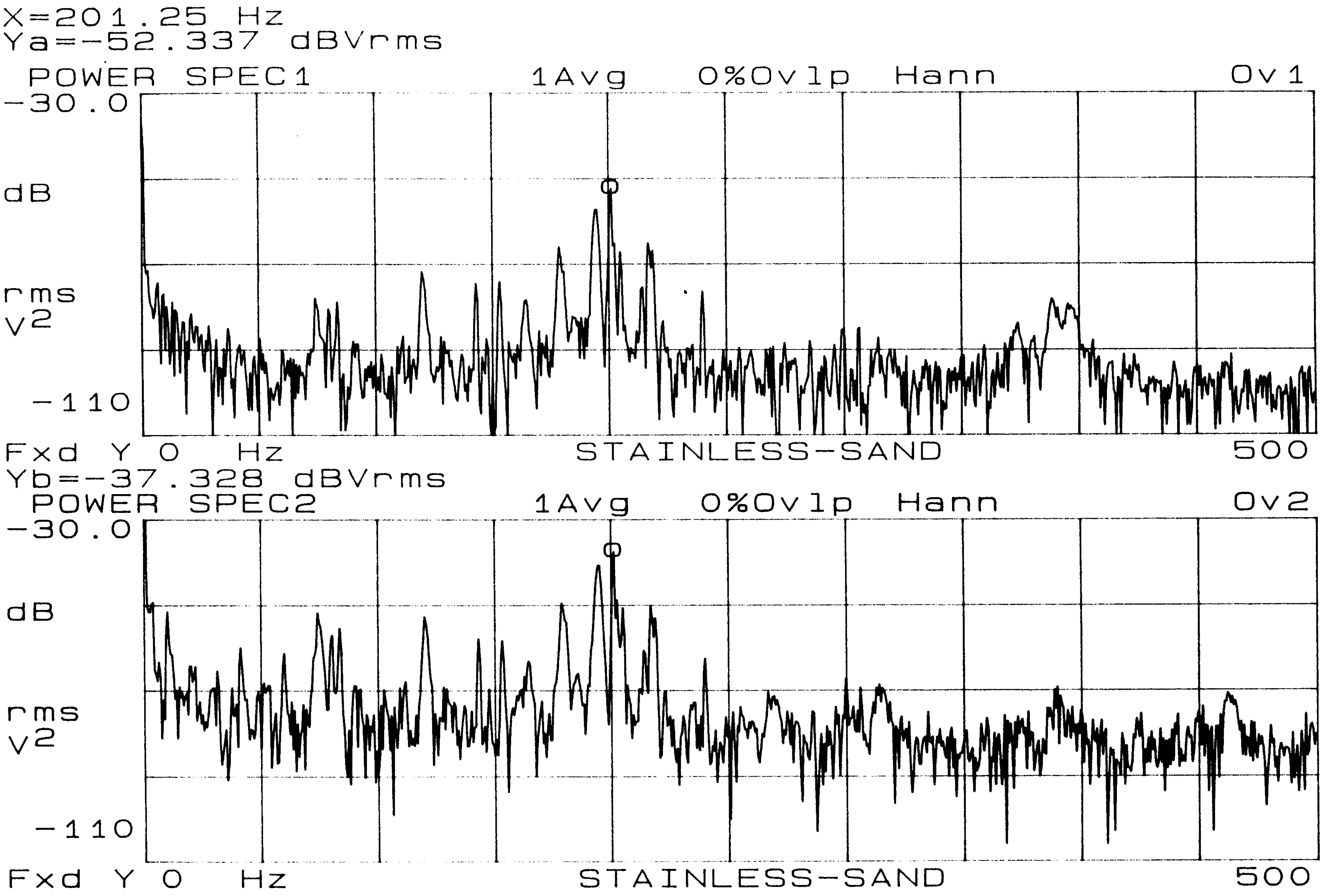
Trace: Steel Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space

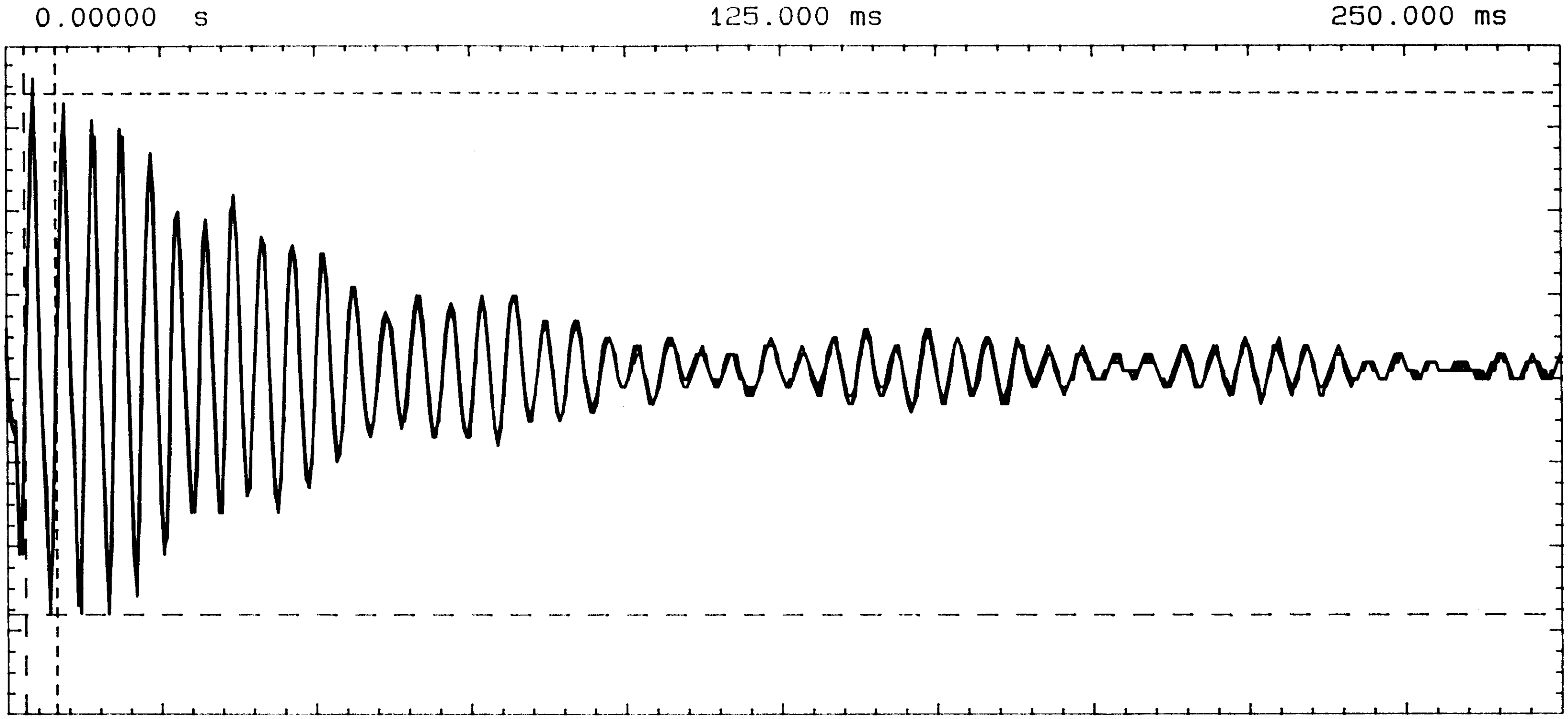


```
Ch. 1       =  200.0 mvolts/div                                         Offset     =  0.000  volts
Ch. 2       =  1.000  volts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  182.110  Hz            Period     =  5.49118 ms
Rise Time =  409.091 us           + Width     =  2.50000 ms             - Width    =  2.99118 ms
Fall Time =  409.091 us           Preshoot    =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  2.812  volts         RMS Volts   =  1.361  volts           Dutycycle  =  45.52 %
```

Top Trace:	Steel Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Steel Specimen	Sand Core	Un-filtered Input	



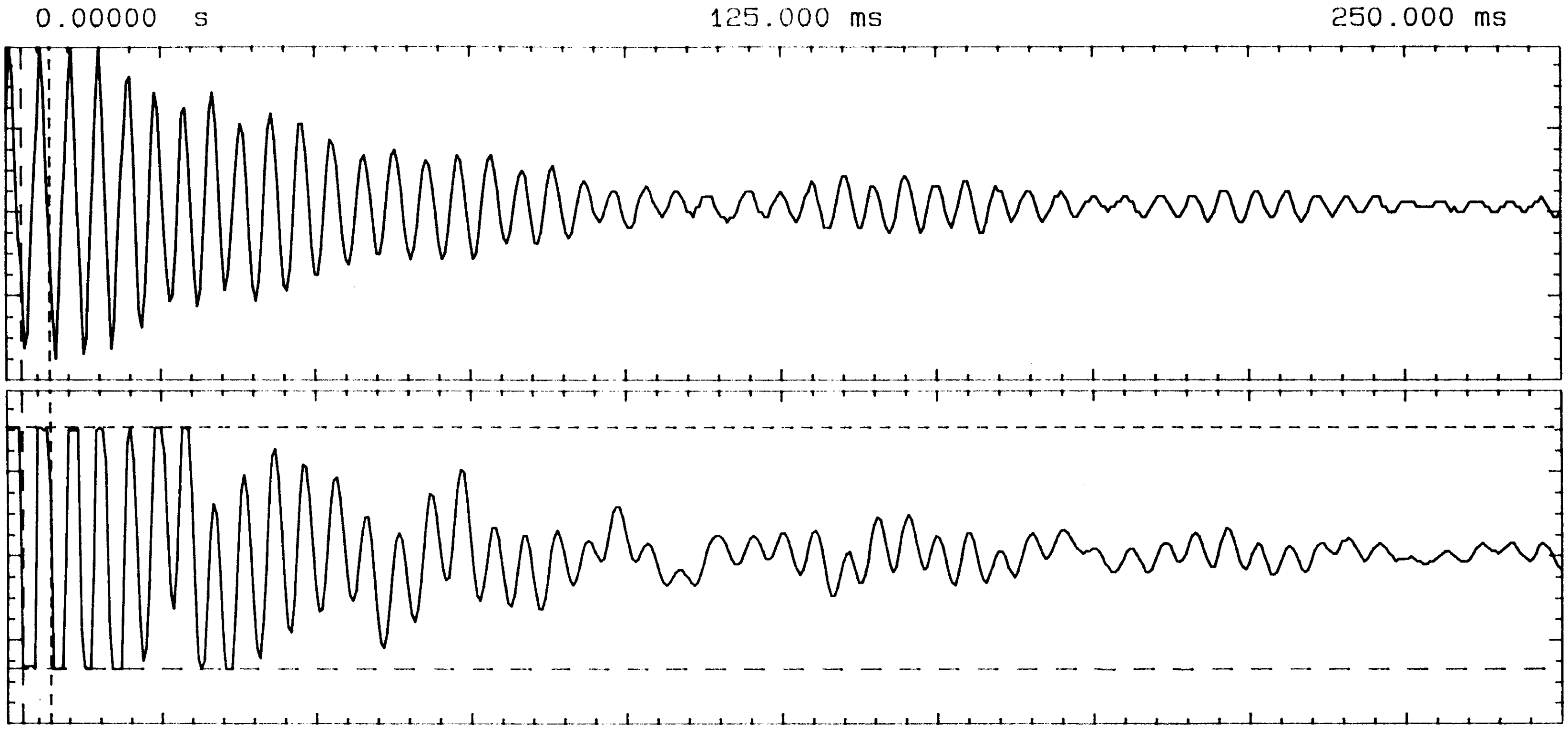
Top Trace:	Steel Specimen	Sand Core	Filtrered Input	Frequency-Space
Bottom Trace:	Steel Specimen	Sand Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Mem 1 Parameters                      Freq.      =  202.716  Hz             Period     =  4.93301 ms
Rise Time =  1.93250 ms               + Width    =  2.27625 ms              - Width    =  2.65676 ms
Fall Time =  2.05413 ms               Preshoot   =  0.000  volts            Overshoot =  0.000  volts
P-P Volts =  777.4 mvolts             RMS Volts =  229.2 mvolts             Dutycycle =  46.14 %
```

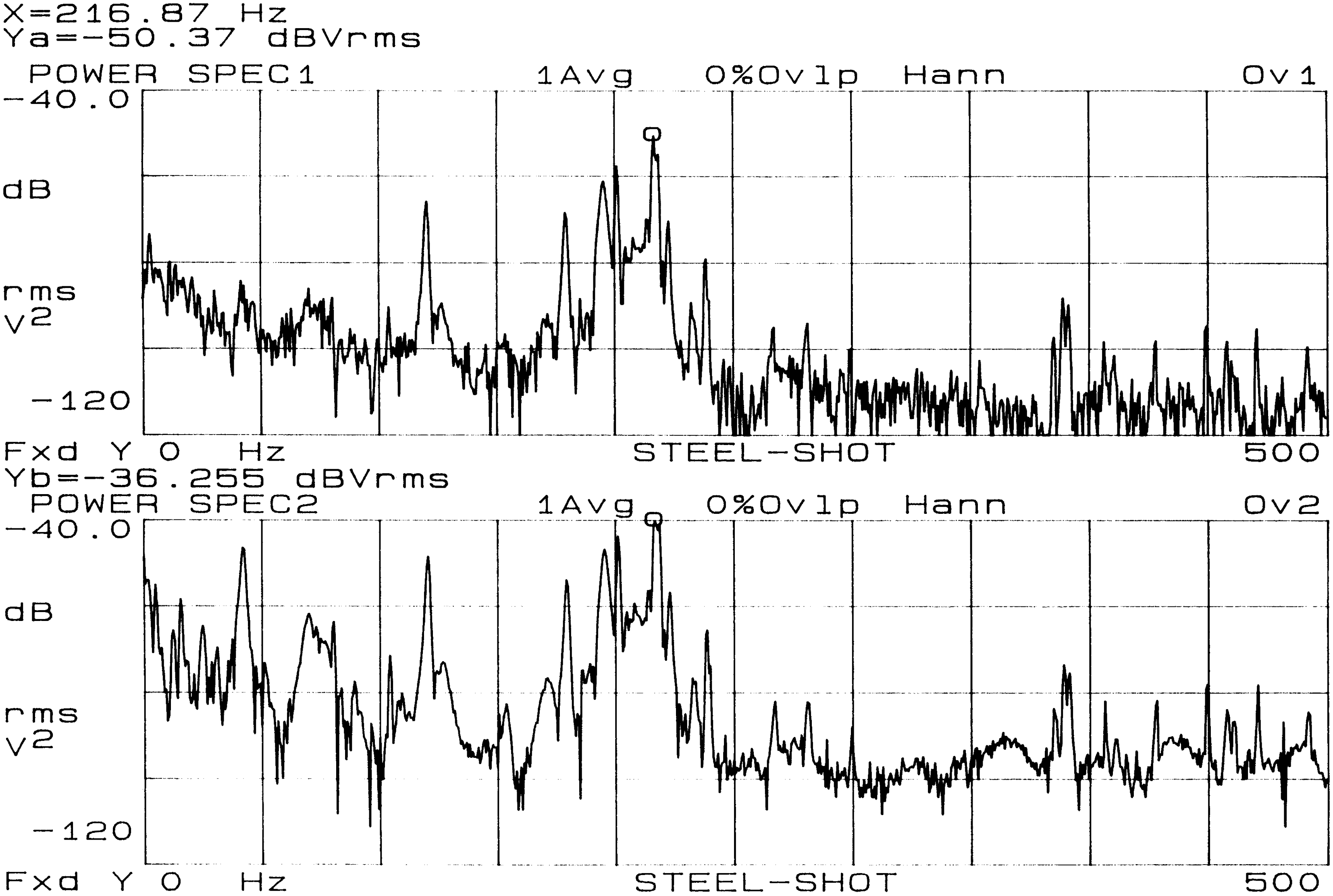
Trace: Steel Specimen Lead Shot Core Filtrered Input

Four Trace Overlay in Time-Space

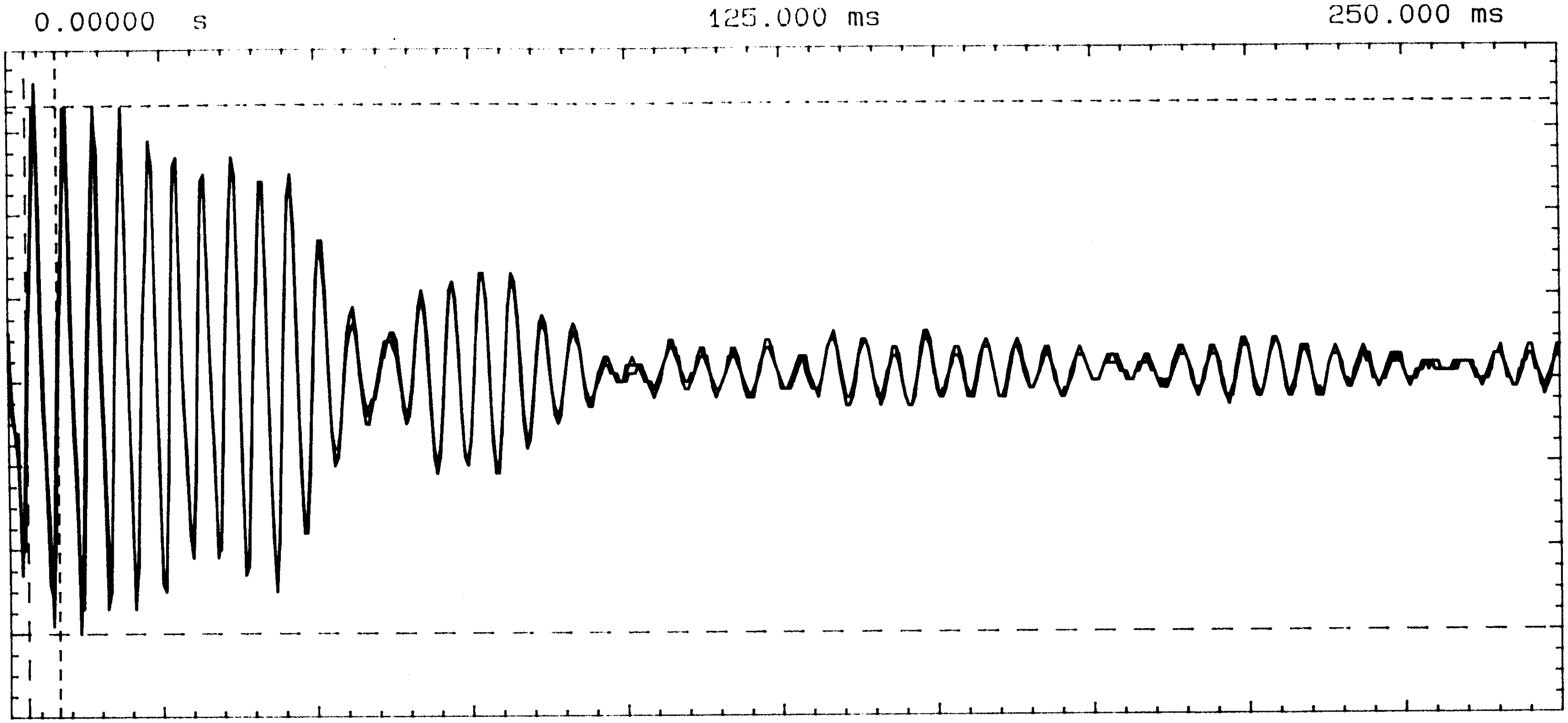


```
Ch. 1      =  200.0 mvolts/div                                         Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                         Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.      =  203.707  Hz          Period     =  4.90902 ms
Rise Time =  400.008 us             + Width    =  2.41176 ms           - Width    =  2.49725 ms
Fall Time =  404.404 us             Preshoot   =  0.000  volts         Overshoot =  0.000  volts
P-P Volts =  2.875  volts           RMS Volts =  1.360  volts          Dutycycle =  49.12 %
```

Top Trace:	Steel Specimen	Lead Shot Core	Filtrered Input	Time-Space
Bottom Trace:	Steel Specimen	Lead Shot Core	Un-filtered Input	



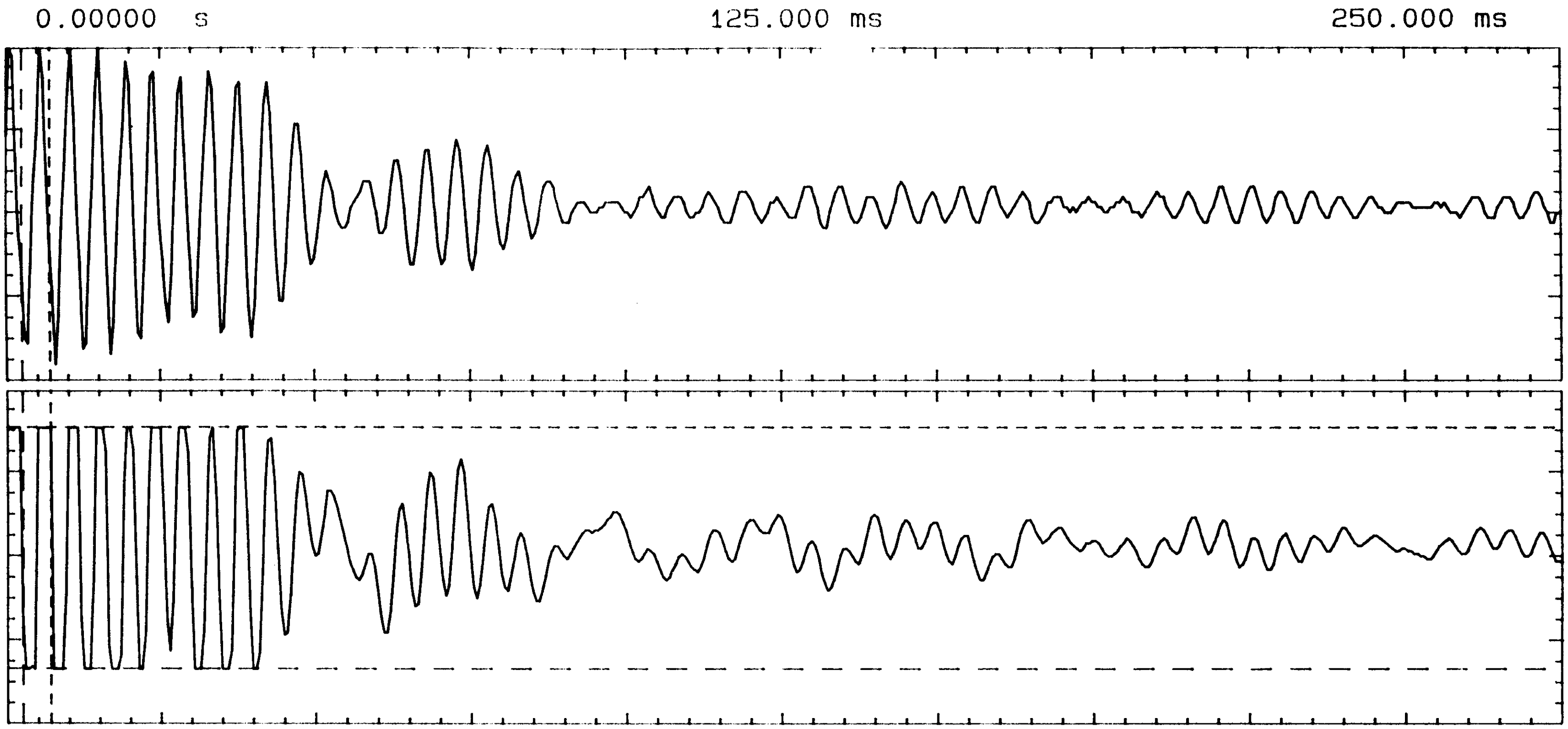
Top Trace:	Steel Specimen	Lead Shot Core	Filtrered Input	**Frequency-Space**
Bottom Trace:	Steel Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 1 Parameters                Freq.      =  201.547  Hz          Period     =  4.96163 ms
Rise Time =  1.75611 ms         + Width    =  2.42372 ms           - Width    =  2.53791 ms
Fall Time =  2.12057 ms         Preshoot   =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  789.1 mvolts       RMS Volts  =  236.1 mvolts         Dutycycle  =  48.84 %
```

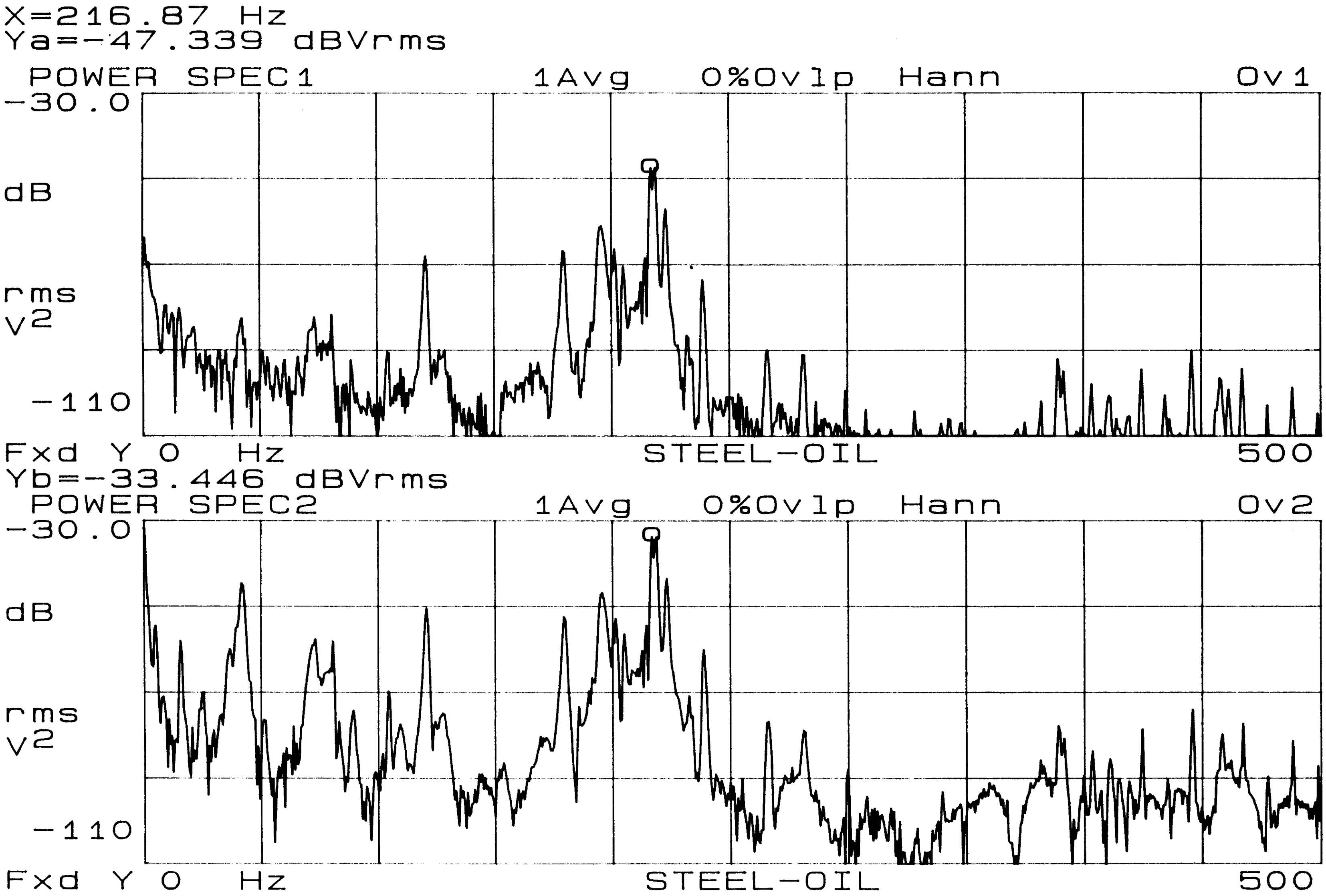
Trace: Steel Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                 Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                 Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                      Delay      =  0.00000  s
Ch. 2 Parameters               Freq.       =  202.817  Hz      Period     =  4.93056 ms
Rise Time  =  400.008 us       + Width     =  2.50000 ms       - Width    =  2.43056 ms
Fall Time  =  706.136 us       Preshoot    =  0.000   volts    Overshoot  =  0.000   volts
P-P Volts  =  2.875  volts     RMS Volts   =  1.392   volts    Dutycycle  =  50.70 %
```

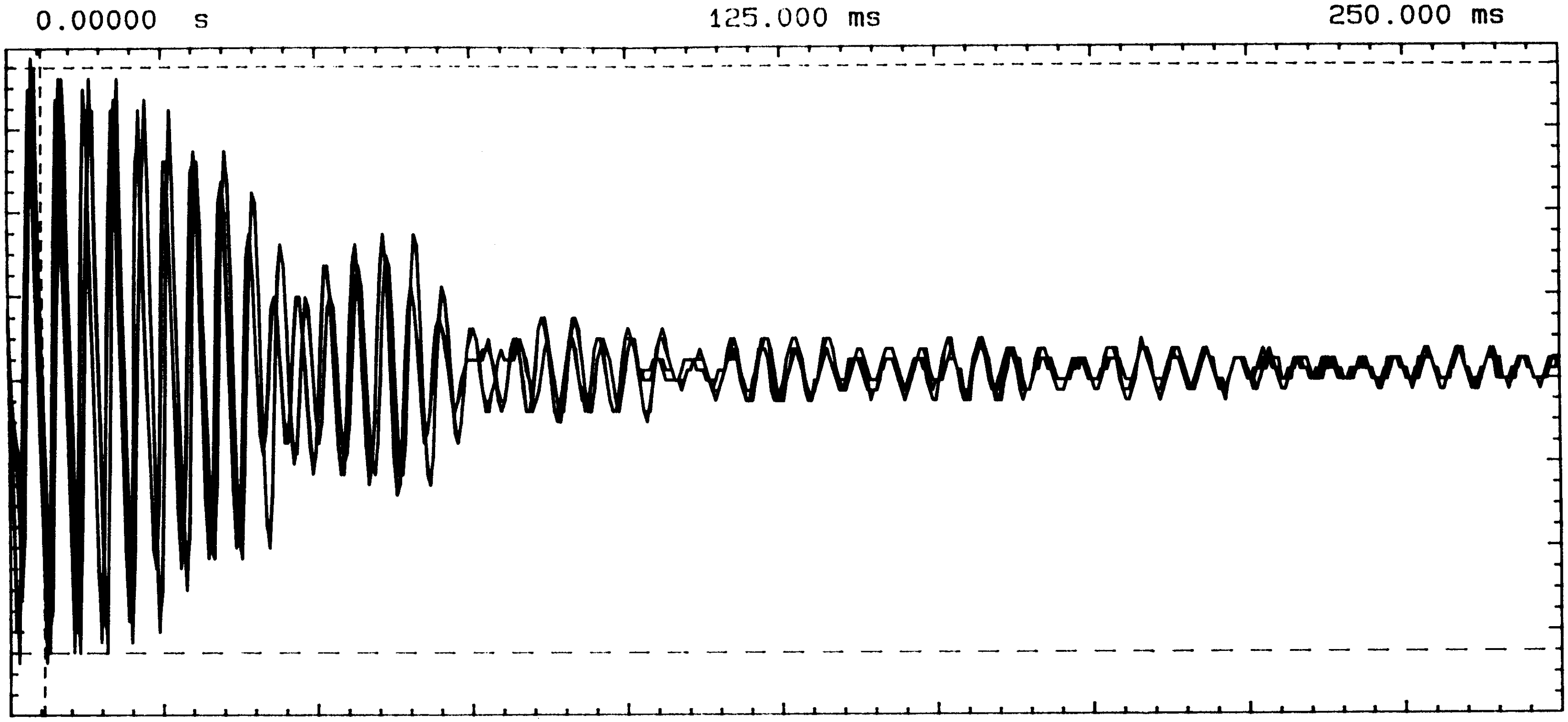
Top Trace:	Steel Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Steel Specimen	Oil Core	Un-filtered Input	



Top Trace: Steel Specimen Oil Core Filtrered Input

Bottom Trace: Steel Specimen Oil Core Un-filtered Input

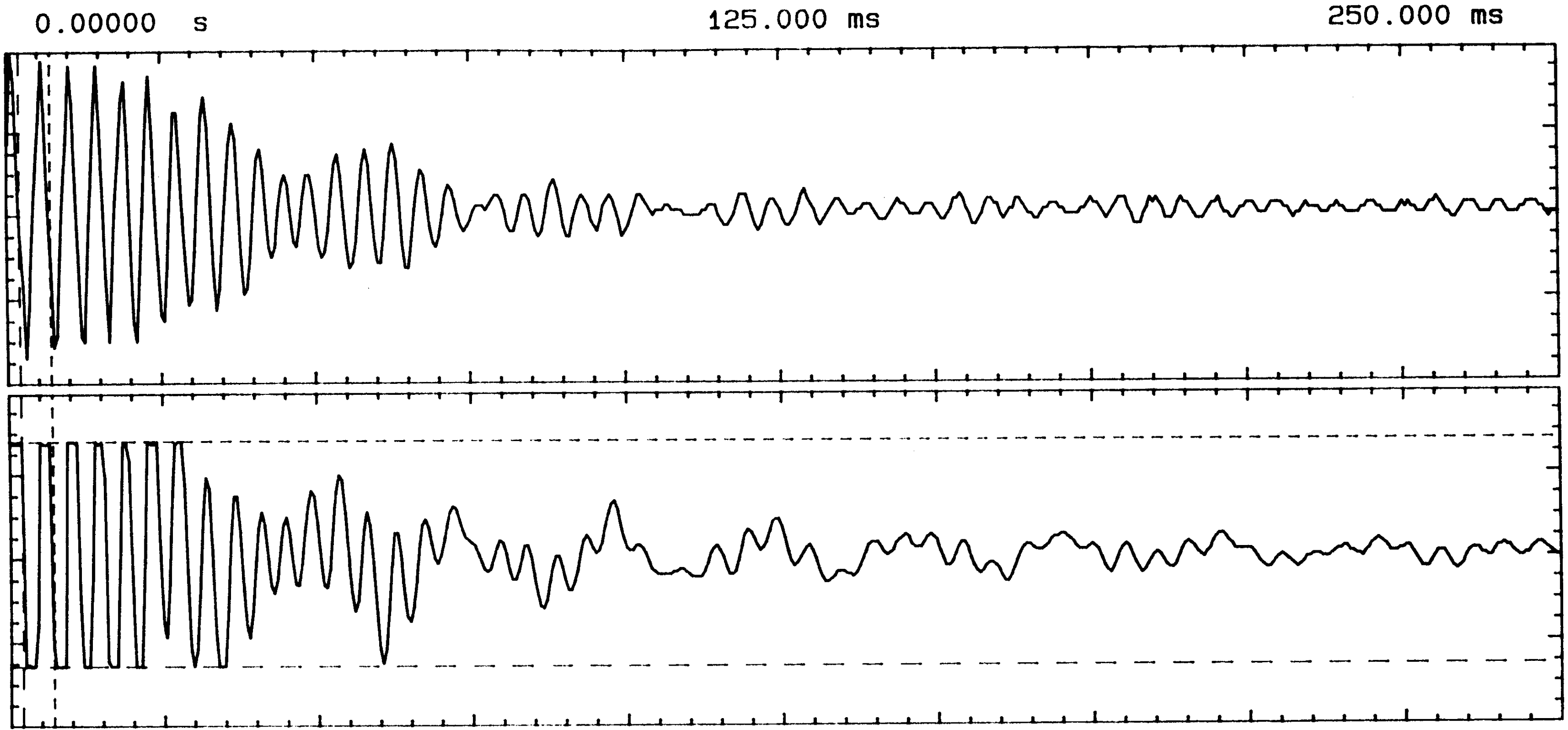
Frequency-Space



```
Timebase  =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1  =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2  =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3  =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4  =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 1 Parameters                  Freq.      =  192.923  Hz       Period     =  5.18343 ms
Rise Time =  1.80326 ms           + Width    =  2.34953 ms        - Width    =  2.83390 ms
Fall Time =  1.69369 ms           Preshoot   =  0.000  volts      Overshoot  =  0.000  volts
P-P Volts =  700.1 mvolts         RMS Volts  =  190.2 mvolts      Dutycycle  =  45.32 %
```

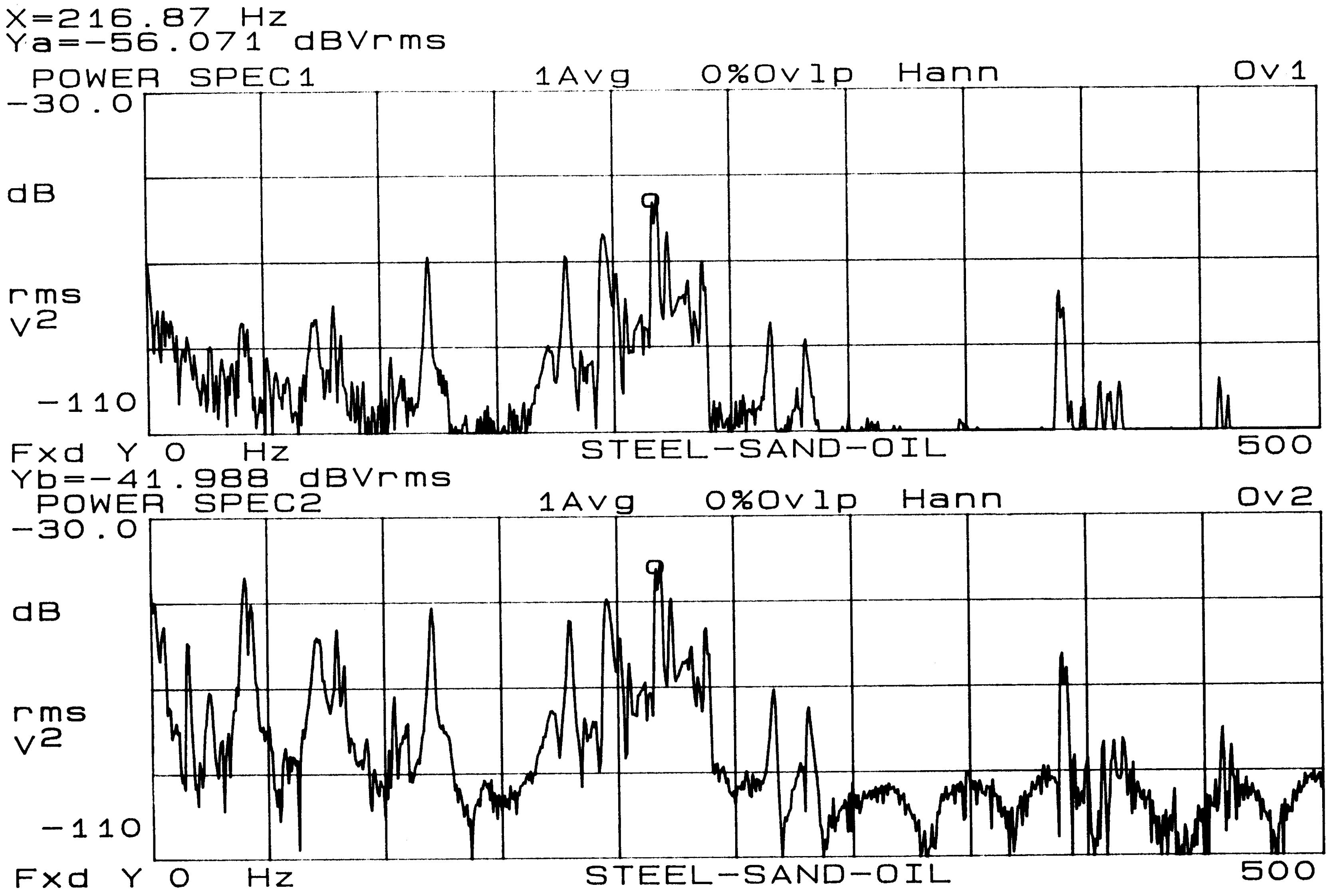
Trace: Steel Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

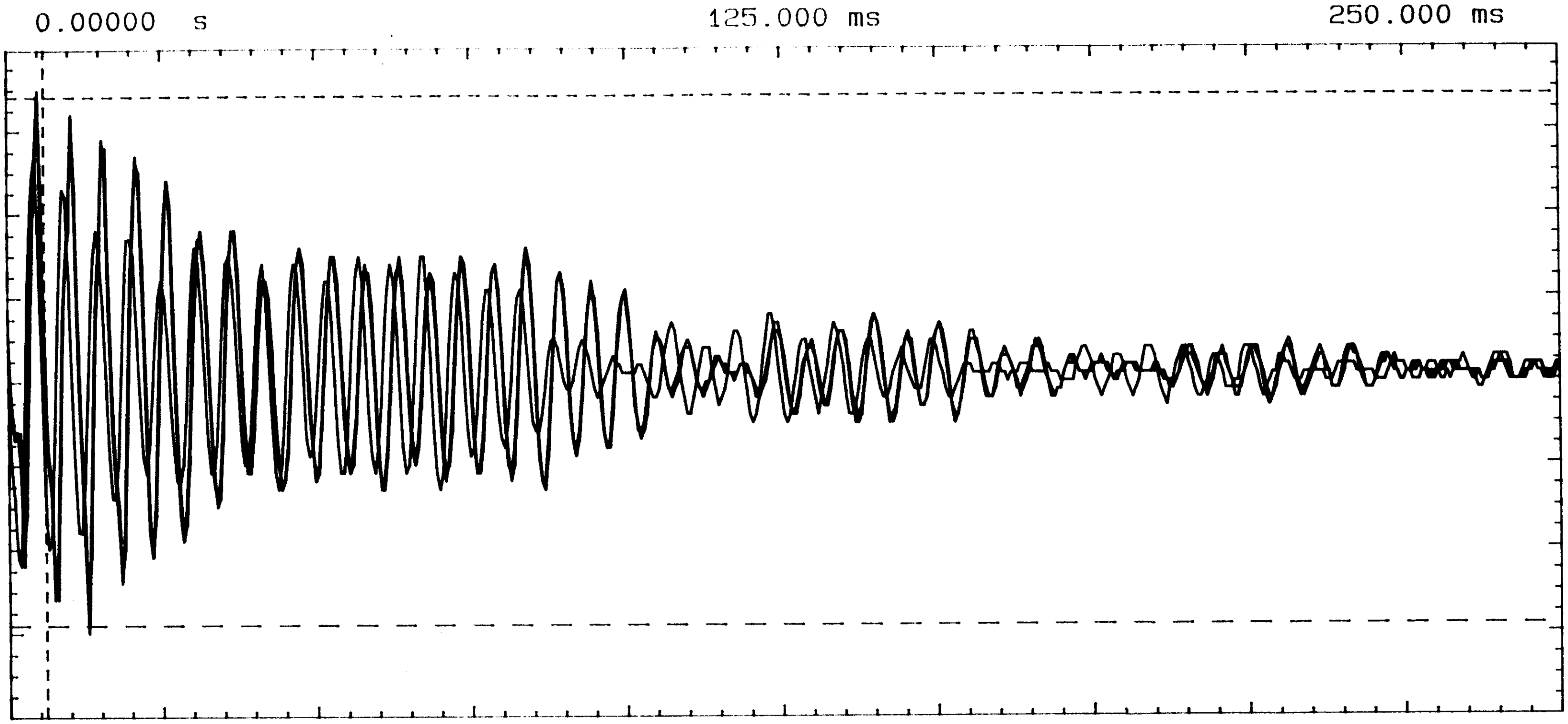


```
Ch. 1      =  200.0 mvolts/div                                          Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                          Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Ch. 2 Parameters                      Freq.       =  220.963  Hz        Period     =  4.52564 ms
Rise Time =  652.706 us               + Width     =  2.07846 ms          - Width   =  2.44718 ms
Fall Time =  399.982 us               Preshoot    =  0.000   volts      Overshoot =  0.000   volts
P-P Volts =  2.687   volts            RMS Volts   =  1.276   volts      Dutycycle =  45.92 %
```

Top Trace:	Steel Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Steel Specimen	Sand/Oil Core	Un-filtered Input	



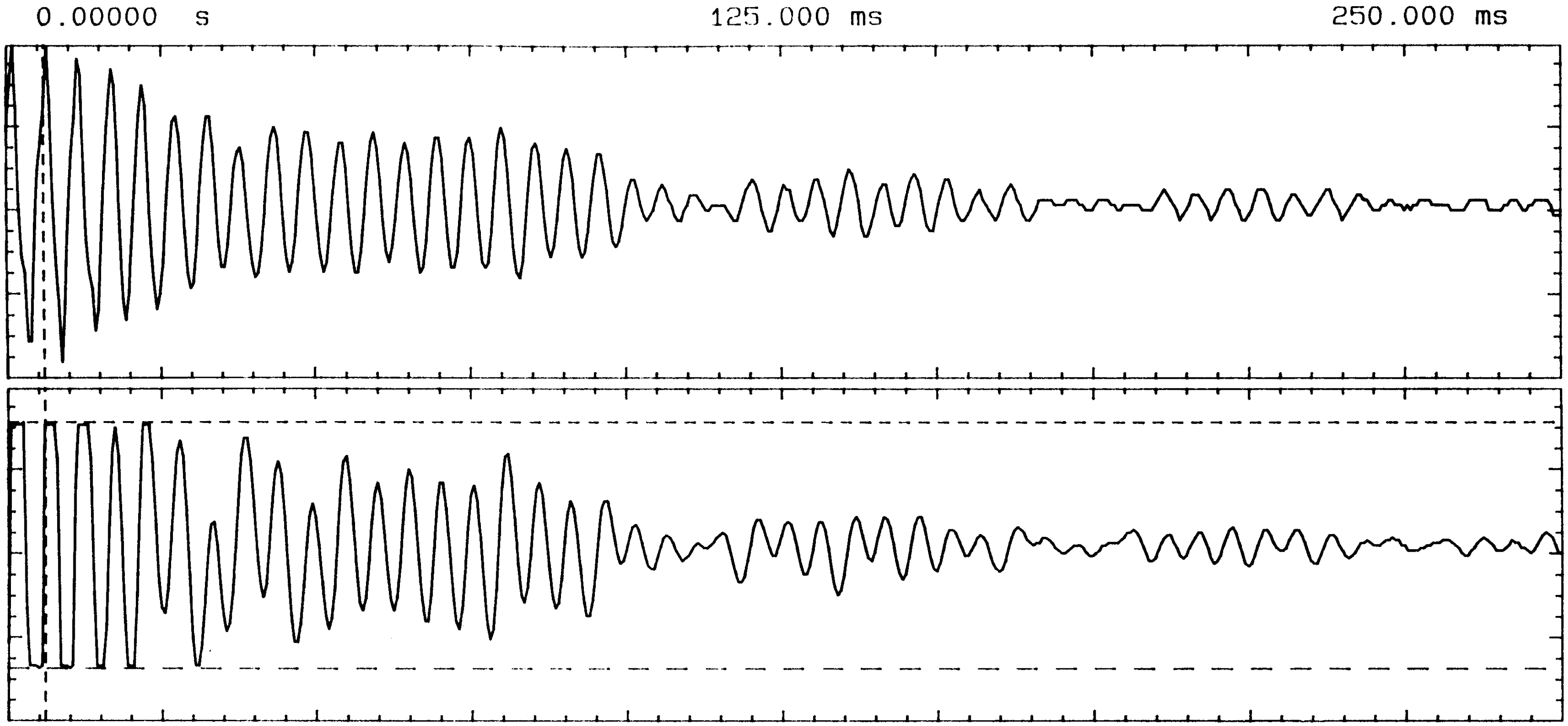
Top Trace:	Steel Specimen	Sand/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Steel Specimen	Sand/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 1 Parameters                 Freq.      =  175.070  Hz         Period     =  5.71200 ms
Rise Time =  2.54492 ms          + Width    =  2.33403 ms           - Width   =  3.37797 ms
Fall Time =  2.18000 ms          Preshoot   =  0.000  volts        Overshoot =  0.000  volts
P-P Volts =  789.1 mvolts        RMS Volts  =  195.9 mvolts        Dutycycle =  40.86 %
```

Trace: Steel Specimen Lead Shot/Oil Core Filtrered Input

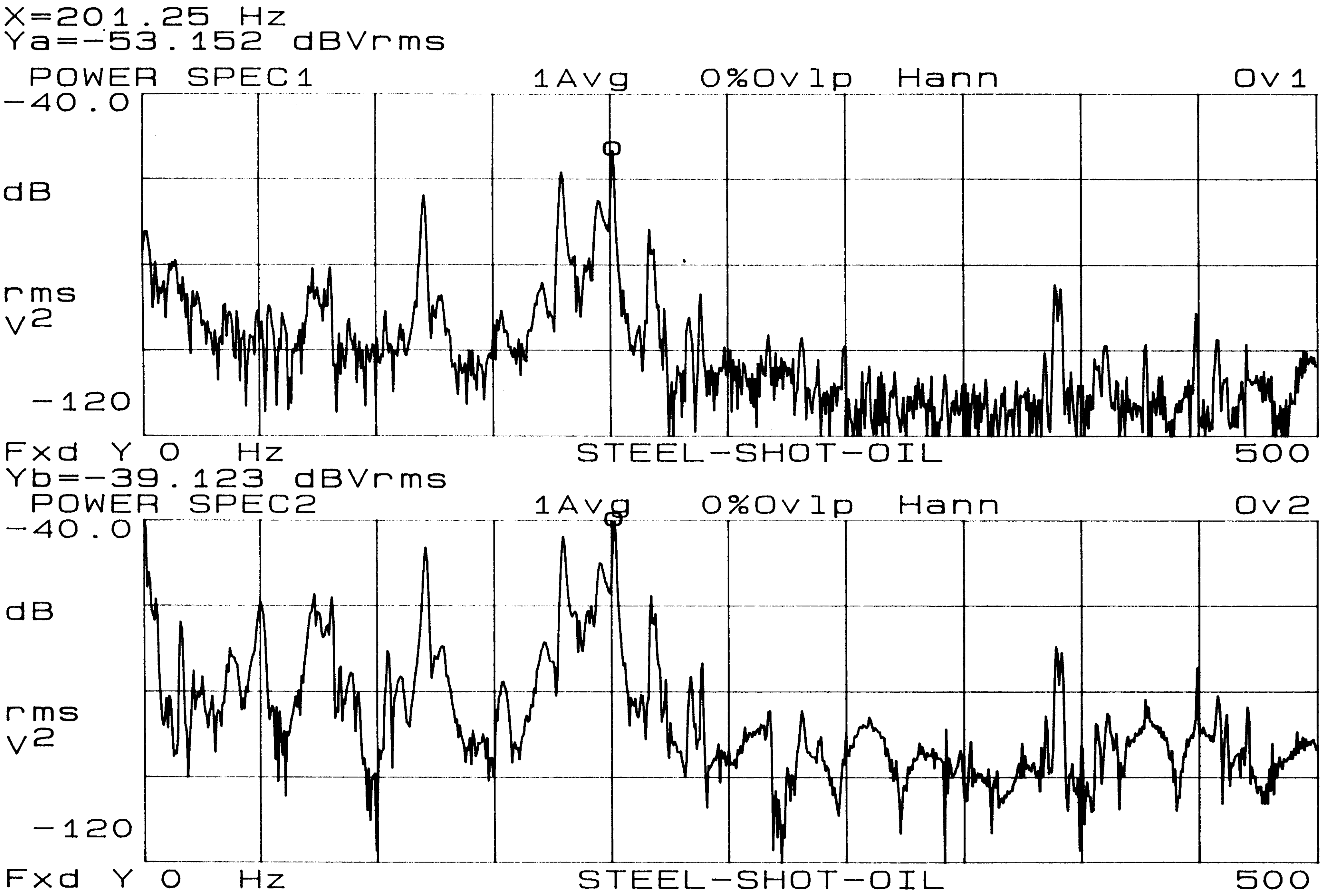
Four Trace Overlay in Time-Space



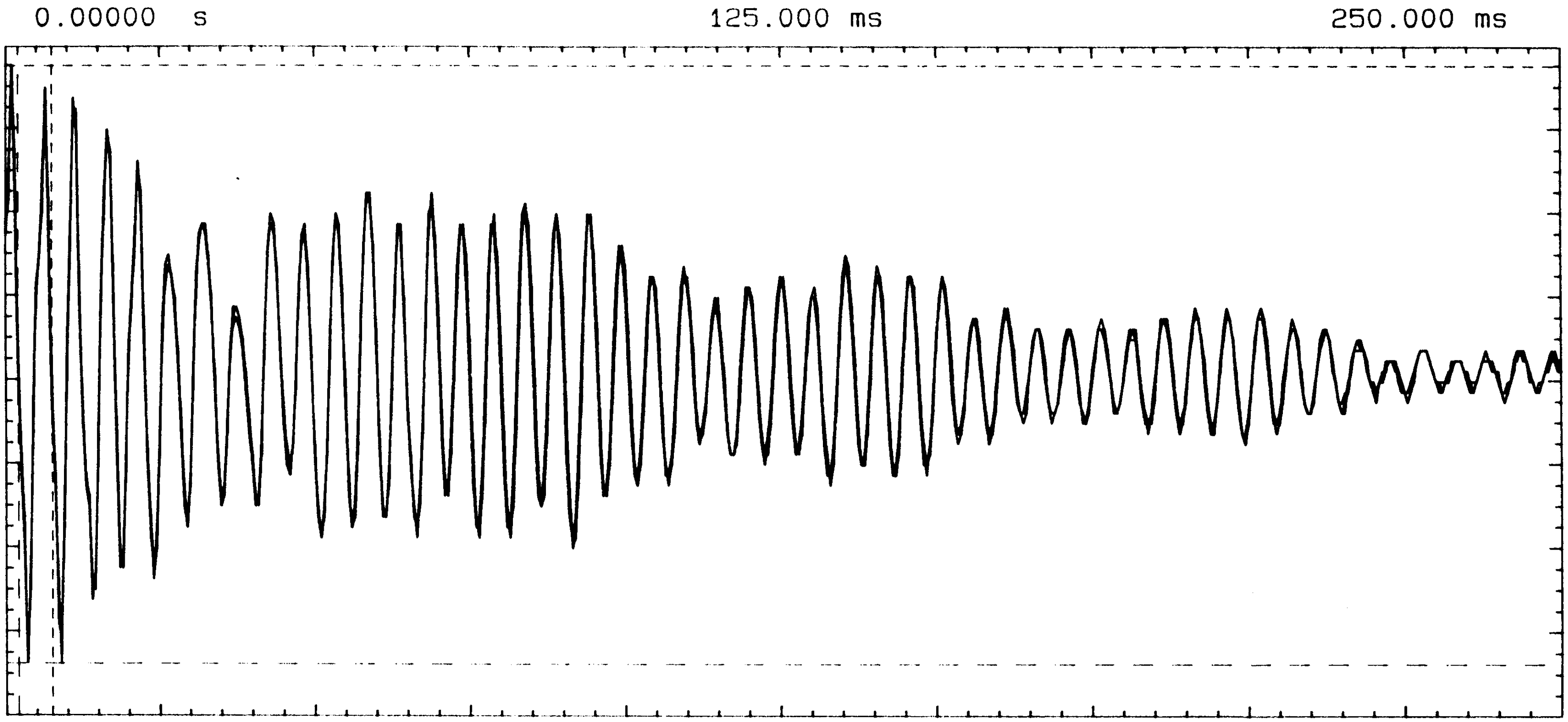
```
Ch. 1       =  200.0 mvolts/div                                              Offset     =  0.000   volts
Ch. 2       =  1.000  volts/div                                              Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                                     Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.        =  180.926  Hz                Period     =  5.52711 ms
Rise Time =  408.713 us           + Width      =  2.60809 ms                 - Width    =  2.91901 ms
Fall Time =  742.940 us           Preshoot     =  0.000  volts               Overshoot  =  0.000   volts
P-P Volts =  2.937  volts         RMS Volts    =  1.382  volts               Dutycycle  =  47.18 %
```

Top Trace: Steel Specimen Lead Shot/Oil Core Filtrered Input Time-Space

Bottom Trace: Steel Specimen Lead Shot/Oil Core Un-filtered Input



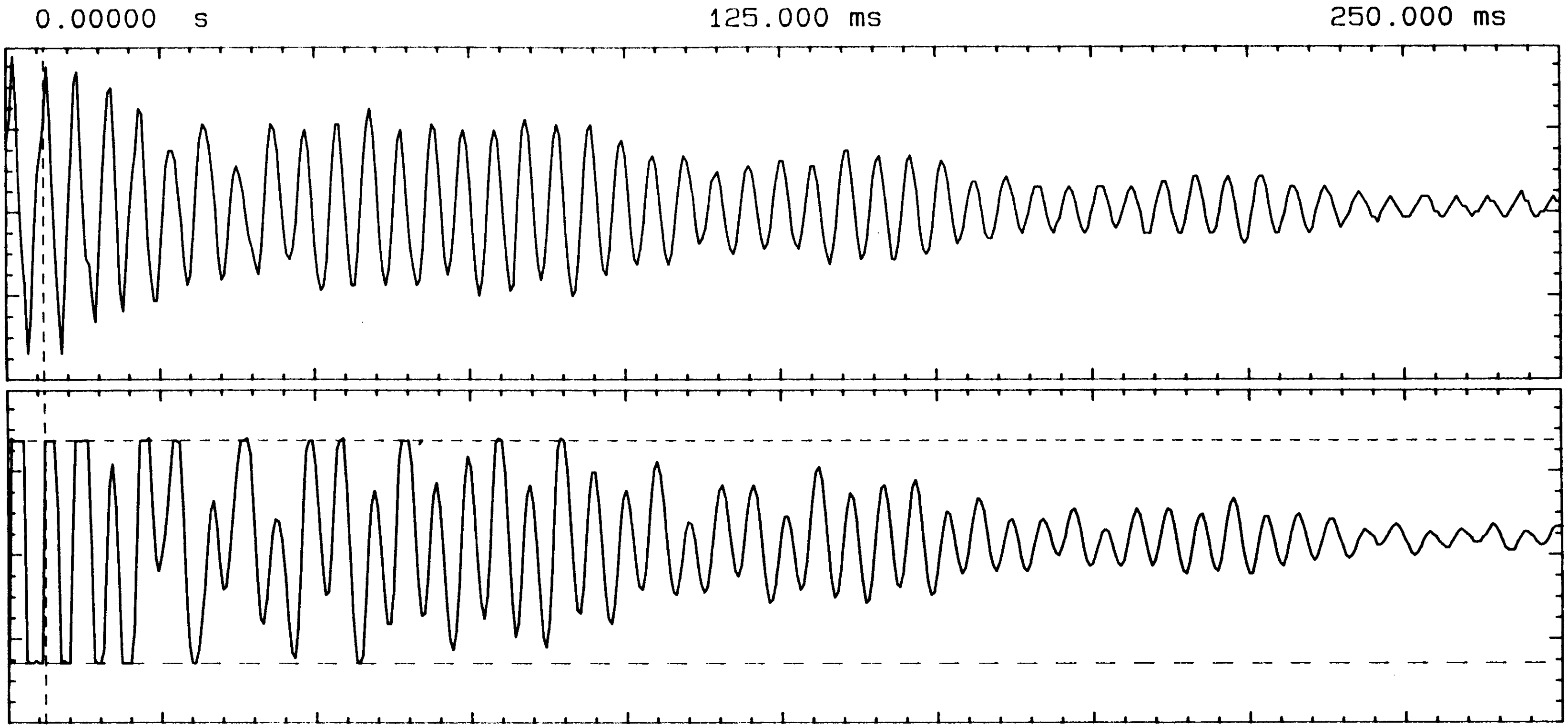
Top Trace:	Steel Specimen	Lead Shot/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Steel Specimen	Lead Shot/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                             Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                             Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                             Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                             Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Mem 3 Parameters                   Freq.      =  185.607  Hz               Period     =  5.38772 ms
Rise Time =  2.50934 ms            + Width    =  2.75085 ms                - Width    =  2.63687 ms
Fall Time =  1.99638 ms            Preshoot   =  0.000  volts              Overshoot =  0.000  volts
P-P Volts =  712.6 mvolts          RMS Volts  =  193.7 mvolts              Dutycycle =  51.05 %
```

Trace: Stainless Steel Specimen Air Core Filtrered Input

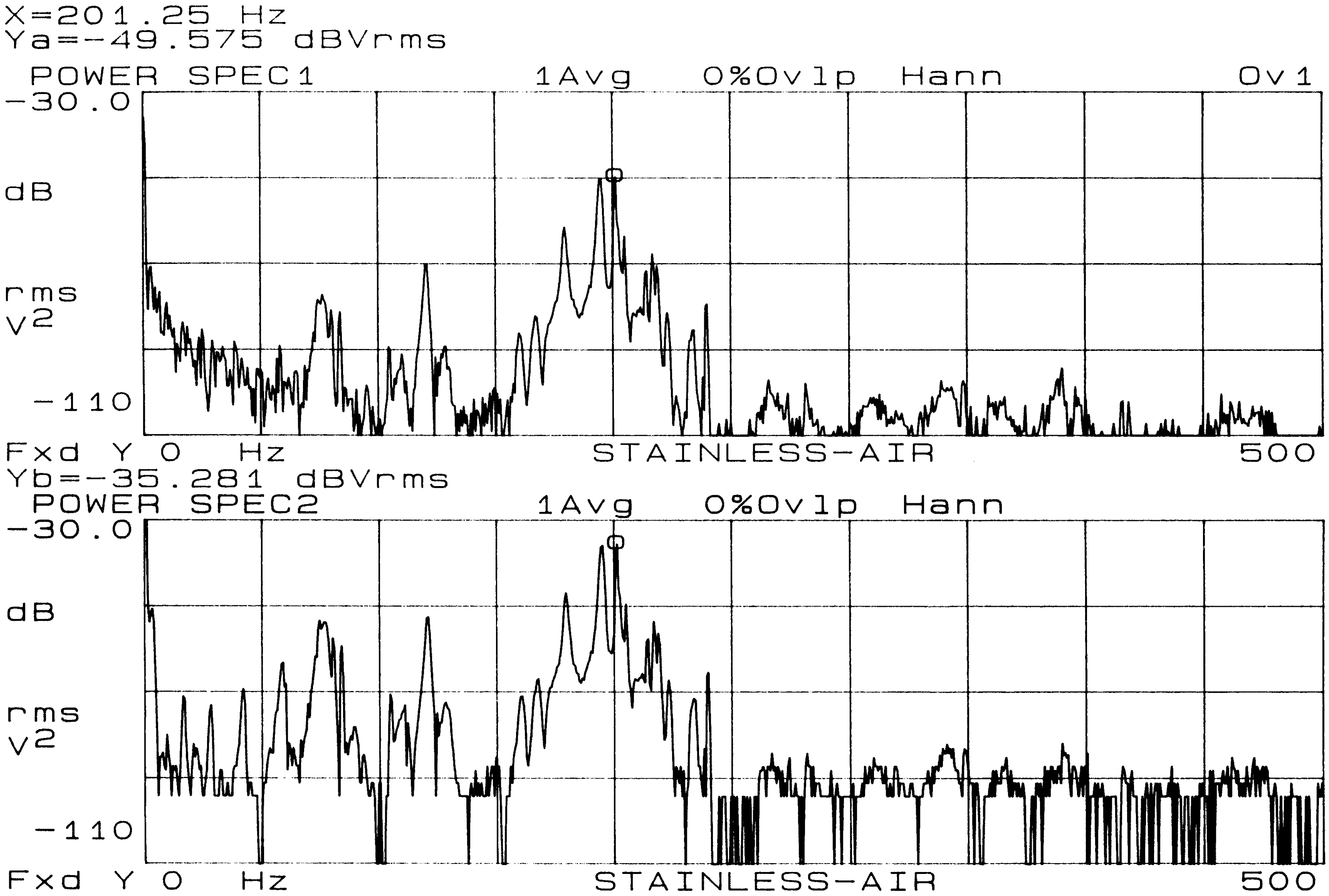
Four Trace Overlay in Time-Space



```
Ch. 1     =  200.0 mvolts/div                                         Offset     =  0.000   volts
Ch. 2     =  1.000  volts/div                                         Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000   s
Ch. 2 Parameters                Freq.      =  181.722  Hz             Period     =  5.50291 ms
Rise Time =  395.349 us         + Width    =  2.50588 ms              - Width    =  2.99702 ms
Fall Time =  404.762 us         Preshoot   =  0.000   volts           Overshoot  =  31.25 mvolts
P-P Volts =  2.687   volts      RMS Volts  =  1.323   volts           Dutycycle  =  45.53 %
```

Top Trace: Stainless Steel Specimen Air Core Filtrered Input Time-Space

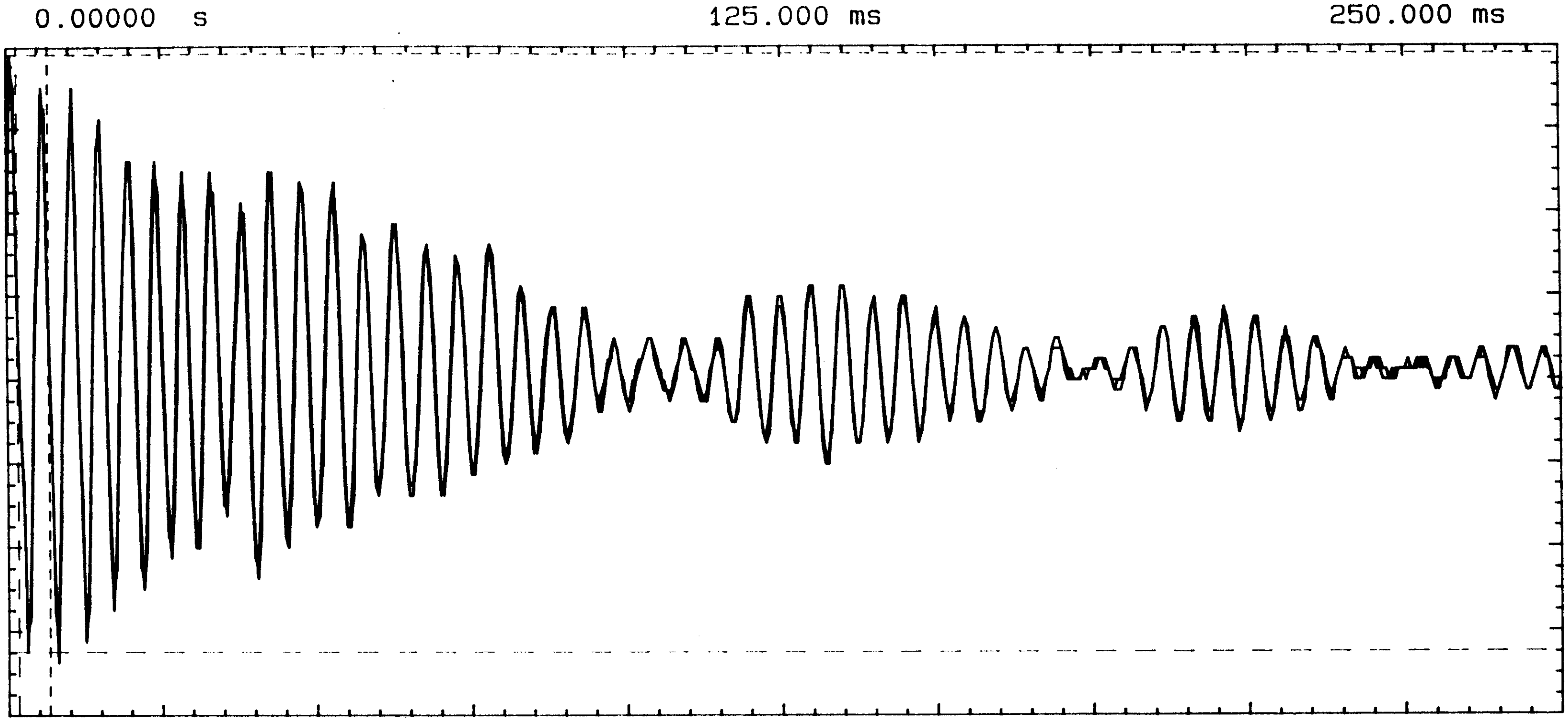
Bottom Trace: Stainless Steel Specimen Air Core Un-filtered Input



Top Trace: Stainless Steel Specimen Air Core Filtrered Input

Frequency-Space

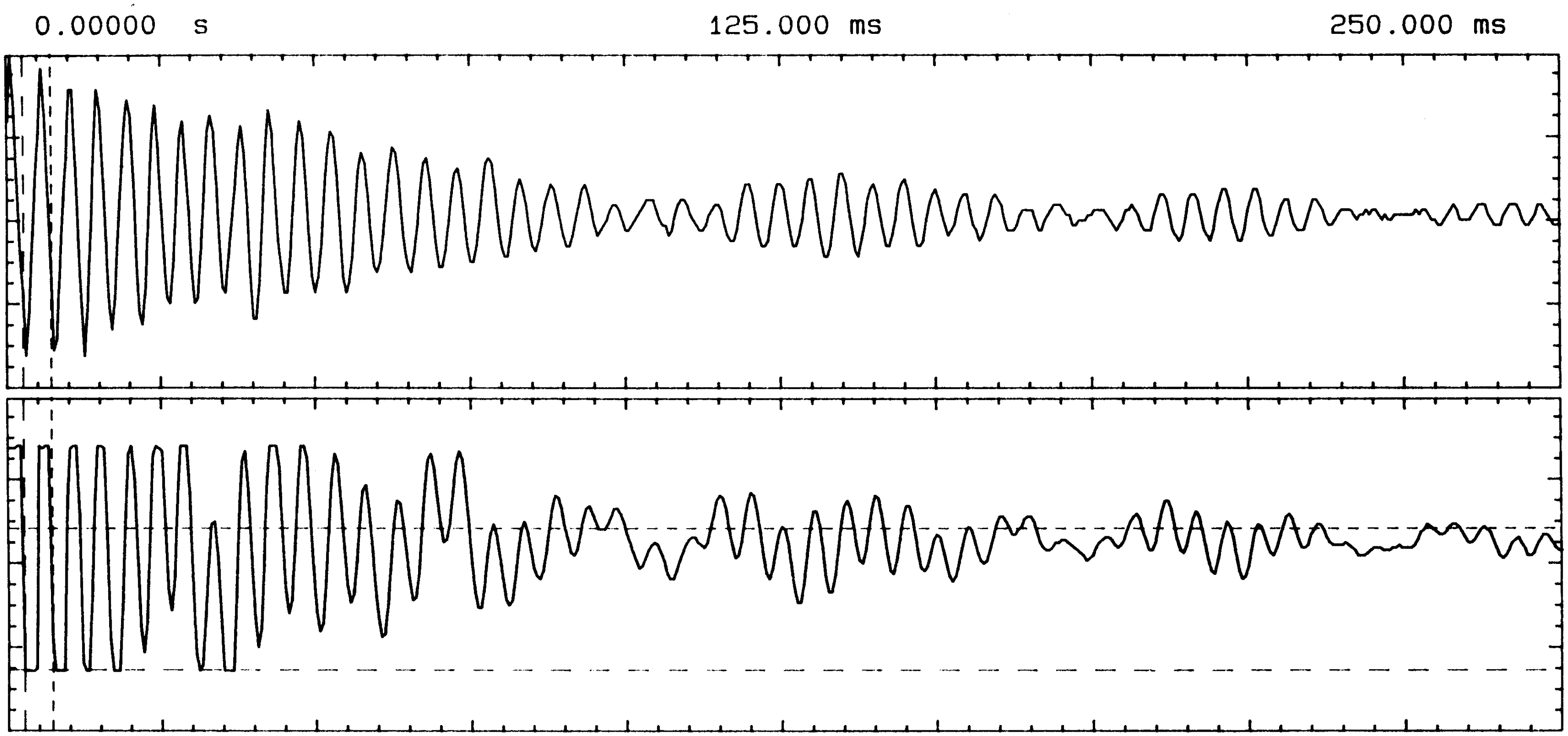
Bottom Trace: Stainless Steel Specimen Air Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Mem 1 Parameters                 Freq.       =  203.126  Hz      Period     =  4.92305 ms
Rise Time =  2.06118 ms          + Width     =  2.36006 ms        - Width    =  2.56299 ms
Fall Time =  1.94705 ms          Preshoot    =  0.000  volts     Overshoot  =  0.000  volts
P-P Volts =  712.6 mvolts        RMS Volts  =  204.7 mvolts      Dutycycle  =  47.93 %
```

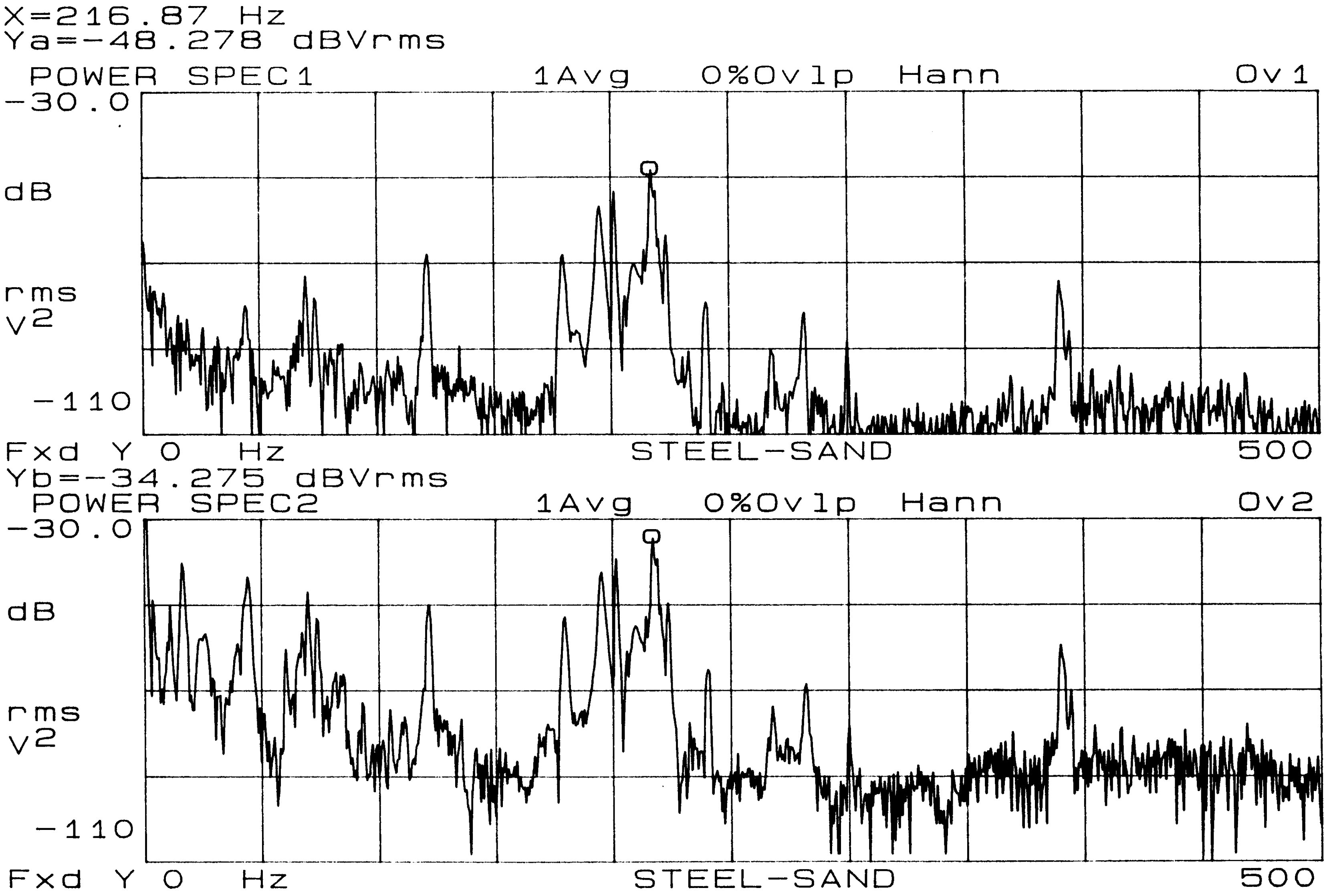
Trace: Stainless Steel Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space

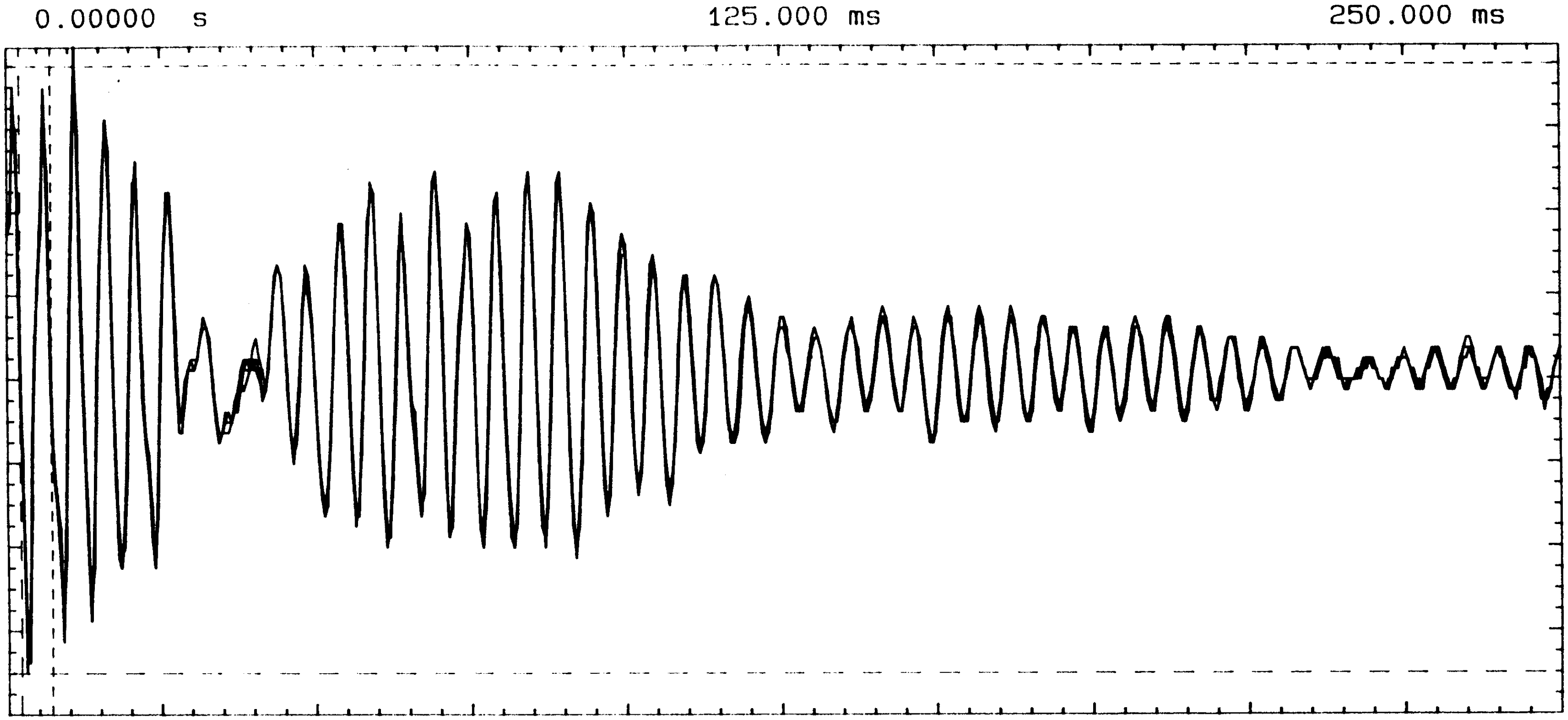


```
Ch. 1      =  200.0 mvolts/div                                  Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Ch. 2 Parameters                 Freq.      =  219.246  Hz      Period     =  4.56109 ms
Rise Time =  254.136 us          + Width    =  2.25117 ms       - Width    =  2.30992 ms
Fall Time =  251.181 us          Preshoot   =  1.000  volts     Overshoot =  0.000  volts
P-P Volts =  2.687   volts       RMS Volts =  1.292  volts      Dutycycle =  49.35 %
```

Top Trace:	Stainless Steel Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Stainless Steel Specimen	Sand Core	Un-filtered Input	



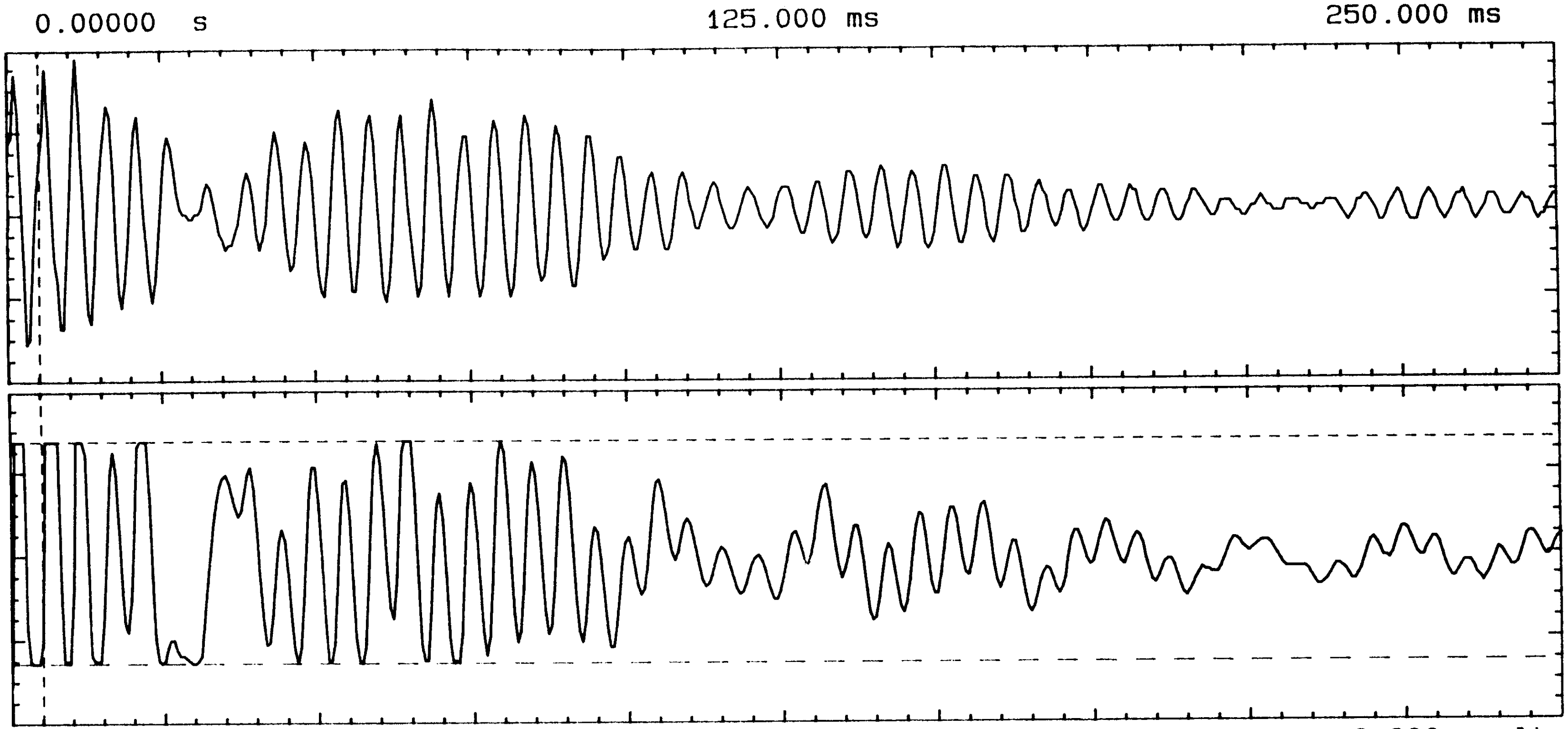
Top Trace:	Stainless Steel Specimen	Sand Core	Filtrered Input	Frequency-Space
Bottom Trace:	Stainless Steel Specimen	Sand Core	Un-filtered Input	



```
Timebase  =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 1  =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 2  =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 3  =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 4  =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                 Delay      =  0.00000  s
Mem 3 Parameters                     Freq.       =  204.083  Hz          Period     =  4.89997 ms
Rise Time =  2.49737 ms              + Width     =  2.60258 ms           - Width    =  2.29739 ms
Fall Time =  1.58187 ms              Preshoot    =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  725.1 mvolts            RMS Volts   =  201.7 mvolts         Dutycycle  =  53.11 %
```

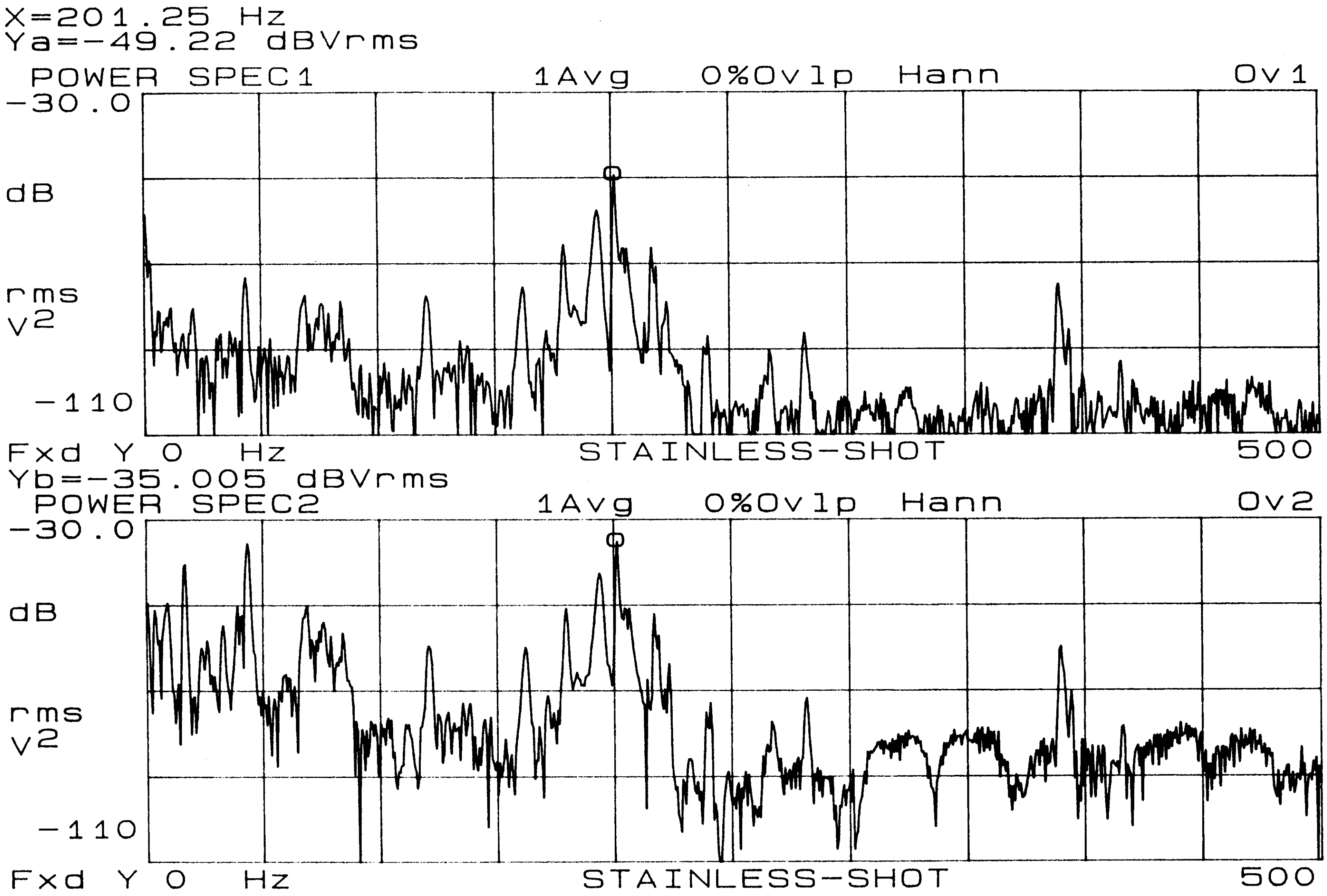
Trace: Stainless Steel Specimen Lead Shot Core Filtrered Input

Four Trace Overlay in Time-Space

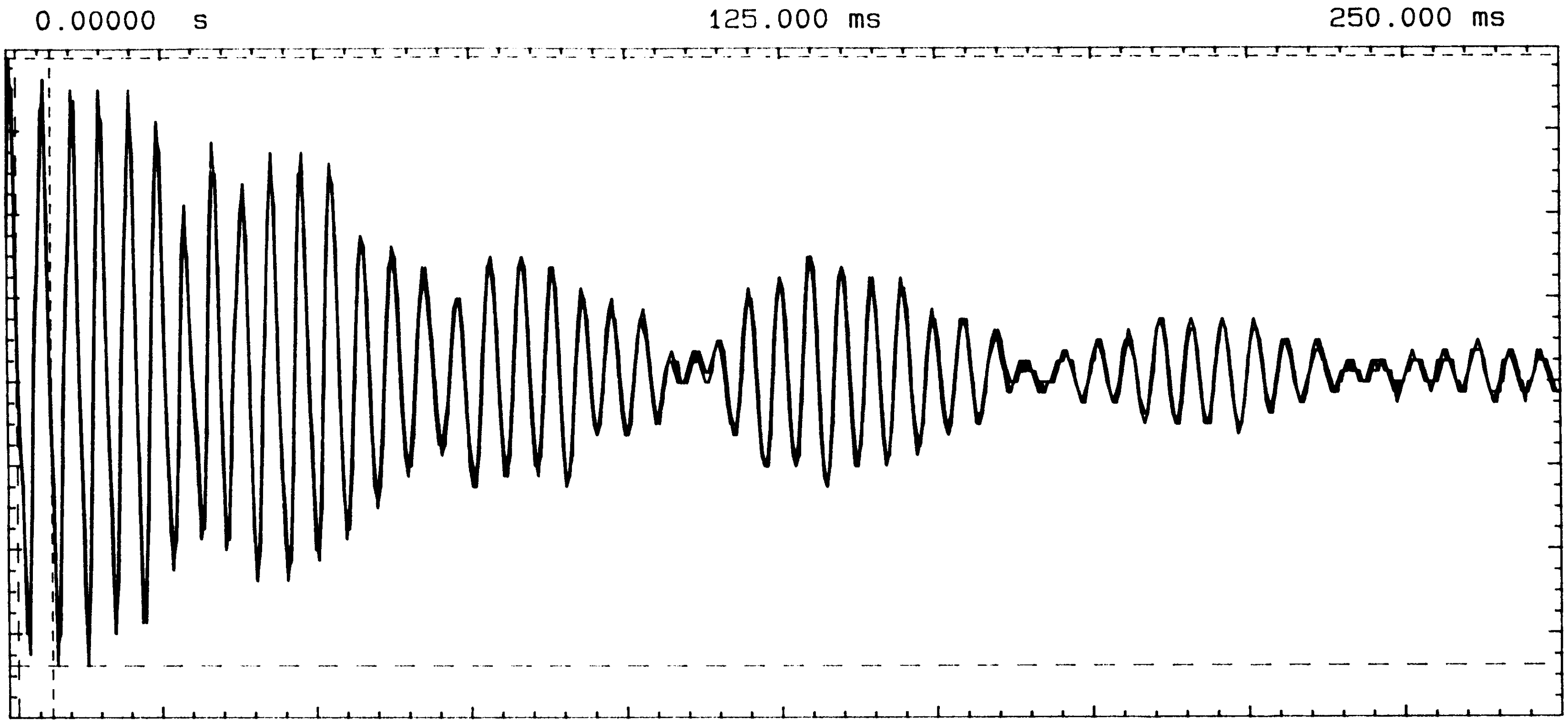


```
Ch. 1      =  200.0 mvolts/div                                     Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Ch. 2 Parameters                   Freq.      =  201.044  Hz      Period     =  4.97403 ms
Rise Time =  400.000 us            + Width    =  2.04514 ms       - Width    =  2.92889 ms
Fall Time =  628.472 us            Preshoot   =  0.000   volts    Overshoot =  0.000   volts
P-P Volts =  2.656   volts         RMS Volts =  1.262   volts    Dutycycle =  41.11 %
```

Top Trace:	Stainless Steel Specimen	Lead Shot Core	Filtrered Input	Time-Space
Bottom Trace:	Stainless Steel Specimen	Lead Shot Core	Un-filtered Input	



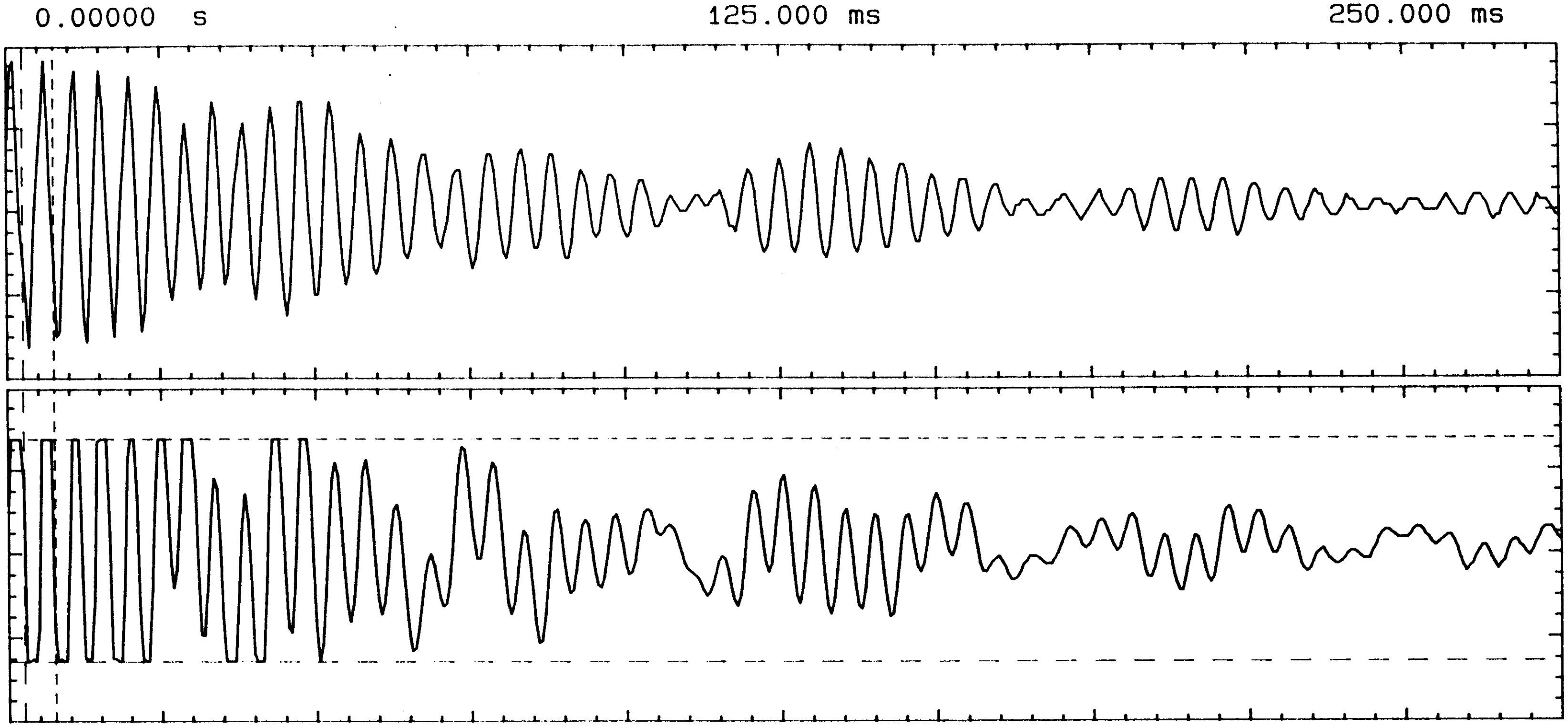
Top Trace:	**Stainless Steel Specimen**	**Lead Shot Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Stainless Steel Specimen**	**Lead Shot Core**	**Un-filtered Input**	



```
Timebase  =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 1  =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 2  =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 3  =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 4  =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                  Delay     =  0.00000  s
Mem 1 Parameters                   Freq.      =  195.781  Hz              Period    =  5.10775 ms
Rise Time =  2.17622 ms            + Width    =  2.44249 ms               - Width   =  2.66527 ms
Fall Time =  2.03048 ms            Preshoot   =  0.000  volts             Overshoot =  0.000  volts
P-P Volts =  725.1 mvolts          RMS Volts  =  200.8 mvolts             Dutycycle =  47.81 %
```

Trace: Stainless Steel Specimen Oil Core Filtrered Input

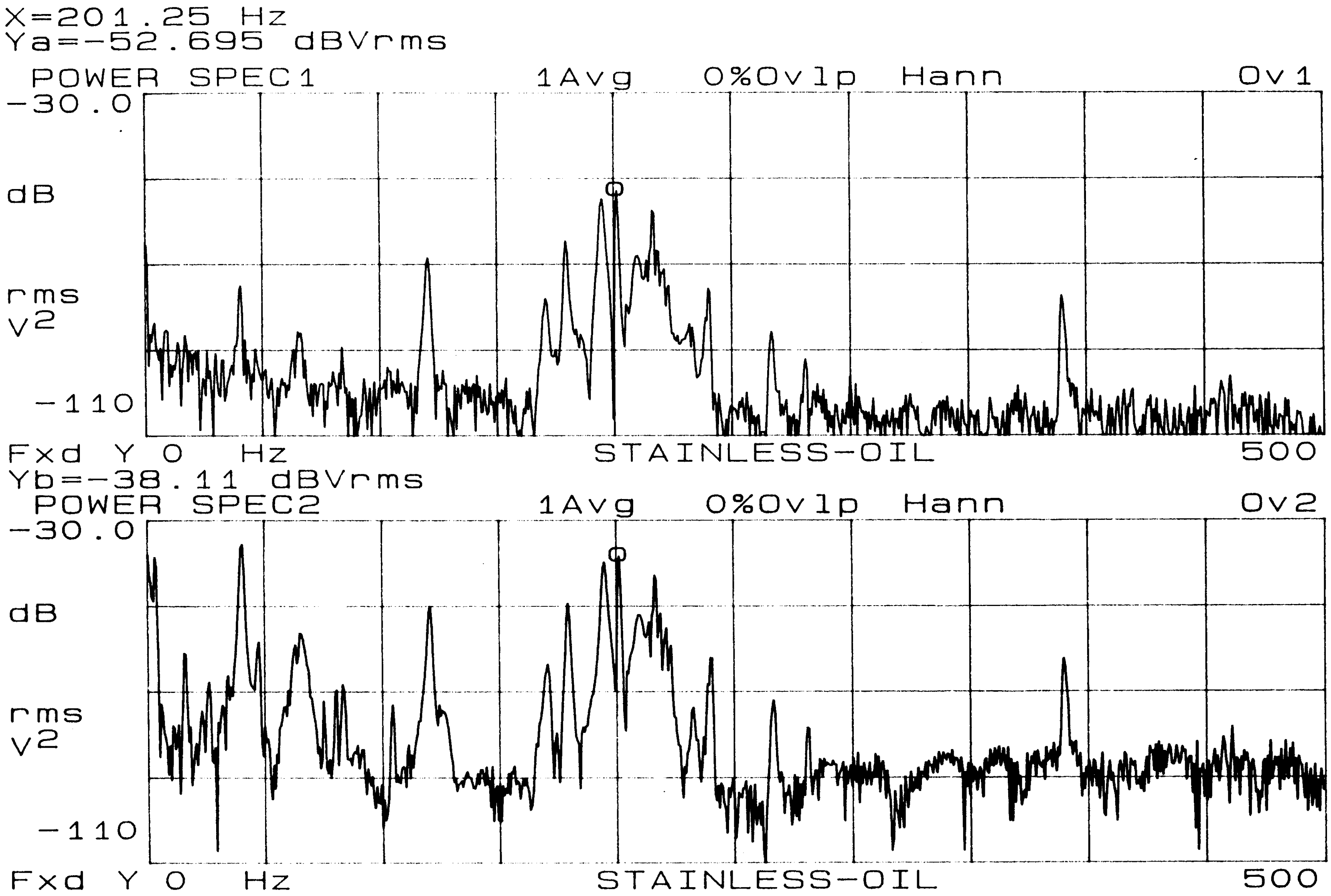
Four Trace Overlay in Time-Space



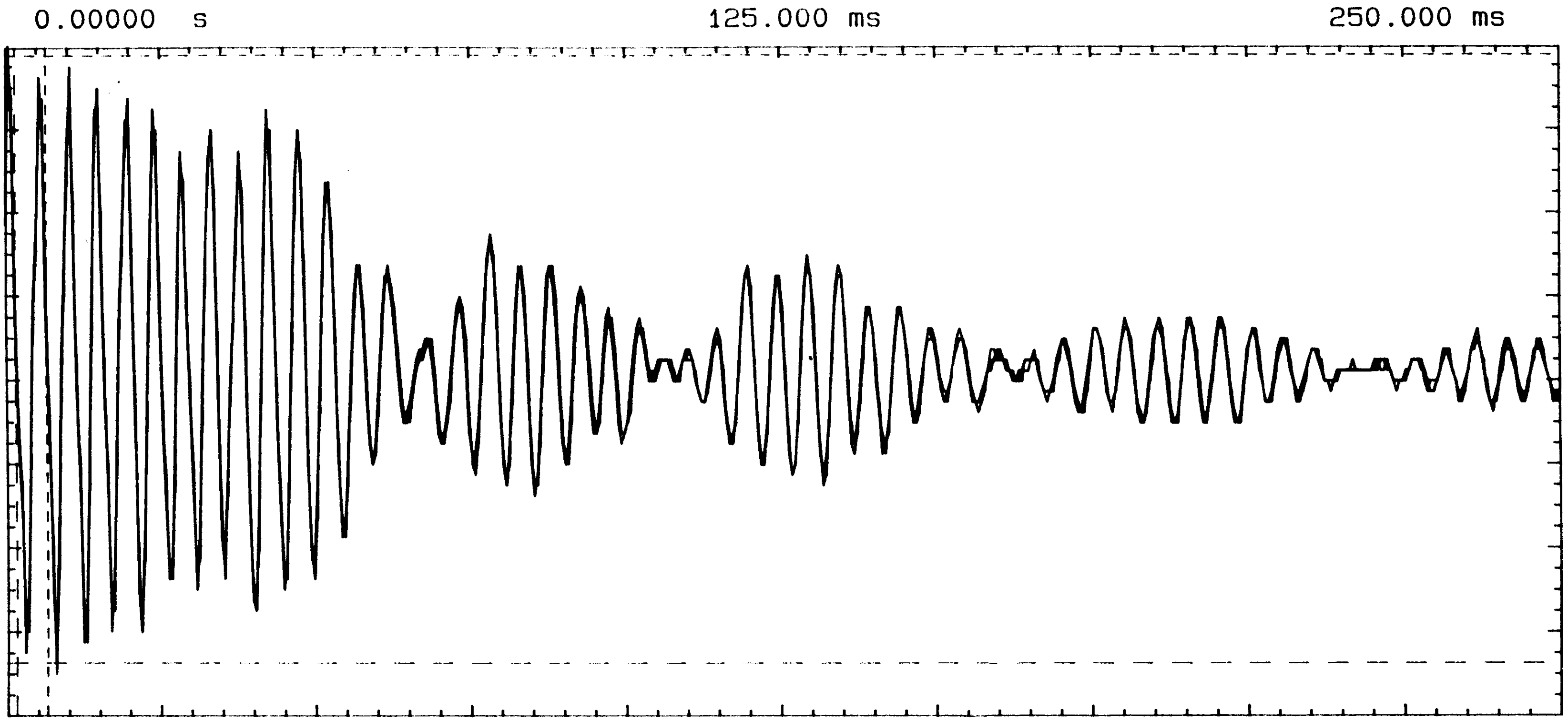
```
Ch. 1      =  200.0 mvolts/div                                   Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                   Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                        Delay      =  0.00000  s
Ch. 2 Parameters                Freq.      =  217.256  Hz        Period     =  4.60287 ms
Rise Time =  587.615 us         + Width    =  2.09039 ms         - Width    =  2.51248 ms
Fall Time =  655.952 us         Preshoot   =  0.000  volts       Overshoot =  0.000  volts
P-P Volts =  2.656  volts       RMS Volts =  1.221  volts        Dutycycle =  45.41 %
```

Top Trace: Stainless Steel Specimen Oil Core Filtrered Input Time-Space

Bottom Trace: Stainless Steel Specimen Oil Core Un-filtered Input



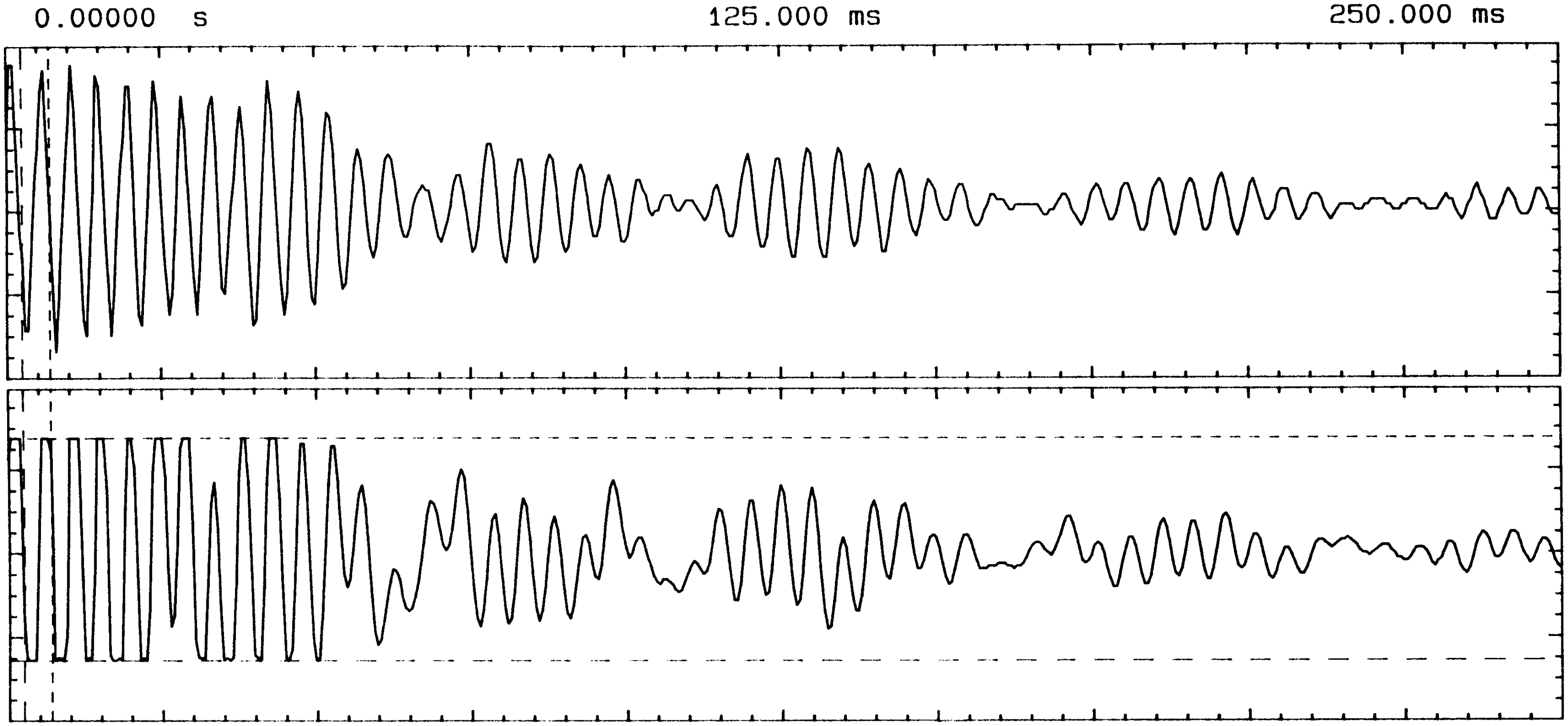
Top Trace:	Stainless Steel Specimen	Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Stainless Steel Specimen	Oil Core	Un-filtered Input	



```
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 1  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 2  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 3  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 4  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Mem 1 Parameters                 Freq.      =  200.000  Hz        Period    =  5.00000 ms
Rise Time =  2.08447 ms          + Width    =  2.40014 ms         - Width   =  2.59986 ms
Fall Time =  1.91509 ms          Preshoot   =  0.000  volts       Overshoot =  0.000  volts
P-P Volts =  725.1 mvolts        RMS Volts  =  207.3 mvolts       Dutycycle =  48.00 %
```

Trace: Stainless Steel Specimen Sand/Oil Core Filtrered Input

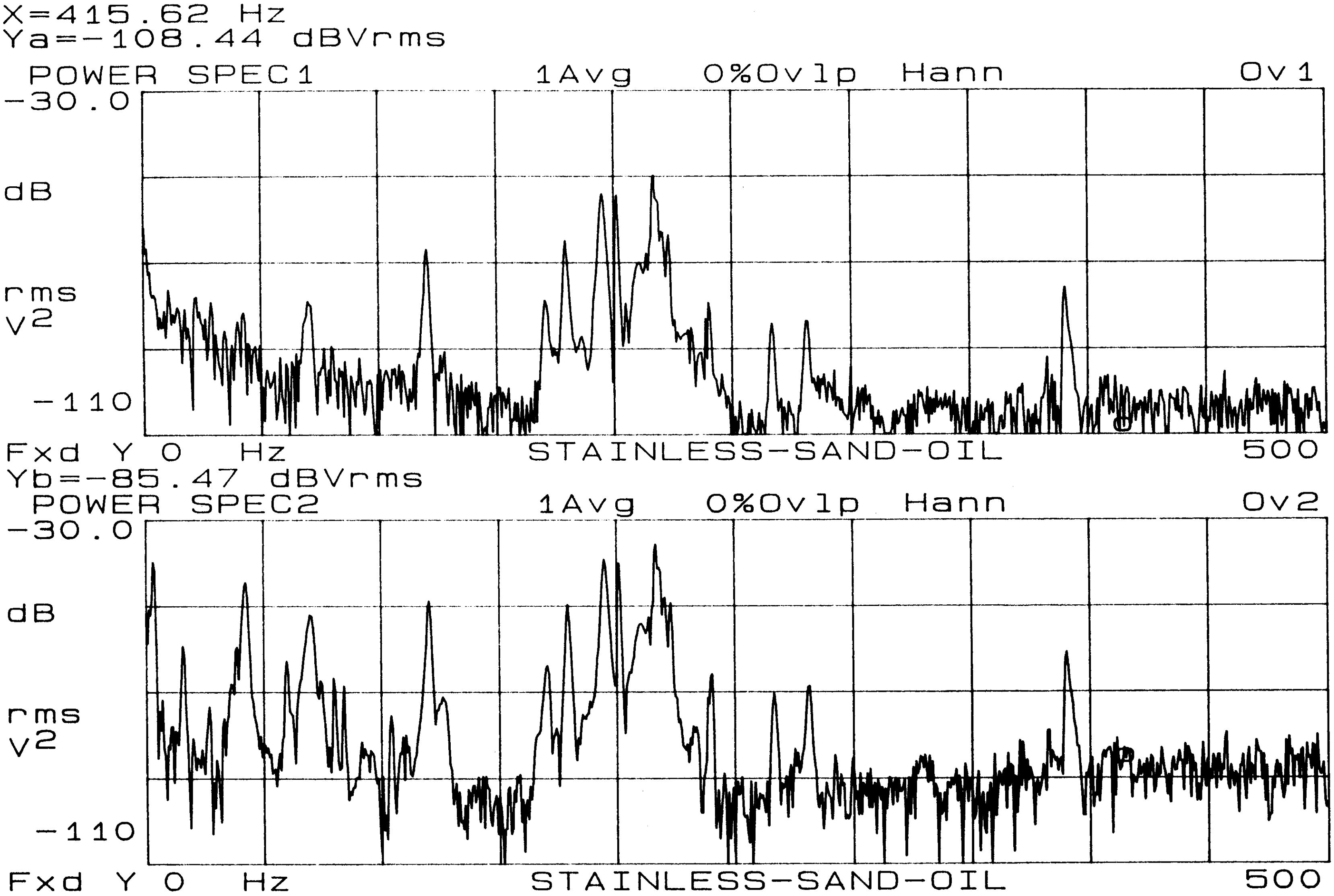
Four Trace Overlay in Time-Space



```
Ch. 1       =  200.0 mvolts/div                                 Offset     =  0.000   volts
Ch. 2       =  1.000  volts/div                                 Offset     =  0.000   volts
Timebase    =  25.0 ms/div                                      Delay      =  0.00000   s
Ch. 2 Parameters                 Freq.       =  203.175  Hz     Period     =  4.92188 ms
Rise Time =  796.594 us          + Width     =  2.29167 ms      - Width    =  2.63021 ms
Fall Time =  703.125 us          Preshoot    =  0.000   volts   Overshoot =  0.000   volts
P-P Volts =  2.656   volts       RMS Volts =  1.193   volts     Dutycycle =  46.56 %
```

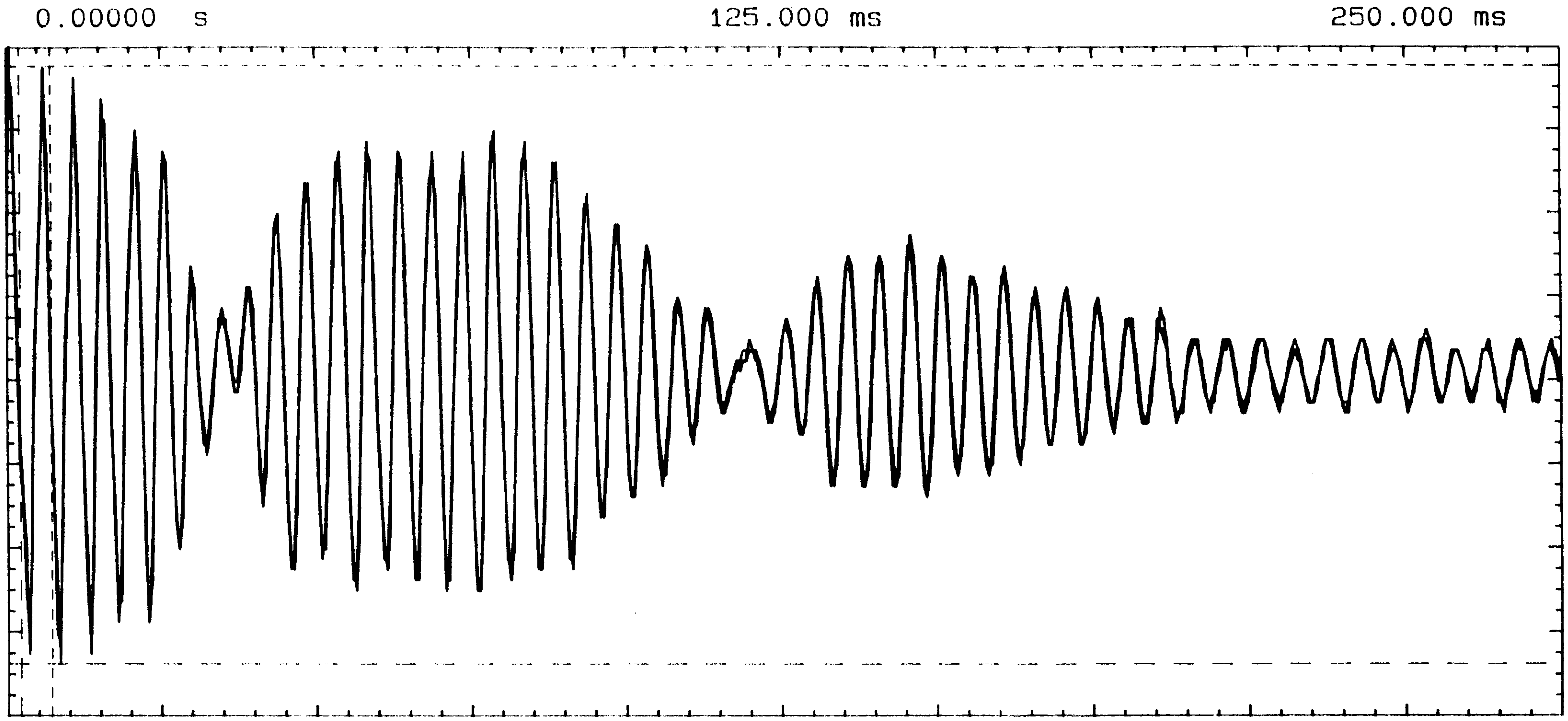
Top Trace: Stainless Steel Specimen Sand/Oil Core Filtrered Input Time-Space

Bottom Trace: Stainless Steel Specimen Sand/Oil Core Un-filtered Input



Top Trace: Stainless Steel Specimen Sand/Oil Core Filtrered Input Frequency-Space

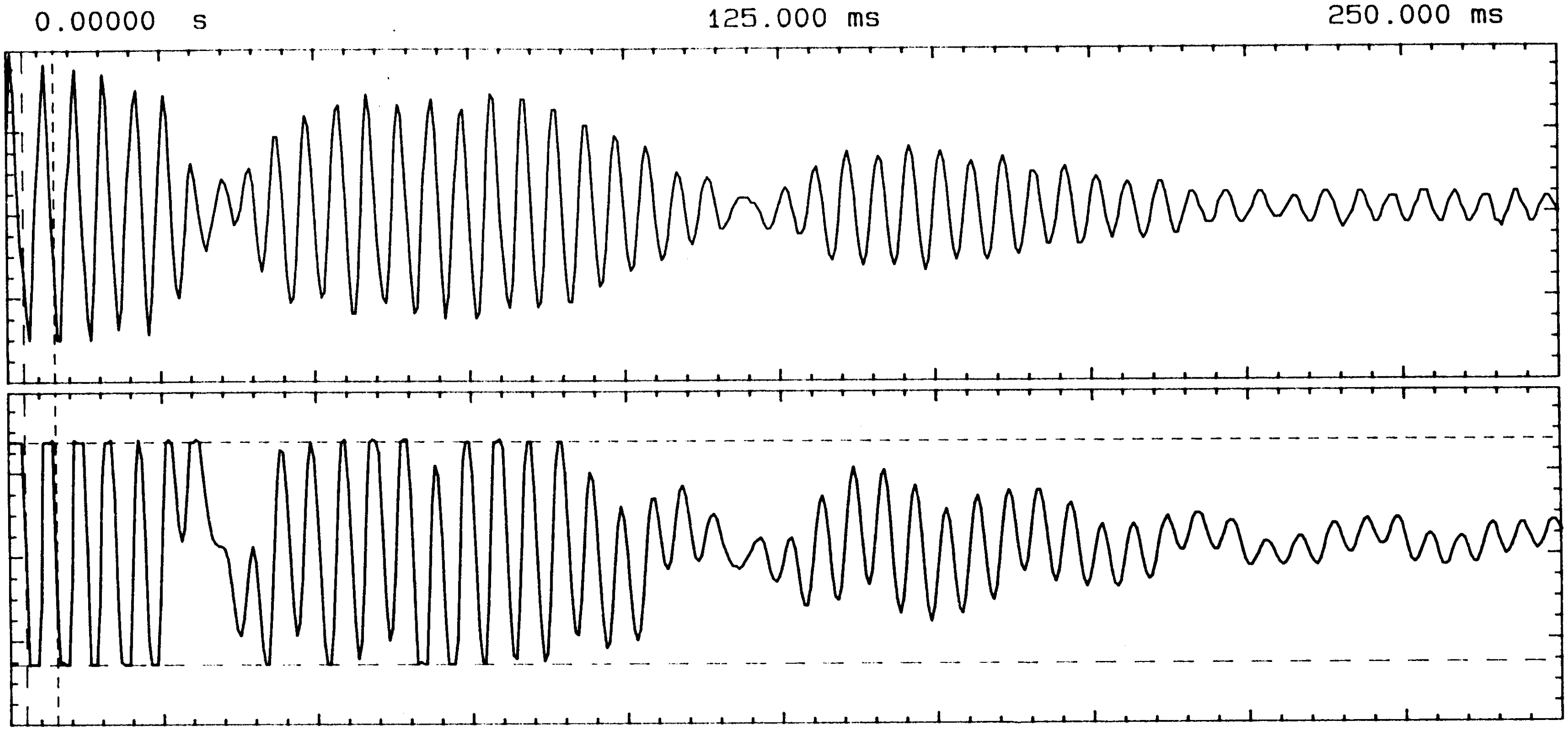
Bottom Trace: Stainless Steel Specimen Sand/Oil Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                            Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Mem 1 Parameters                 Freq.      =  187.648  Hz                Period     =  5.32912 ms
Rise Time =  2.04626 ms          + Width    =  2.57031 ms                 - Width    =  2.75882 ms
Fall Time =  2.20241 ms          Preshoot   =  0.000  volts               Overshoot  =  0.000  volts
P-P Volts =  712.6 mvolts        RMS Volts  =  208.8 mvolts               Dutycycle  =  48.23 %
```

Trace: Stainless Steel Specimen Lead Shot/Oil Core Filtrered Input

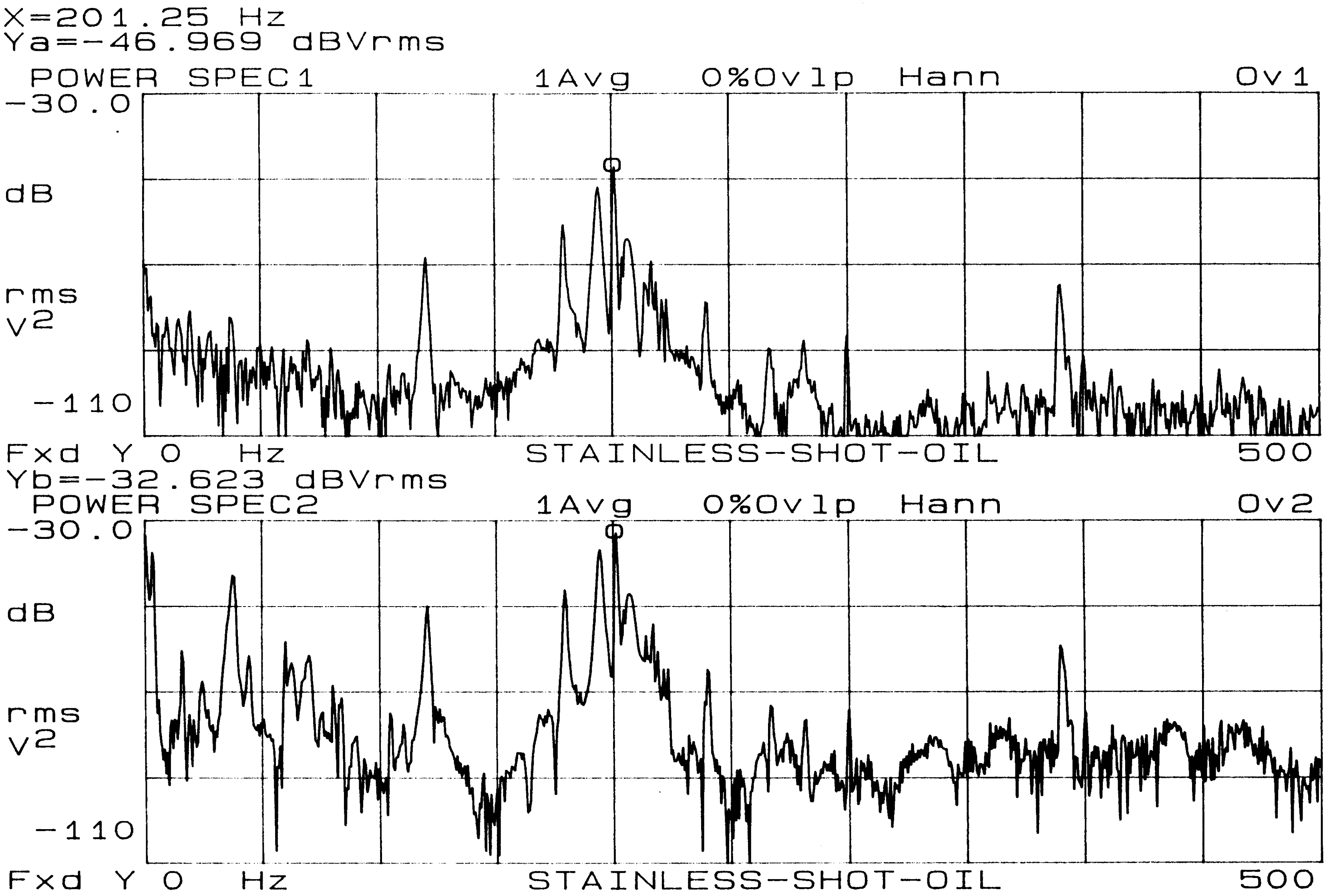
Four Trace Overlay in Time-Space



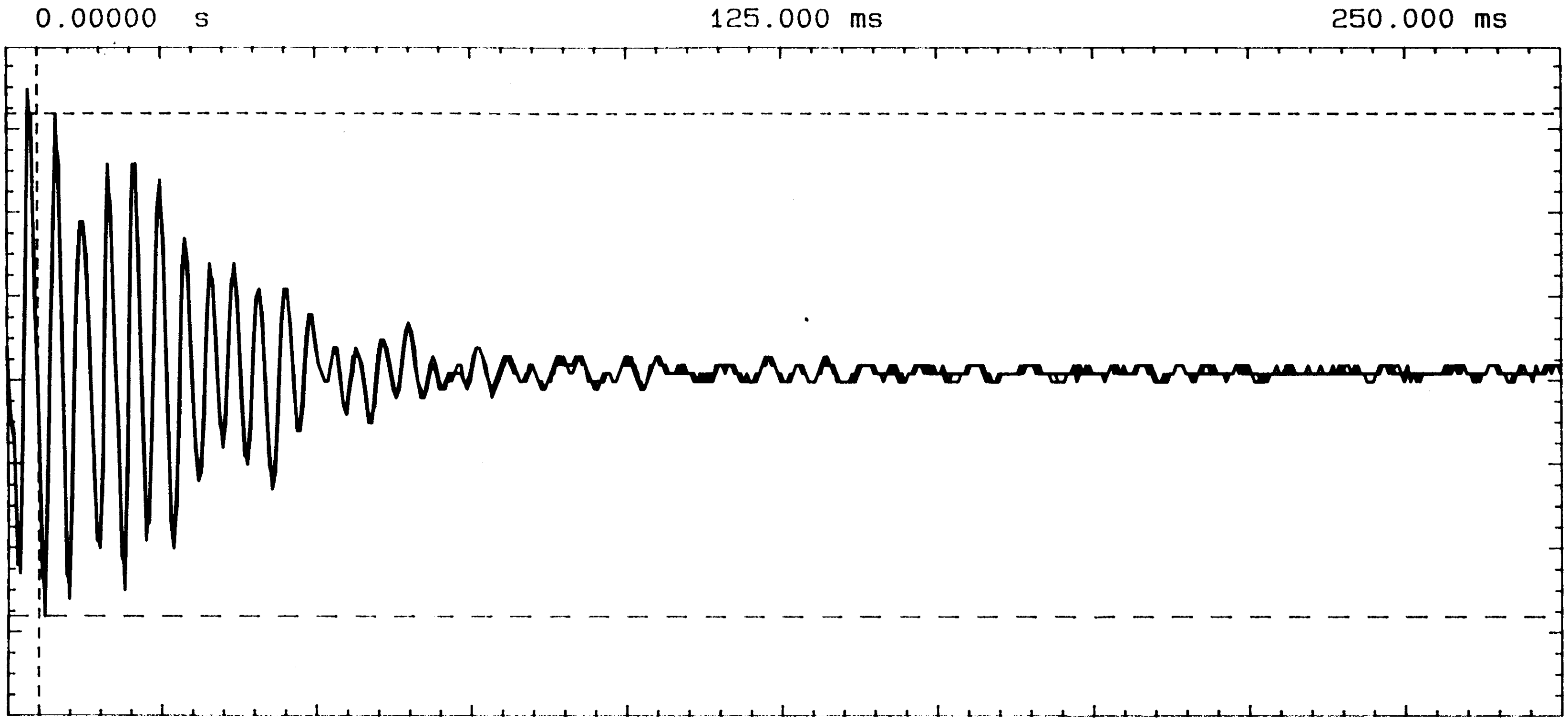
```
Ch. 1      =  200.0 mvolts/div                                       Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                       Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  208.615  Hz         Period     =  4.79351 ms
Rise Time =  746.670 us           + Width     =  2.19355 ms          - Width    =  2.59997 ms
Fall Time =  796.594 us           Preshoot    =  31.25 mvolts        Overshoot  =  0.000   volts
P-P Volts =  2.687  volts         RMS Volts   =  1.162  volts        Dutycycle  =  45.76 %
```

Top Trace: Stainless Steel Specimen Lead Shot/Oil Core Filtrered Input Time-Space

Bottom Trace: Stainless Steel Specimen Lead Shot/Oil Core Un-filtered Input



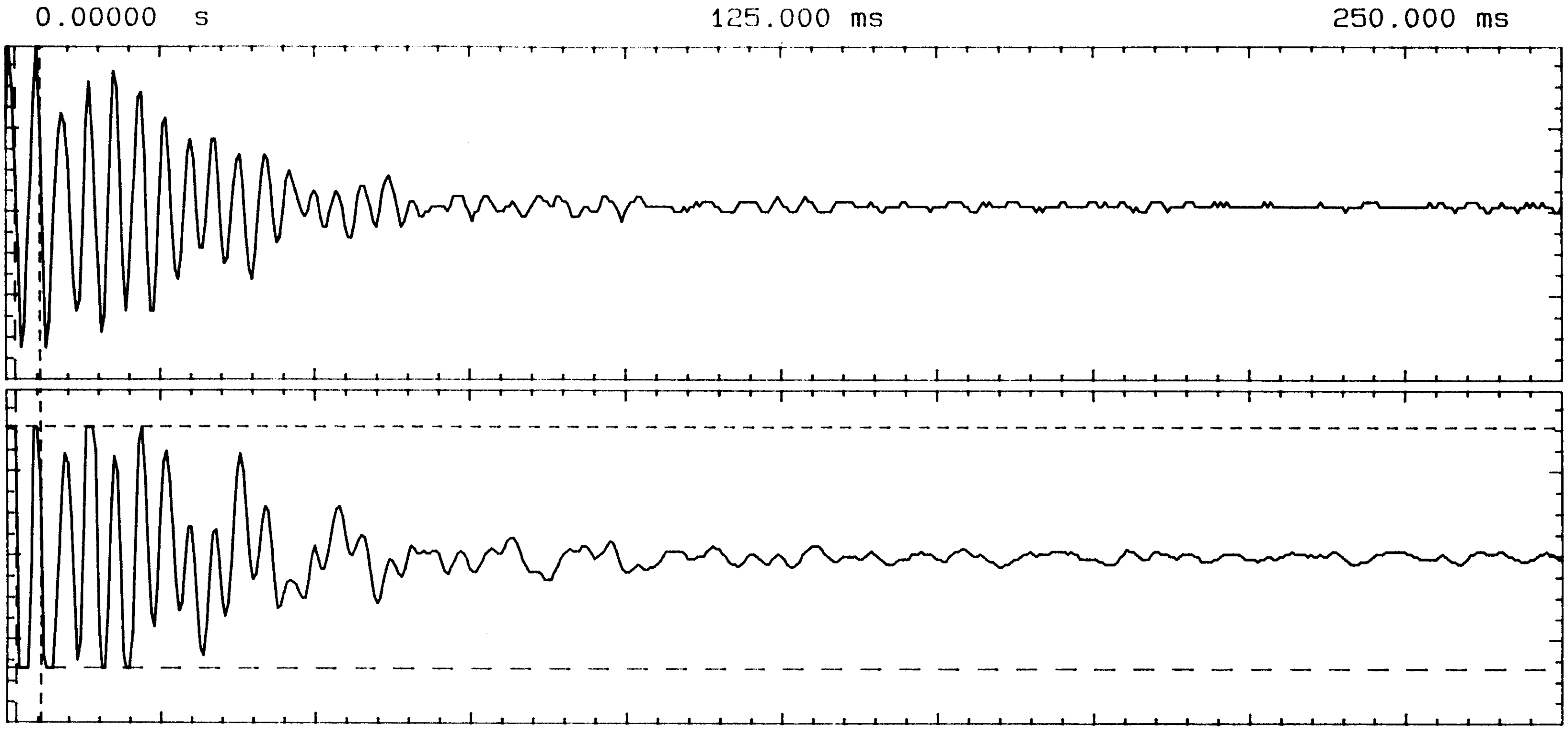
Top Trace:	Stainless Steel Specimen	Lead Shot/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Stainless Steel Specimen	Lead Shot/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Mem 1 Parameters                 Freq.       =  209.316  Hz          Period     =  4.77747 ms
Rise Time =  1.66922 ms          + Width     =  2.11392 ms           - Width    =  2.66355 ms
Fall Time =  1.52639 ms          Preshoot    =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  750.1 mvolts        RMS Volts   =  214.7 mvolts         Dutycycle  =  44.24 %
```

Trace: Titanium Specimen Air Core Filtrered Input

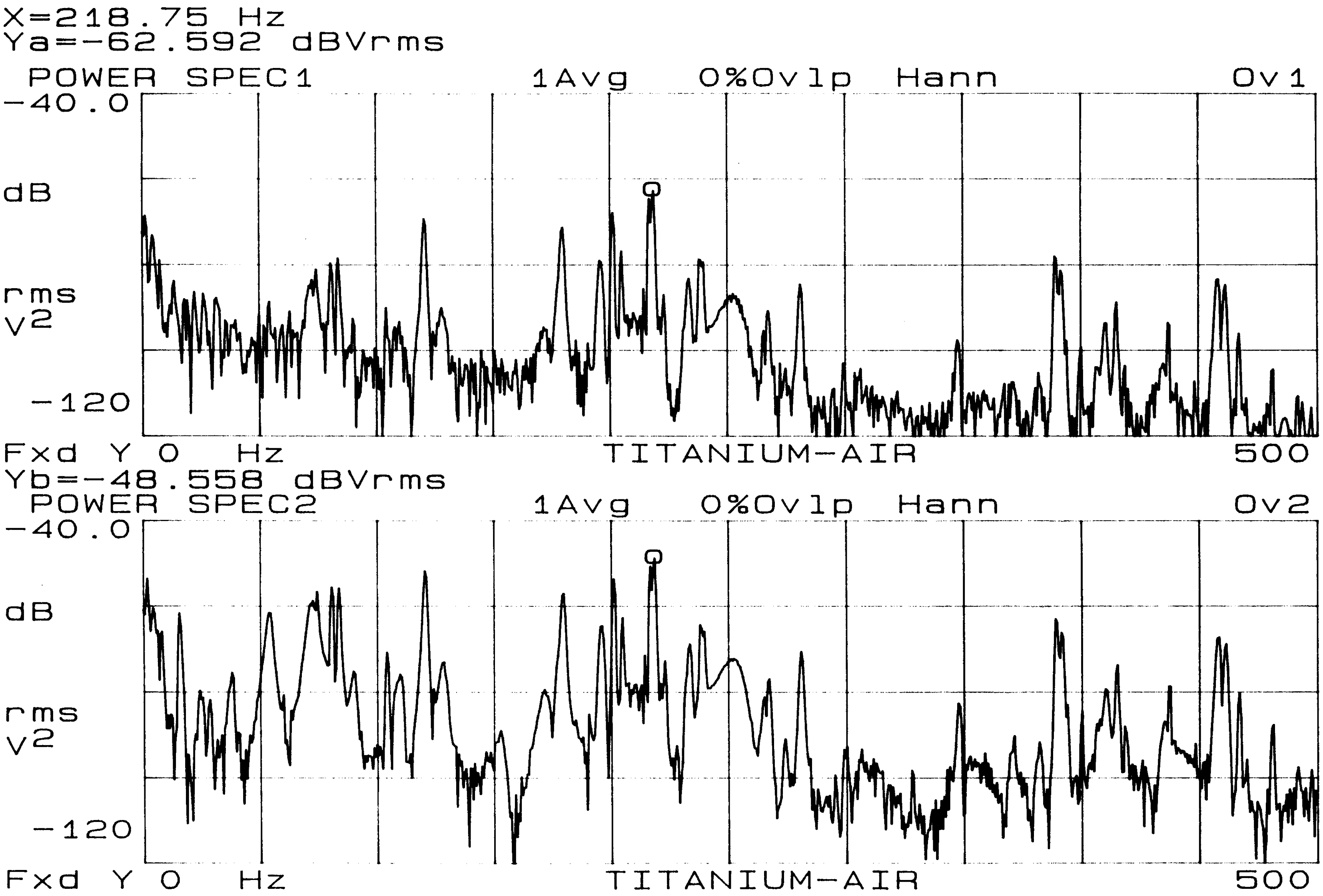
Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                      Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                      Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.      =  253.548  Hz         Period     =  3.94403 ms
Rise Time  =  792.057 us          + Width    =  1.61221 ms          - Width    =  2.33182 ms
Fall Time  =  400.009 us          Preshoot   =  0.000  volts        Overshoot  =  0.000  volts
P-P Volts  =  2.875  volts        RMS Volts  =  1.263  volts        Dutycycle  =  40.87 %
```

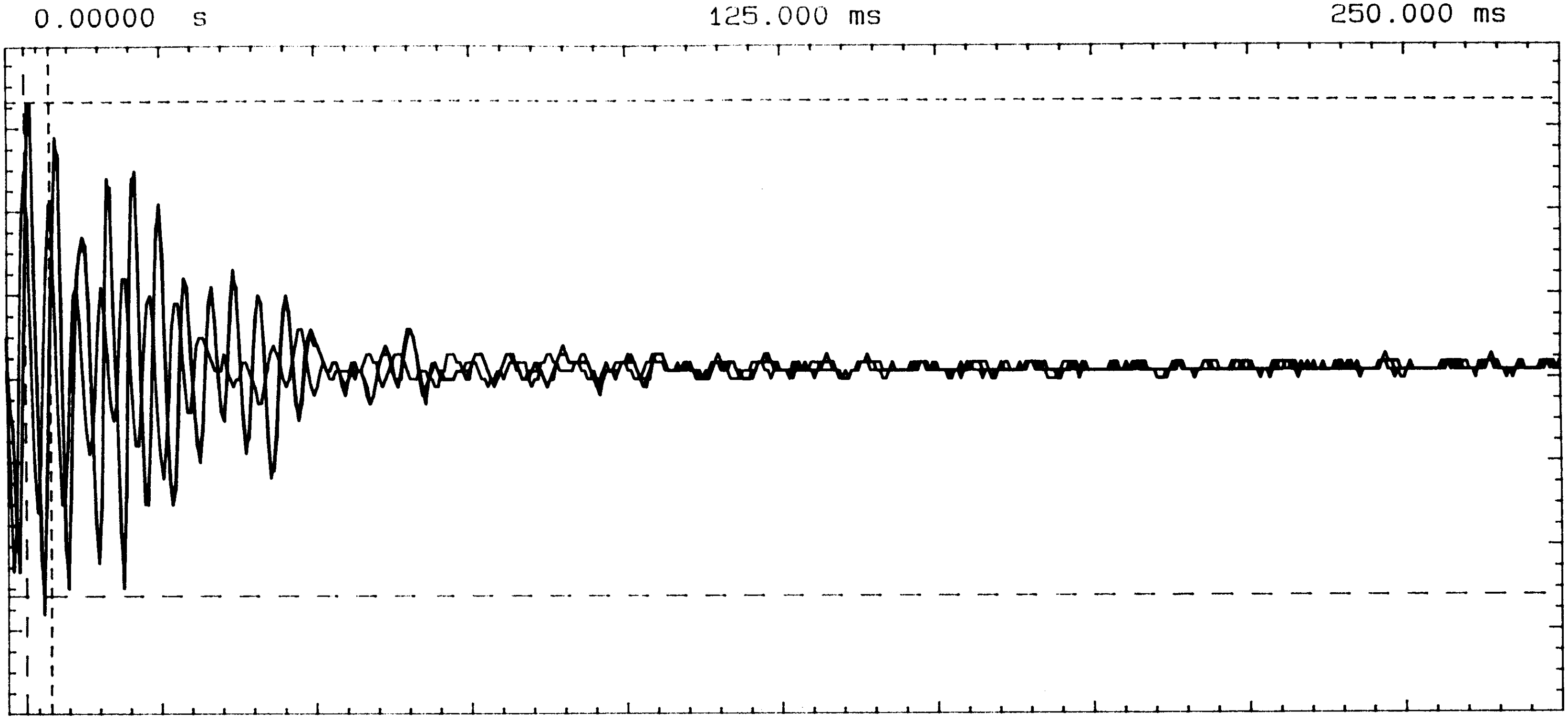
Top Trace: Titanium Specimen Air Core Filtrered Input Time-Space

Bottom Trace: Titanium Specimen Air Core Un-filtered Input



Top Trace: Titanium Specimen Air Core Filtrered Input Frequency-Space

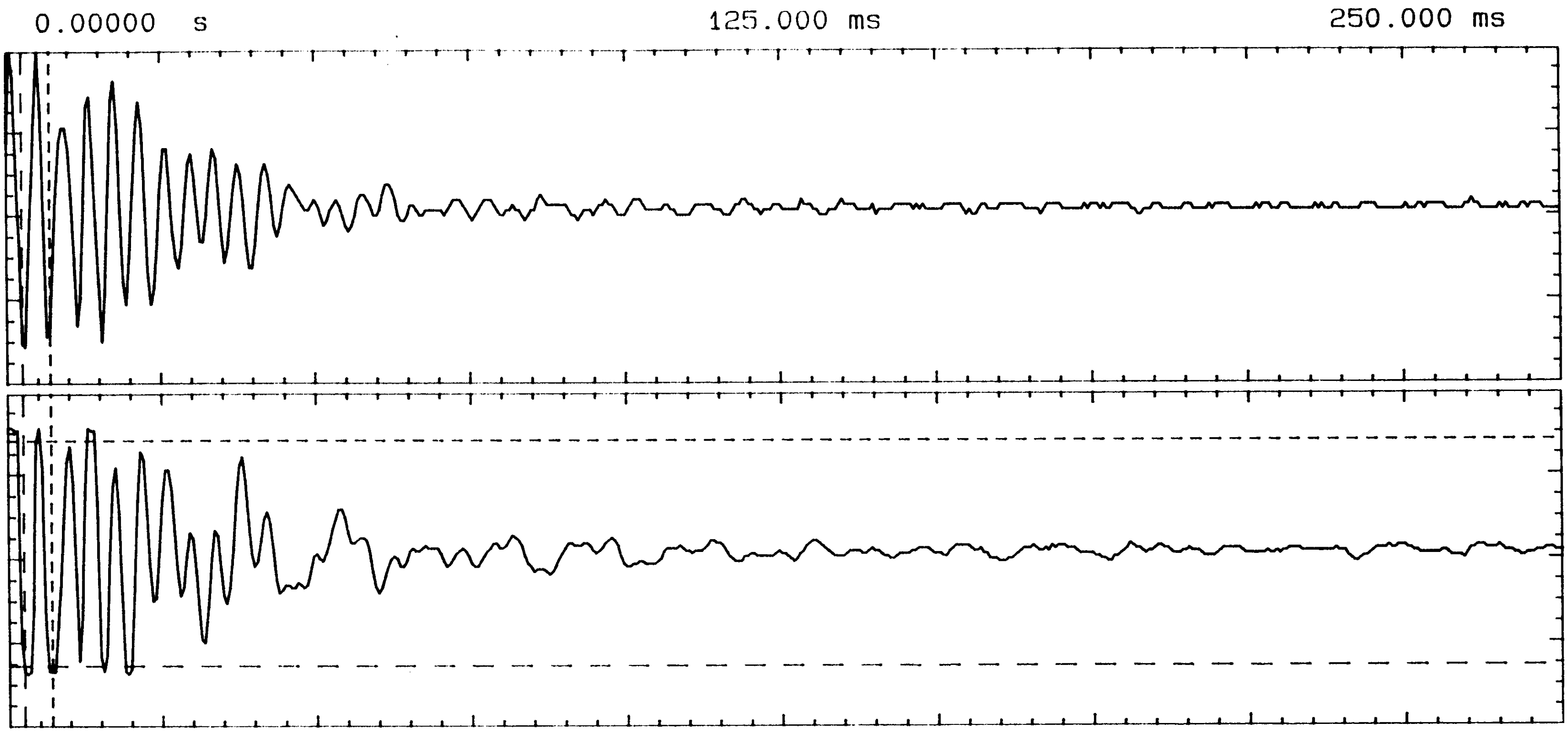
Bottom Trace: Titanium Specimen Air Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Mem 4 Parameters                     Freq.      =  234.781  Hz               Period     =  4.25929 ms
Rise Time =  1.72362 ms              + Width    =  2.01335 ms                - Width    =  2.24594 ms
Fall Time =  1.54942 ms              Preshoot   =  0.000  volts              Overshoot  =  0.000  volts
P-P Volts =  738.4 mvolts            RMS Volts  =  249.7 mvolts              Dutycycle  =  47.26 %
```

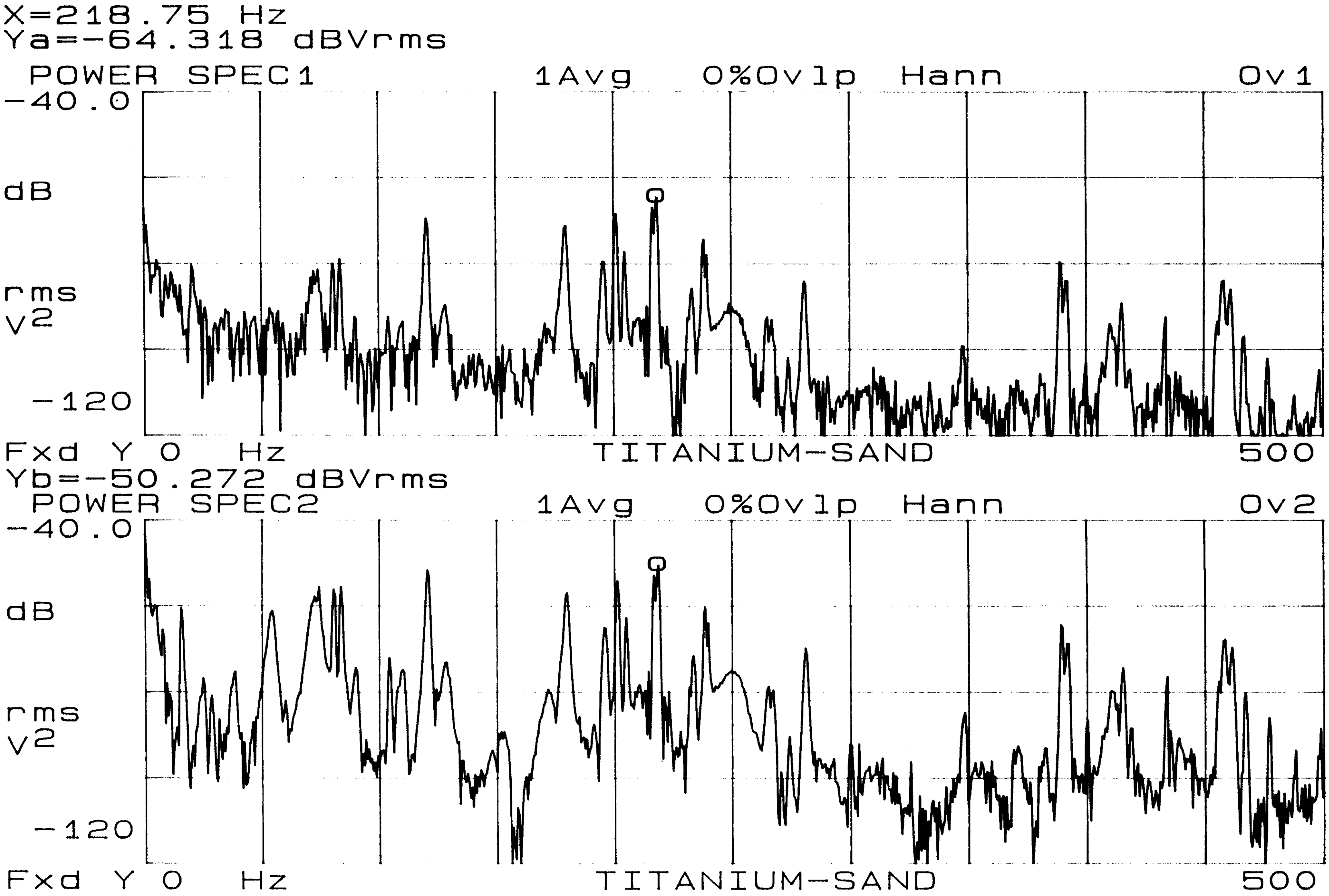
Trace: Titanium Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space

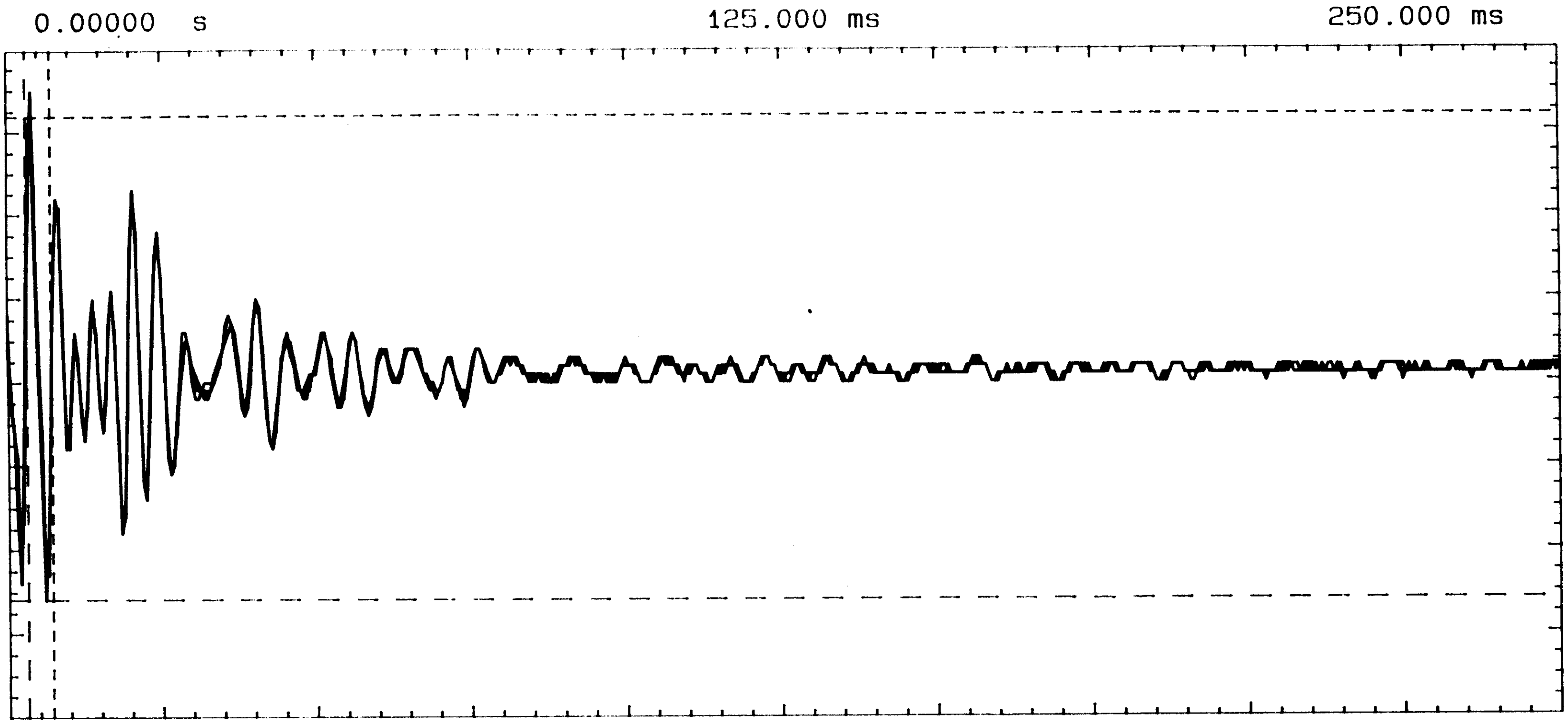


```
Ch. 1      =  200.0 mvolts/div                                Offset    =  0.000   volts
Ch. 2      =  1.000  volts/div                                Offset    =  0.000   volts
Timebase   =  25.0 ms/div                                     Delay     =  0.00000  s
Start      =  2.64407 ms        Stop      =  7.14167 ms       Delta T   =  4.49760 ms
Vmarker1   = -1.2800  volts     Vmarker2  =  1.4100  volts    Delta V   =  2.690   volts
```

Top Trace:	Titanium Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Titanium Specimen	Sand Core	Un-filtered Input	



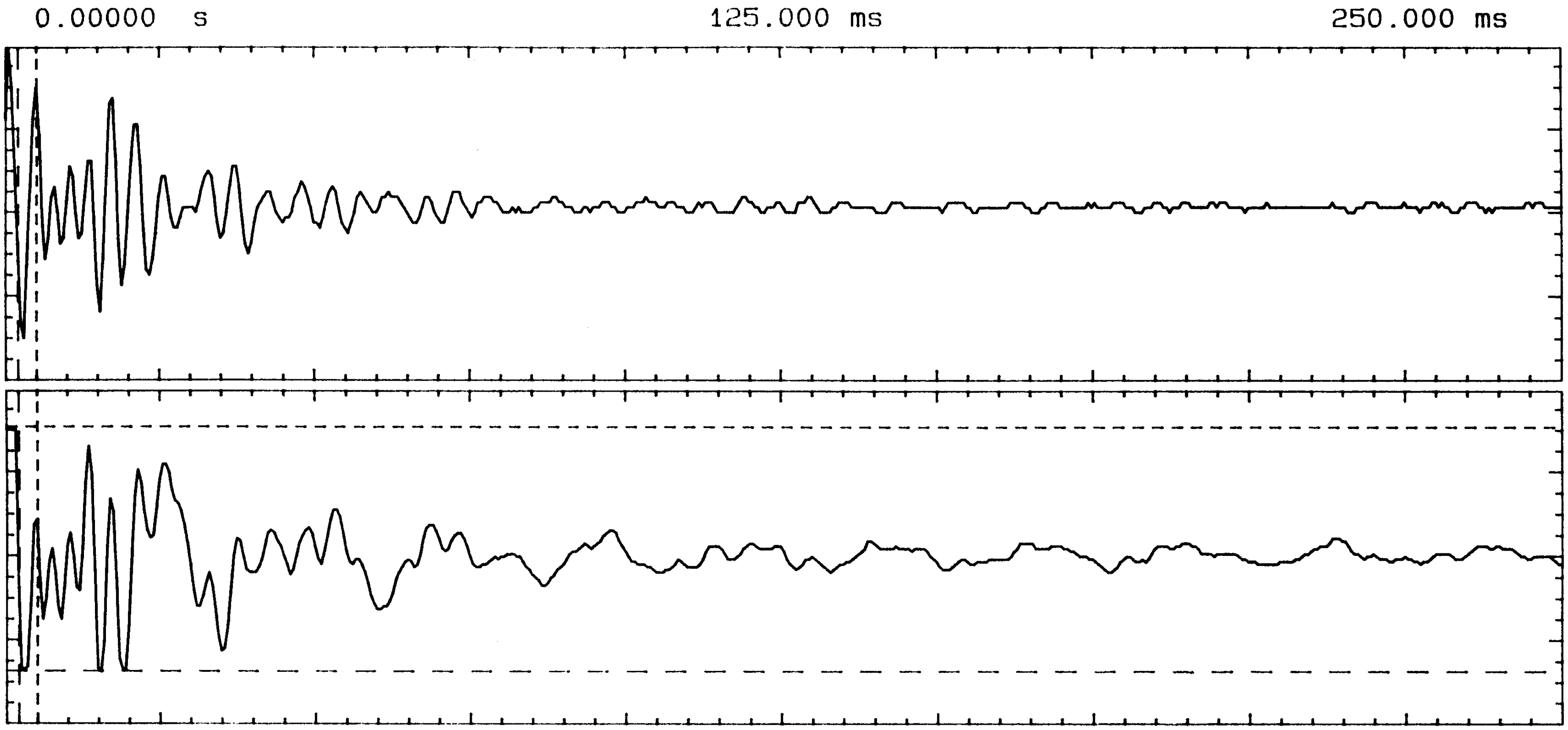
Top Trace:	Titanium Specimen	Sand Core	Filtrered Input	Frequency-Space
Bottom Trace:	Titanium Specimen	Sand Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Mem 1 Parameters                 Freq.      =  231.189  Hz            Period     =  4.32546 ms
Rise Time =  1.30987 ms          + Width    =  2.05485 ms             - Width    =  2.27060 ms
Fall Time =  1.57229 ms          Preshoot   =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  722.7 mvolts        RMS Volts  =  244.3 mvolts           Dutycycle  =  47.50 %
```

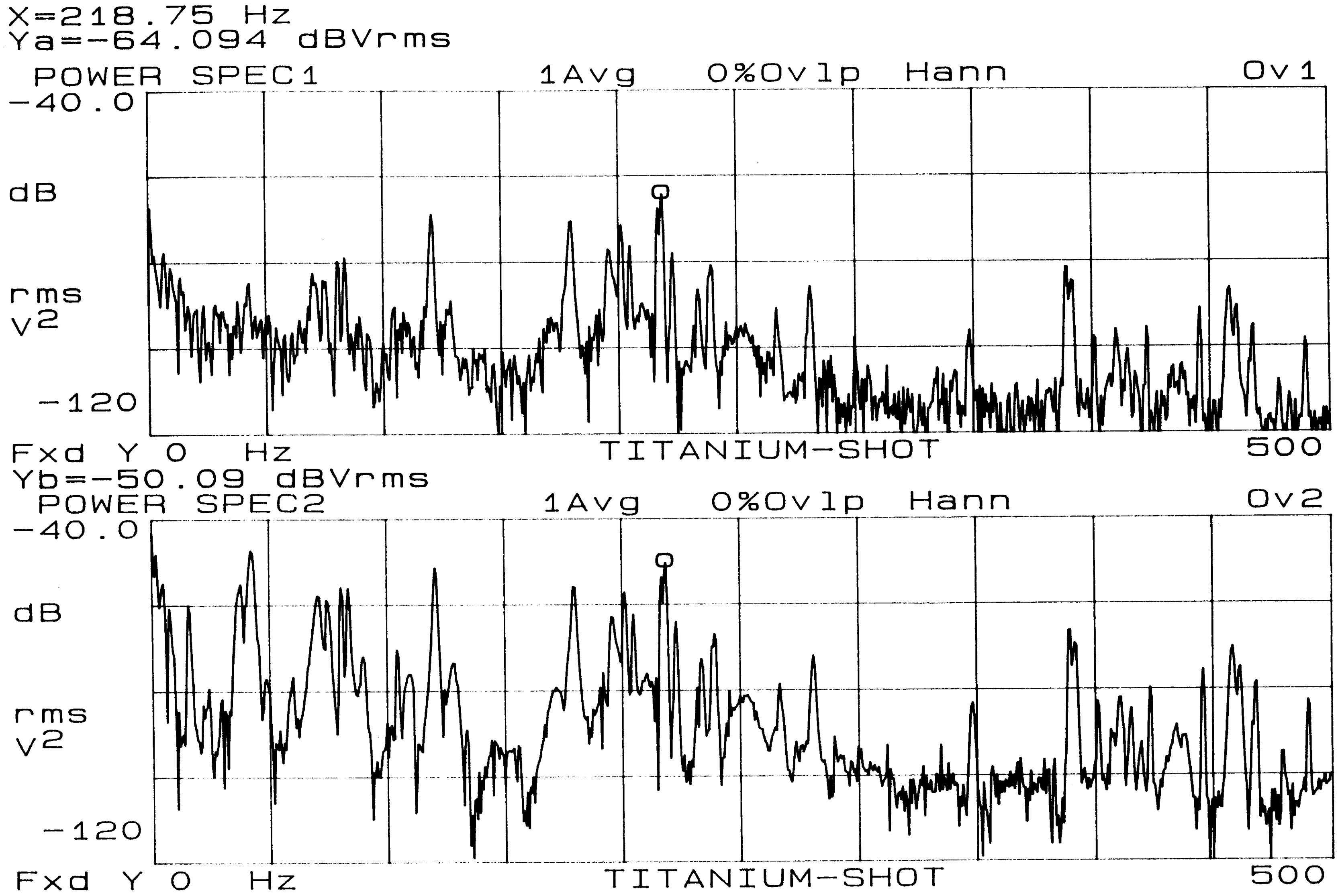
Trace: Titanium Specimen Lead Shot Core Filtrered Input

Four Trace Overlay in Time-Space

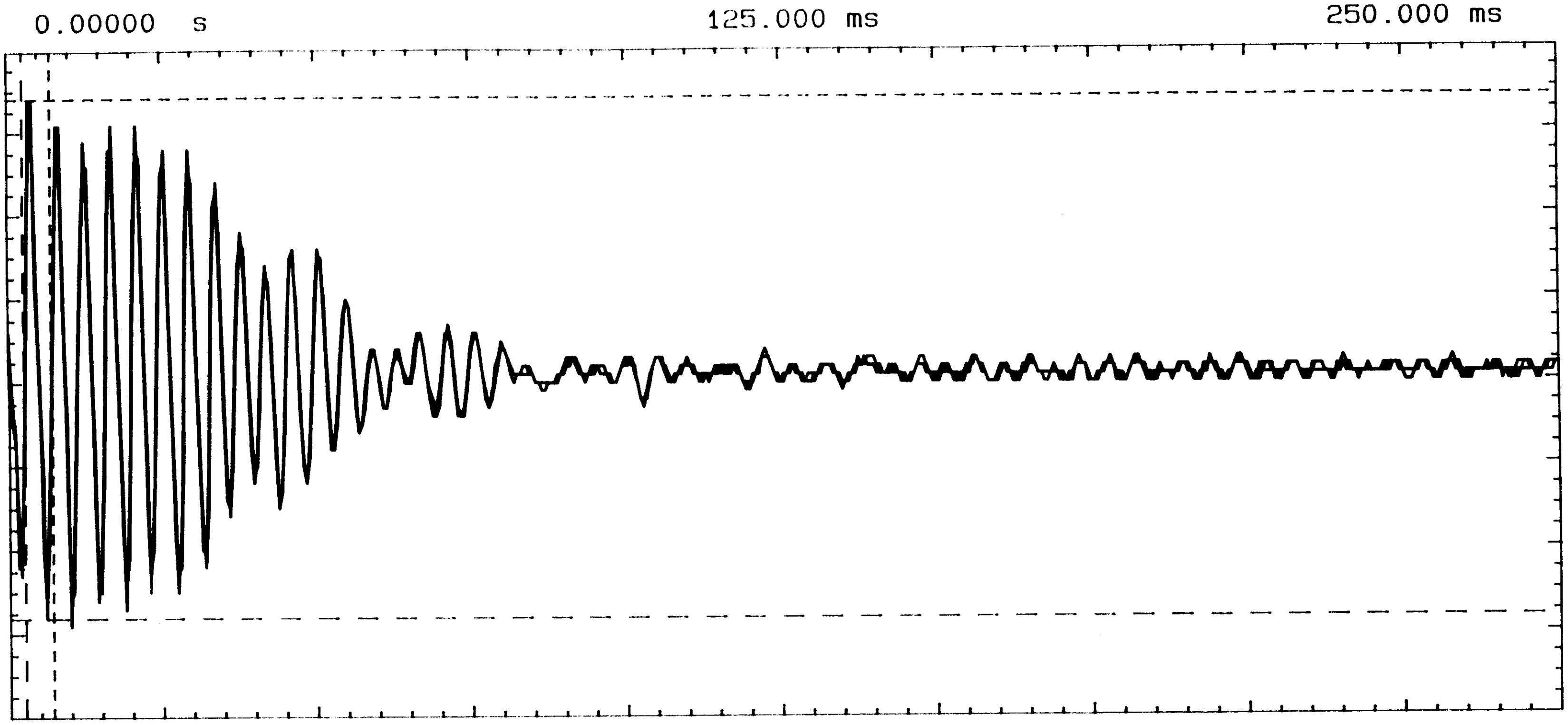


```
Ch. 1       =  200.0 mvolts/div                                    Offset     =  0.000  volts
Ch. 2       =  1.000  volts/div                                    Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                         Delay      =  0.00000  s
Ch. 2 Parameters                 Freq.      =  299.516  Hz         Period     =  3.33872 ms
Rise Time =  9.76573 ms          + Width    =  897.917 us          - Width    =  2.44080 ms
Fall Time =  797.751 us          Preshoot   =  0.000  volts        Overshoot =  0.000  volts
P-P Volts =  2.906  volts        RMS Volts =  930.5 mvolts         Dutycycle =  26.89 %
```

Top Trace:	Titanium Specimen	Lead Shot Core	Filtrered Input	Time-Space
Bottom Trace:	Titanium Specimen	Lead Shot Core	Un-filtered Input	



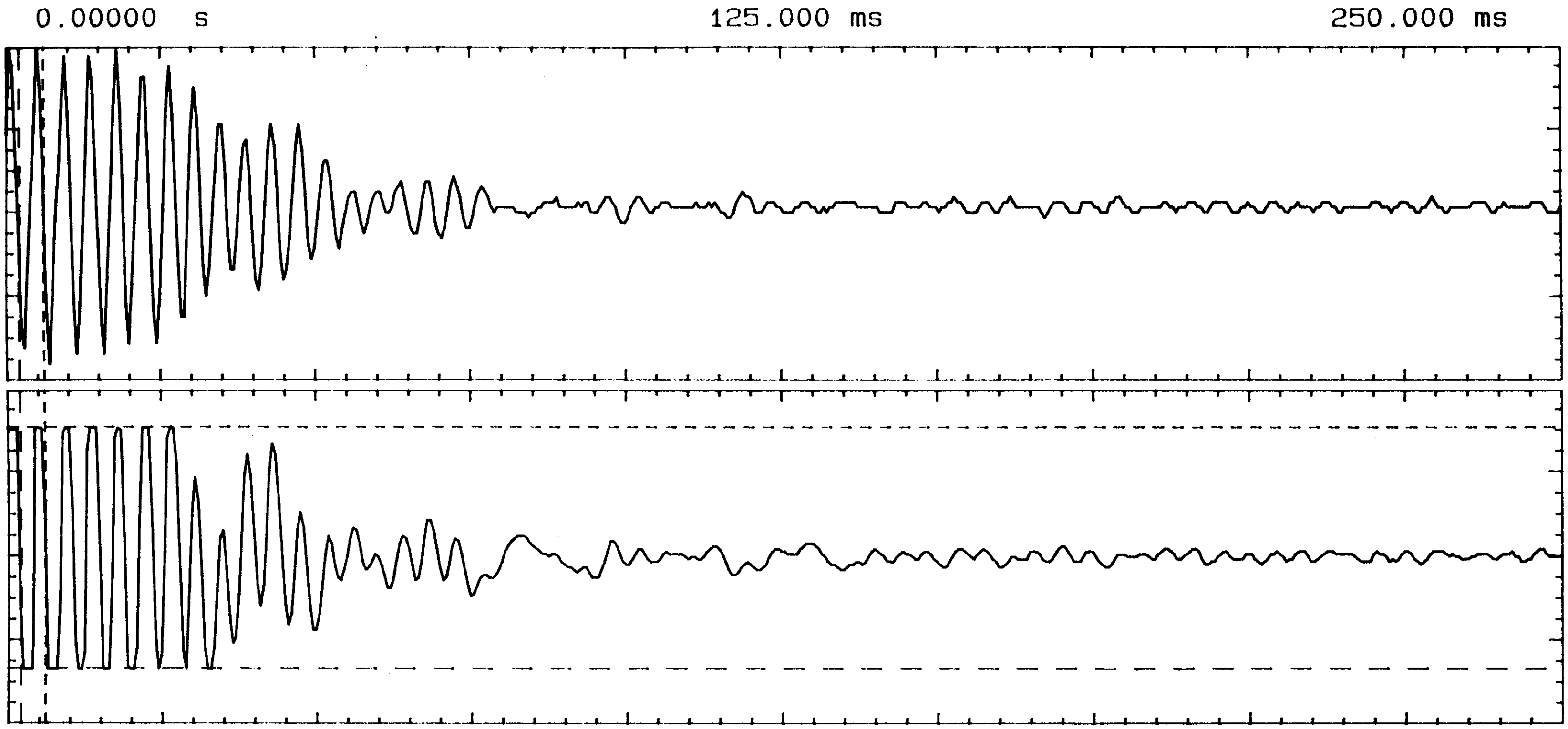
Top Trace:	Titanium Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Titanium Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                                 Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                                 Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                                 Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                                 Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Mem 1 Parameters                    Freq.       =  227.506  Hz                 Period     =  4.39548 ms
Rise Time =  1.72563 ms             + Width     =  2.13100 ms                  - Width    =  2.26448 ms
Fall Time =  1.57979 ms             Preshoot    =  0.000  volts                Overshoot  =  0.000  volts
P-P Volts =  777.4 mvolts           RMS Volts   =  238.0 mvolts                Dutycycle  =  48.48 %
```

Trace: Titanium Specimen Oil Core Filtrered Input

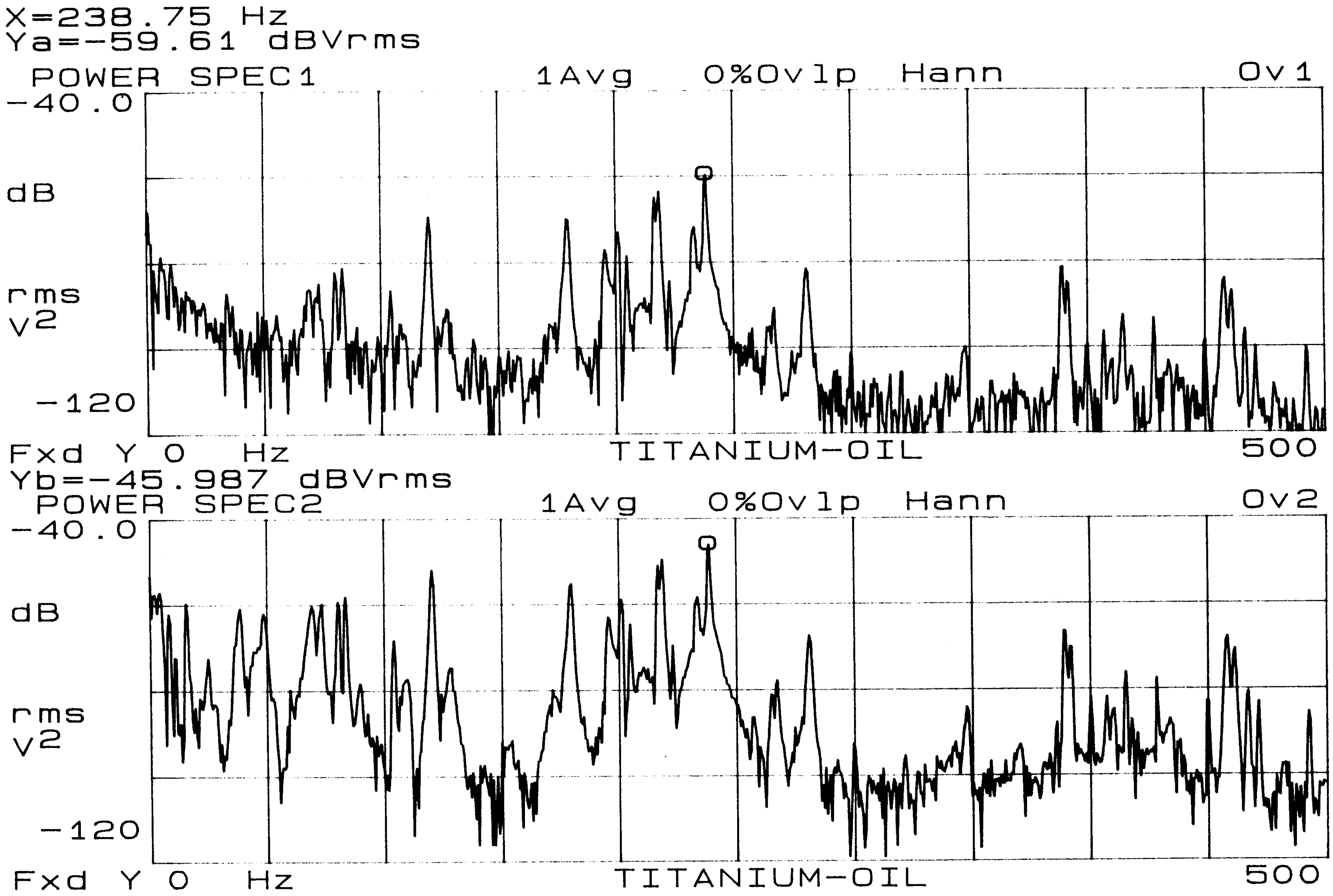
Four Trace Overlay in Time-Space



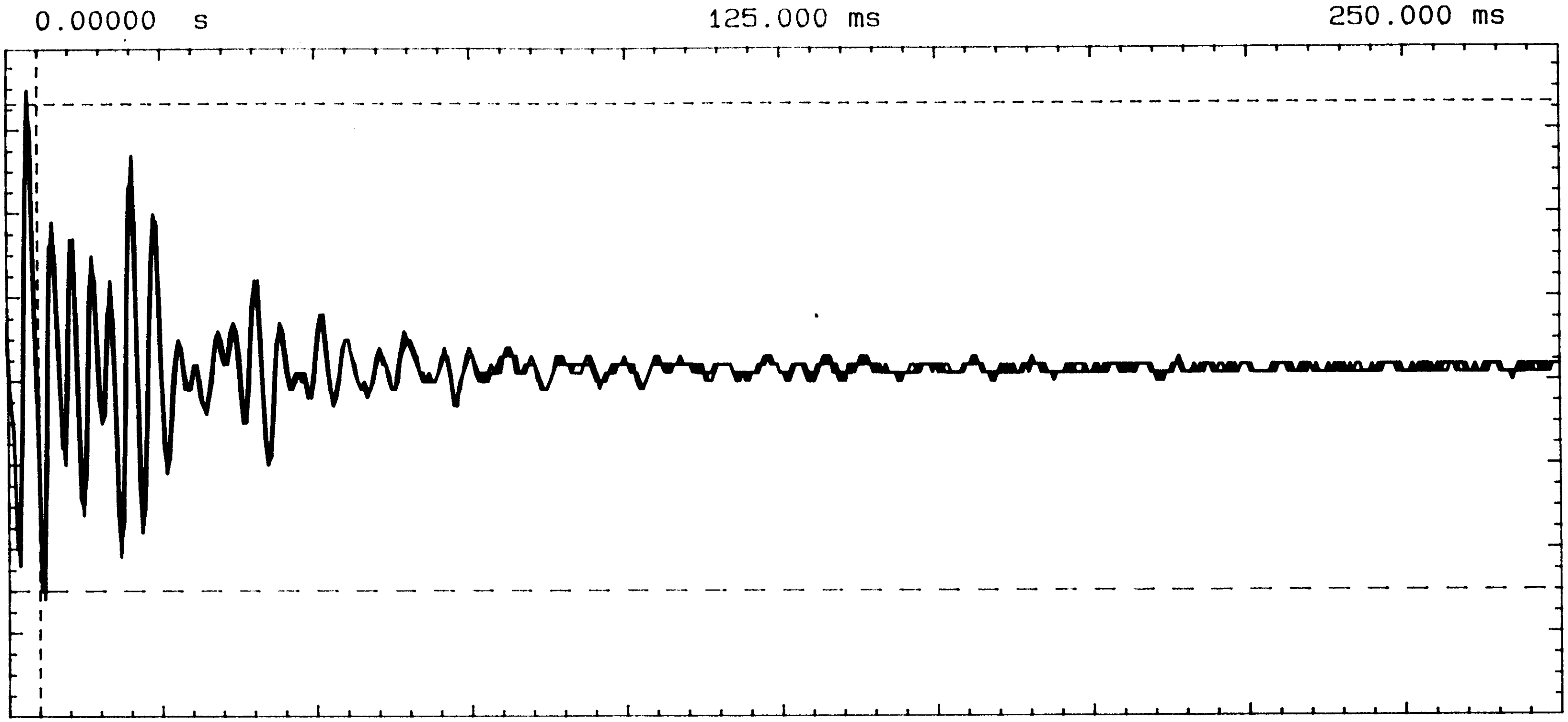
```
Ch. 1      =  200.0 mvolts/div                                         Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                         Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000   s
Ch. 2 Parameters                 Freq.       =  233.121  Hz            Period     =  4.28962 ms
Rise Time  =  400.008 us         + Width     =  1.87295 ms             - Width    =  2.41667 ms
Fall Time  =  733.356 us         Preshoot    =  0.000   volts          Overshoot  =  0.000   volts
P-P Volts  =  2.875   volts      RMS Volts   =  1.289   volts          Dutycycle  =  43.66 %
```

Top Trace: Titanium Specimen Oil Core Filtrered Input Time-Space

Bottom Trace: Titanium Specimen Oil Core Un-filtered Input



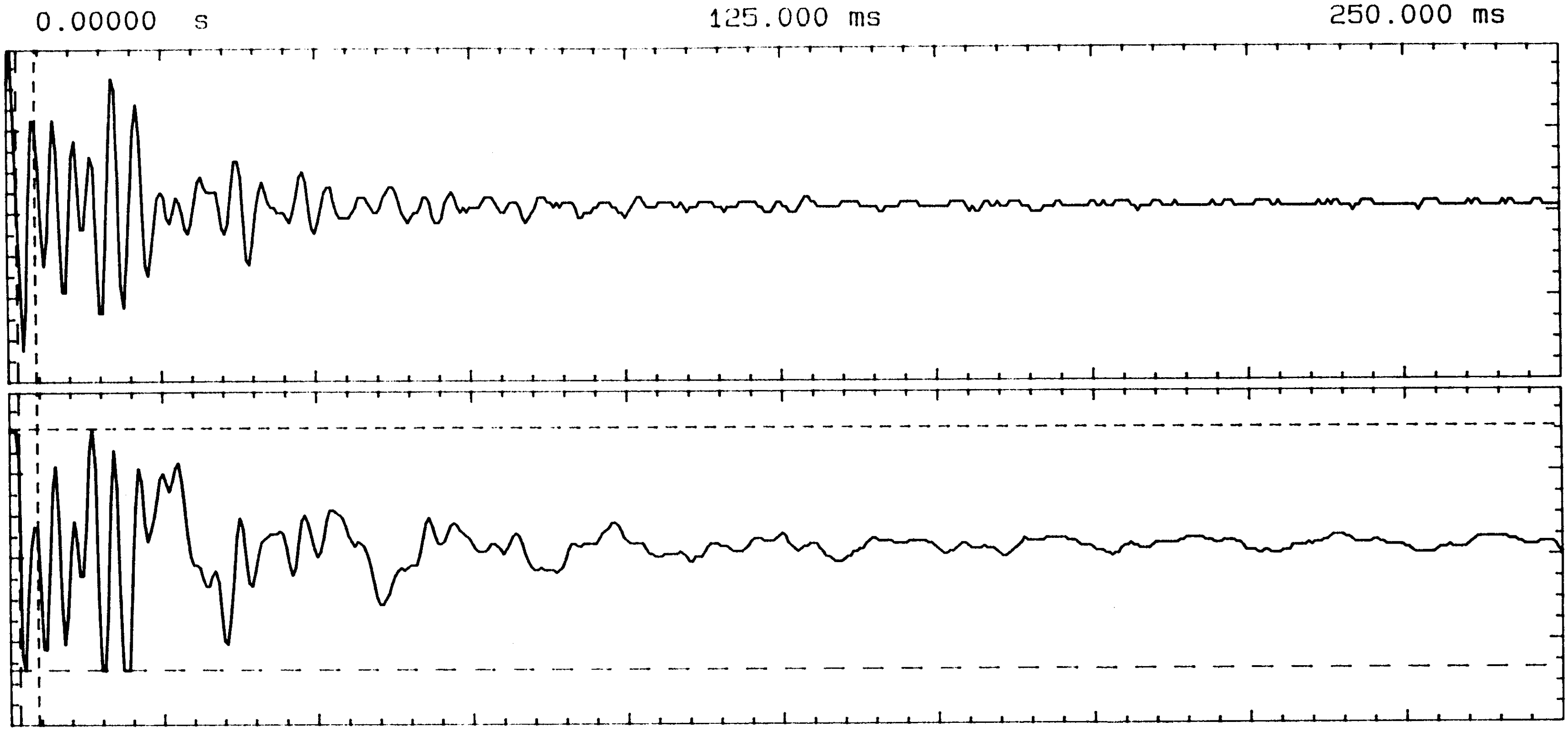
Top Trace:	Titanium Specimen	Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Titanium Specimen	Oil Core	Un-filtered Input	



```
Timebase  =  25.0 ms/div                                                Delay     =  0.00000  s
Memory 1  =  125.0 mvolts/div                                           Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                Delay     =  0.00000  s
Memory 2  =  125.0 mvolts/div                                           Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                Delay     =  0.00000  s
Memory 3  =  125.0 mvolts/div                                           Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                Delay     =  0.00000  s
Memory 4  =  125.0 mvolts/div                                           Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                Delay     =  0.00000  s
Mem 1 Parameters                   Freq.      =  212.847  Hz            Period    =  4.69822 ms
Rise Time =  1.28799 ms            + Width    =  1.97302 ms             - Width   =  2.72520 ms
Fall Time =  1.60959 ms            Preshoot   =  0.000  volts           Overshoot =  0.000  volts
P-P Volts =  726.6 mvolts          RMS Volts  =  211.1 mvolts           Dutycycle =  41.99 %
```

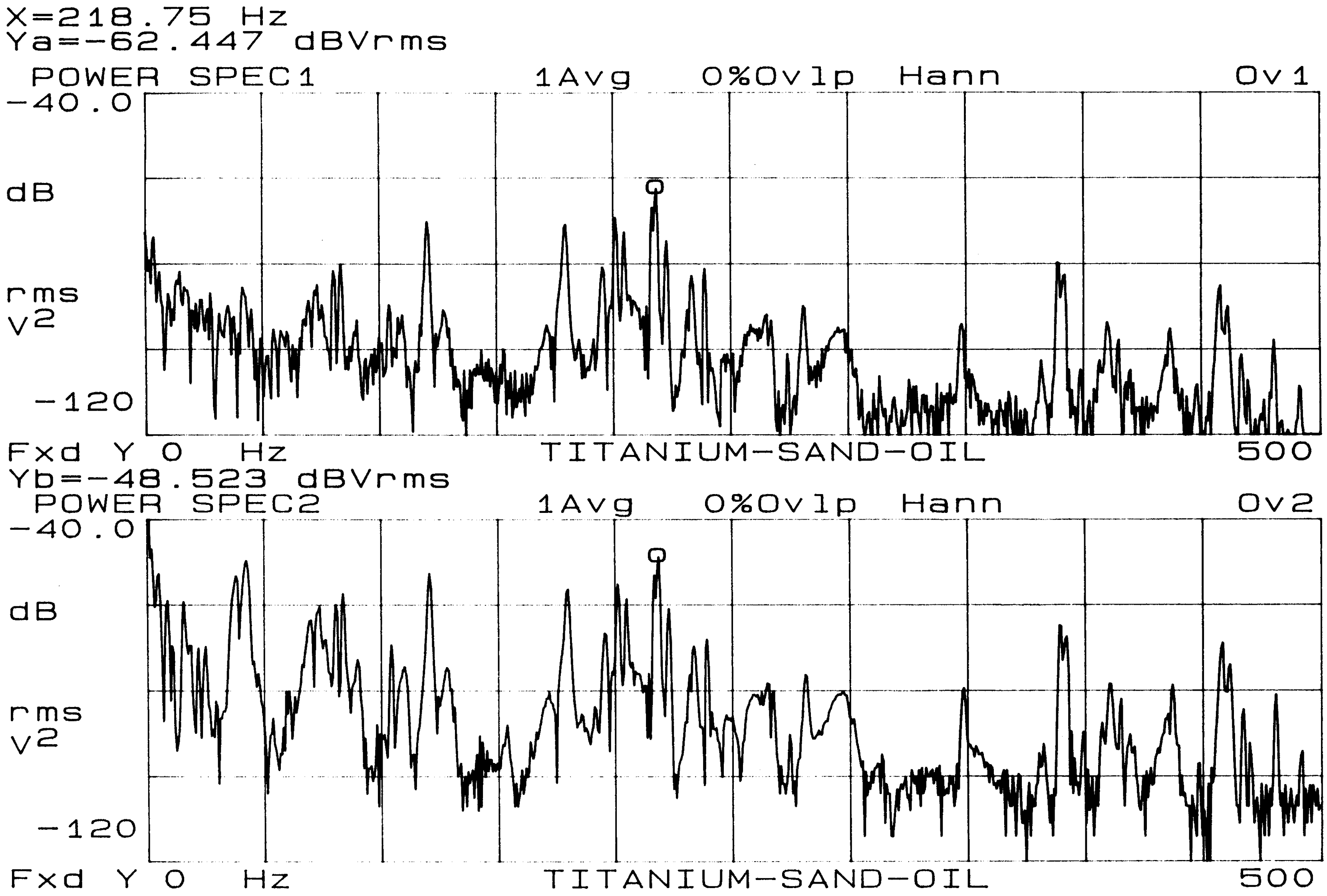
Trace: Titanium Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

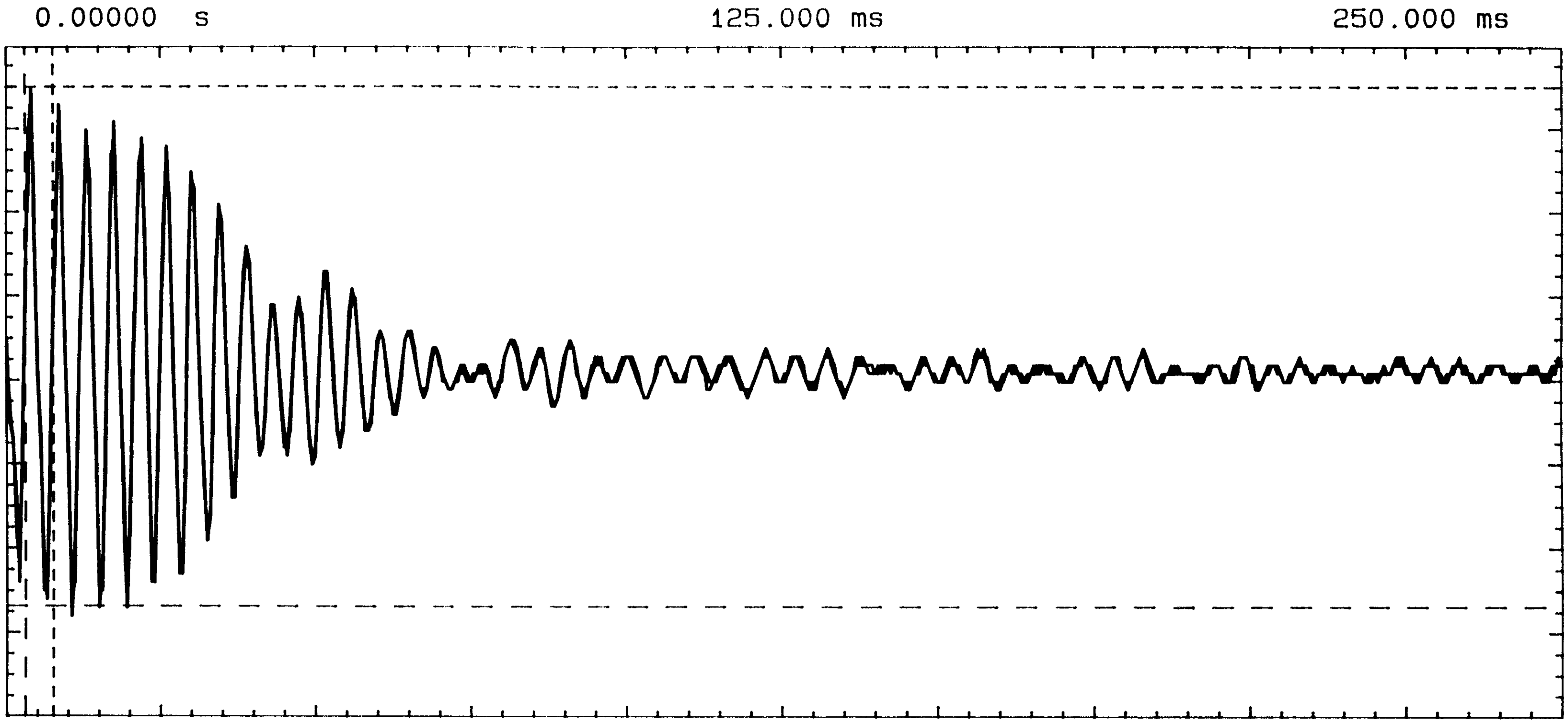


```
Ch. 1      =  200.0 mvolts/div                                              Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Ch. 2 Parameters                         Freq.       =  338.164  Hz         Period     =  2.95714 ms
Rise Time  =  10.5021 ms                 + Width     =  1.06404 ms          - Width    =  1.89310 ms
Fall Time  =  747.673 us                 Preshoot    =  0.000  volts        Overshoot  =  0.000  volts
P-P Volts  =  2.875  volts               RMS Volts   =  853.7 mvolts        Dutycycle  =  35.98 %
```

Top Trace:	Titanium Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Titanium Specimen	Sand/Oil Core	Un-filtered Input	



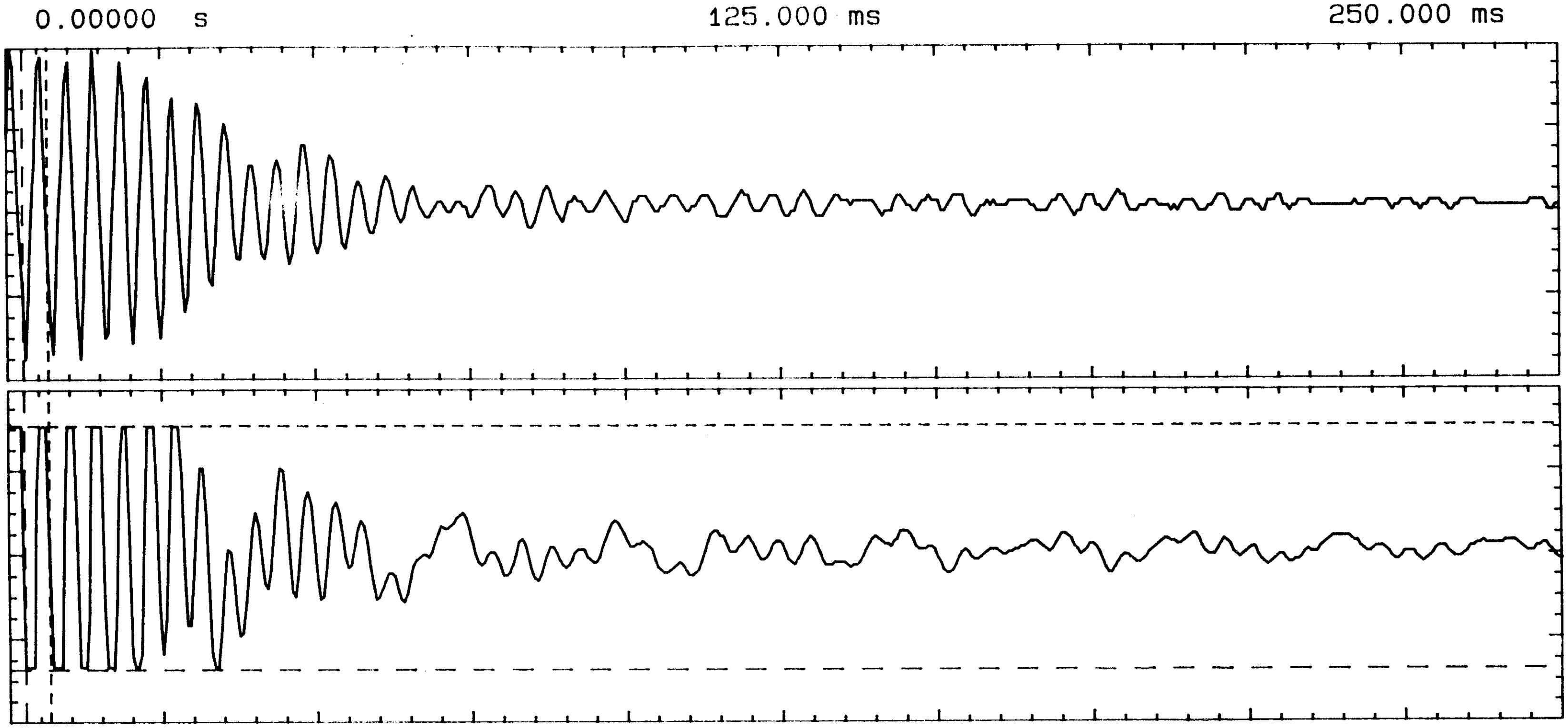
Top Trace:	**Titanium Specimen**	**Sand/Oil Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Titanium Specimen**	**Sand/Oil Core**	**Un-filtered Input**	



```
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Mem 1 Parameters                Freq.       =  217.269  Hz              Period     =  4.60259 ms
Rise Time =  1.66618 ms         + Width     =  2.13110 ms               - Width    =  2.47148 ms
Fall Time =  1.91362 ms         Preshoot    =  0.000  volts             Overshoot  =  0.000  volts
P-P Volts =  773.5 mvolts       RMS Volts   =  234.8 mvolts             Dutycycle  =  46.30 %
```

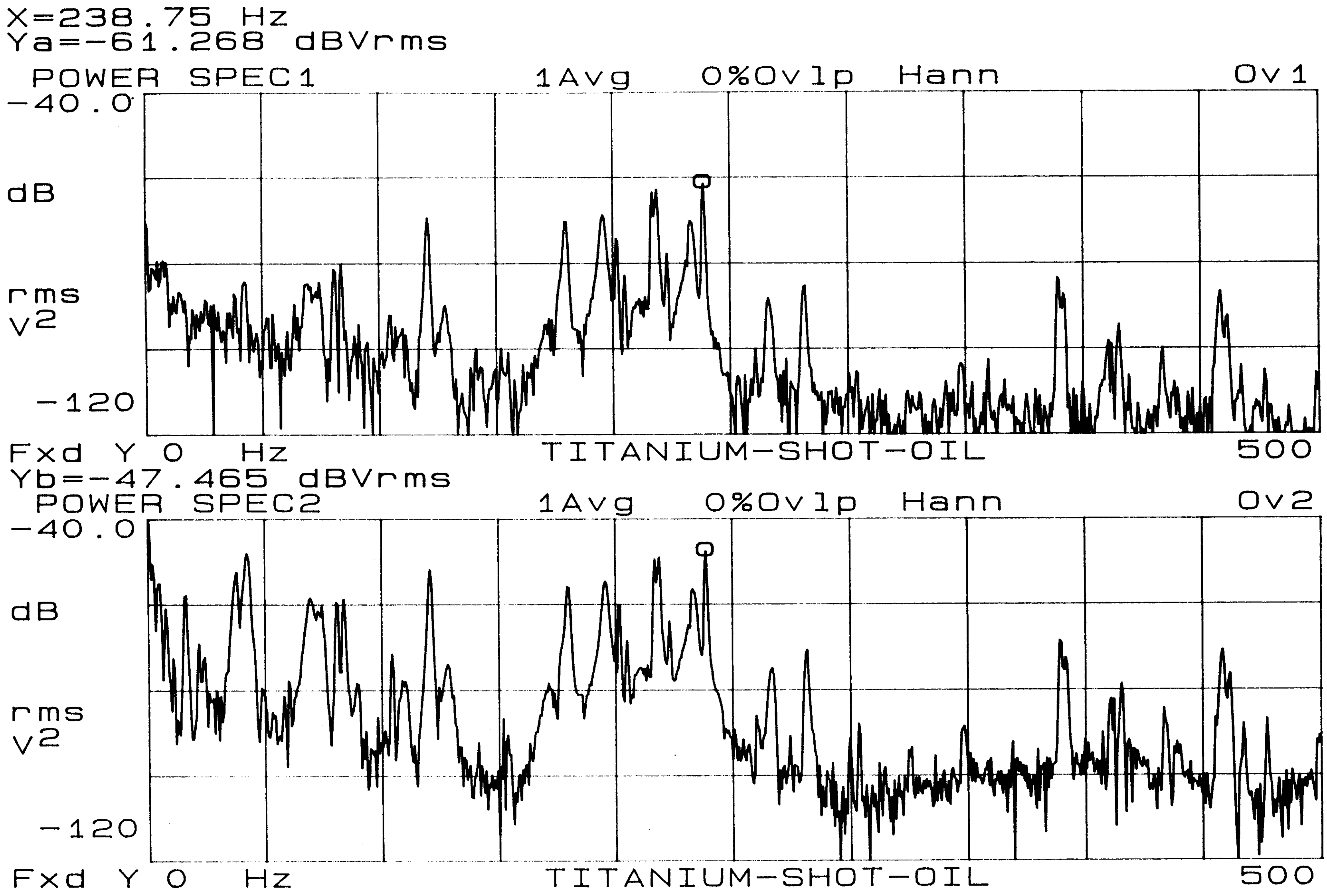
Trace: Titanium Specimen Lead Shot/Oil Core Filtrered Input

Four Trace Overlay in Time-Space



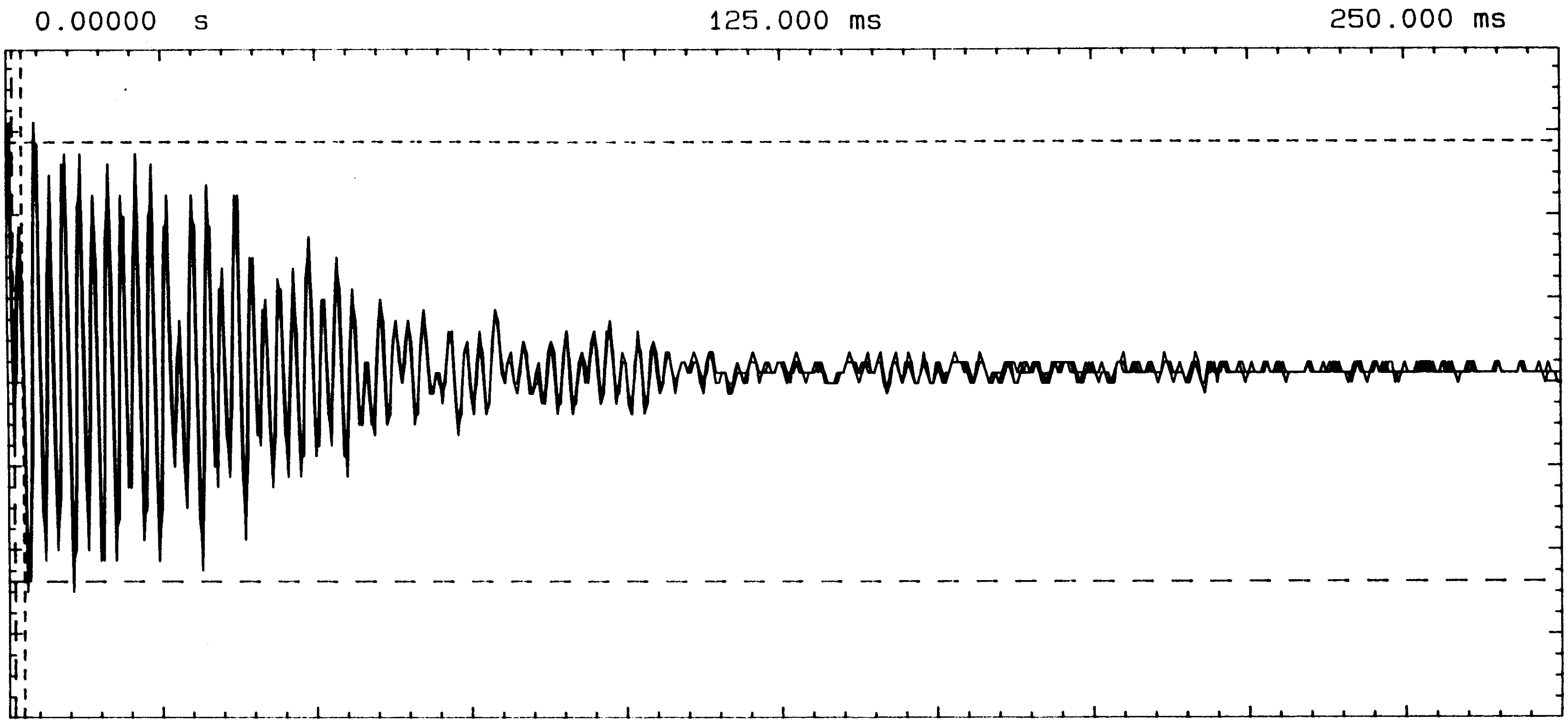
```
Ch. 1      =  200.0 mvolts/div                                       Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                       Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000   s
Ch. 2 Parameters                     Freq.       =  234.010  Hz      Period     =  4.27332 ms
Rise Time =  752.039 us              + Width     =  2.18649 ms        - Width    =  2.08684 ms
Fall Time =  404.339 us              Preshoot    =  31.25 mvolts      Overshoot =  0.000   volts
P-P Volts =  2.937   volts           RMS Volts  =  1.284   volts      Dutycycle =  51.16 %
```

Top Trace:	Titanium Specimen	Lead Shot/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Titanium Specimen	Lead Shot/Oil Core	Un-filtered Input	



Top Trace:	Titanium Specimen	Lead Shot/Oil Core	Filtrered Input
Bottom Trace:	Titanium Specimen	Lead Shot/Oil Core	Un-filtered Input

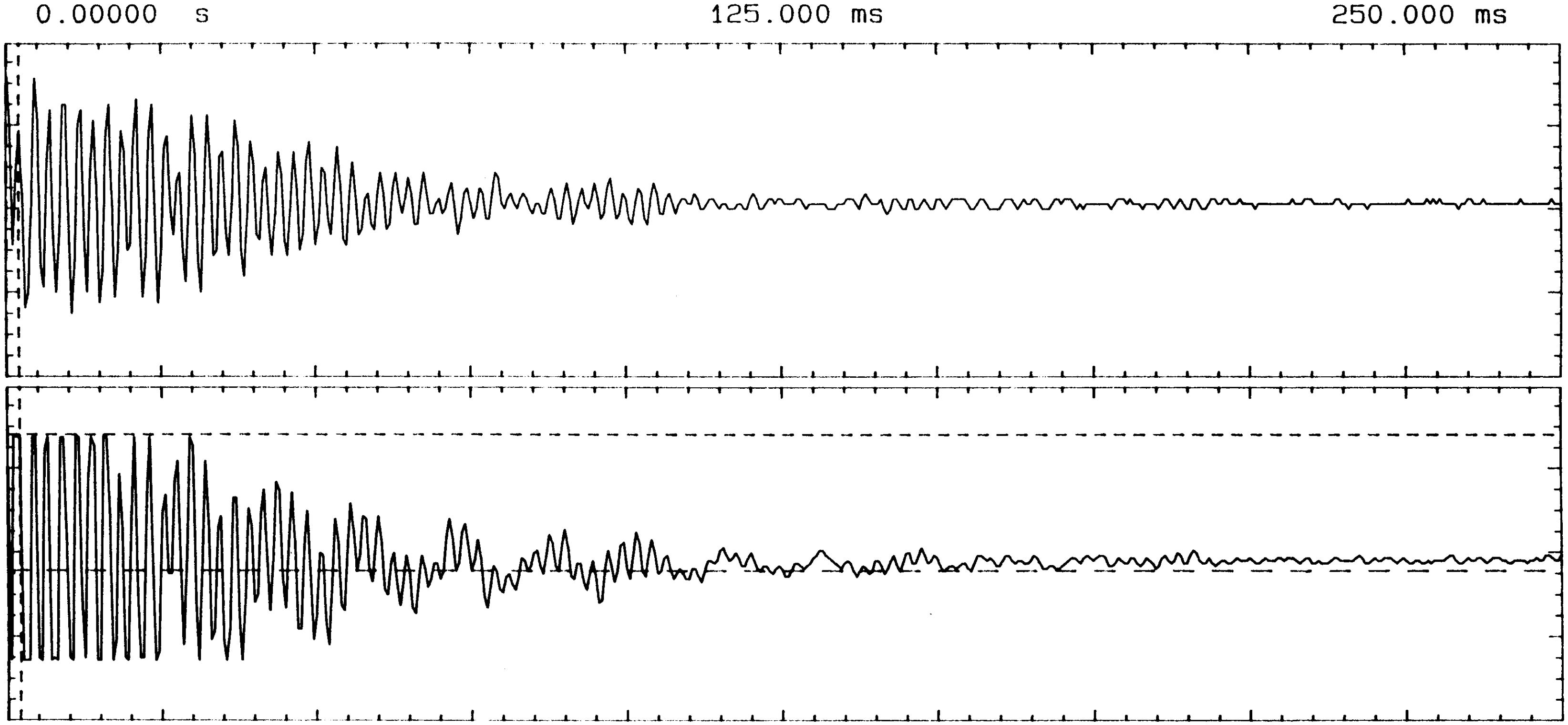
Frequency-Space



```
Timebase     =  25.0 ms/div                                                 Delay       =  0.00000  s
Memory 1     =  100.0 mvolts/div                                            Offset      =  0.000  volts
Timebase     =  25.0 ms/div                                                 Delay       =  0.00000  s
Memory 2     =  100.0 mvolts/div                                            Offset      =  0.000  volts
Timebase     =  25.0 ms/div                                                 Delay       =  0.00000  s
Memory 3     =  100.0 mvolts/div                                            Offset      =  0.000  volts
Timebase     =  25.0 ms/div                                                 Delay       =  0.00000  s
Memory 4     =  100.0 mvolts/div                                            Offset      =  0.000  volts
Timebase     =  25.0 ms/div                                                 Delay       =  0.00000  s
Mem 1 Parameters                 Freq.       =  580.001  Hz                 Period      =  1.72414 ms
Rise Time =  840.823 us          + Width     =  1.22869 ms                  - Width     =  495.442 us
Fall Time =  2.41033 ms          Preshoot    =  0.000  volts                Overshoot =  0.000  volts
P-P Volts =  525.0 mvolts        RMS Volts =  109.3 mvolts                  Dutycycle =  71.26 %
```

Trace: Aluminum Specimen Air Core Filtrered Input

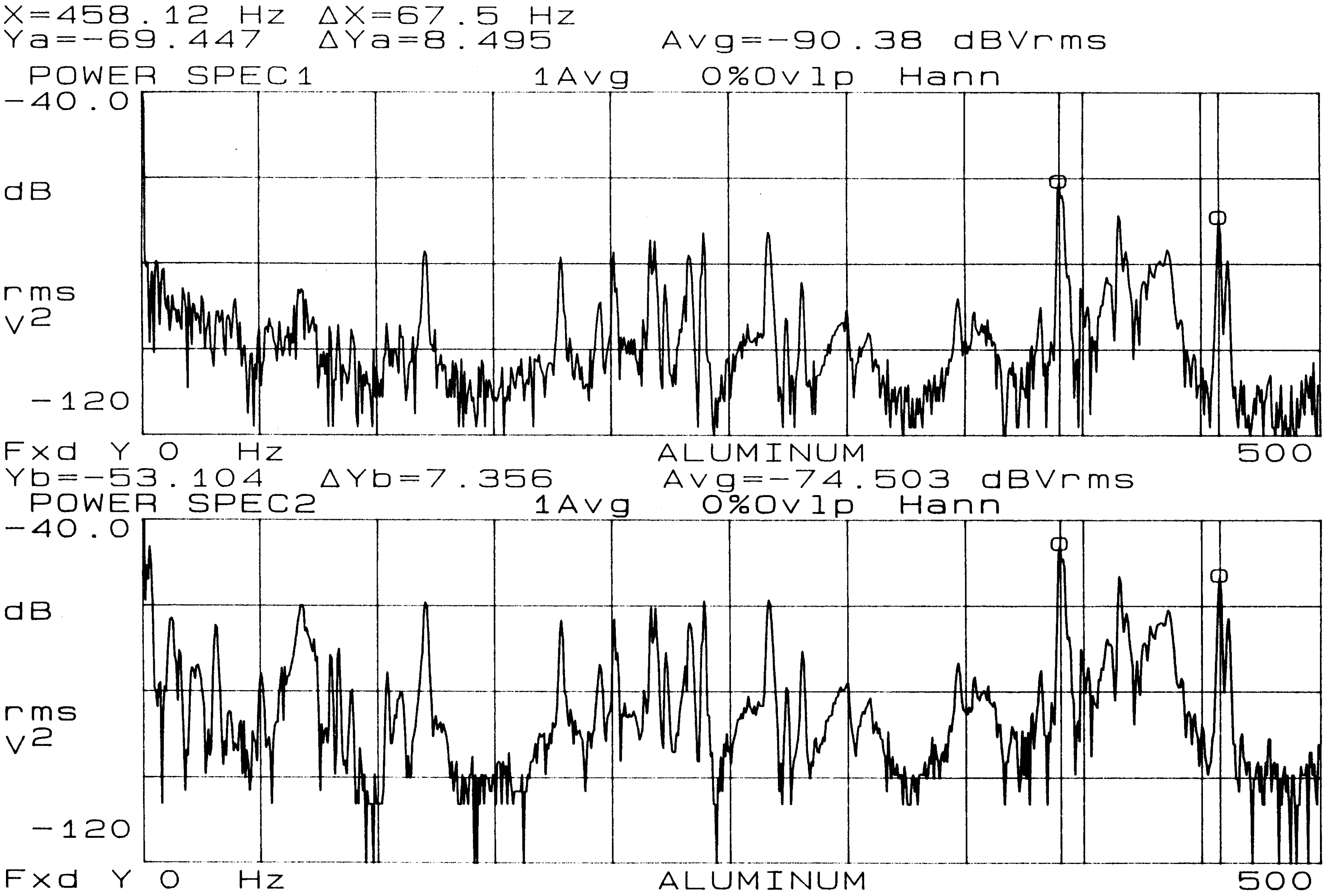
Four Trace Overlay in Time-Space



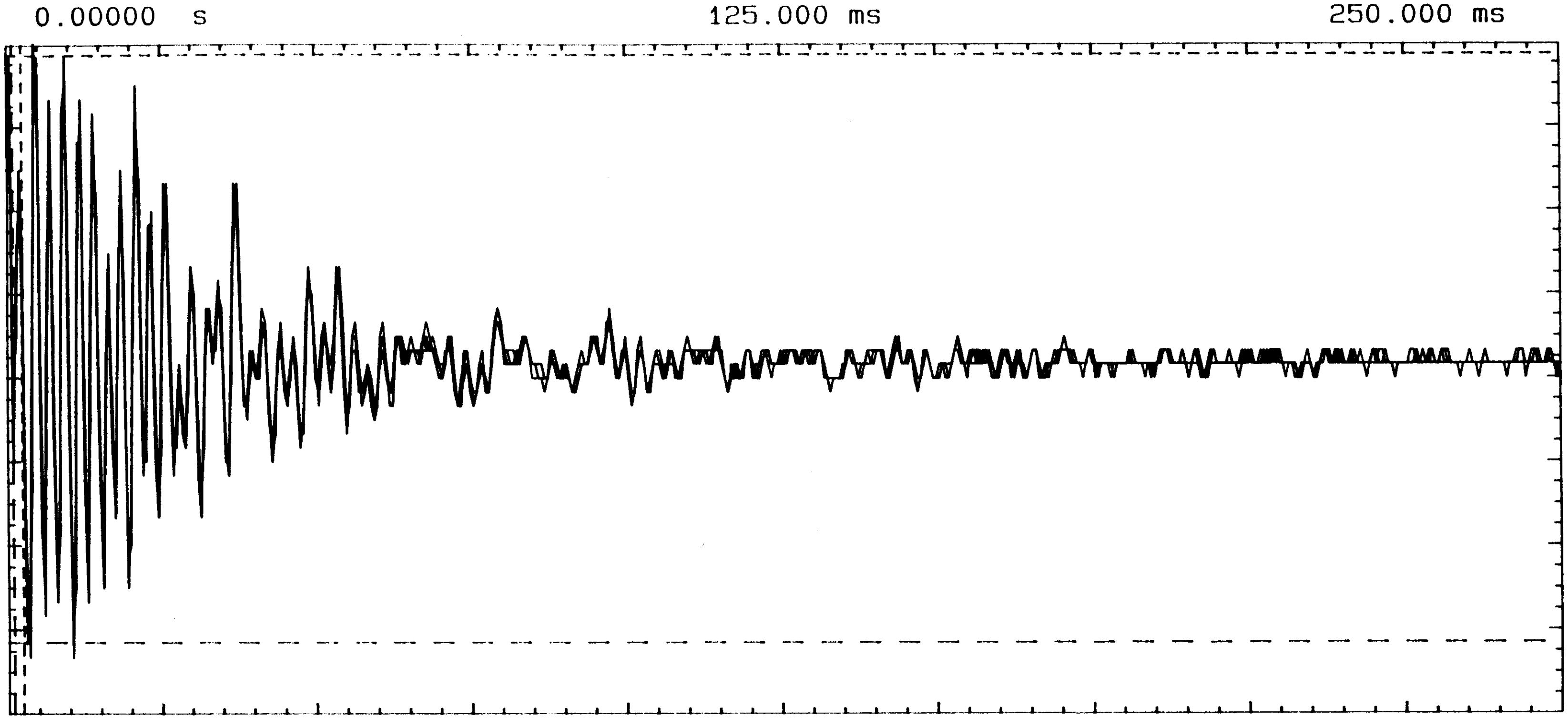
```
Ch. 1     =  200.0 mvolts/div                                     Offset    =  0.000  volts
Ch. 2     =  1.000  volts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Ch. 2 Parameters                 Freq.      =  482.230  Hz        Period    =  2.07370 ms
Rise Time =  241.870 us          + Width    =  1.30233 ms         - Width   =  771.372 us
Fall Time =  241.870 us          Preshoot   =  0.000  volts       Overshoot =  1.062  volts
P-P Volts =  2.687  volts        RMS Volts  =  1.293  volts       Dutycycle =  62.80 %
```

Top Trace: Aluminum Specimen Air Core Filtrered Input Time-Space

Bottom Trace: Aluminum Specimen Air Core Un-filtered Input



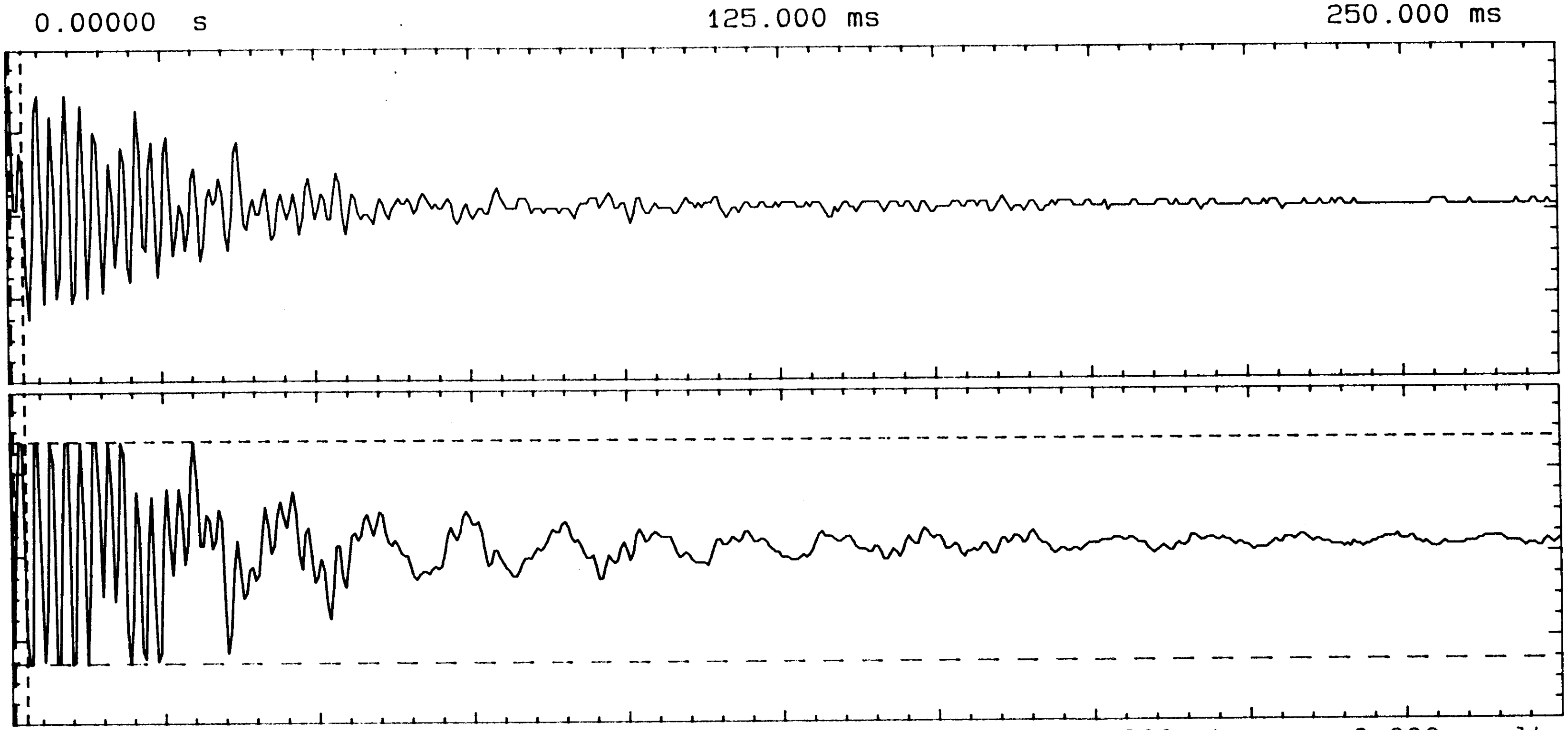
Top Trace:	**Aluminum Specimen**	**Air Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Aluminum Specimen**	**Air Core**	**Un-filtered Input**	



```
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 1  =  75.00 mvolts/div                                         Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 2  =  75.00 mvolts/div                                         Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 3  =  75.00 mvolts/div                                         Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 4  =  75.00 mvolts/div                                         Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                              Delay      =  0.00000  s
Mem 1 Parameters                Freq.       =  575.832  Hz            Period     =  1.73662 ms
Rise Time =  811.683 us         + Width     =  1.26818 ms             - Width    =  468.440 us
Fall Time =  2.77261 ms         Preshoot    =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  525.0 mvolts       RMS Volts   =  107.4 mvolts           Dutycycle  =  73.02 %
```

Trace: Aluminum Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space

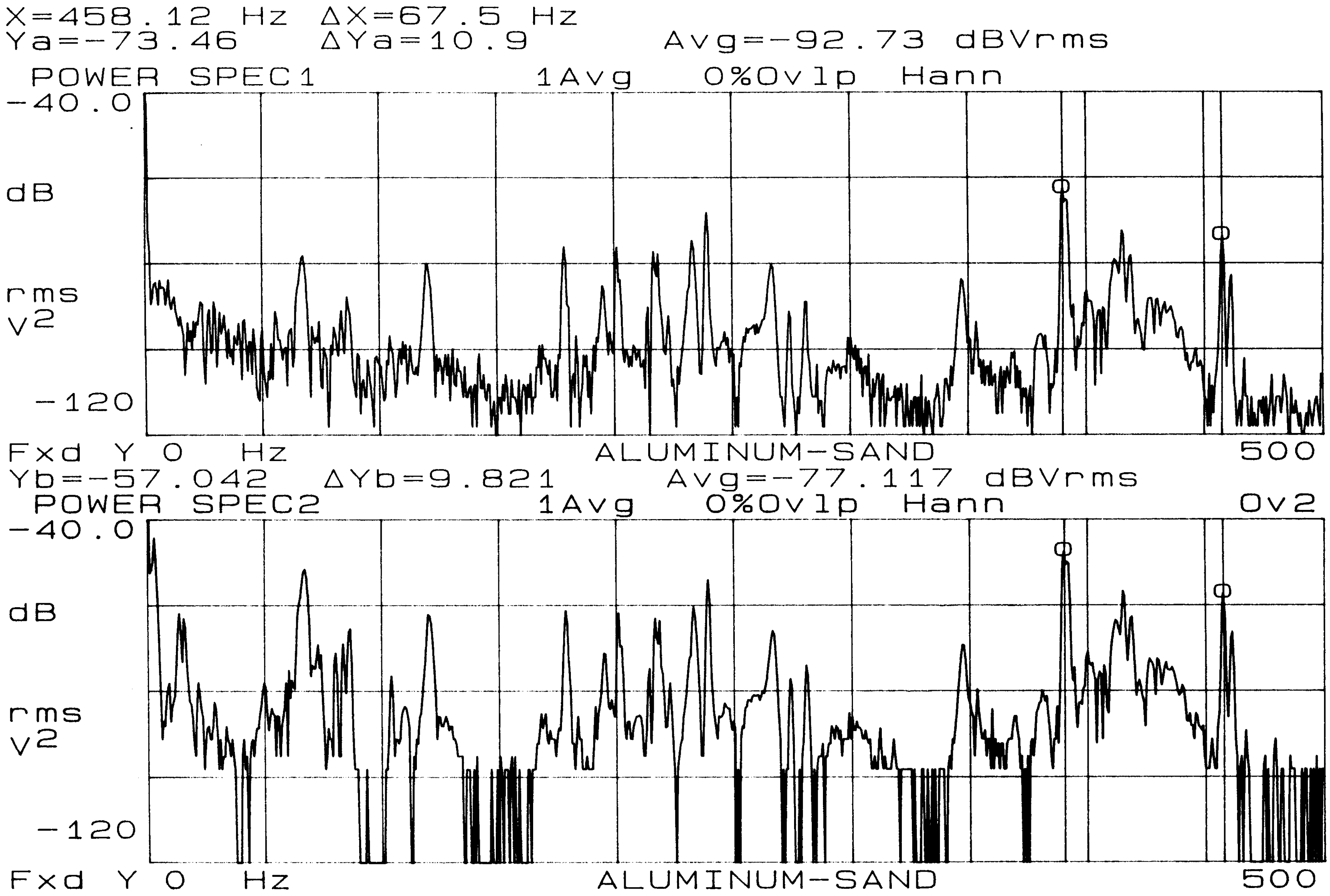


Ch. 1 = 200.0 mvolts/div
Ch. 2 = 1.000 volts/div
Timebase = 25.0 ms/div
Ch. 2 Parameters
Rise Time = 400.000 us
Fall Time = 2.65332 ms
P-P Volts = 2.656 volts

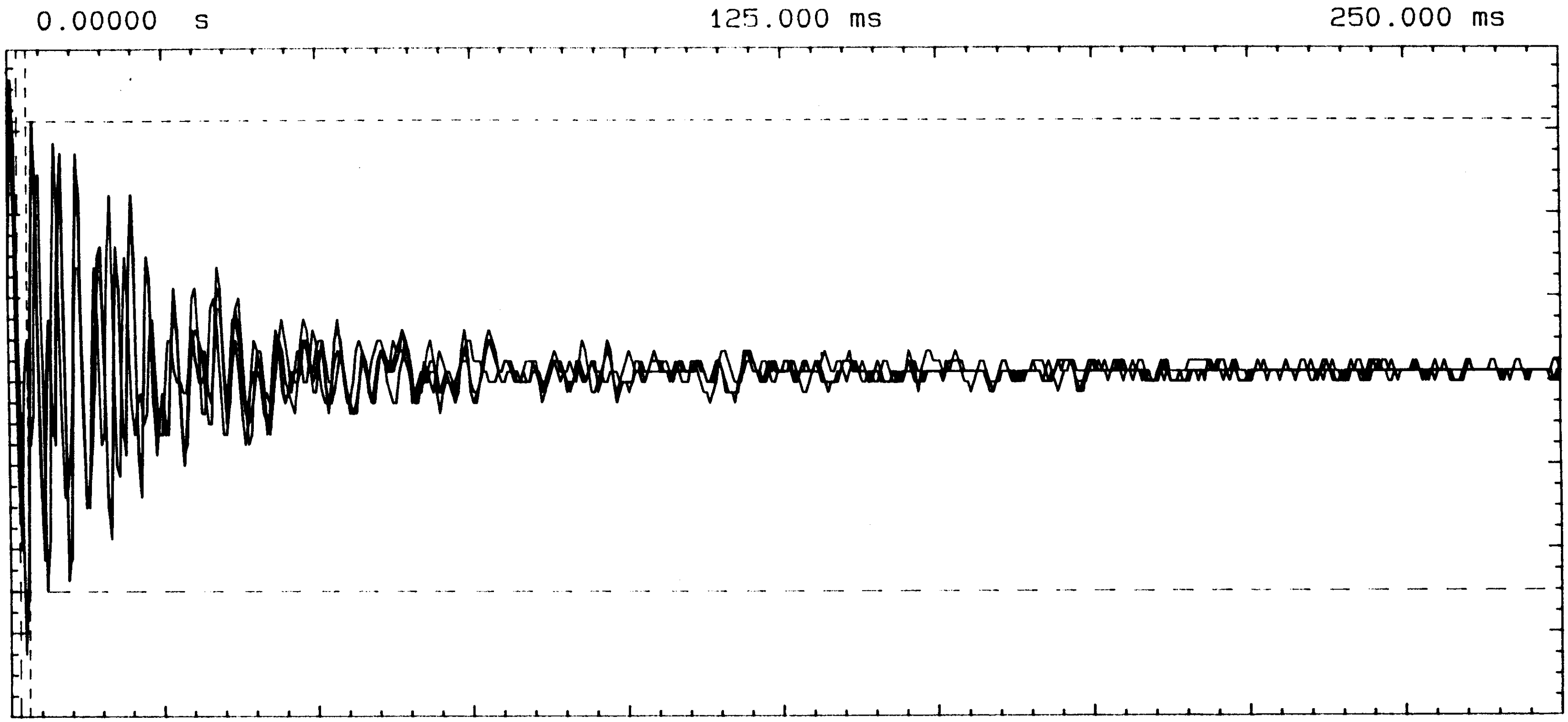
Freq. = 497.958 Hz
+ Width = 1.48159 ms
Preshoot = 0.000 volts
RMS Volts = 1.064 volts

Offset = 0.000 volts
Offset = 0.000 volts
Delay = 0.00000 s
Period = 2.00820 ms
- Width = 526.612 us
Overshoot = 0.000 volts
Dutycycle = 73.77 %

Top Trace:	Aluminum Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Aluminum Specimen	Sand Core	Un-filtered Input	



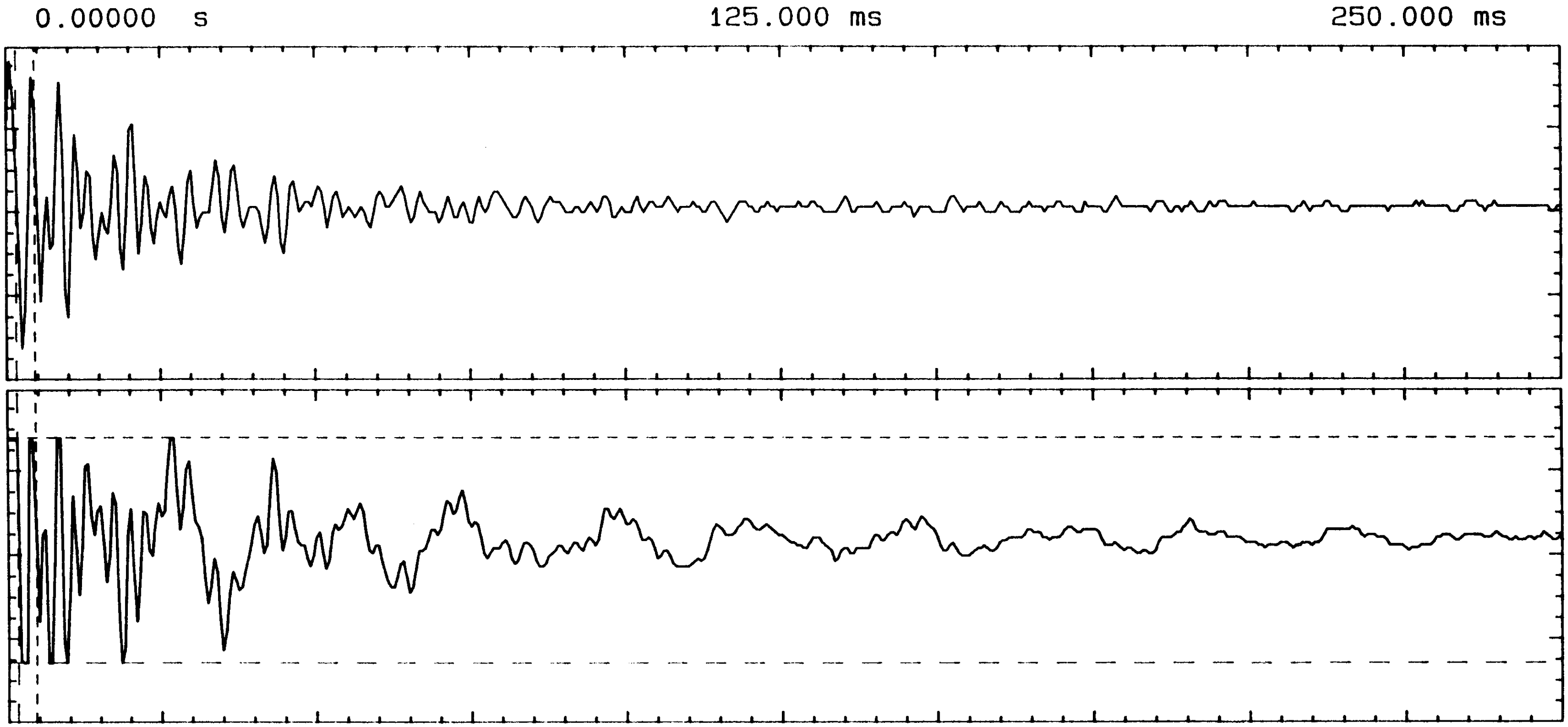
Top Trace:	**Aluminum Specimen**	**Sand Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Aluminum Specimen**	**Sand Core**	**Un-filtered Input**	



```
Timebase    =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 1    =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 2    =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 3    =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 4    =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                             Delay      =  0.00000  s
Mem 1 Parameters                    Freq.      =  551.133  Hz          Period     =  1.81445 ms
Rise Time =  1.15056 ms             + Width    =  261.489 us           - Width    =  1.55296 ms
Fall Time =  5.17324 ms             Preshoot   =  0.000  volts         Overshoot =  0.000  volts
P-P Volts =  562.5 mvolts           RMS Volts =  117.4 mvolts          Dutycycle =  14.41 %
```

Trace: Aluminum Specimen Lead Shot Core Filtrered Input

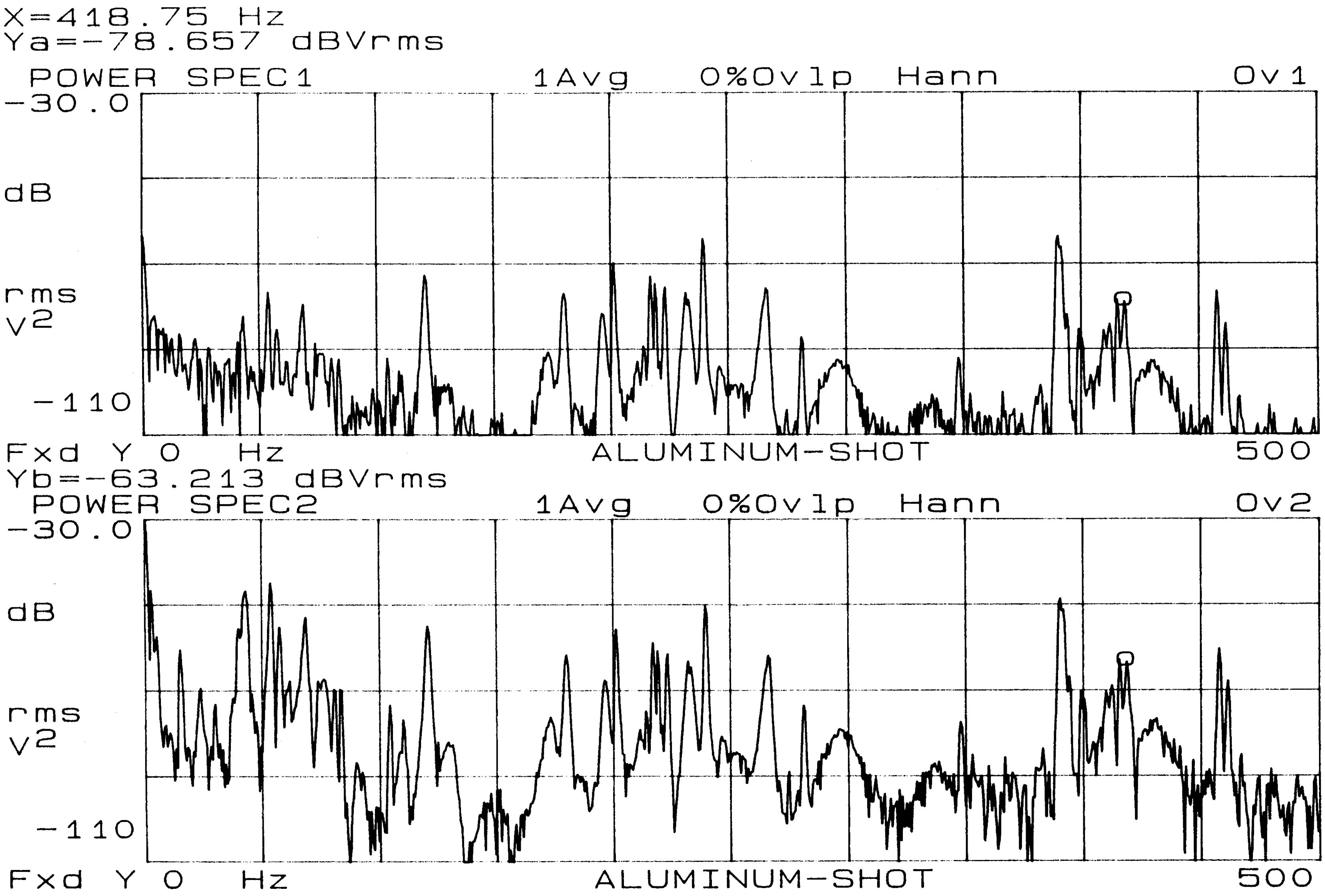
Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                      Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                      Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Ch. 2 Parameters                 Freq.       =  345.455  Hz         Period     =  2.89474 ms
Rise Time =  404.687 us          + Width     =  1.39180 ms          - Width    =  1.50294 ms
Fall Time =  409.505 us          Preshoot    =  0.000  volts        Overshoot =  0.000  volts
P-P Volts =  2.687  volts        RMS Volts =  1.210  volts          Dutycycle =  48.08 %
```

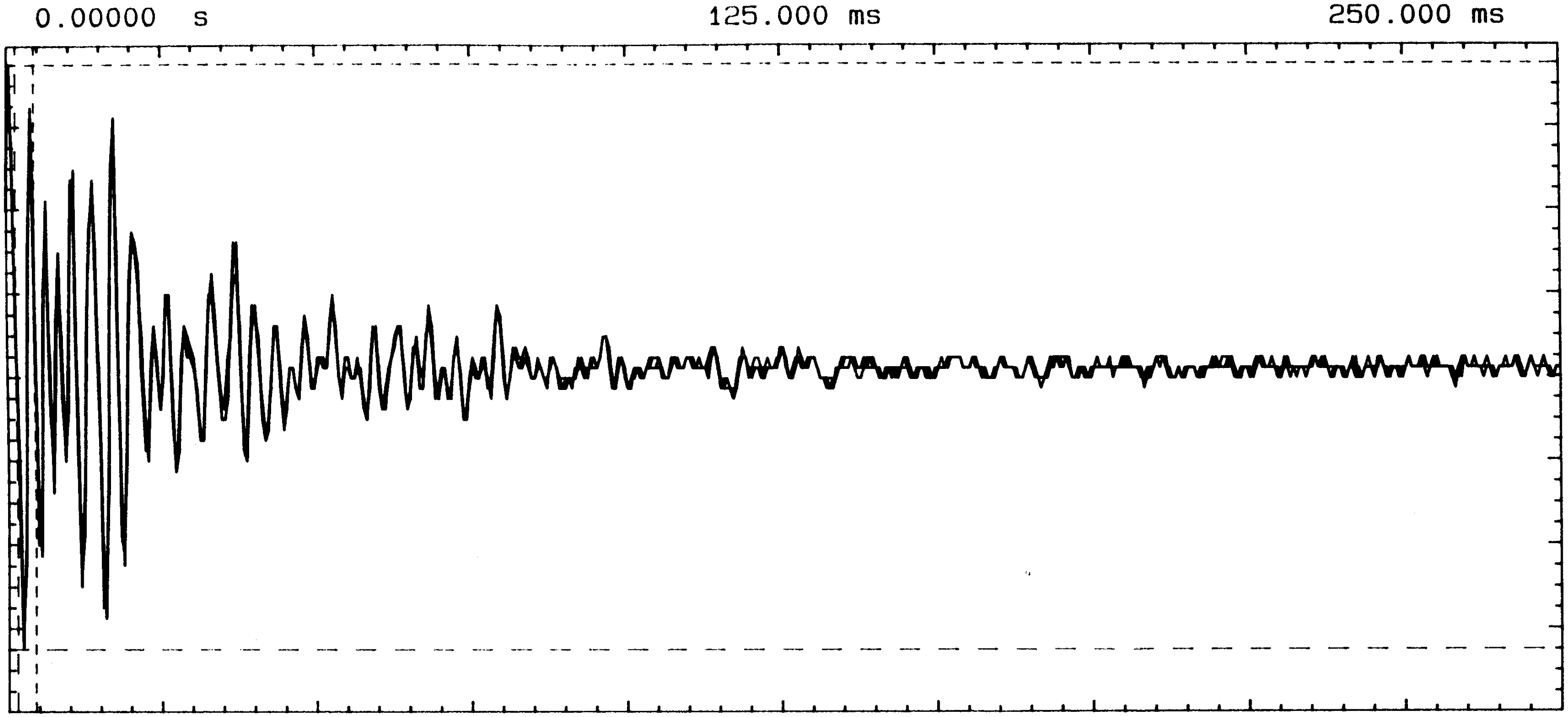
Top Trace: Aluminum Specimen Lead Shot Core Filtrered Input Time-Space

Bottom Trace: Aluminum Specimen Lead Shot Core Un-filtered Input



Top Trace:	**Aluminum Specimen**	**Lead Shot Core**	**Filtrered Input**
Bottom Trace:	**Aluminum Specimen**	**Lead Shot Core**	**Un-filtered Input**

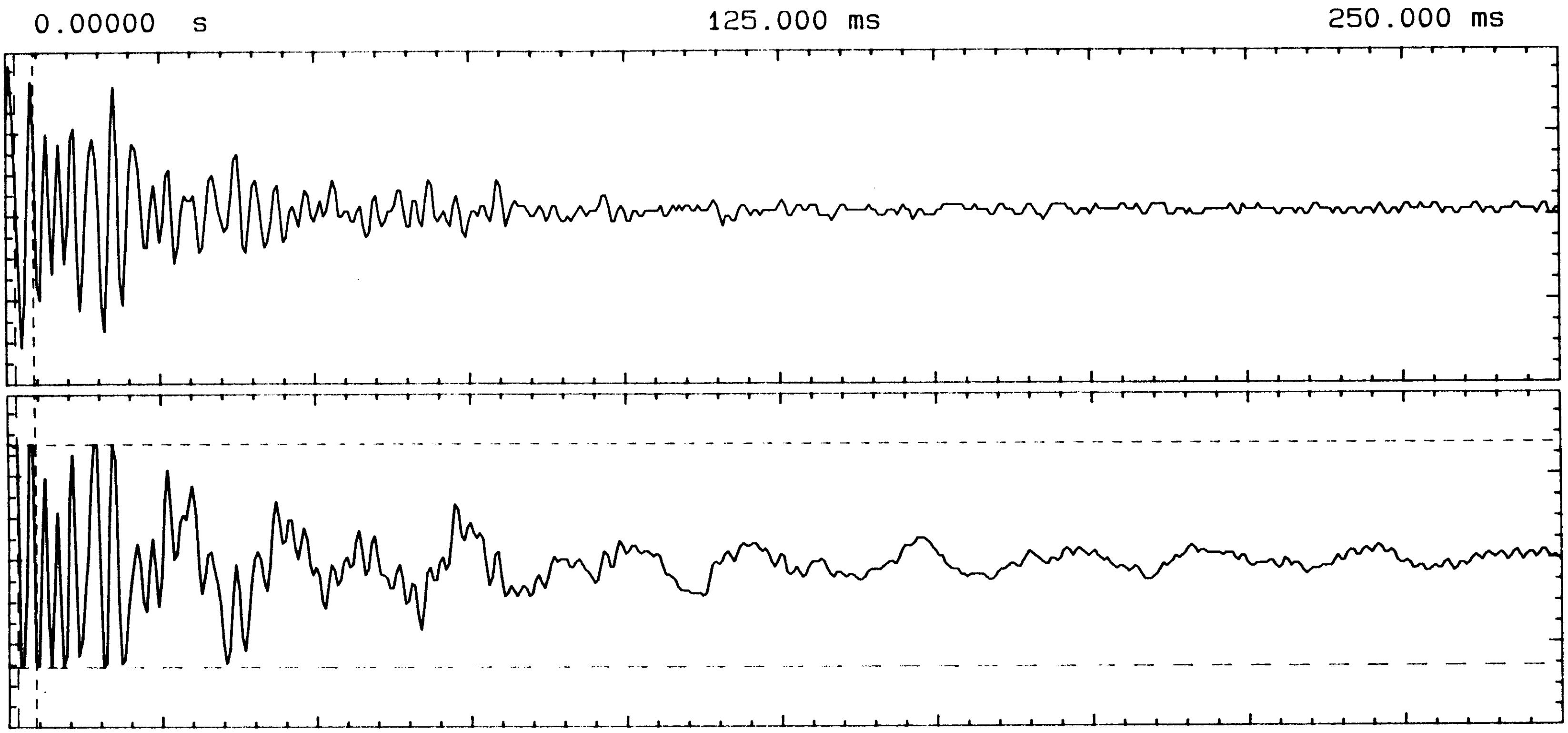
Frequency-Space



```
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Mem 2 Parameters                Freq.       =  321.521  Hz            Period     =  3.11021 ms
Rise Time =  1.21997 ms         + Width     =  1.33712 ms             - Width    =  1.77309 ms
Fall Time =  1.43496 ms         Preshoot    =  0.000  volts           Overshoot =  0.000  volts
P-P Volts =  700.1 mvolts       RMS Volts =  212.5 mvolts             Dutycycle =  42.99 %
```

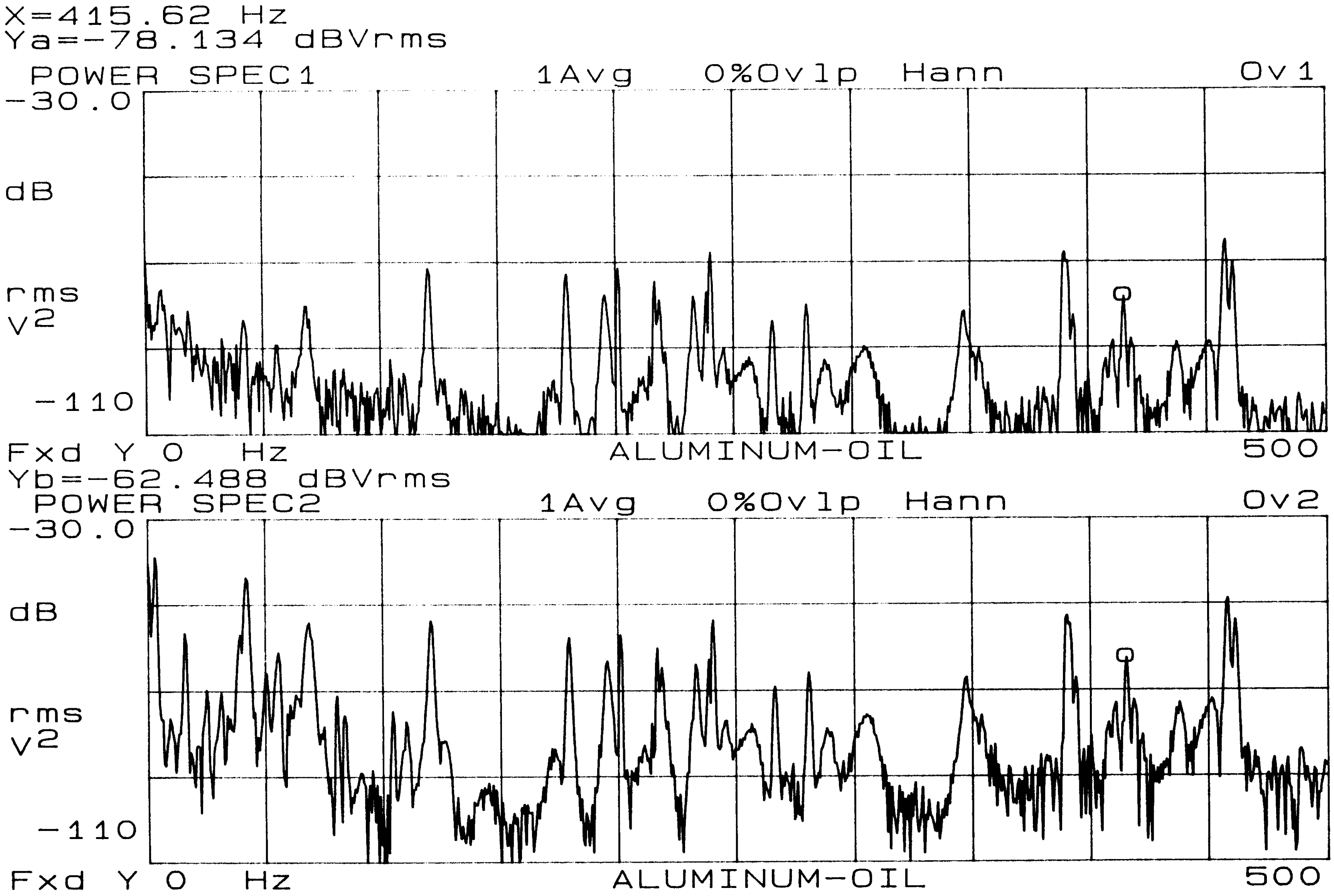
Trace: Aluminum Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space

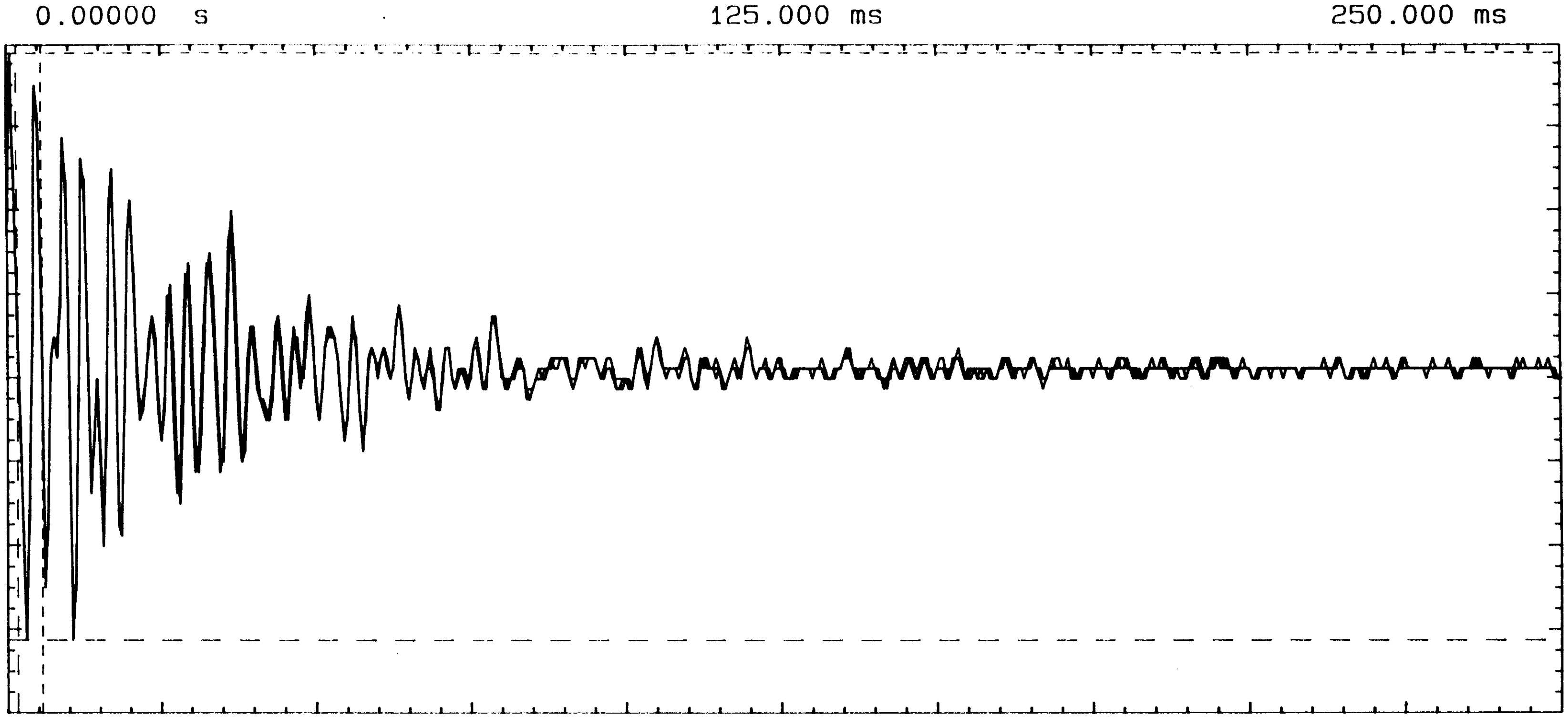


```
Ch. 1       =  200.0 mvolts/div                                     Offset     =  0.000   volts
Ch. 2       =  1.000  volts/div                                     Offset     =  0.000   volts
Timebase    =  25.0 ms/div                                          Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.      =  399.038  Hz       Period     =  2.50602 ms
Rise Time =  786.550 us             + Width    =  1.12883 ms        - Width    =  1.37719 ms
Fall Time =  400.000 us             Preshoot   =  0.000   volts     Overshoot =  0.000   volts
P-P Volts =  2.656  volts           RMS Volts =  1.199   volts      Dutycycle =  45.04 %
```

Top Trace:	Aluminum Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Aluminum Specimen	Oil Core	Un-filtered Input	



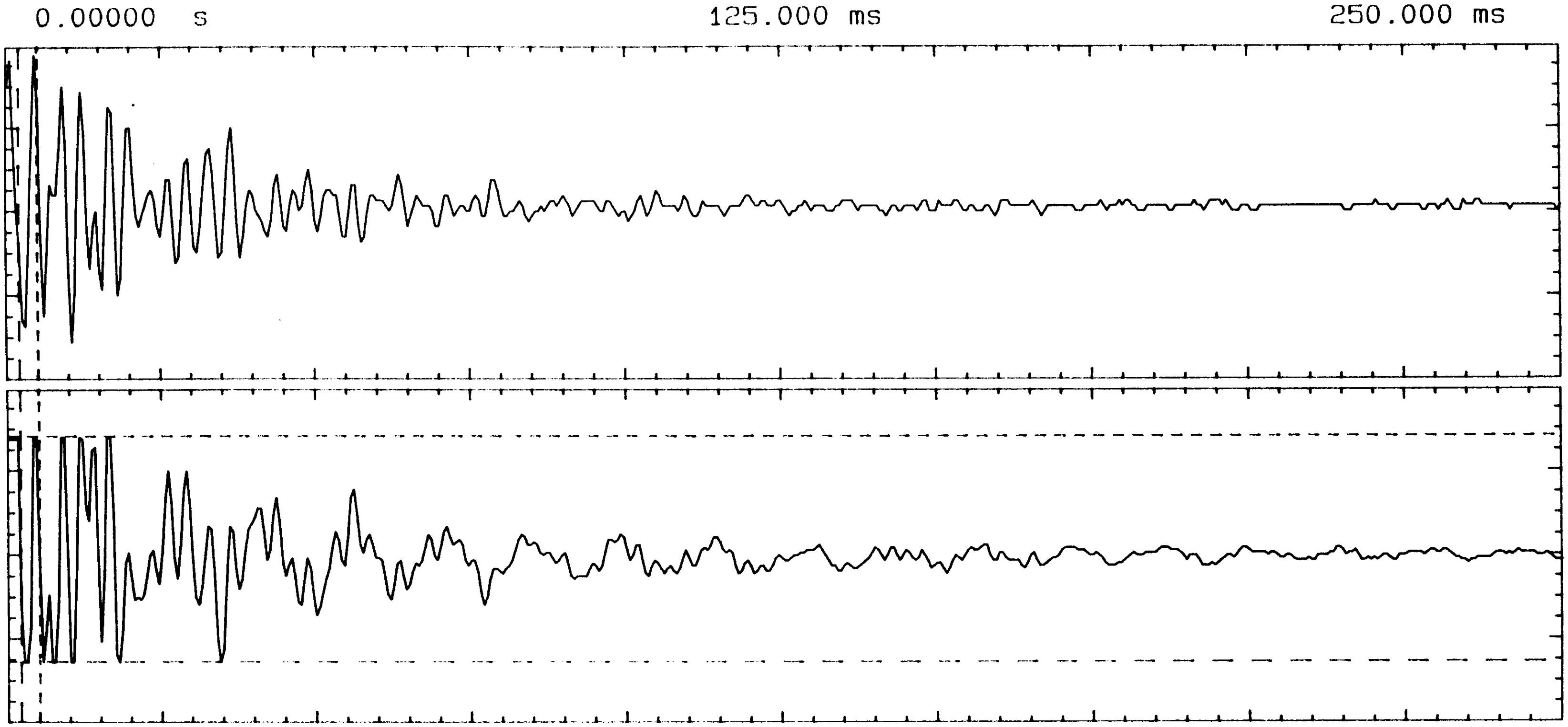
Top Trace:	**Aluminum Specimen**	**Oil Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Aluminum Specimen**	**Oil Core**	**Un-filtered Input**	



```
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Mem 1 Parameters                  Freq.      =  256.632  Hz             Period     =  3.89664 ms
Rise Time =  1.21272 ms           + Width    =  1.58861 ms              - Width    =  2.30803 ms
Fall Time =  1.96597 ms           Preshoot   =  0.000  volts            Overshoot  =  0.000  volts
P-P Volts =  700.1 mvolts         RMS Volts  =  208.4 mvolts            Dutycycle  =  40.76 %
```

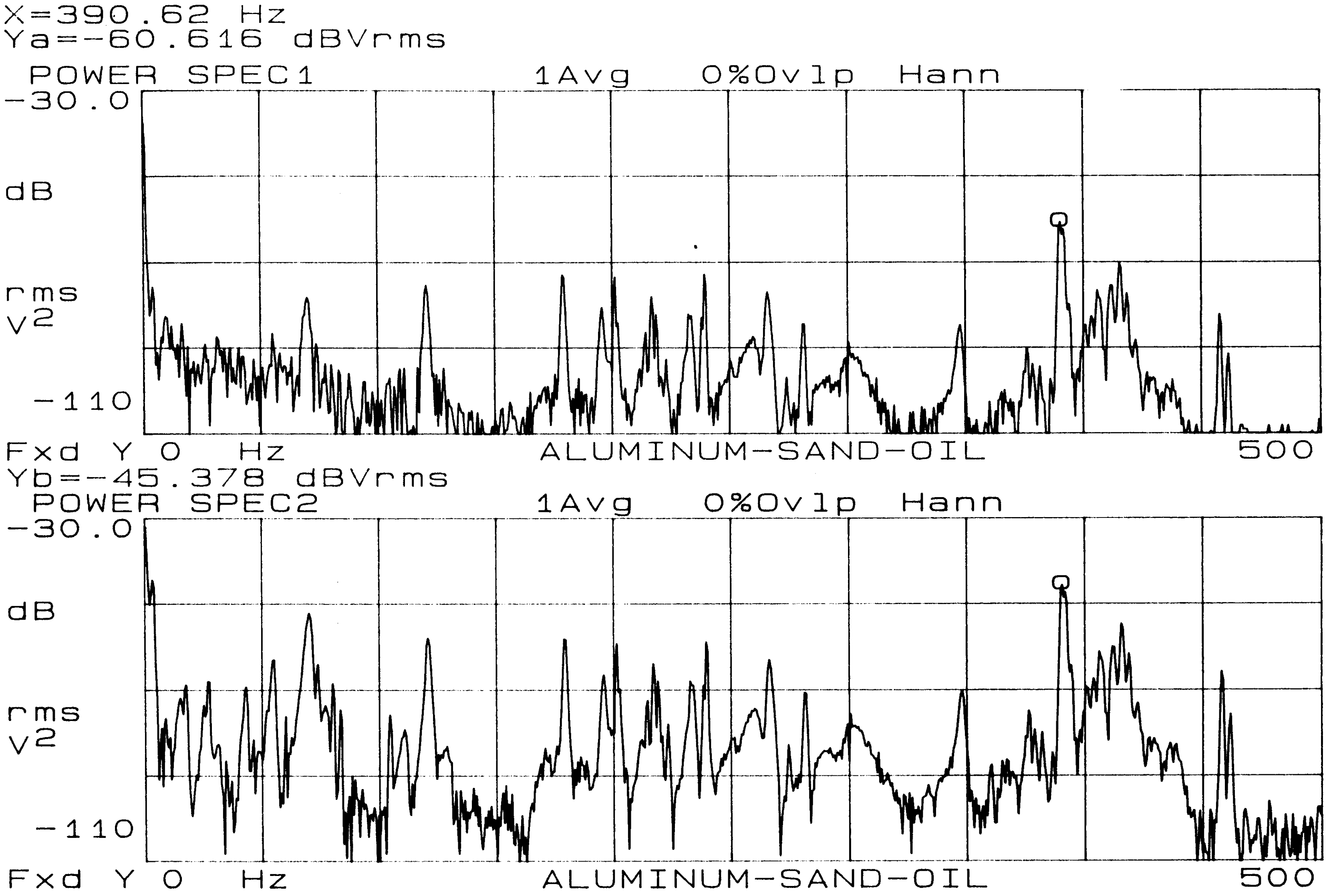
Trace: Aluminum Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

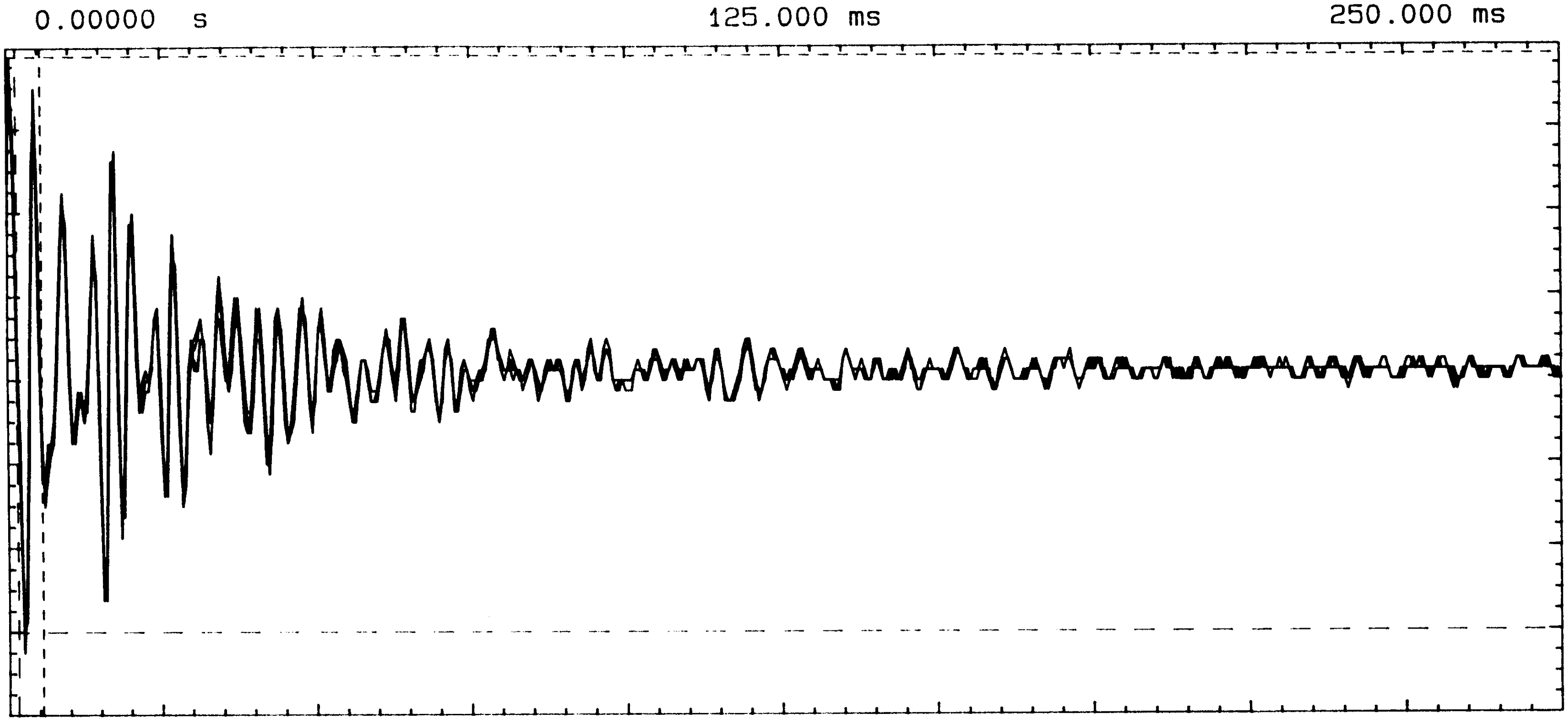


```
Ch. 1      =  200.0 mvolts/div                                             Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                             Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Ch. 2 Parameters                       Freq.       =  322.863  Hz          Period     =  3.09729 ms
Rise Time =  610.256 us                + Width     =  1.20798 ms           - Width    =  1.88930 ms
Fall Time =  697.821 us                Preshoot    =  0.000   volts        Overshoot =  0.000   volts
P-P Volts =  2.687   volts             RMS Volts  =  1.106   volts         Dutycycle =  39.00 %
```

Top Trace:	Aluminum Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Aluminum Specimen	Sand/Oil Core	Un-filtered Input	



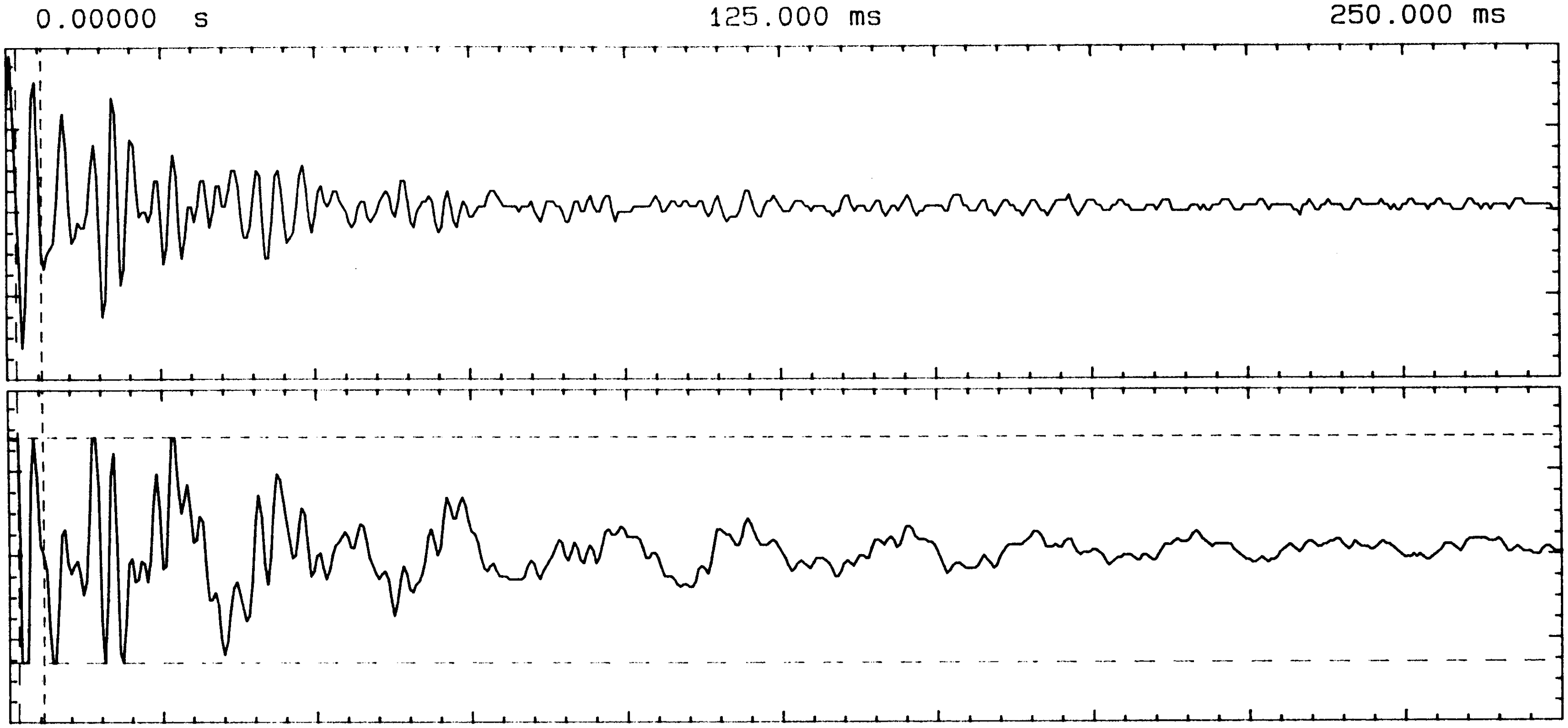
Top Trace:	**Aluminum Specimen**	**Sand/Oil Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Aluminum Specimen**	**Sand/Oil Core**	**Un-filtered Input**	



```
Timebase    =   25.0 ms/div                                         Delay       =   0.00000  s
Memory 1    =   100.0 mvolts/div                                    Offset      =   0.000  volts
Timebase    =   25.0 ms/div                                         Delay       =   0.00000  s
Memory 2    =   100.0 mvolts/div                                    Offset      =   0.000  volts
Timebase    =   25.0 ms/div                                         Delay       =   0.00000  s
Memory 3    =   100.0 mvolts/div                                    Offset      =   0.000  volts
Timebase    =   25.0 ms/div                                         Delay       =   0.00000  s
Memory 4    =   100.0 mvolts/div                                    Offset      =   0.000  volts
Timebase    =   25.0 ms/div                                         Delay       =   0.00000  s
Mem 1 Parameters                Freq.      =   274.591  Hz          Period      =   3.64179 ms
Rise Time =   1.26700 ms        + Width    =   1.51339 ms           - Width     =   2.12840 ms
Fall Time =   1.46324 ms        Preshoot   =   0.000  volts         Overshoot   =   0.000  volts
P-P Volts =   687.6 mvolts      RMS Volts  =   206.1 mvolts         Dutycycle   =   41.55 %
```

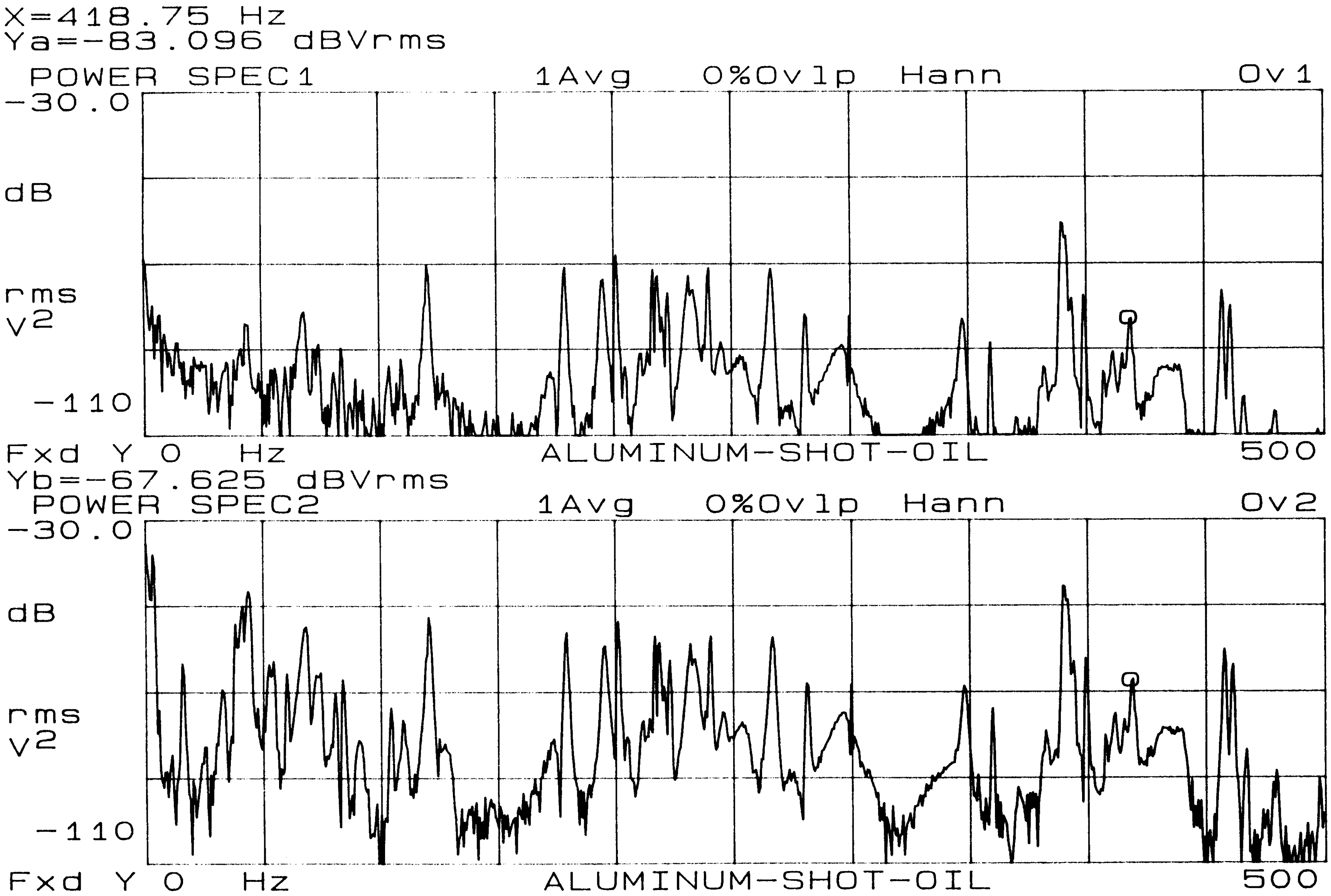
Trace: Aluminum Specimen Lead Shot/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

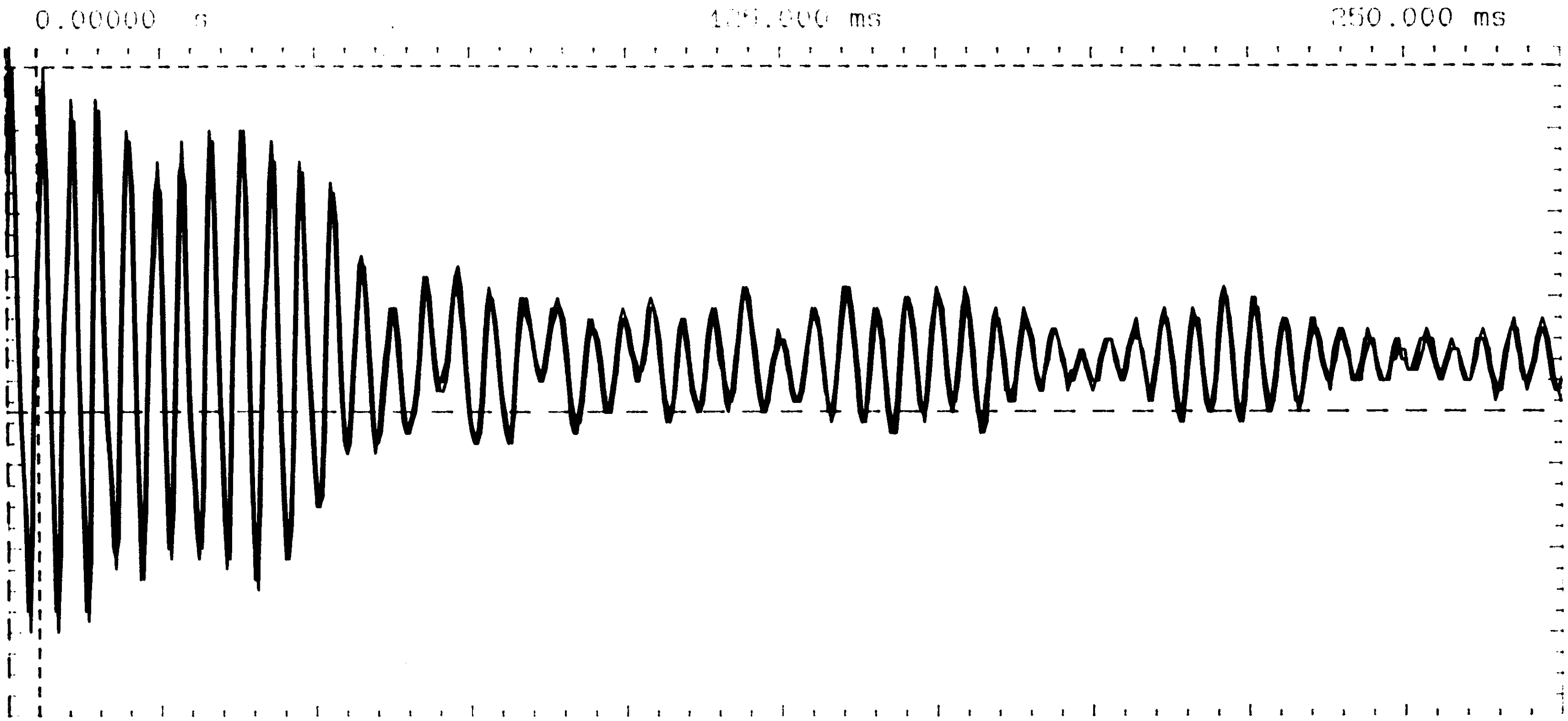


```
Ch. 1      =  200.0 mvolts/div                                             Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                             Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Ch. 2 Parameters                      Freq.       =  267.111  Hz           Period     =  3.74377 ms
Rise Time =  704.340 us               + Width     =  2.17739 ms            - Width    =  1.56637 ms
Fall Time =  404.687 us               Preshoot    =  0.000   volts         Overshoot =  0.000   volts
P-P Volts =  2.687   volts            RMS Volts =  1.070   volts           Dutycycle =  58.16 %
```

Top Trace:	Aluminum Specimen	Lead Shot/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Aluminum Specimen	Lead Shot/Oil Core	Un-filtered Input	



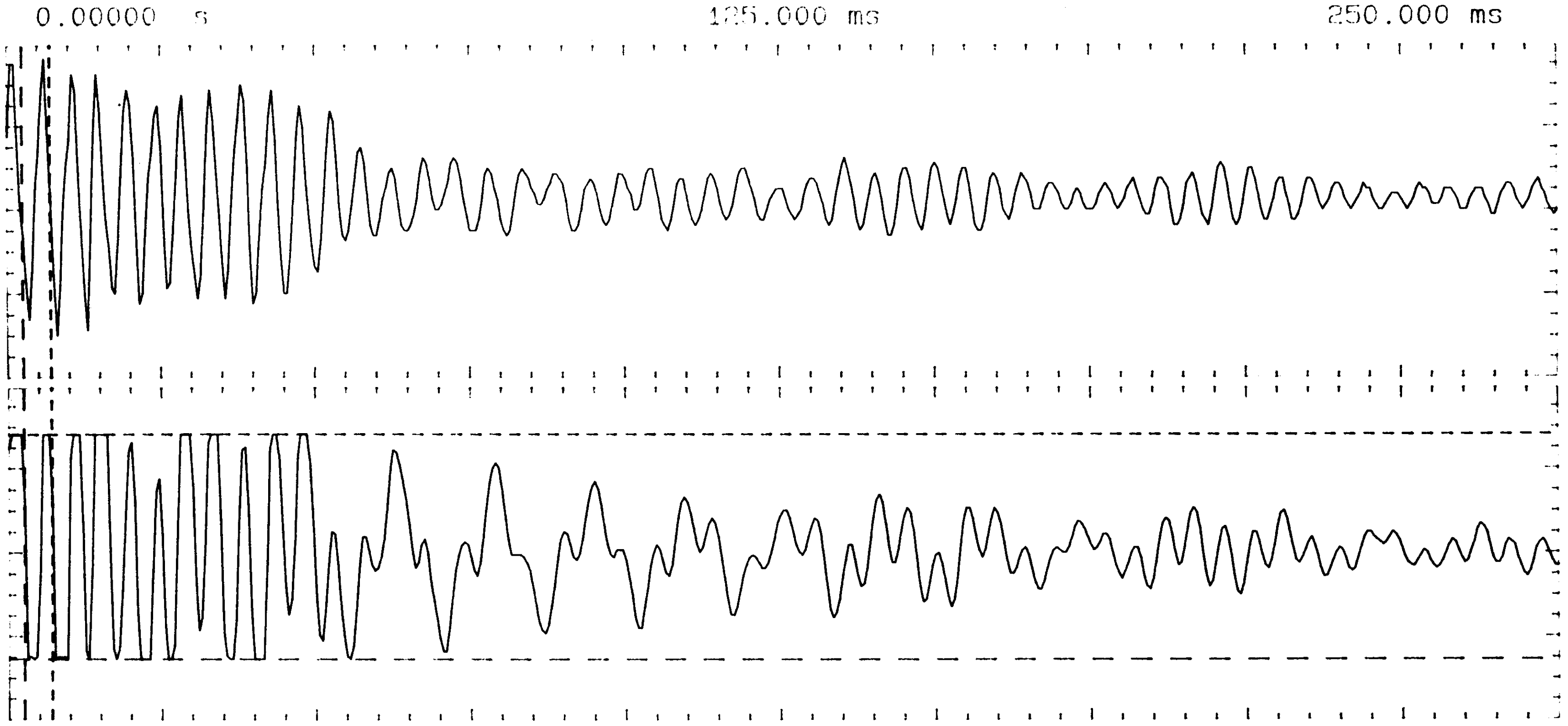
Top Trace:	**Aluminum Specimen**	**Lead Shot/Oil Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Aluminum Specimen**	**Lead Shot/Oil Core**	**Un-filtered Input**	



```
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Memory 1  =  100.0 mvolts/div                                  Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Memory 2  =  100.0 mvolts/div                                  Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Memory 3  =  100.0 mvolts/div                                  Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Memory 4  =  100.0 mvolts/div                                  Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Mem 4 Parameters                 Freq.      =  194.670  Hz     Period    =  5.13691 ms
Rise Time =  1.28215 ms          + Width    =  1.53095 ms      - Width   =  3.60596 ms
Fall Time =  976.613 us          Preshoot   =  262.5 mvolts    Overshoot =  0.000  volts
P-P Volts =  675.1 mvolts        RMS Volts  =  207.1 mvolts    Dutycycle =  29.80 %
```

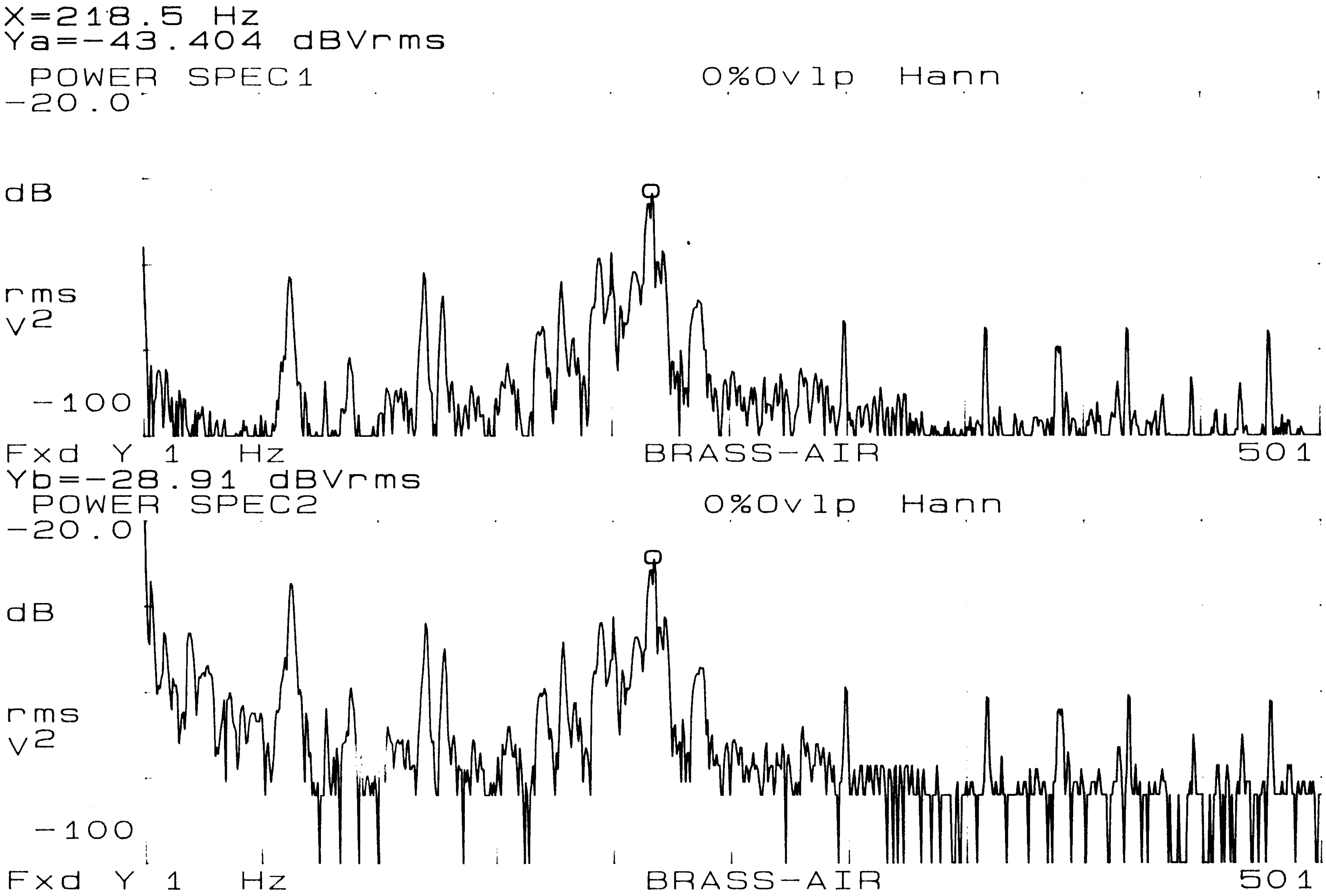
Trace: Brass Specimen Air Core Filtrered Input

Four Trace Overlay in Time-Space



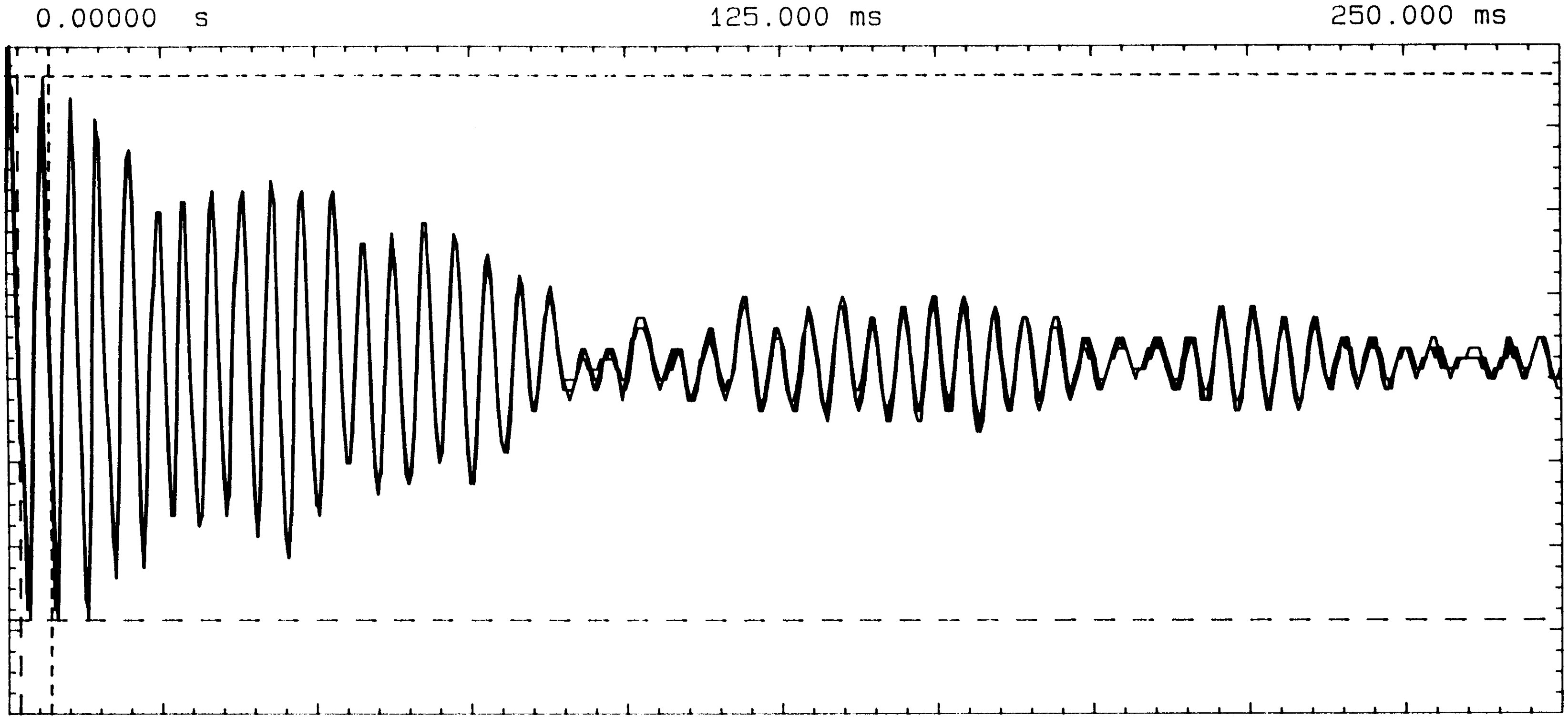
```
Ch. 1      =  200.0 mvolts/div                                      Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                      Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.       =  222.341  Hz      Period     =  4.49760 ms
Rise Time =  795.111 us             + Width     =  2.03258 ms       - Width    =  2.46502 ms
Fall Time =  770.165 us             Preshoot    =  0.000  volts     Overshoot =  0.000  volts
P-P Volts =  2.687  volts           RMS Volts =  1.143  volts       Dutycycle =  45.19 %
```

Top Trace:	**Brass Specimen**	**Air Core**	**Filtrered Input**	**Time-Space**
Bottom Trace:	**Brass Specimen**	**Air Core**	**Un-filtered Input**	



Top Trace:	**Brass Specimen**	**Air Core**	**Filtrered Input**
Bottom Trace:	**Brass Specimen**	**Air Core**	**Un-filtered Input**

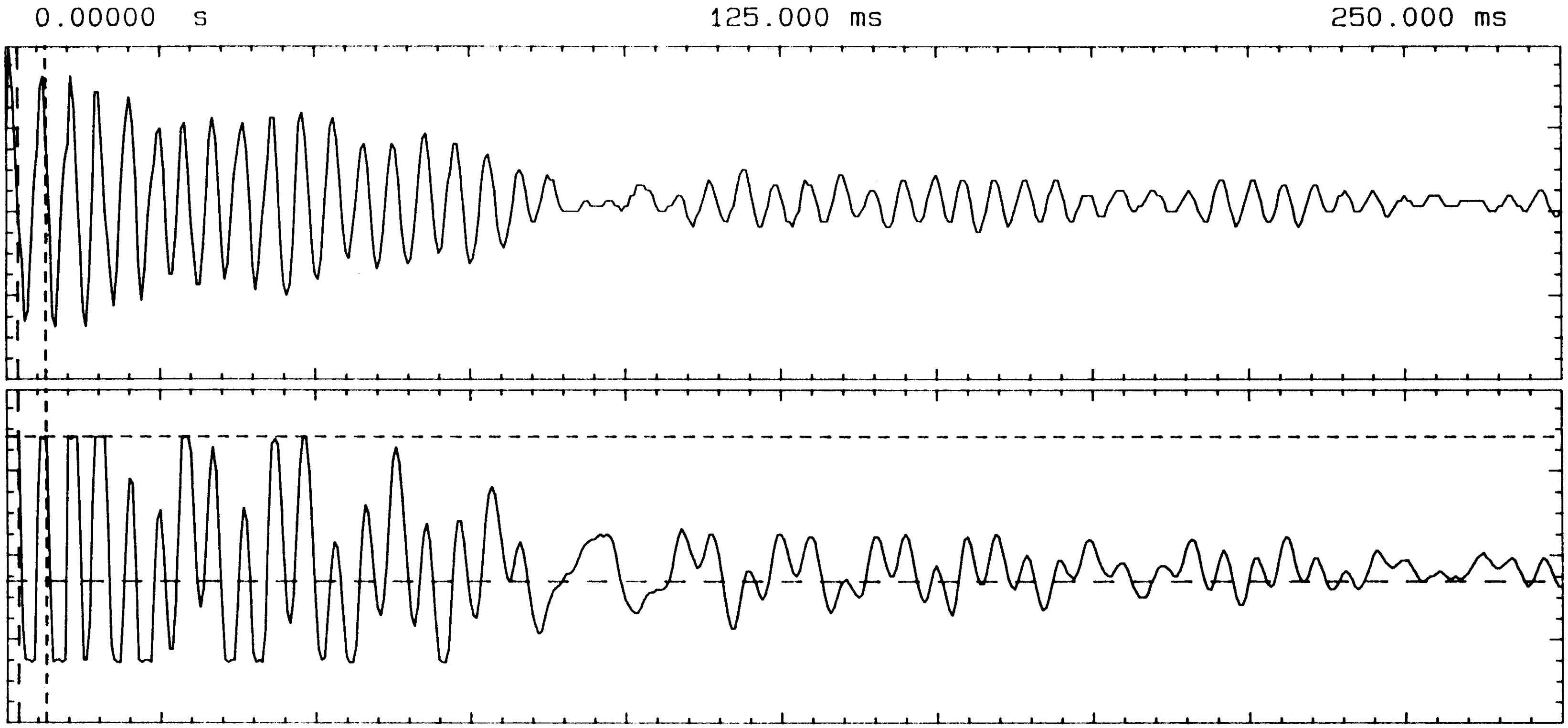
Frequency-Space



```
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 1    =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 2    =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 3    =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 4    =  100.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Mem 4 Parameters                  Freq.      =  196.835  Hz            Period     =  5.08039 ms
Rise Time =  1.99507 ms           + Width    =  2.34613 ms             - Width    =  2.73426 ms
Fall Time =  1.98890 ms           Preshoot   =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  650.1 mvolts         RMS Volts  =  192.8 mvolts           Dutycycle  =  46.18 %
```

Trace: Brass Specimen Sand Core Filtrered Input

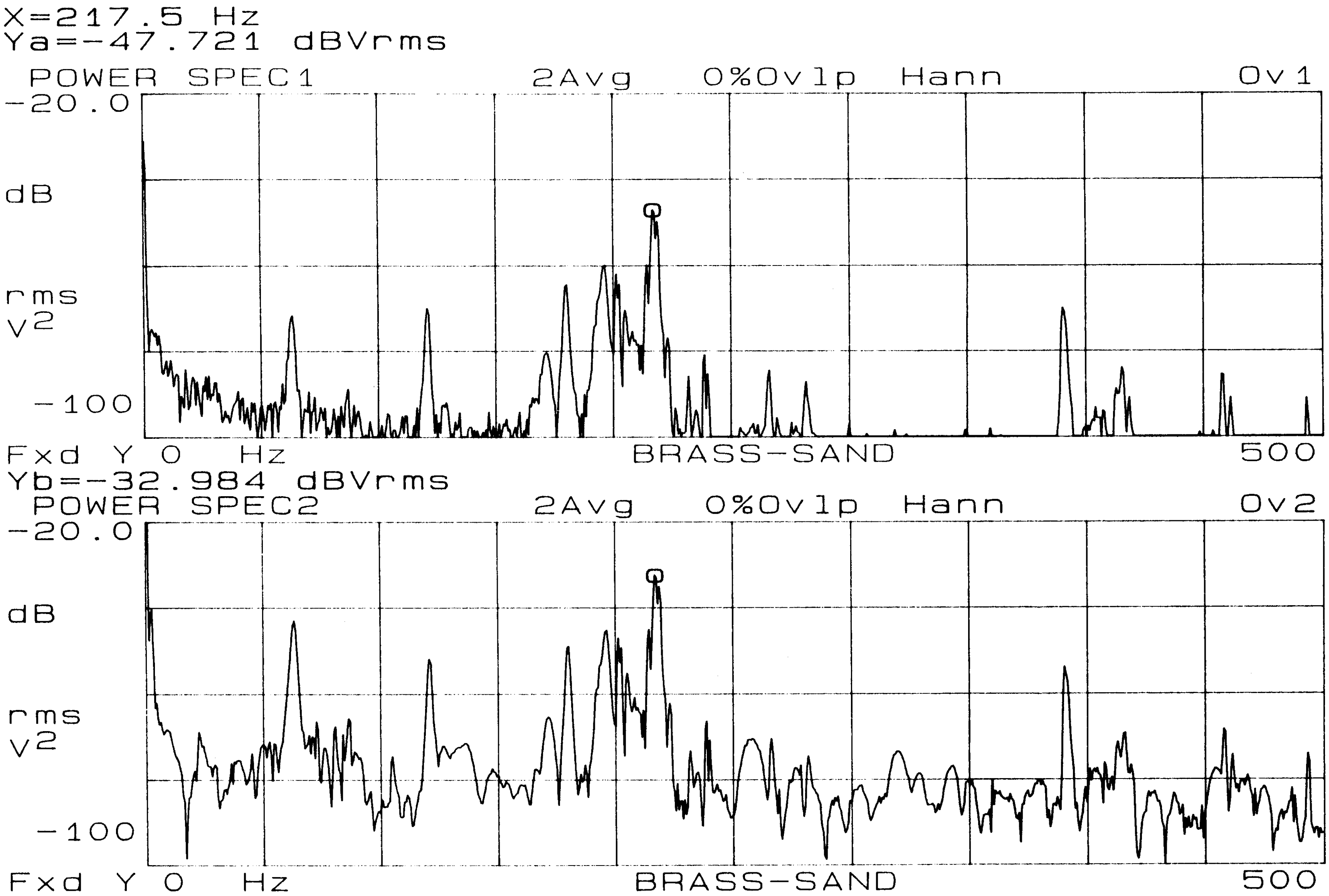
Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                  Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  219.898  Hz    Period     =  4.54757 ms
Rise Time =  594.167 us           + Width     =  1.76206 ms     - Width    =  2.78550 ms
Fall Time =  309.859 us           Preshoot    =  0.000  volts   Overshoot  =  968.7 mvolts
P-P Volts =  2.687   volts        RMS Volts   =  1.233  volts   Dutycycle  =  38.74 %
```

Top Trace: Brass Specimen Sand Core Filtrered Input Time-Space

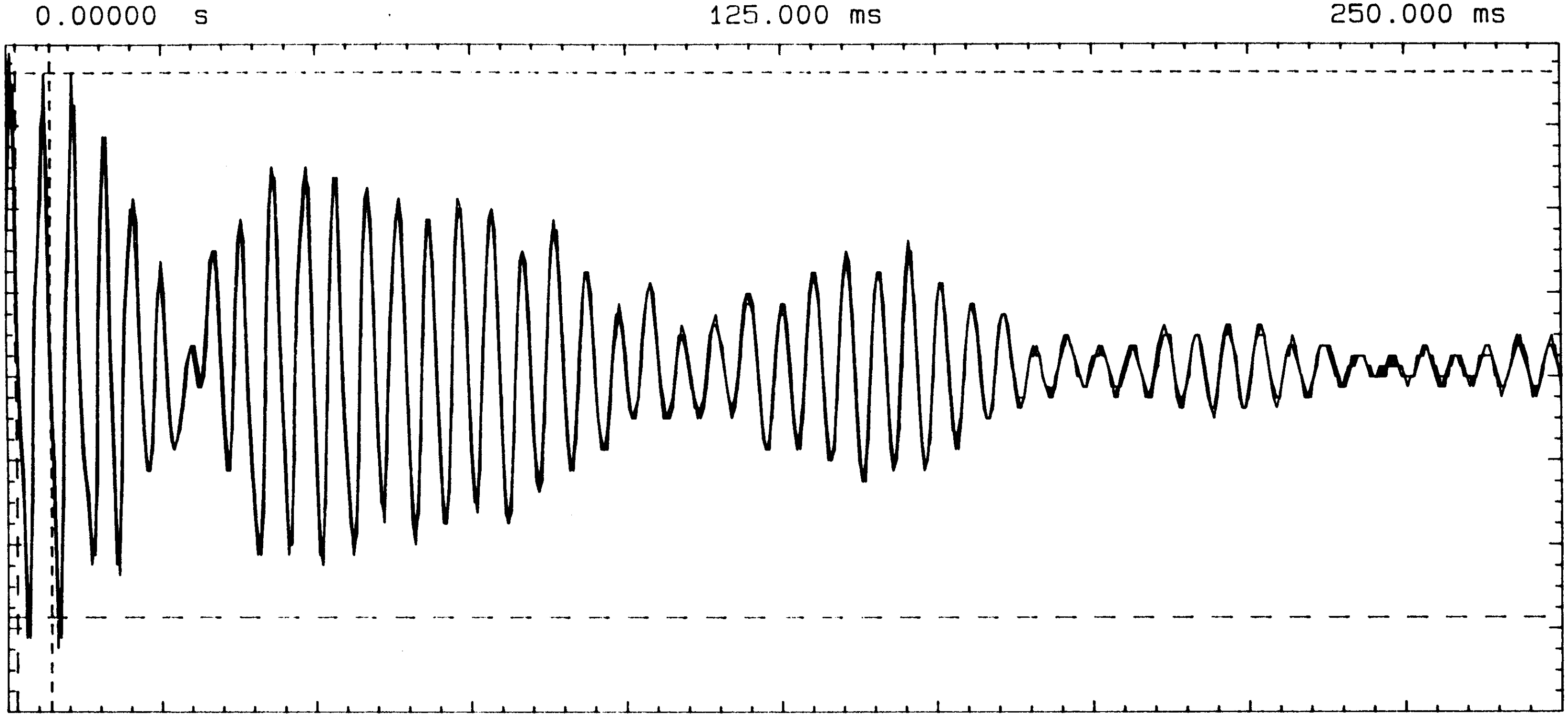
Bottom Trace: Brass Specimen Sand Core Un-filtered Input



Top Trace: Brass Specimen Sand Core Filtrered Input

Bottom Trace: Brass Specimen Sand Core Un-filtered Input

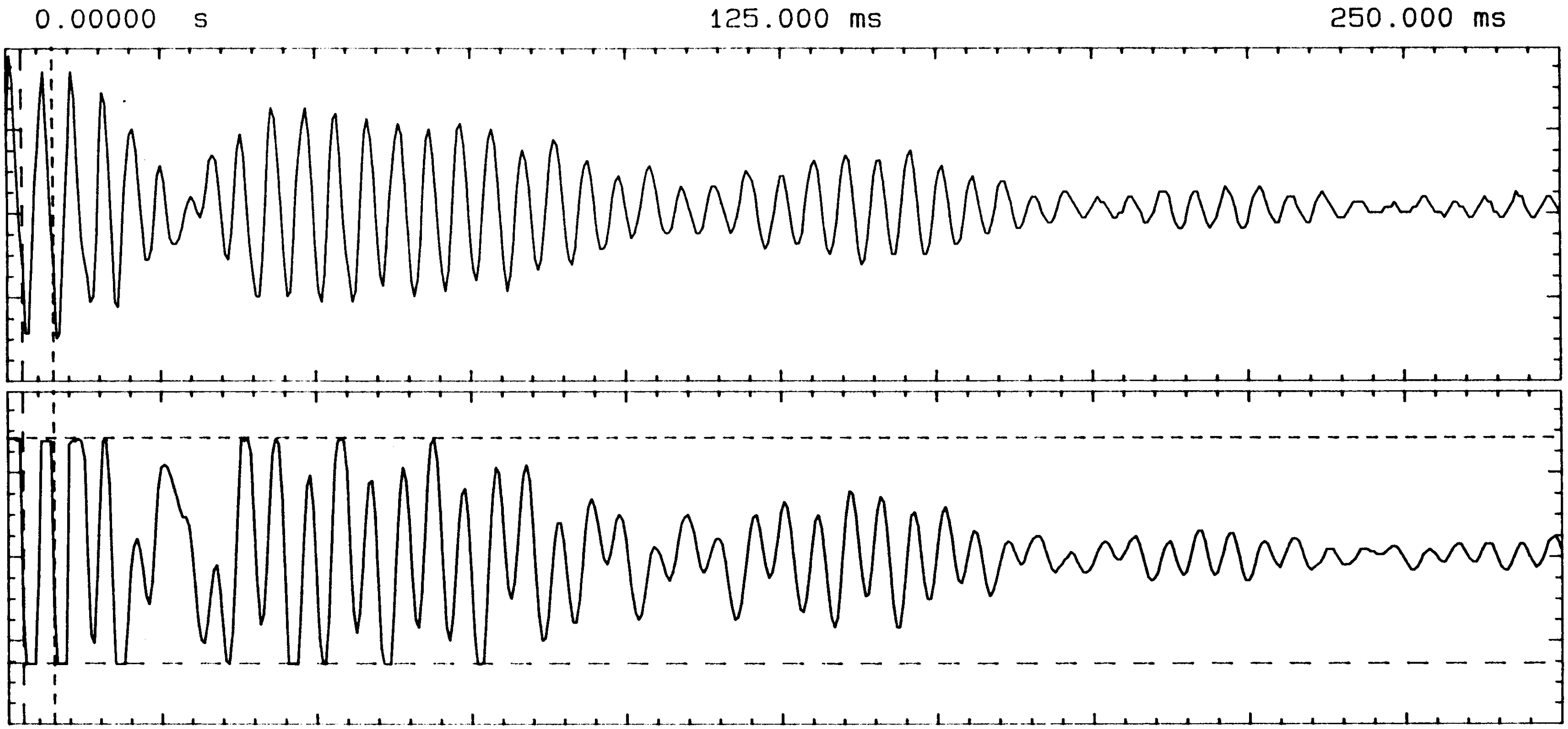
Frequency-Space



```
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Mem 1 Parameters                 Freq.       =  193.939  Hz          Period     =  5.15625 ms
Rise Time =  2.05248 ms          + Width     =  2.47727 ms           - Width    =  2.67898 ms
Fall Time =  1.73123 ms          Preshoot    =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  650.1 mvolts        RMS Volts   =  194.2 mvolts         Dutycycle  =  48.04 %
```

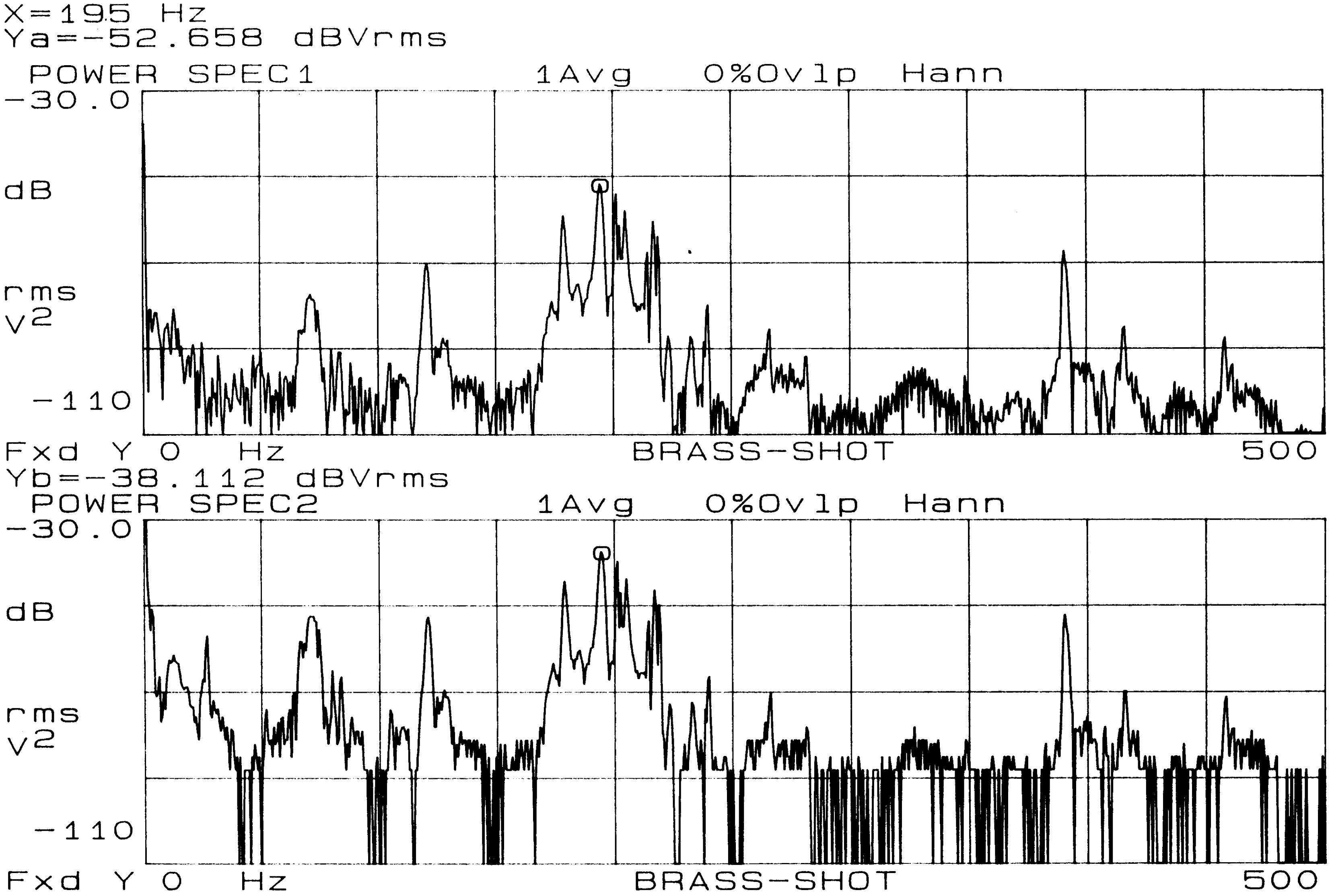
Trace: Brass Specimen Lead Shot Core Filtrered Input

Four Trace Overlay in Time-Space

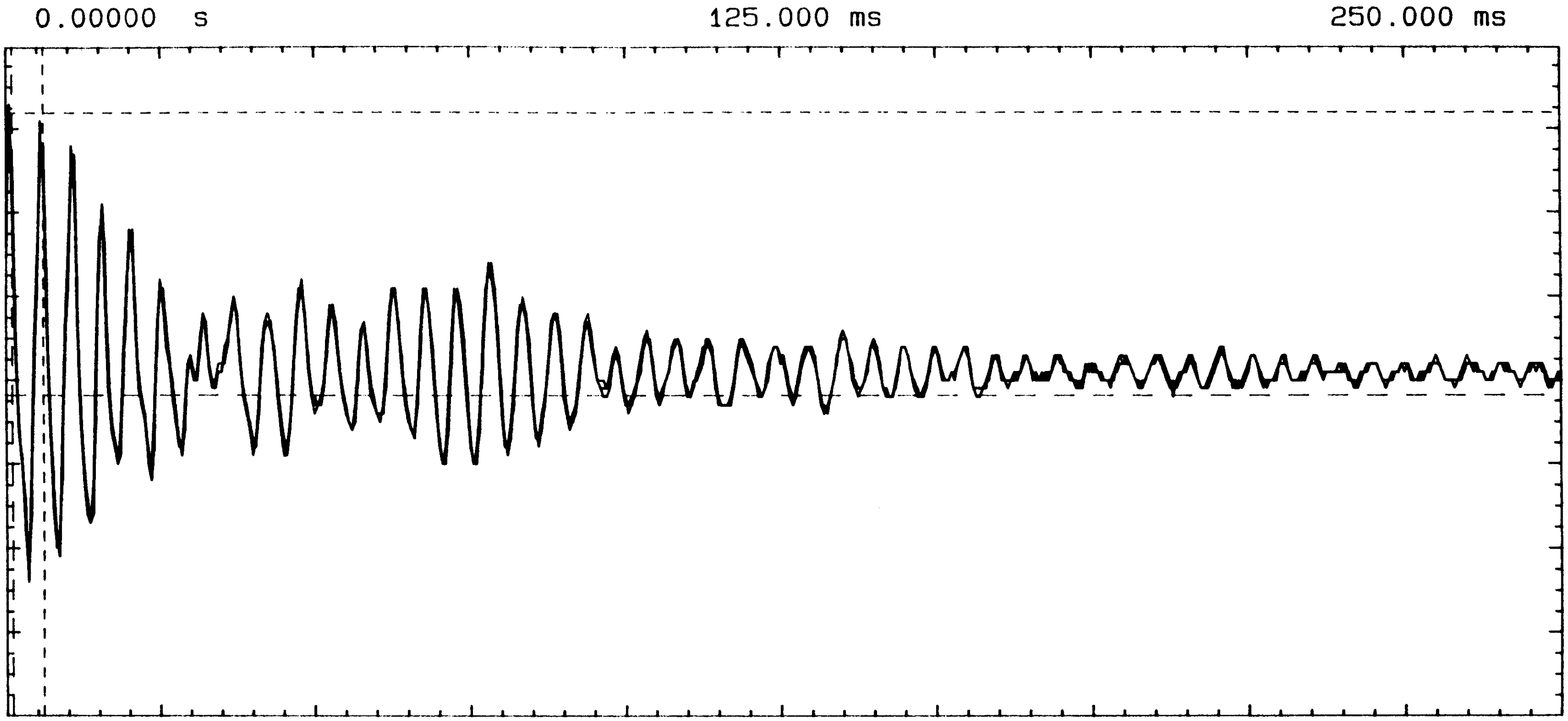


```
Ch. 1      =  200.0 mvolts/div                                       Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                       Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Ch. 2 Parameters                   Freq.       =  199.103  Hz        Period     =  5.02253 ms
Rise Time =  796.581 us            + Width     =  2.24256 ms          - Width   =  2.77998 ms
Fall Time =  697.821 us            Preshoot    =  0.000   volts      Overshoot =  0.000   volts
P-P Volts =  2.687   volts         RMS Volts =   1.168   volts       Dutycycle =  44.64 %
```

Top Trace:	Brass Specimen	Lead Shot Core	Filtrered Input	Time-Space
Bottom Trace:	Brass Specimen	Lead Shot Core	Un-filtered Input	



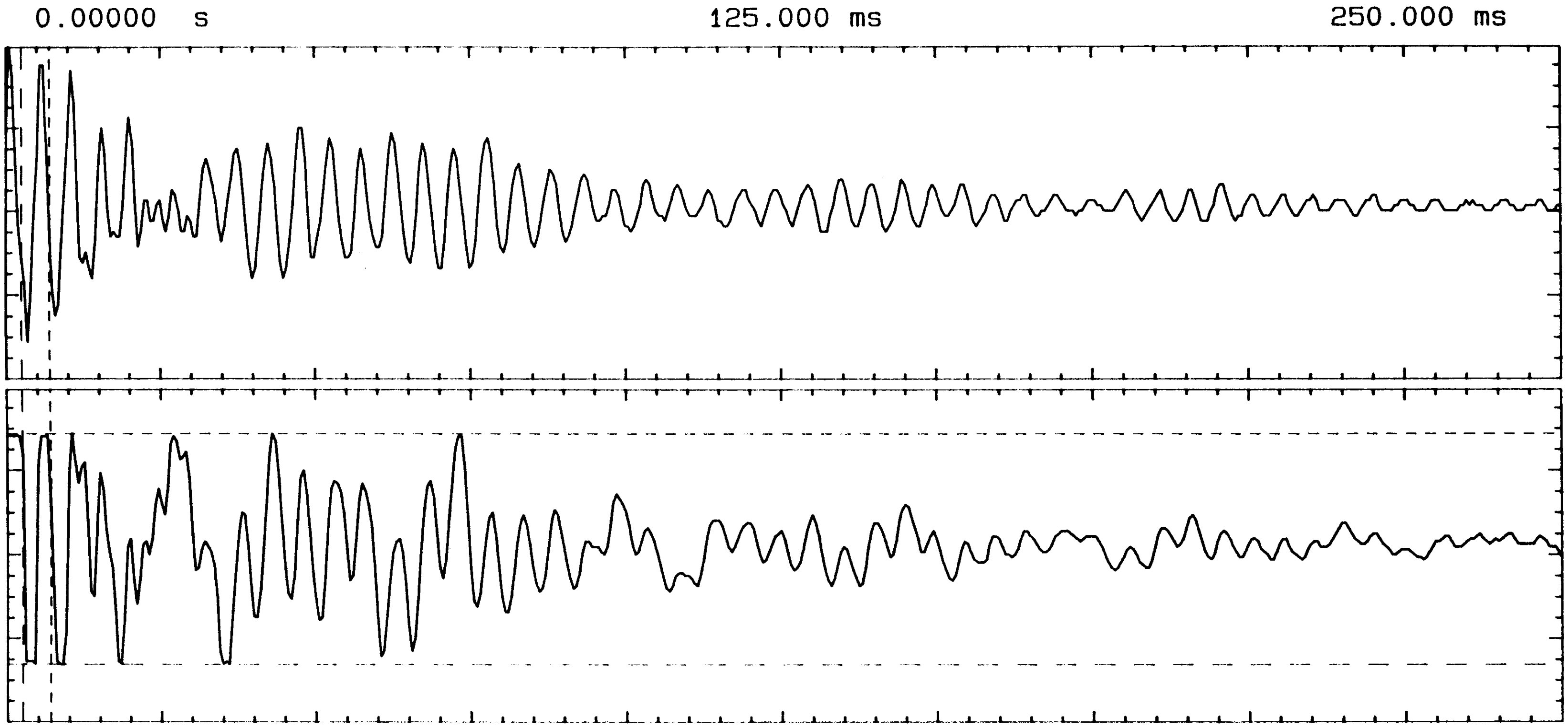
Top Trace:	Brass Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Brass Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase    =  25.0 ms/div                                          Delay       =  0.00000  s
Memory 1    =  125.0 mvolts/div                                     Offset      =  0.000  volts
Timebase    =  25.0 ms/div                                          Delay       =  0.00000  s
Memory 2    =  125.0 mvolts/div                                     Offset      =  0.000  volts
Timebase    =  25.0 ms/div                                          Delay       =  0.00000  s
Memory 3    =  125.0 mvolts/div                                     Offset      =  0.000  volts
Timebase    =  25.0 ms/div                                          Delay       =  0.00000  s
Memory 4    =  125.0 mvolts/div                                     Offset      =  0.000  volts
Timebase    =  25.0 ms/div                                          Delay       =  0.00000  s
Mem 2 Parameters                  Freq.      =  195.122  Hz         Period      =  5.12500 ms
Rise Time =  1.01145 ms           + Width    =  1.31108 ms          - Width     =  3.81392 ms
Fall Time =  948.930 us           Preshoot   =  0.000  volts        Overshoot =  265.6 mvolts
P-P Volts =  687.6 mvolts         RMS Volts =  213.4 mvolts         Dutycycle =  25.58 %
```

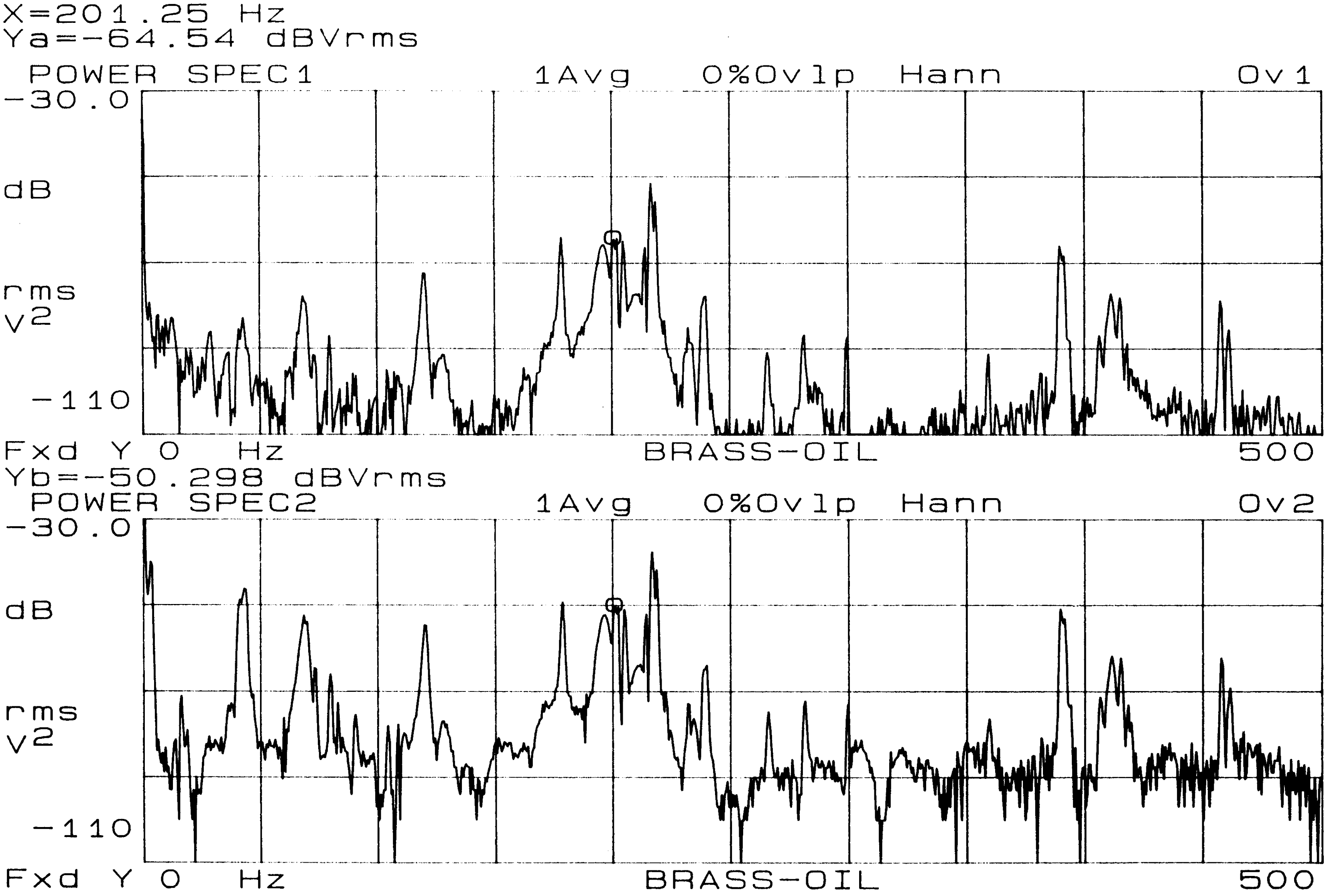
Trace: Brass Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space



```
Ch. 1     =  200.0 mvolts/div                                  Offset    =  0.000  volts
Ch. 2     =  1.000  volts/div                                  Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay     =  0.00000  s
Ch. 2 Parameters                 Freq.       =  221.134  Hz    Period    =  4.52215 ms
Rise Time =  616.296 us          + Width     =  2.45667 ms      - Width  =  2.06549 ms
Fall Time =  720.387 us          Preshoot    =  0.000  volts   Overshoot =  0.000  volts
P-P Volts =  2.750  volts        RMS Volts   =  1.239  volts   Dutycycle =  54.32 %
```

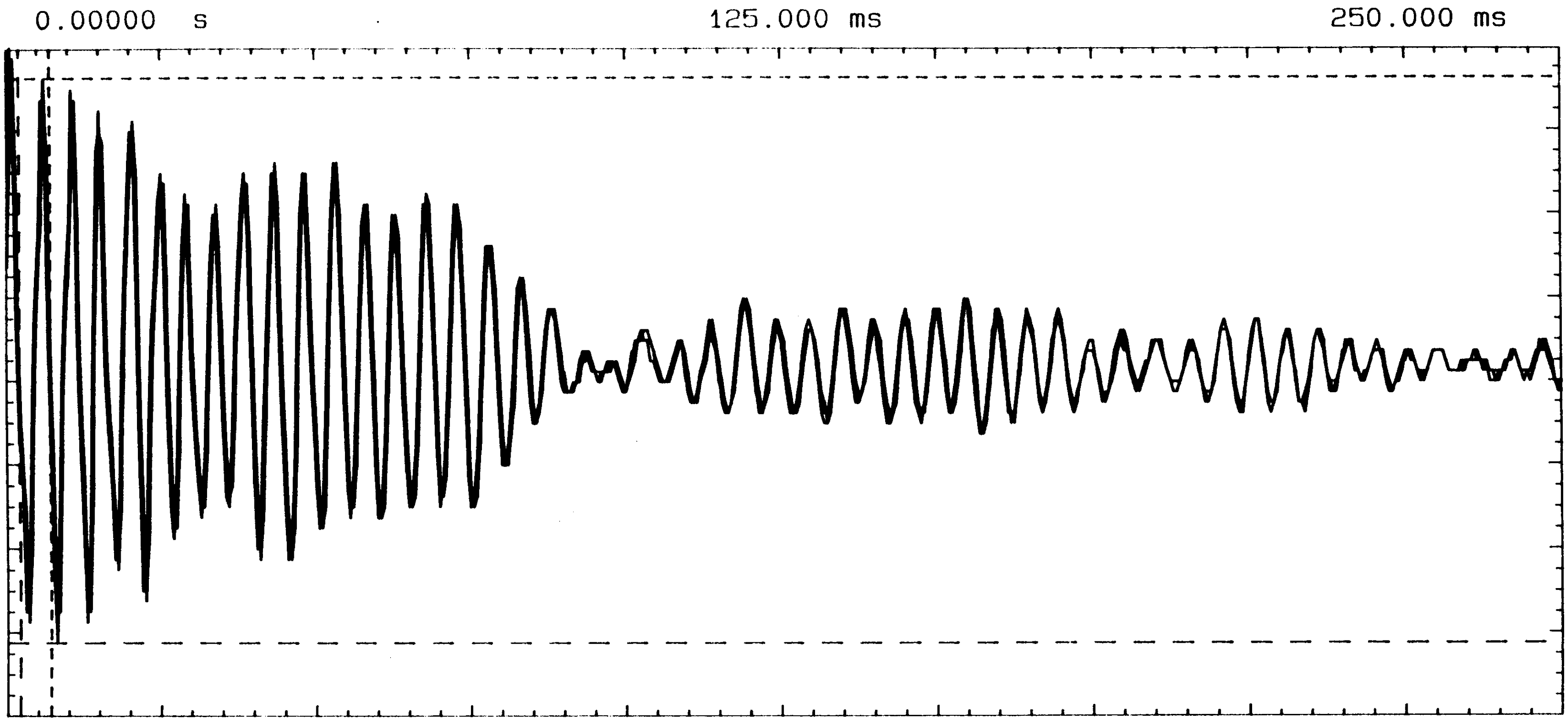
Top Trace:	Brass Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Brass Specimen	Oil Core	Un-filtered Input	



Top Trace: Brass Specimen Oil Core Filtrered Input

Bottom Trace: Brass Specimen Oil Core Un-filtered Input

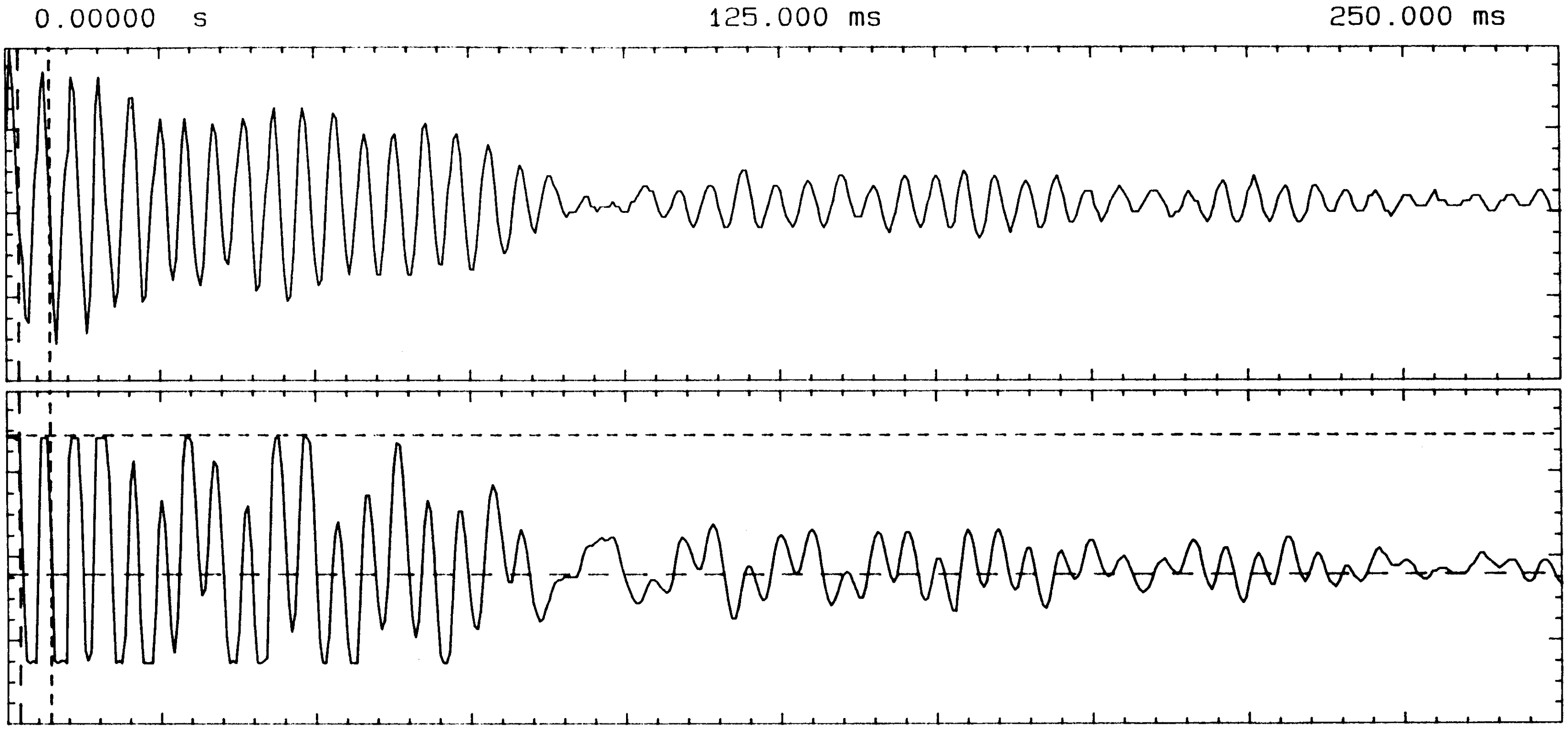
Frequency-Space



```
Timebase   =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 1   =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 2   =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 3   =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay     =  0.00000  s
Memory 4   =  100.0 mvolts/div                                             Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                  Delay     =  0.00000  s
Mem 4 Parameters                    Freq.     =  193.070  Hz               Period    =  5.17947 ms
Rise Time =  2.05886 ms             + Width   =  2.46456 ms                - Width   =  2.71490 ms
Fall Time =  2.15113 ms             Preshoot  =  0.000  volts              Overshoot =  0.000  volts
P-P Volts =  675.1 mvolts           RMS Volts =  192.2 mvolts              Dutycycle =  47.58 %
```

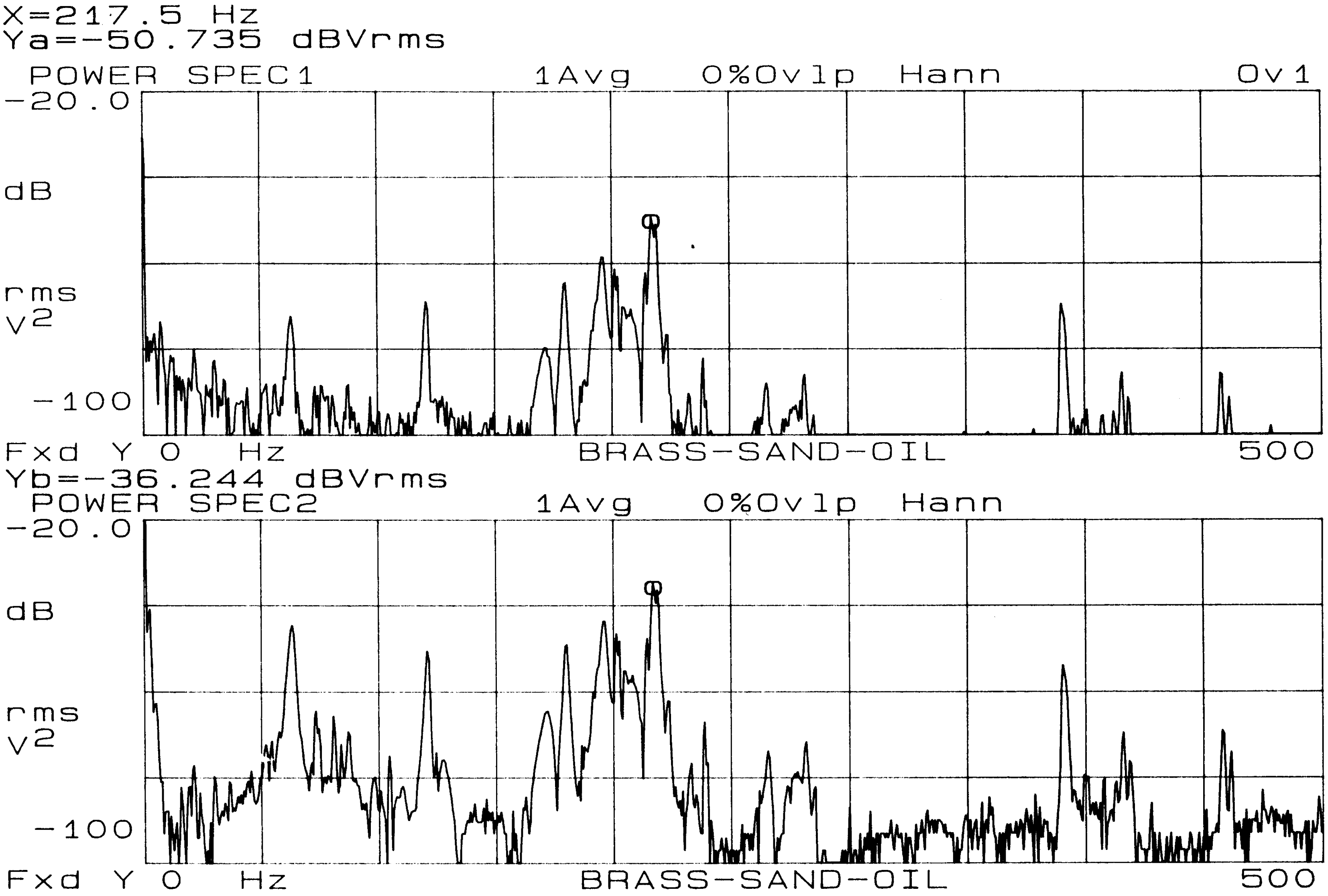
Trace: Brass Specimen   Sand/Oil Core   Filtrered Input

Four Trace Overlay in Time-Space



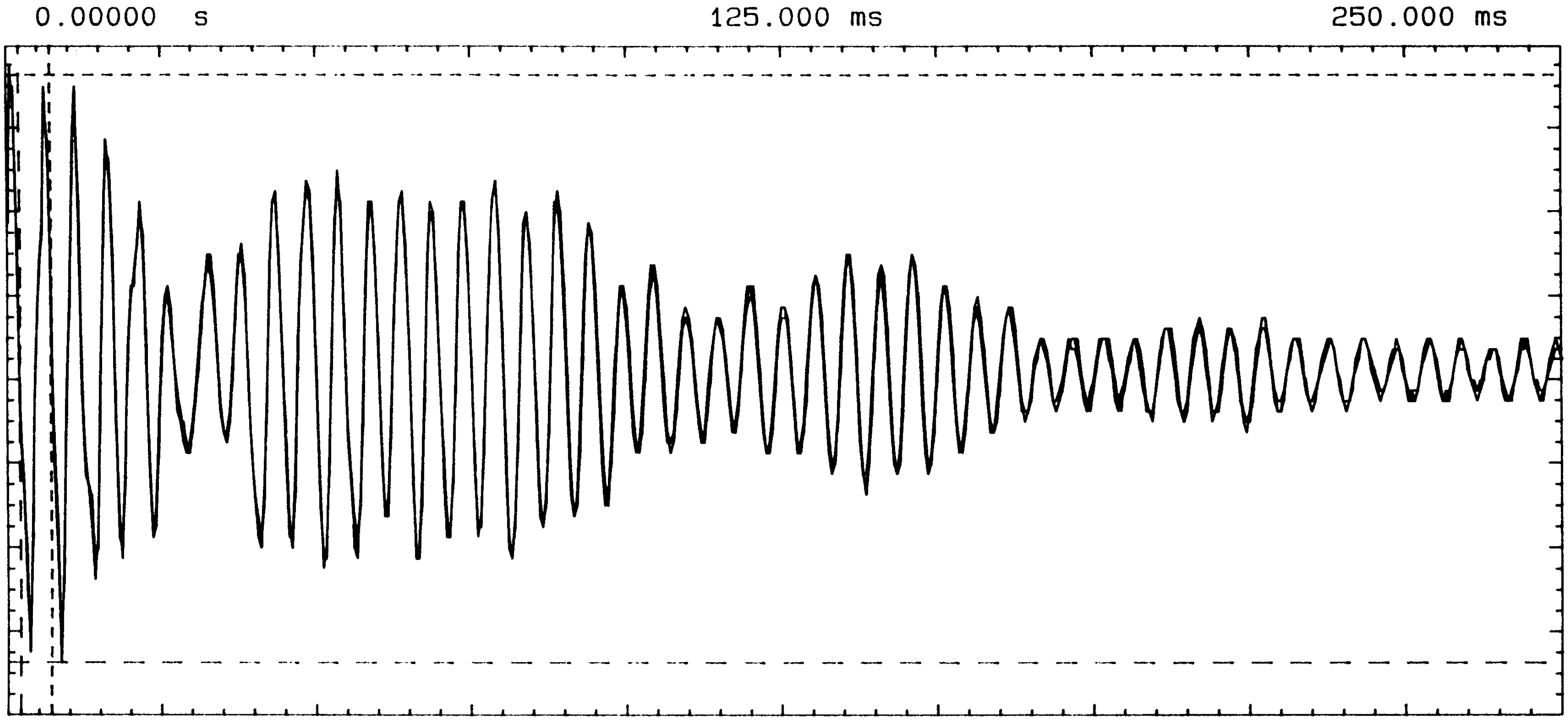
```
Ch. 1      =  200.0 mvolts/div                                           Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                           Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Ch. 2 Parameters                        Freq.      =  214.655  Hz        Period     =  4.65864 ms
Rise Time =  519.059 us                 + Width    =  1.68304 ms         - Width    =  2.97561 ms
Fall Time =  341.923 us                 Preshoot   =  0.000   volts      Overshoot =  1.062   volts
P-P Volts =  2.718  volts               RMS Volts =  1.156   volts       Dutycycle =  36.12 %
```

Top Trace:	**Brass Specimen**	**Sand/Oil Core**	**Filtrered Input**	**Time-Space**
Bottom Trace:	**Brass Specimen**	**Sand/Oil Core**	**Un-filtered Input**	



Top Trace: Brass Specimen Sand/Oil Core Filtrered Input Frequency-Space

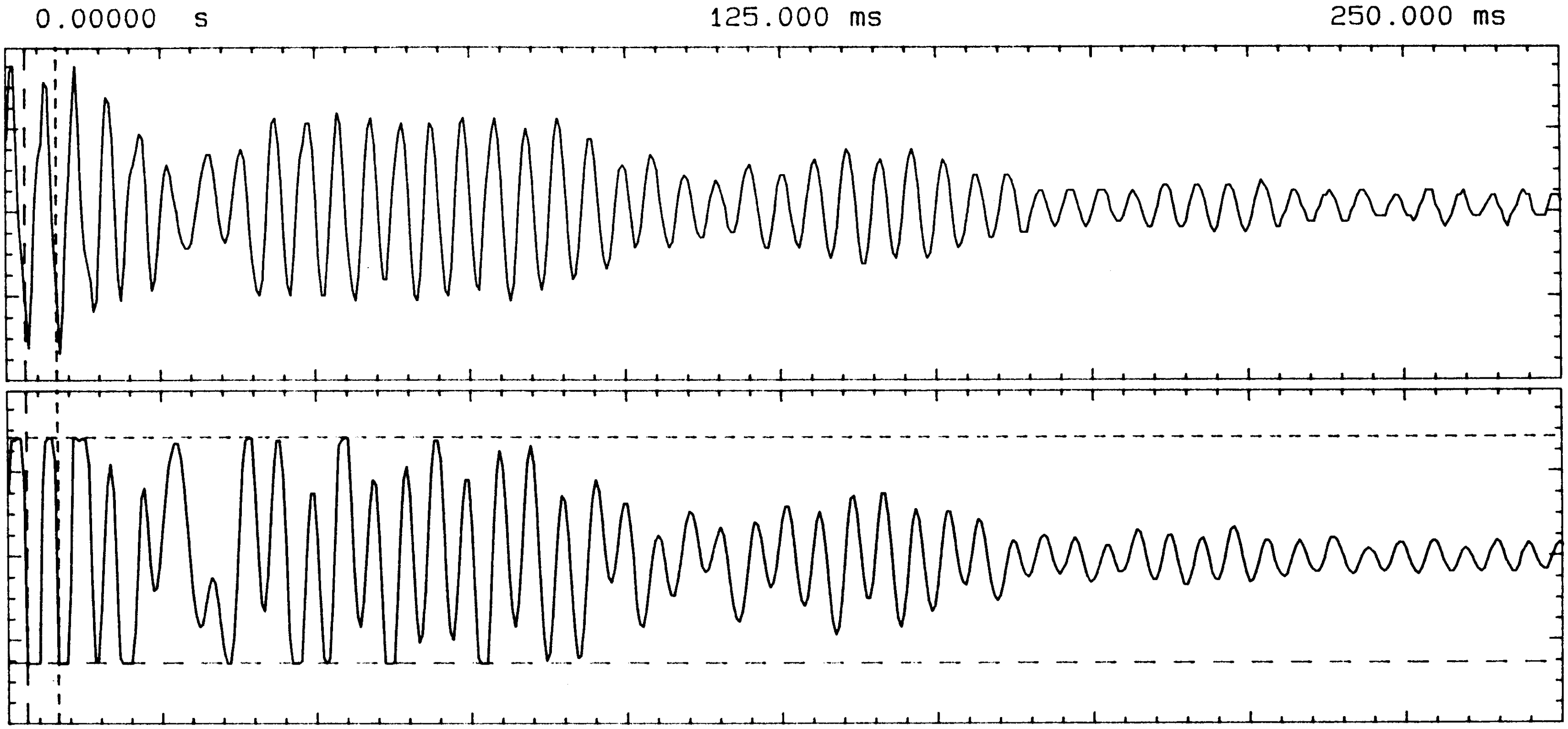
Bottom Trace: Brass Specimen Sand/Oil Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 1 Parameters              Freq.      =  185.636  Hz            Period     =  5.38688 ms
Rise Time =  2.14663 ms       + Width    =  2.66623 ms             - Width    =  2.72066 ms
Fall Time =  2.10703 ms       Preshoot   =  0.000  volts           Overshoot  =  0.000  volts
P-P Volts =  700.1 mvolts     RMS Volts  =  204.3 mvolts           Dutycycle  =  49.49 %
```

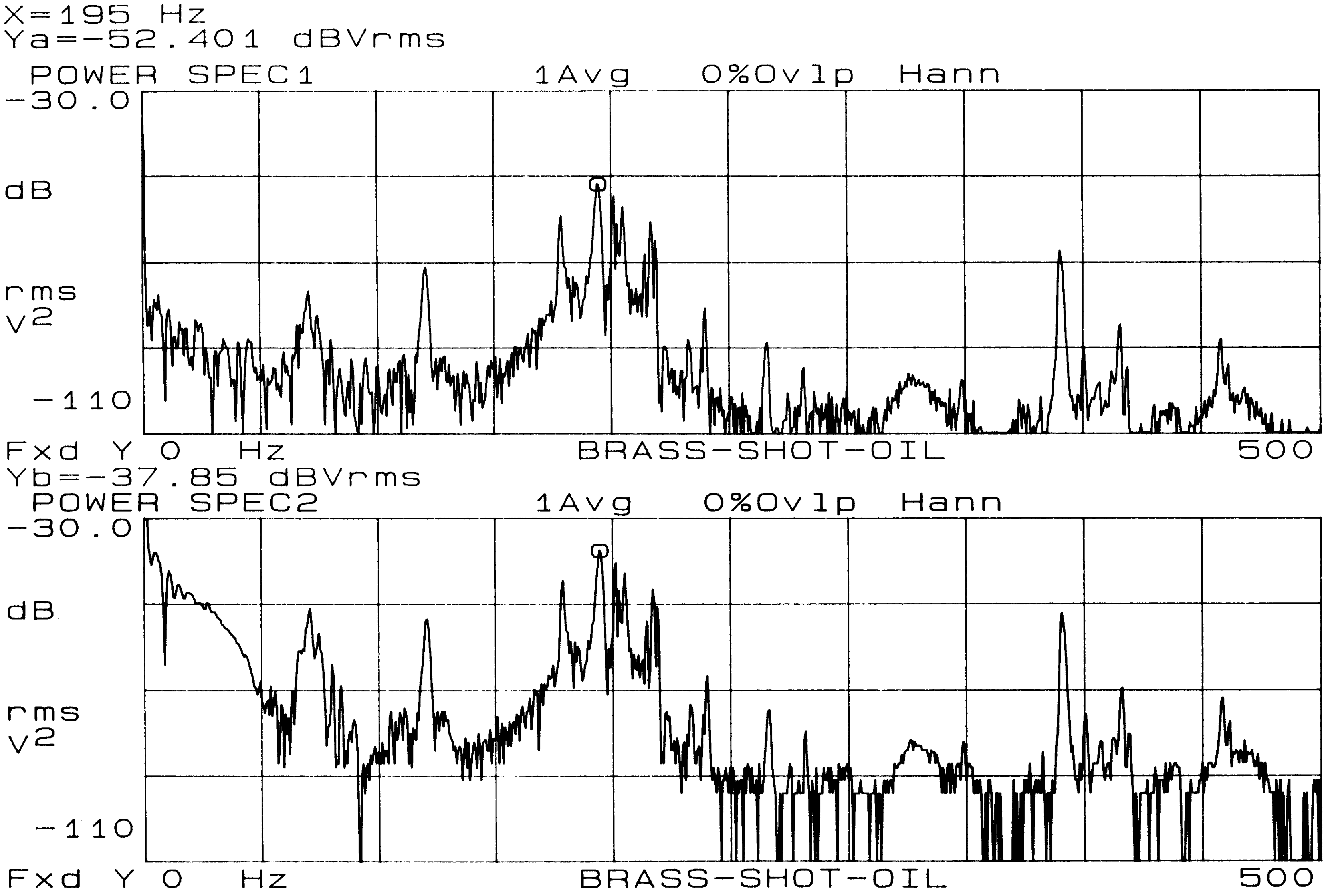
Trace: Brass Specimen Lead Shot/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

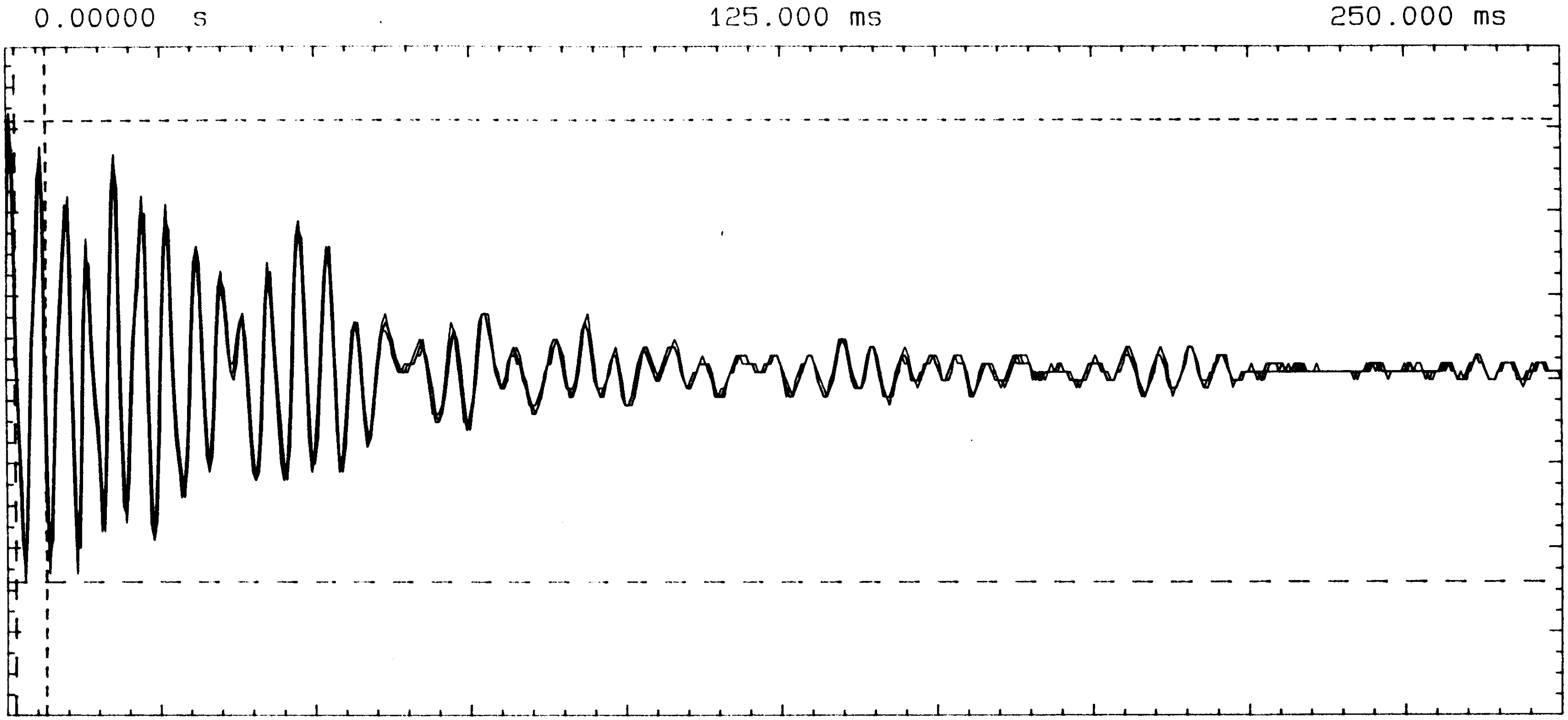


```
Ch. 1      =  200.0 mvolts/div                                    Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                    Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                         Delay      =  0.00000  s
Ch. 2 Parameters                 Freq.       =  199.513  Hz       Period     =  5.01220 ms
Rise Time =  684.683 us          + Width     =  2.45060 ms        - Width    =  2.56159 ms
Fall Time =  399.982 us          Preshoot    =  0.000   volts     Overshoot  =  0.000   volts
P-P Volts =  2.687   volts       RMS Volts   =  1.287   volts     Dutycycle  =  48.89 %
```

Top Trace:	Brass Specimen	Lead Shot/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Brass Specimen	Lead Shot/Oil Core	Un-filtered Input	



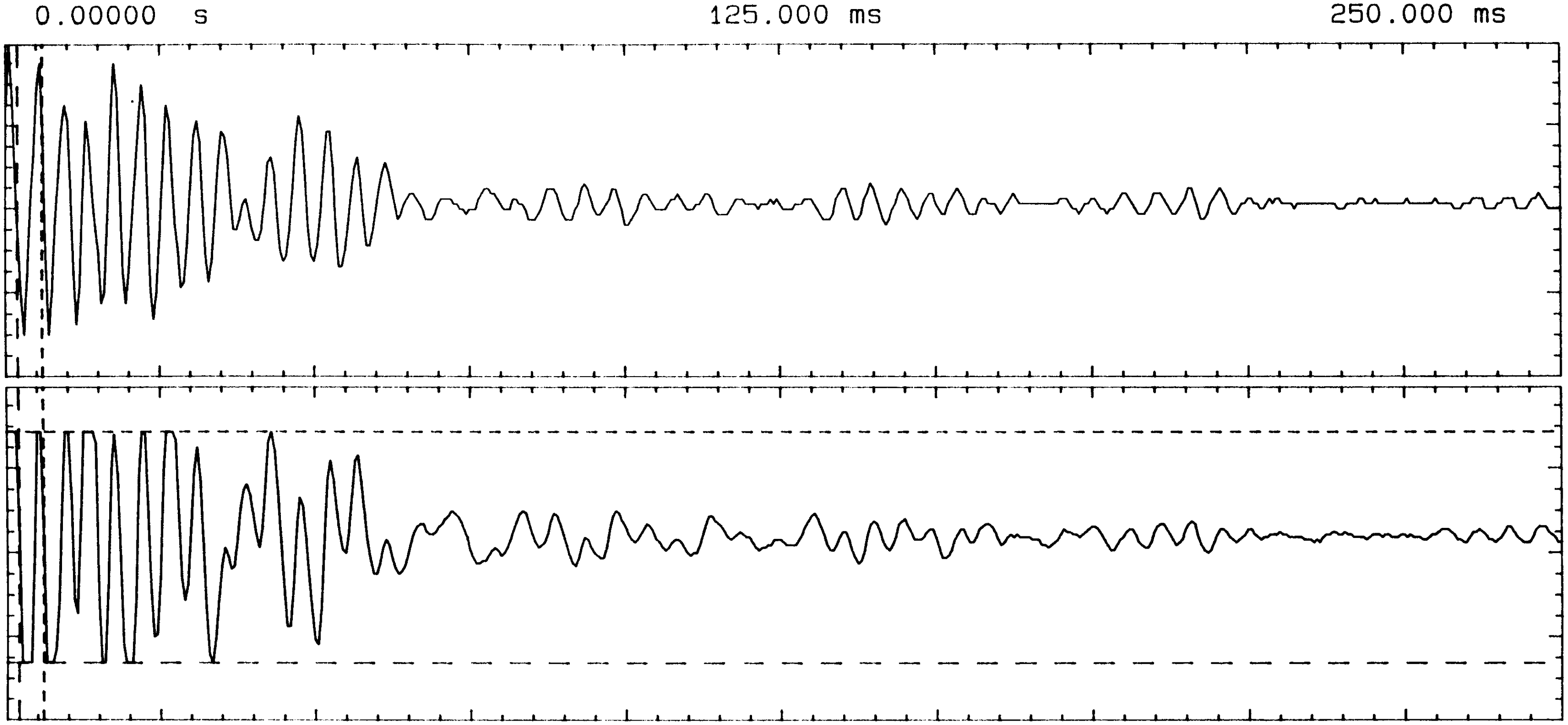
Top Trace:	Brass Specimen	Lead Shot/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Brass Specimen	Lead Shot/Oil Core	Un-filtered Input	



```
Timebase    =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 1    =  125.0 mvolts/div                                   Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 2    =  125.0 mvolts/div                                   Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 3    =  125.0 mvolts/div                                   Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                        Delay      =  0.00000  s
Memory 4    =  125.0 mvolts/div                                   Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                        Delay      =  0.00000  s
Mem 1 Parameters                Freq.      =  215.294  Hz         Period     =  4.64481 ms
Rise Time =  2.01334 ms         + Width    =  2.10413 ms          - Width    =  2.54068 ms
Fall Time =  1.92471 ms         Preshoot   =  0.000  volts        Overshoot  =  0.000  volts
P-P Volts =  687.6 mvolts       RMS Volts  =  192.8 mvolts        Dutycycle  =  45.30 %
```

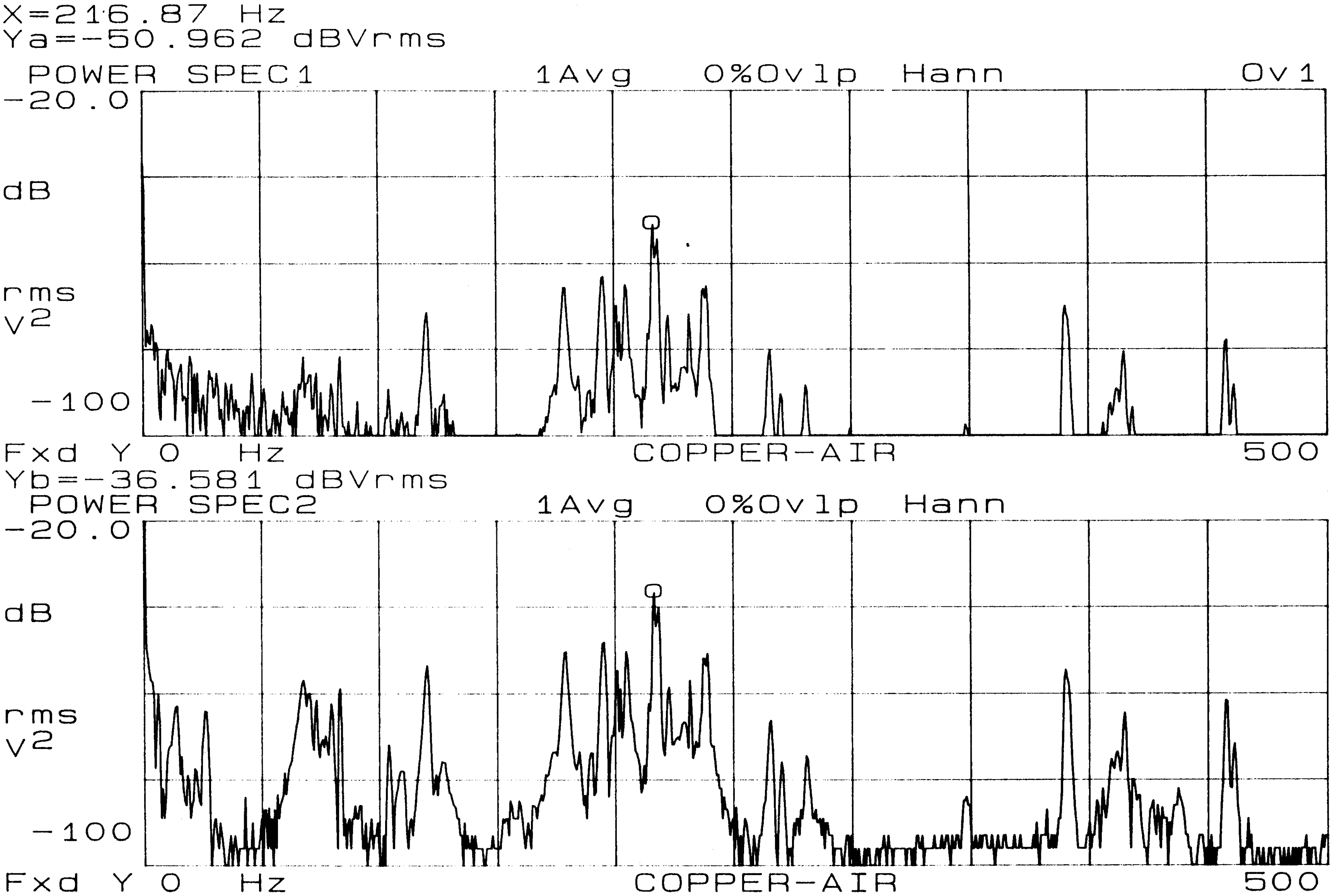
Trace: **Copper Specimen** **Air Core** **Filtrered Input**

Four Trace Overlay in Time-Space



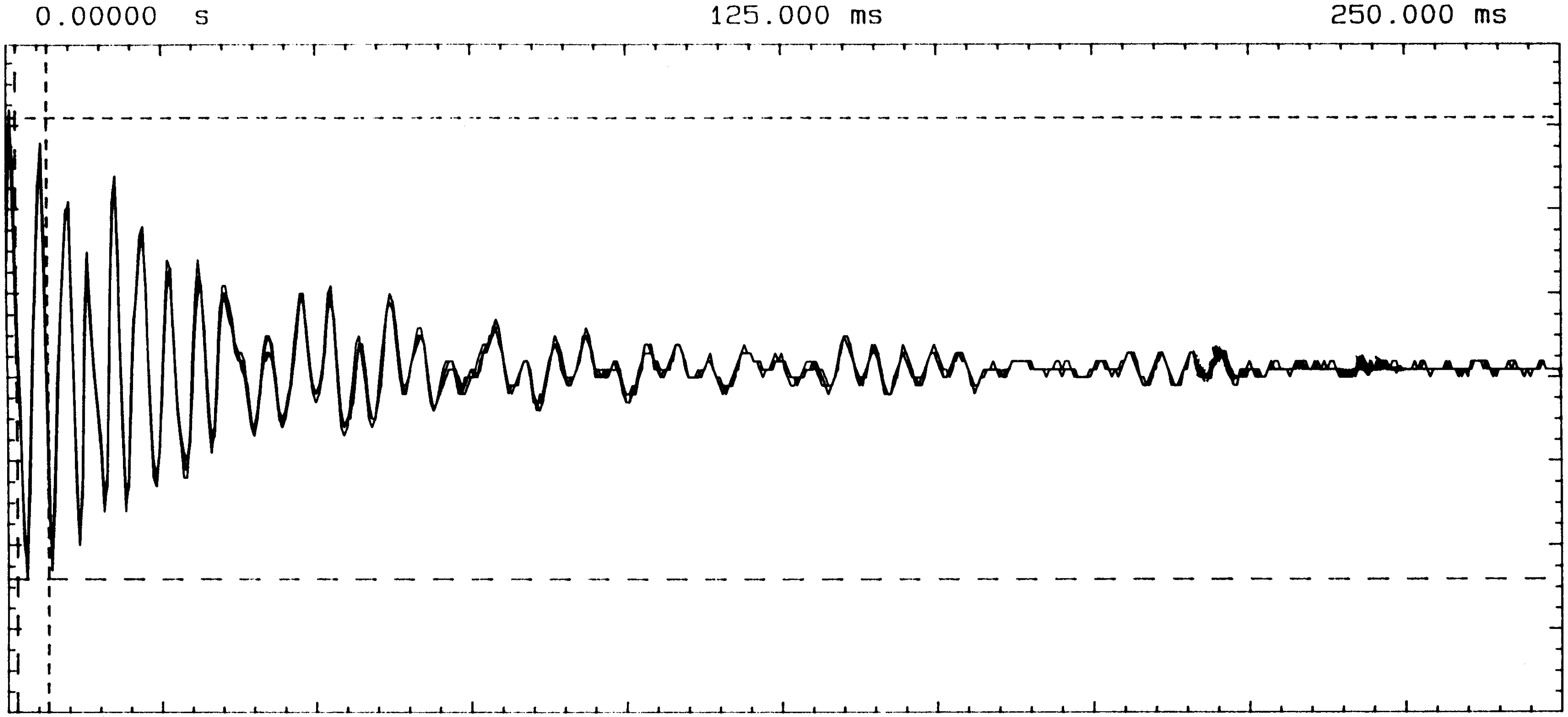
```
Ch. 1      =  200.0 mvolts/div                                         Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                         Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                              Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.       =  251.768  Hz        Period     =  3.97192 ms
Rise Time =  799.568 us             + Width     =  1.52434 ms         - Width    =  2.44758 ms
Fall Time =  796.192 us             Preshoot    =  0.000  volts       Overshoot =  0.000   volts
P-P Volts =  2.750  volts           RMS Volts   =  1.111  volts       Dutycycle =  38.37 %
```

Top Trace:	**Copper Specimen**	**Air Core**	**Filtrered Input**	**Time-Space**
Bottom Trace:	**Copper Specimen**	**Air Core**	**Un-filtered Input**	



Top Trace:	**Copper Specimen**	**Air Core**	**Filtrered Input**
Bottom Trace:	**Copper Specimen**	**Air Core**	**Un-filtered Input**

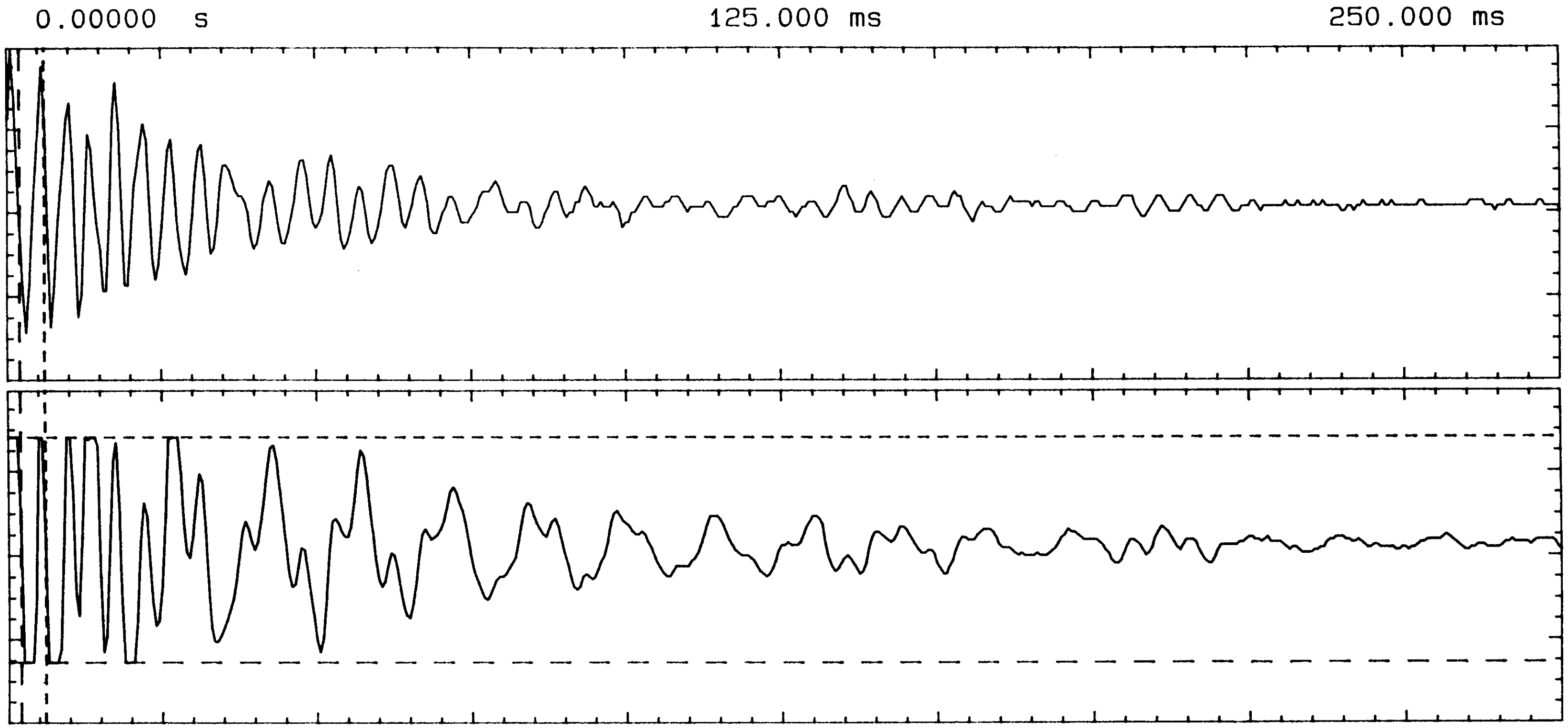
Frequency-Space



```
Timebase  =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 1  =  125.0 mvolts/div                                  Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 2  =  125.0 mvolts/div                                  Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 3  =  125.0 mvolts/div                                  Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay      =  0.00000  s
Memory 4  =  125.0 mvolts/div                                  Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                       Delay      =  0.00000  s
Mem 3 Parameters                 Freq.      =  214.932  Hz     Period     =  4.65263 ms
Rise Time =  2.06776 ms          + Width    =  2.06062 ms      - Width    =  2.59200 ms
Fall Time =  1.85868 ms          Preshoot   =  0.000  volts    Overshoot  =  0.000  volts
P-P Volts =  687.5 mvolts        RMS Volts  =  196.6 mvolts    Dutycycle  =  44.28 %
```

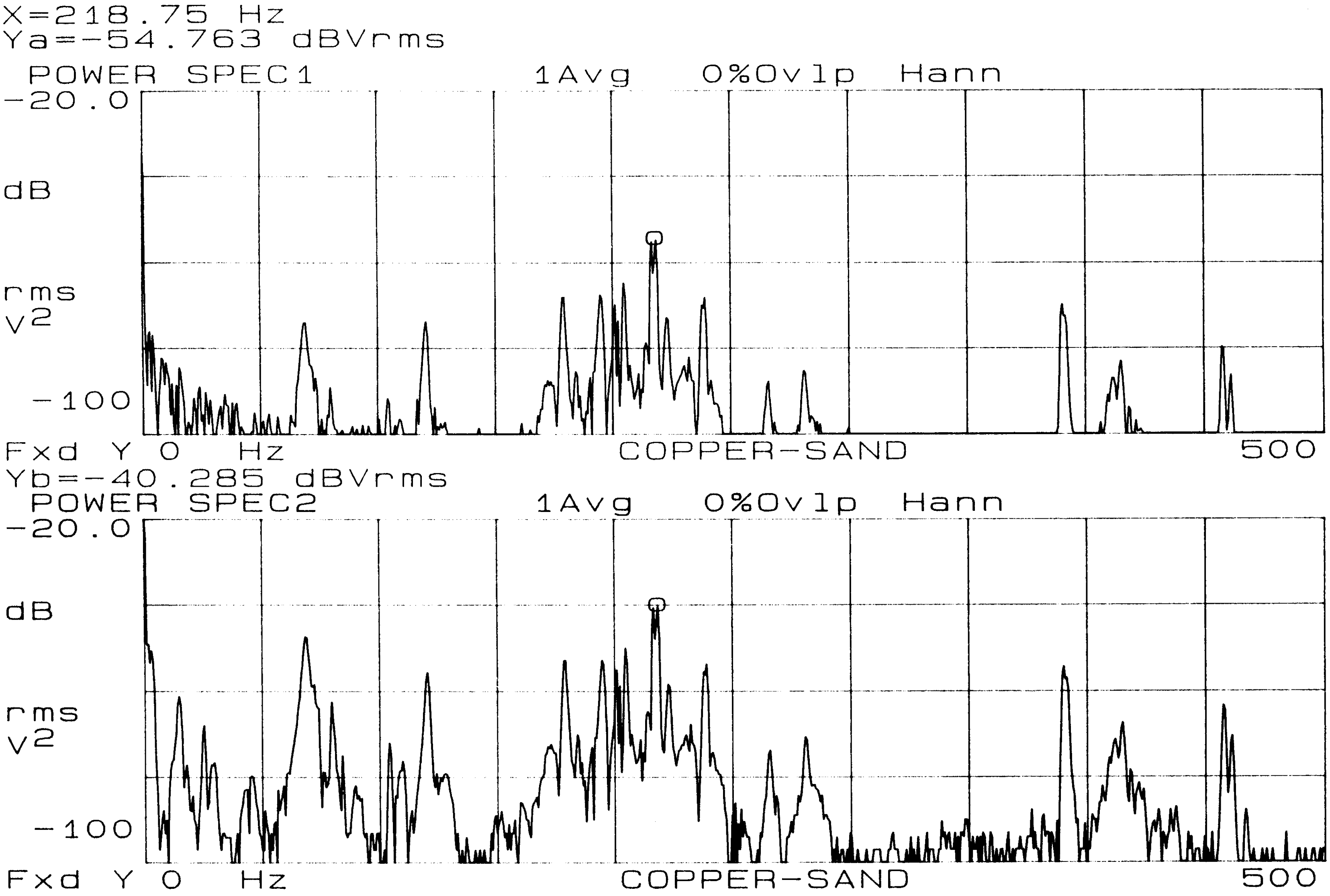
Trace: Copper Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space



```
Ch. 1       =   200.0 mvolts/div                                     Offset     =   0.000   volts
Ch. 2       =   1.000  volts/div                                     Offset     =   0.000   volts
Timebase    =   25.0 ms/div                                          Delay      =   0.00000  s
Ch. 2 Parameters                Freq.       =   254.064  Hz          Period     =   3.93601 ms
Rise Time =   737.310 us        + Width     =   1.38802 ms           - Width    =   2.54799 ms
Fall Time =   779.841 us        Preshoot    =   0.000  volts         Overshoot  =   0.000   volts
P-P Volts =   2.687   volts     RMS Volts =     1.112  volts         Dutycycle  =   35.26 %
```

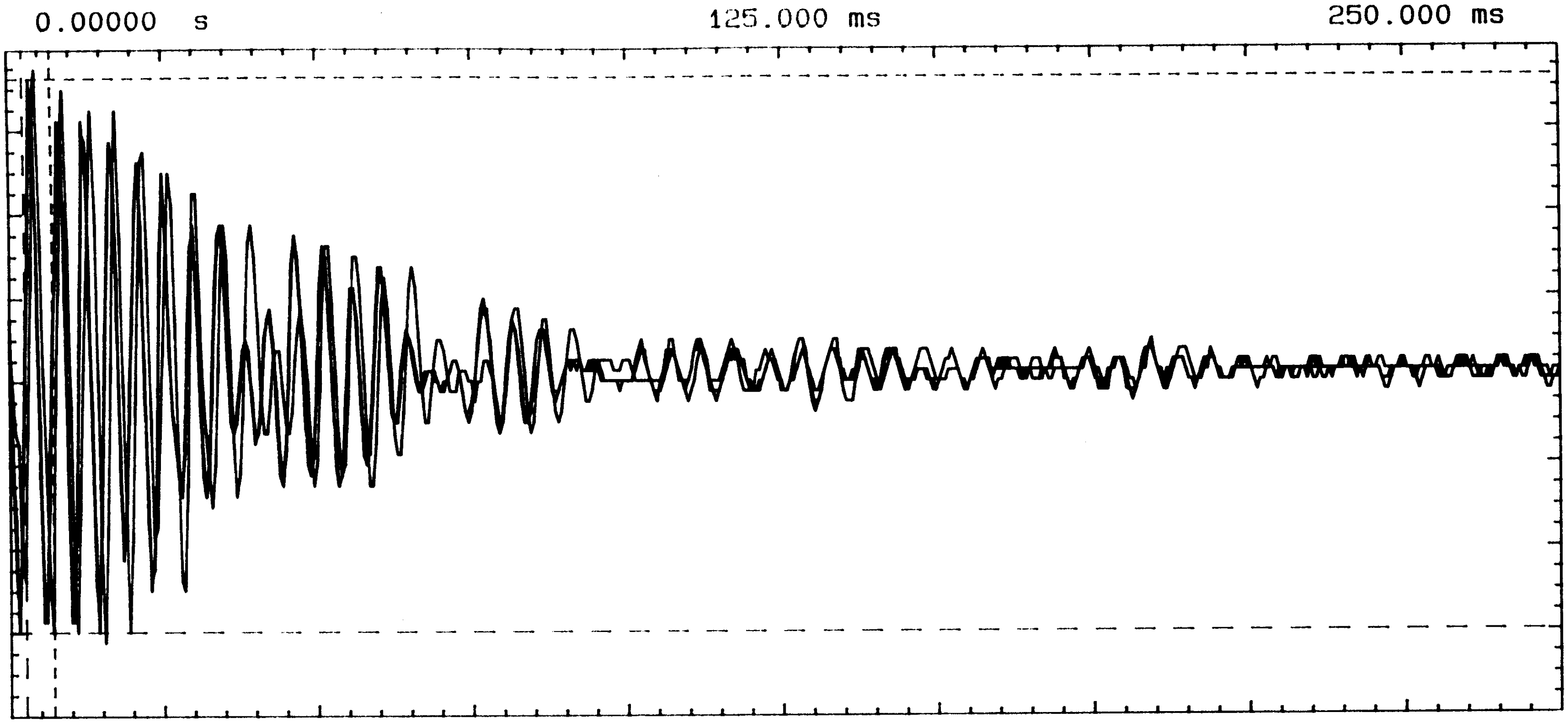
Top Trace:	Copper Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Copper Specimen	Sand Core	Un-filtered Input	



Top Trace: Copper Specimen Sand Core Filtrered Input

Frequency-Space

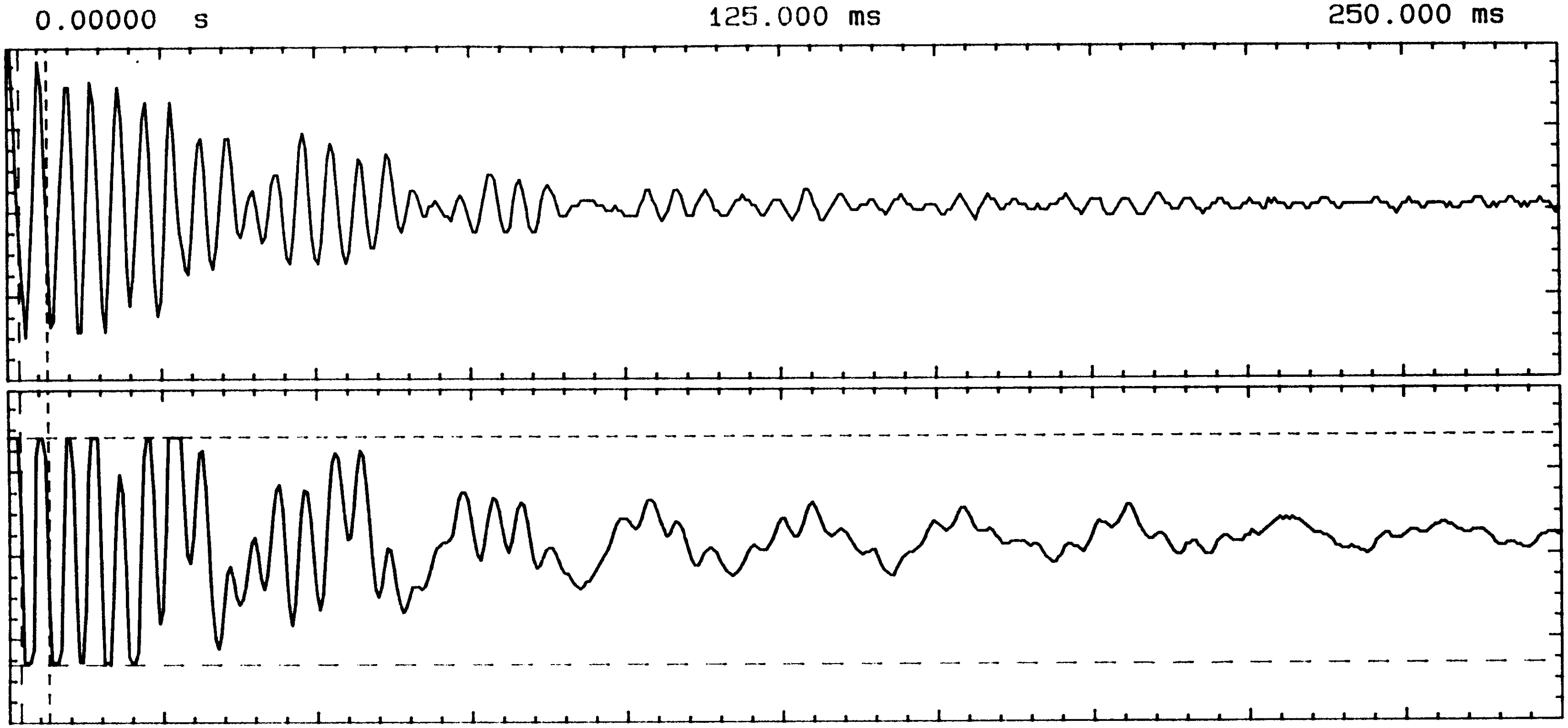
Bottom Trace: Copper Specimen Sand Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Mem 1 Parameters                   Freq.       =  226.552  Hz                Period     =  4.41400 ms
Rise Time =  1.57564 ms            + Width     =  2.09842 ms                 - Width    =  2.31559 ms
Fall Time =  1.46846 ms            Preshoot    =  0.000  volts               Overshoot  =  0.000  volts
P-P Volts =  662.6 mvolts          RMS Volts   =  206.8 mvolts               Dutycycle  =  47.54 %
```

Trace: Copper Specimen Lead Shot Core Filtrered Input

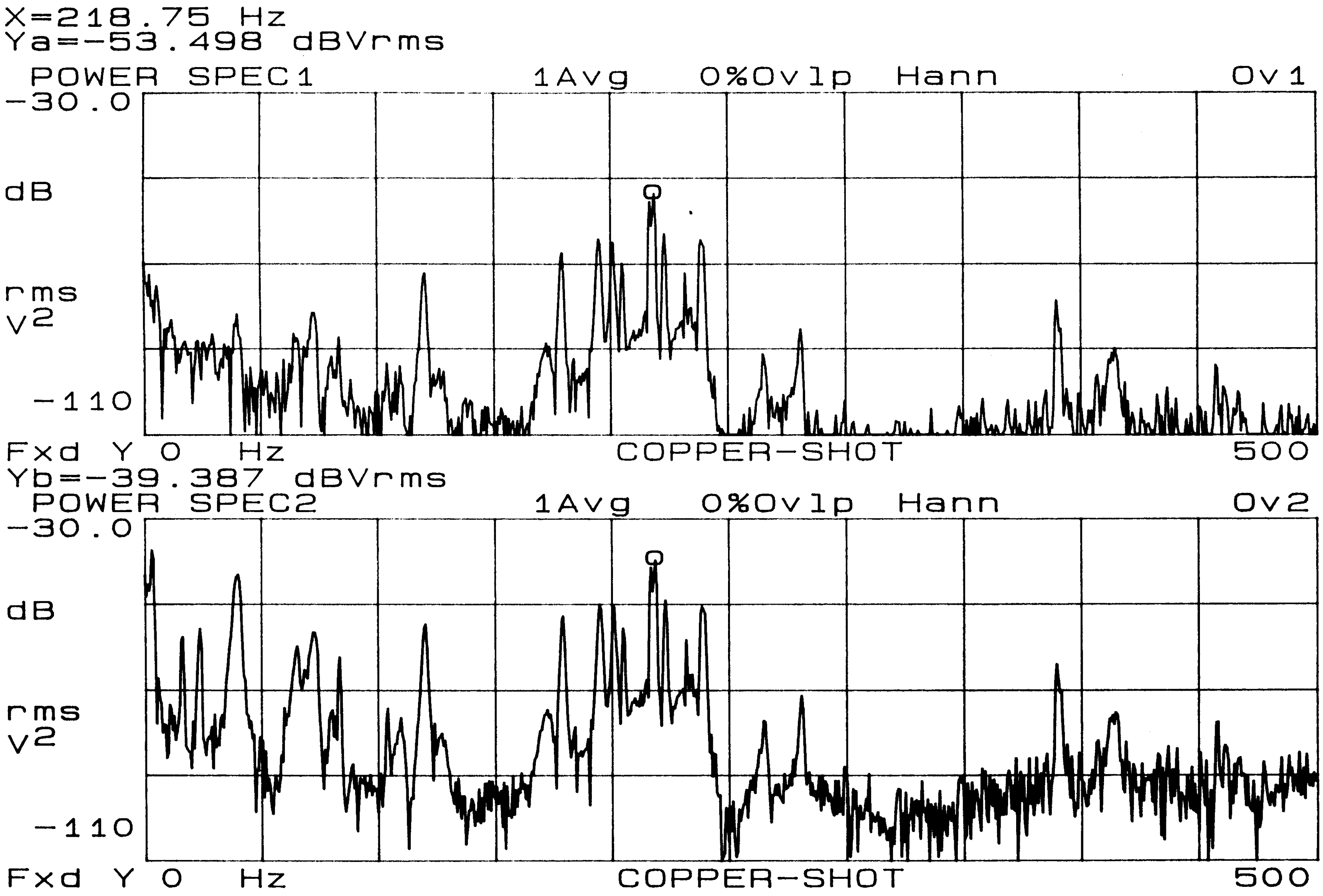
Four Trace Overlay in Time-Space



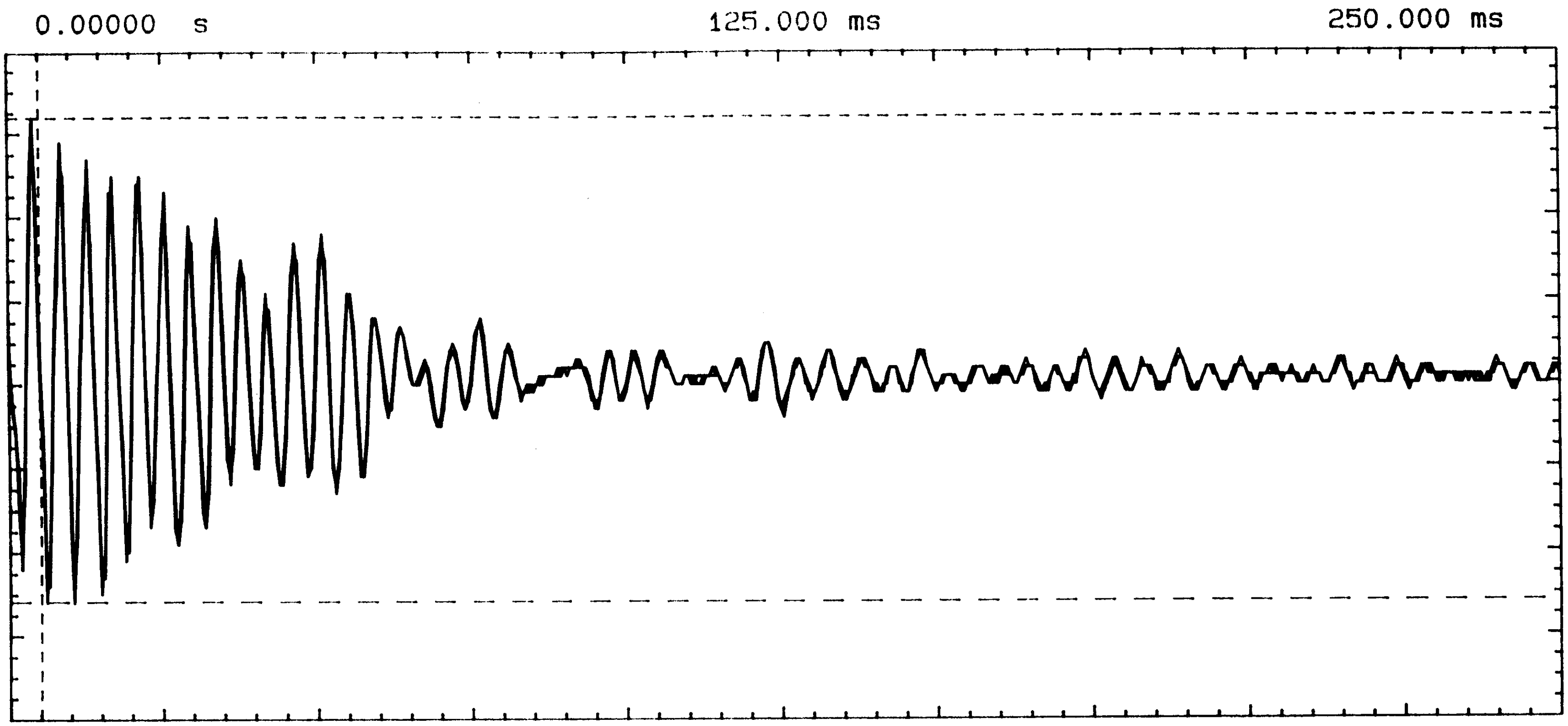
```
Ch. 1      =  200.0 mvolts/div                                            Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                            Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                 Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.        =  237.833  Hz           Period     =  4.20463 ms
Rise Time =  736.504 us             + Width      =  2.07844 ms            - Width    =  2.12619 ms
Fall Time =  782.477 us             Preshoot     =  0.000   volts         Overshoot  =  0.000   volts
P-P Volts =  2.718   volts          RMS Volts    =  1.161   volts         Dutycycle  =  49.43 %
```

Top Trace: Copper Specimen Lead Shot Core Filtrered Input Time-Space

Bottom Trace: Copper Specimen Lead Shot Core Un-filtered Input



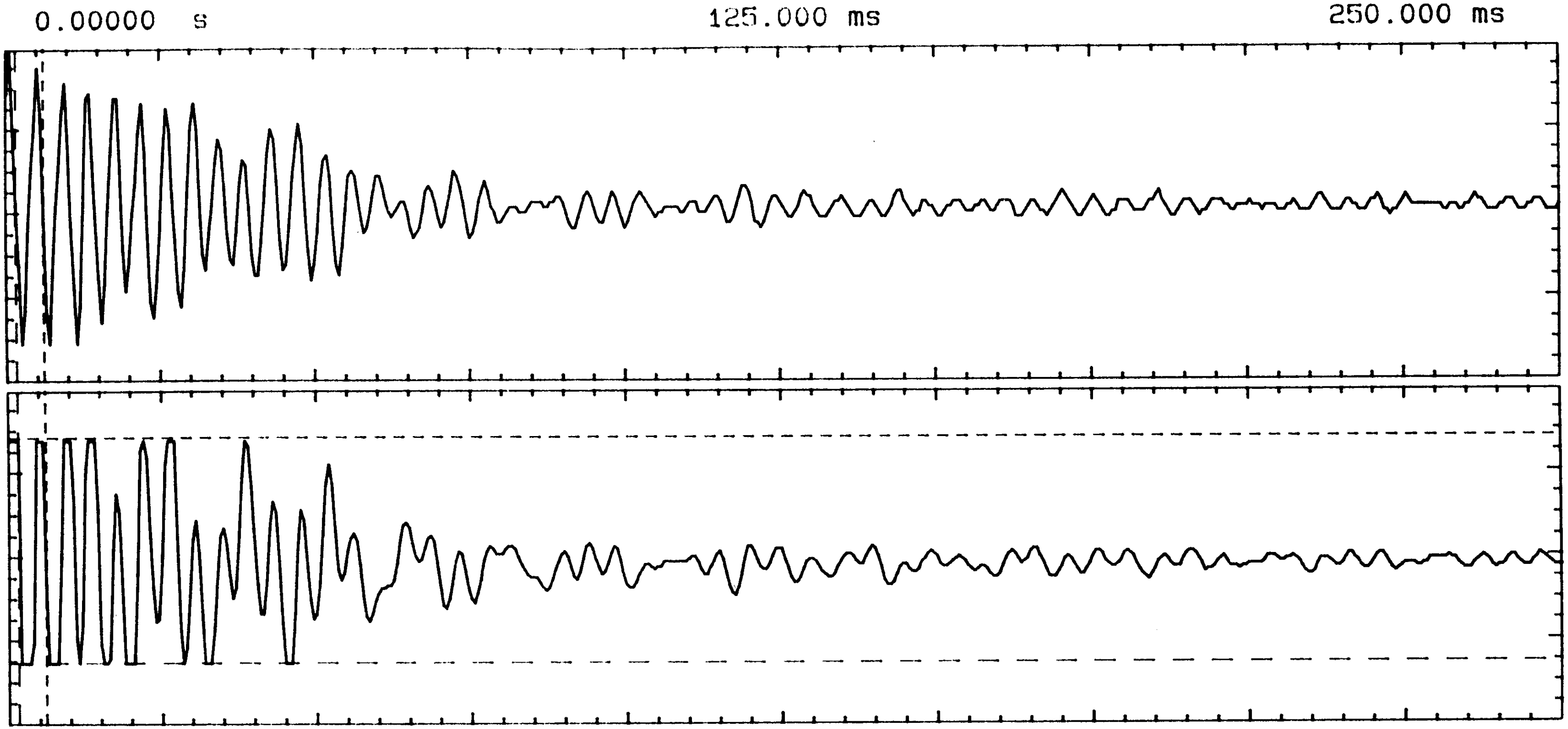
Top Trace:	Copper Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Copper Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 1    =  125.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 2    =  125.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 3    =  125.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Memory 4    =  125.0 mvolts/div                                         Offset     =  0.000  volts
Timebase    =  25.0 ms/div                                              Delay      =  0.00000  s
Mem 4 Parameters                   Freq.      =  203.193  Hz            Period     =  4.92143 ms
Rise Time =  1.70107 ms            + Width    =  2.10501 ms              - Width   =  2.81643 ms
Fall Time =  1.85618 ms            Preshoot   =  0.000  volts           Overshoot =  0.000  volts
P-P Volts =  722.7 mvolts          RMS Volts =  195.3 mvolts            Dutycycle =  42.77 %
```

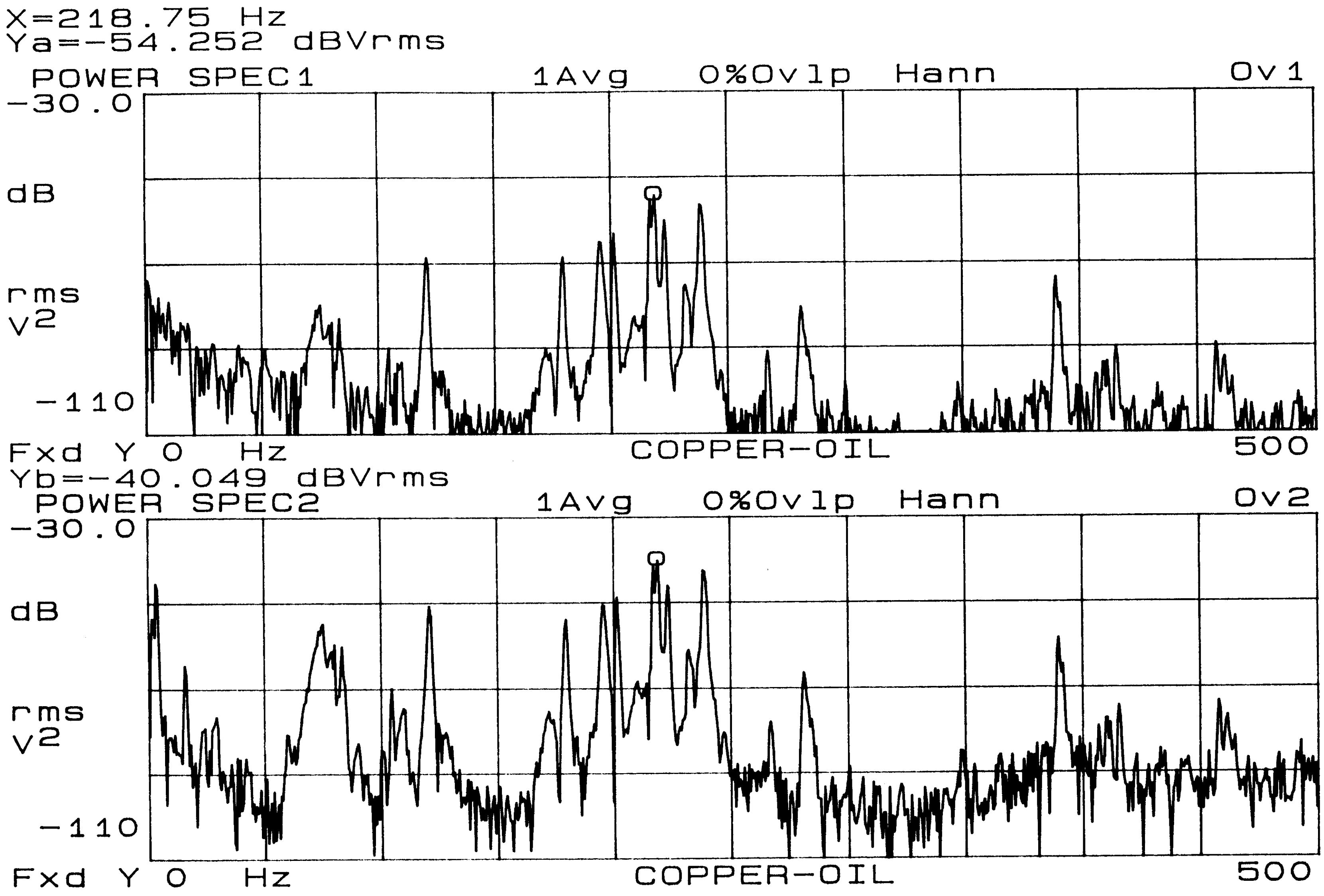
Trace: Copper Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space

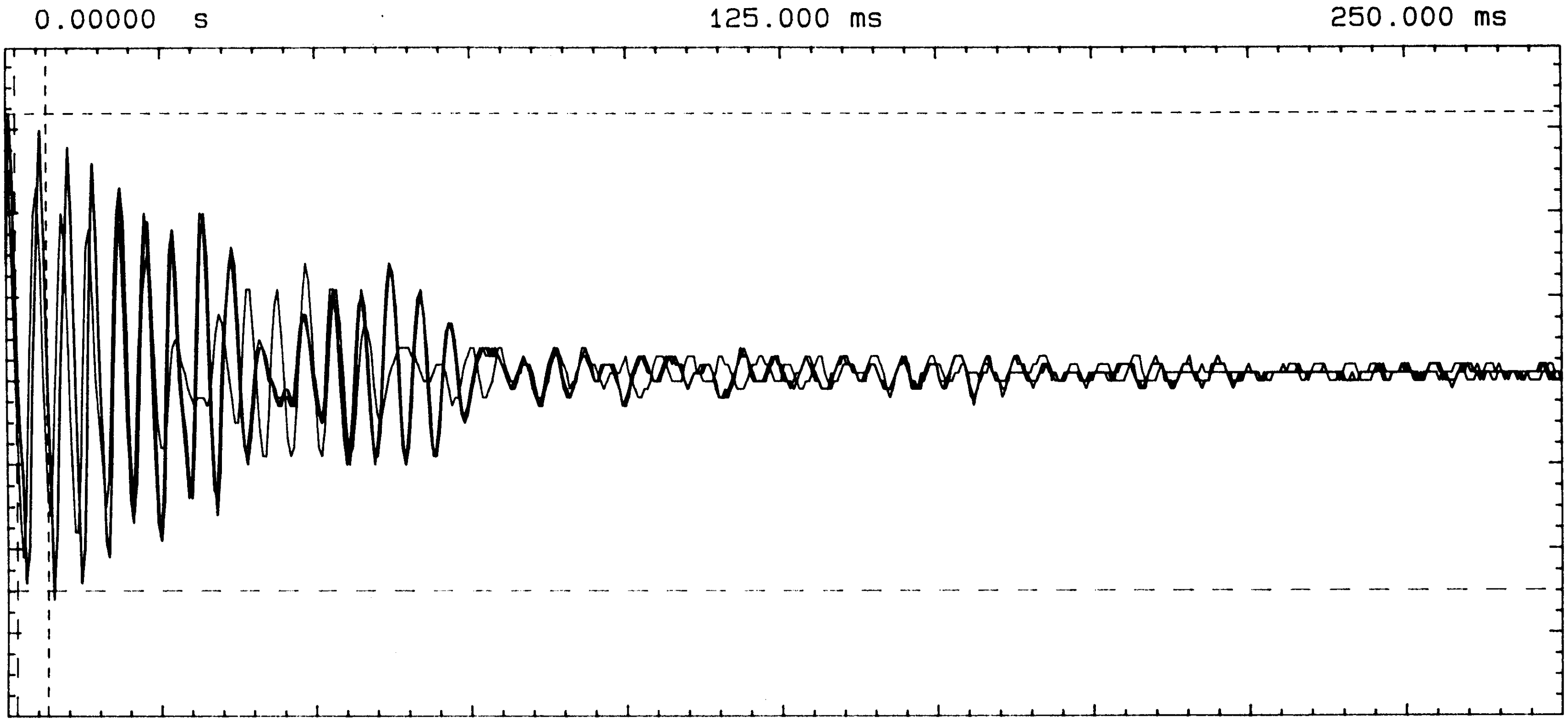


```
Ch. 1     =  200.0 mvolts/div                                    Offset     =  0.000   volts
Ch. 2     =  1.000  volts/div                                    Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                         Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.      =  241.012  Hz      Period     =  4.14917 ms
Rise Time =  714.150 us           + Width    =  1.66895 ms       - Width    =  2.48021 ms
Fall Time =  404.687 us           Preshoot   =  0.000   volts    Overshoot  =  0.000   volts
P-P Volts =  2.687   volts        RMS Volts  =  1.235   volts    Dutycycle  =  40.22 %
```

Top Trace:	Copper Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Copper Specimen	Oil Core	Un-filtered Input	



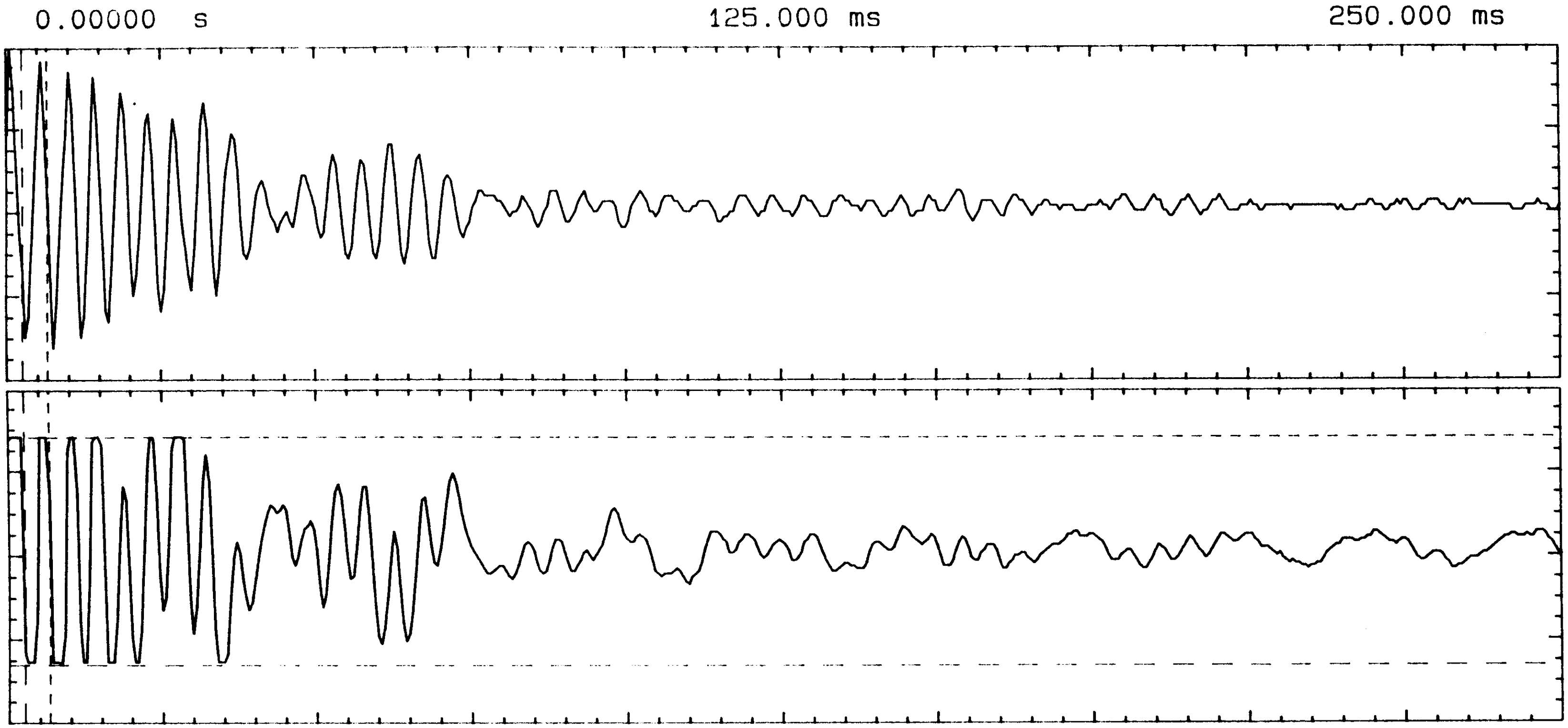
Top Trace:	Copper Specimen	Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Copper Specimen	Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                     Delay      =  0.00000  s
Memory 1   =  125.0 mvolts/div                                                Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                     Delay      =  0.00000  s
Memory 2   =  125.0 mvolts/div                                                Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                     Delay      =  0.00000  s
Memory 3   =  125.0 mvolts/div                                                Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                     Delay      =  0.00000  s
Memory 4   =  125.0 mvolts/div                                                Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                     Delay      =  0.00000  s
Mem 1 Parameters                      Freq.      =  208.535  Hz               Period     =  4.79536 ms
Rise Time =  1.98392 ms               + Width    =  2.13337 ms                - Width    =  2.66199 ms
Fall Time =  2.00847 ms               Preshoot   =  0.000  volts              Overshoot  =  0.000  volts
P-P Volts =  711.0 mvolts             RMS Volts  =  201.4 mvolts              Dutycycle  =  44.48 %
```

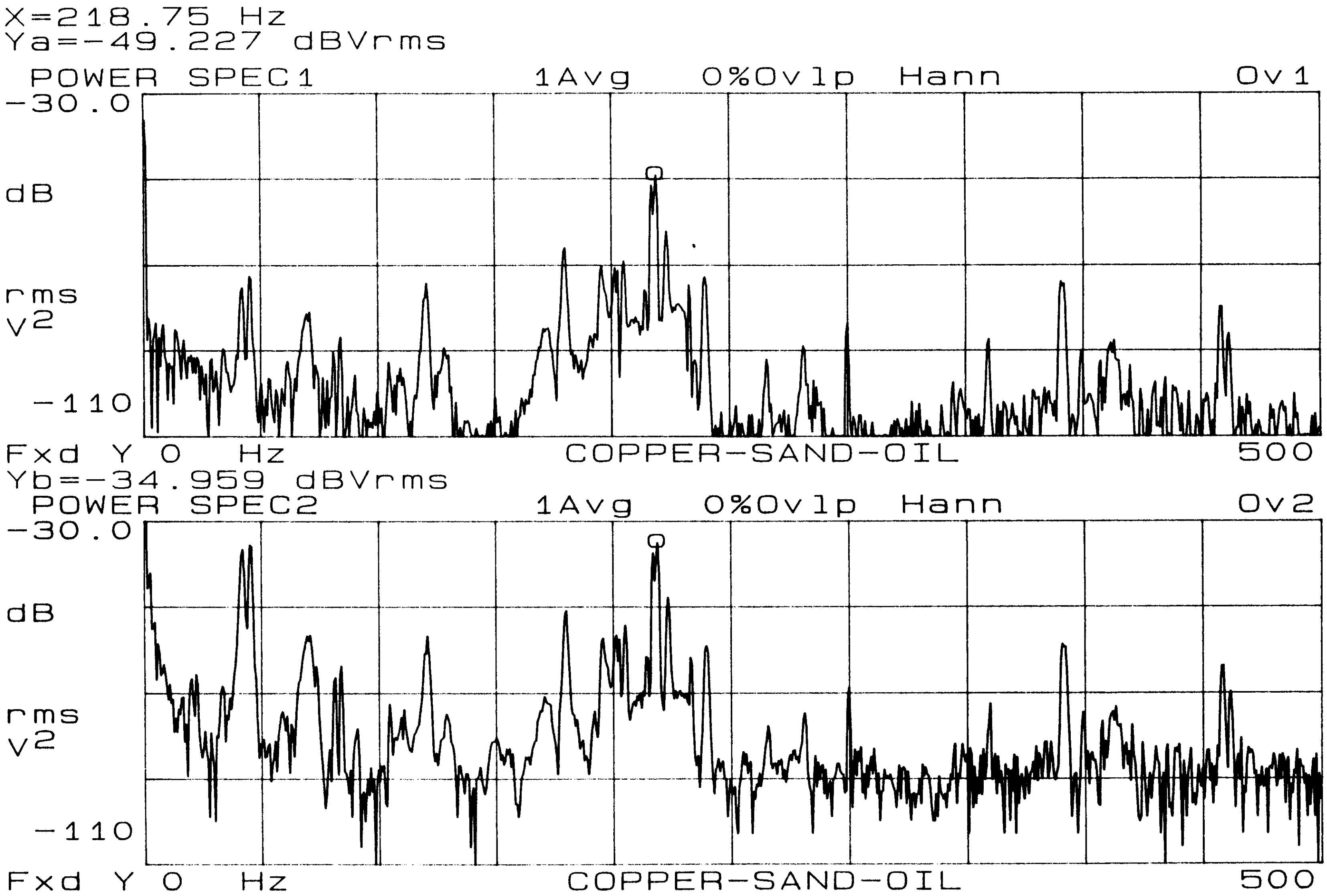
Trace: Copper Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

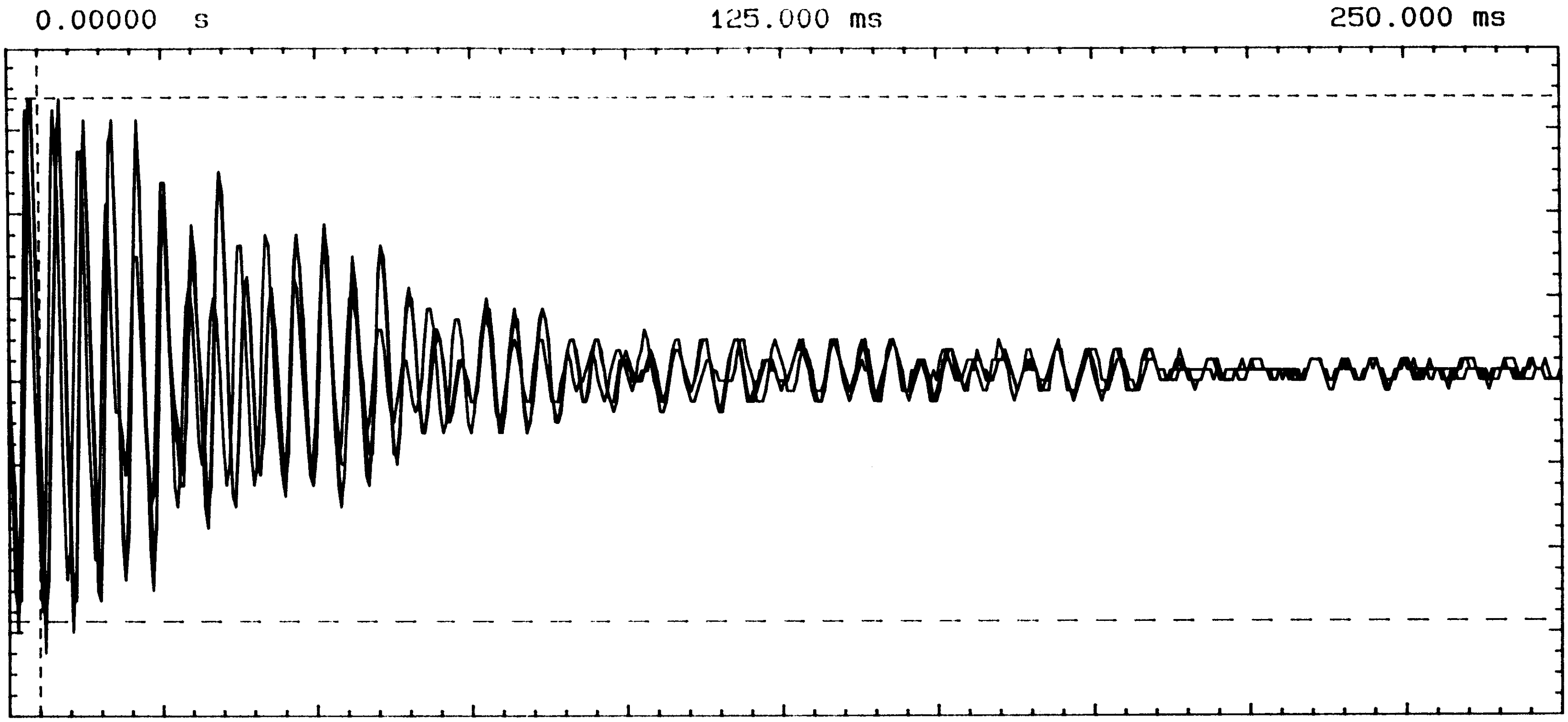


```
Ch. 1      =  200.0 mvolts/div                                        Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.      =  226.869  Hz           Period     =  4.40783 ms
Rise Time =  697.263 us           + Width    =  1.98379 ms            - Width    =  2.42404 ms
Fall Time =  424.400 us           Preshoot   =  0.000  volts          Overshoot =  0.000  volts
P-P Volts =  2.718  volts         RMS Volts =  1.218  volts           Dutycycle =  45.00 %
```

Top Trace:	Copper Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Copper Specimen	Sand/Oil Core	Un-filtered Input	



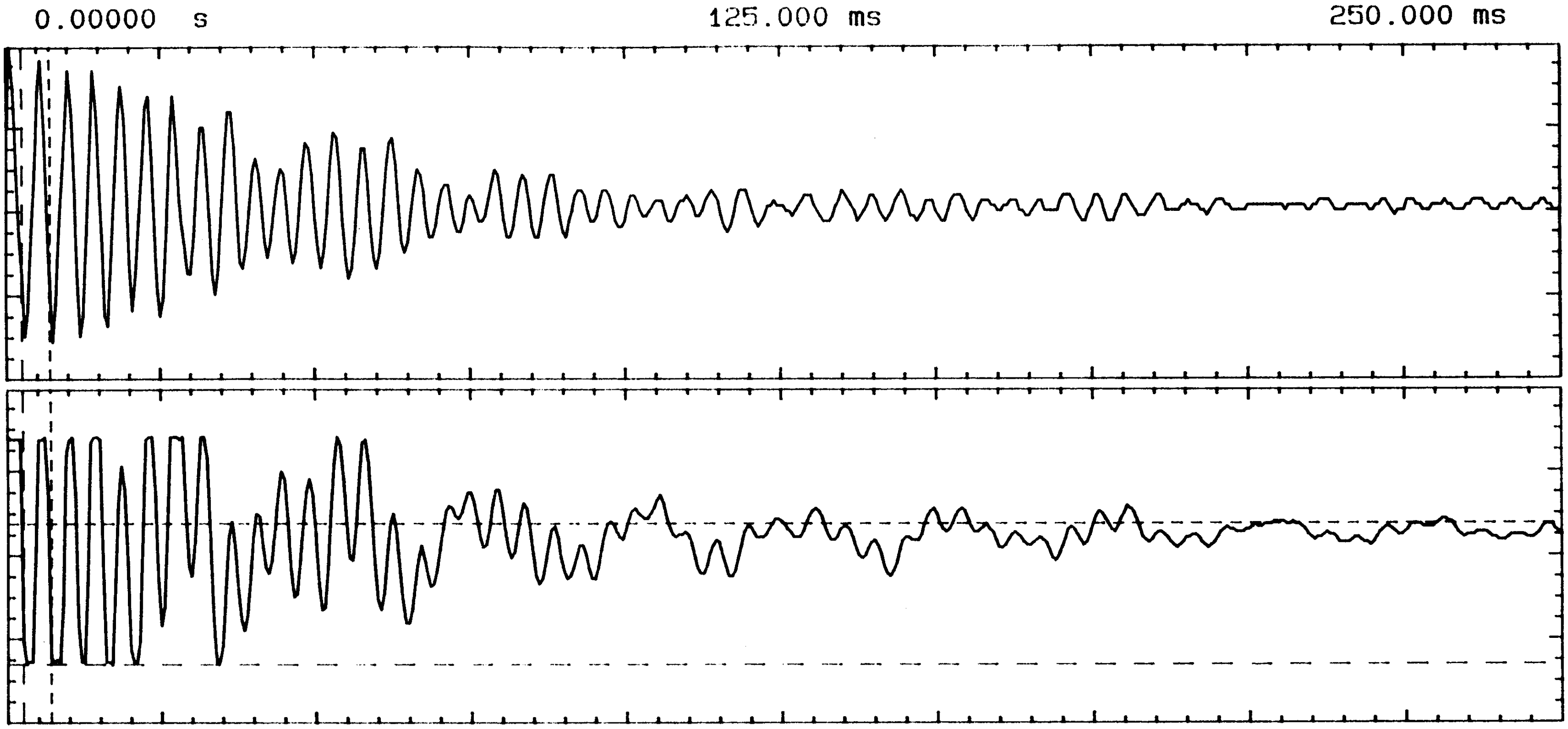
Top Trace:	Copper Specimen	Sand/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Copper Specimen	Sand/Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                     Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 4 Parameters                 Freq.      =  211.209  Hz         Period     =  4.73464 ms
Rise Time =  1.28785 ms          + Width    =  2.06272 ms           - Width   =  2.67192 ms
Fall Time =  1.62531 ms          Preshoot   =  0.000  volts        Overshoot =  0.000  volts
P-P Volts =  625.1 mvolts        RMS Volts  =  195.1 mvolts        Dutycycle =  43.56 %
```

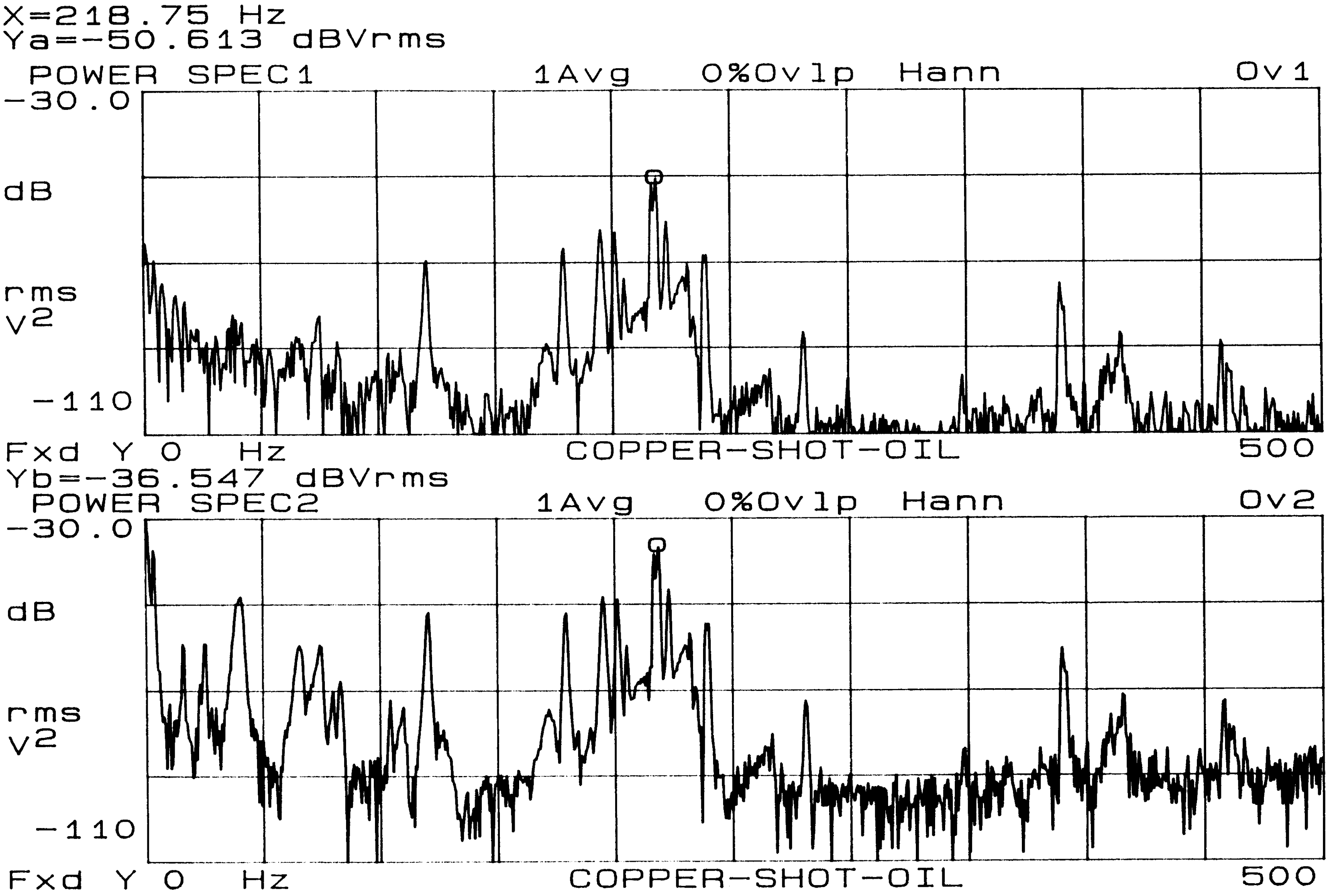
Trace: Copper Specimen Lead Shot/Oil Core Filtrered Input

Four Trace Overlay in Time-Space



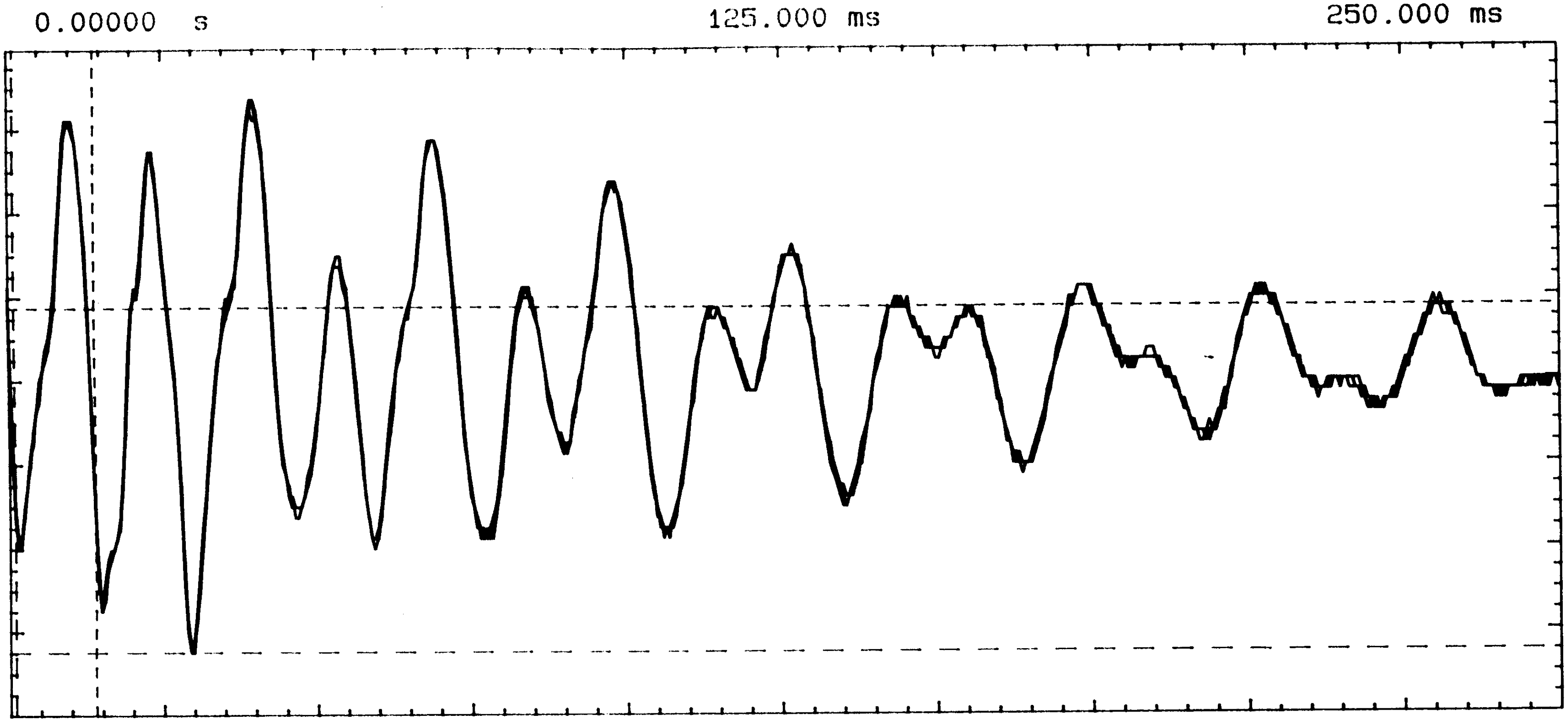
```
Ch. 1      =  200.0 mvolts/div                                     Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000   s
Ch. 2 Parameters                  Freq.       =  225.917  Hz       Period     =  4.42641 ms
Rise Time =  529.482 us           + Width     =  2.48452 ms        - Width    =  1.94188 ms
Fall Time =  482.251 us           Preshoot    =  1.031   volts     Overshoot =  0.000   volts
P-P Volts =  2.718   volts        RMS Volts  =  1.174   volts      Dutycycle =  56.12 %
```

Top Trace:	Copper Specimen	Lead Shot/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Copper Specimen	Lead Shot/Oil Core	Un-filtered Input	



Top Trace:	Copper Specimen	Lead Shot/Oil Core	Filtrered Input
Bottom Trace:	Copper Specimen	Lead Shot/Oil Core	Un-filtered Input

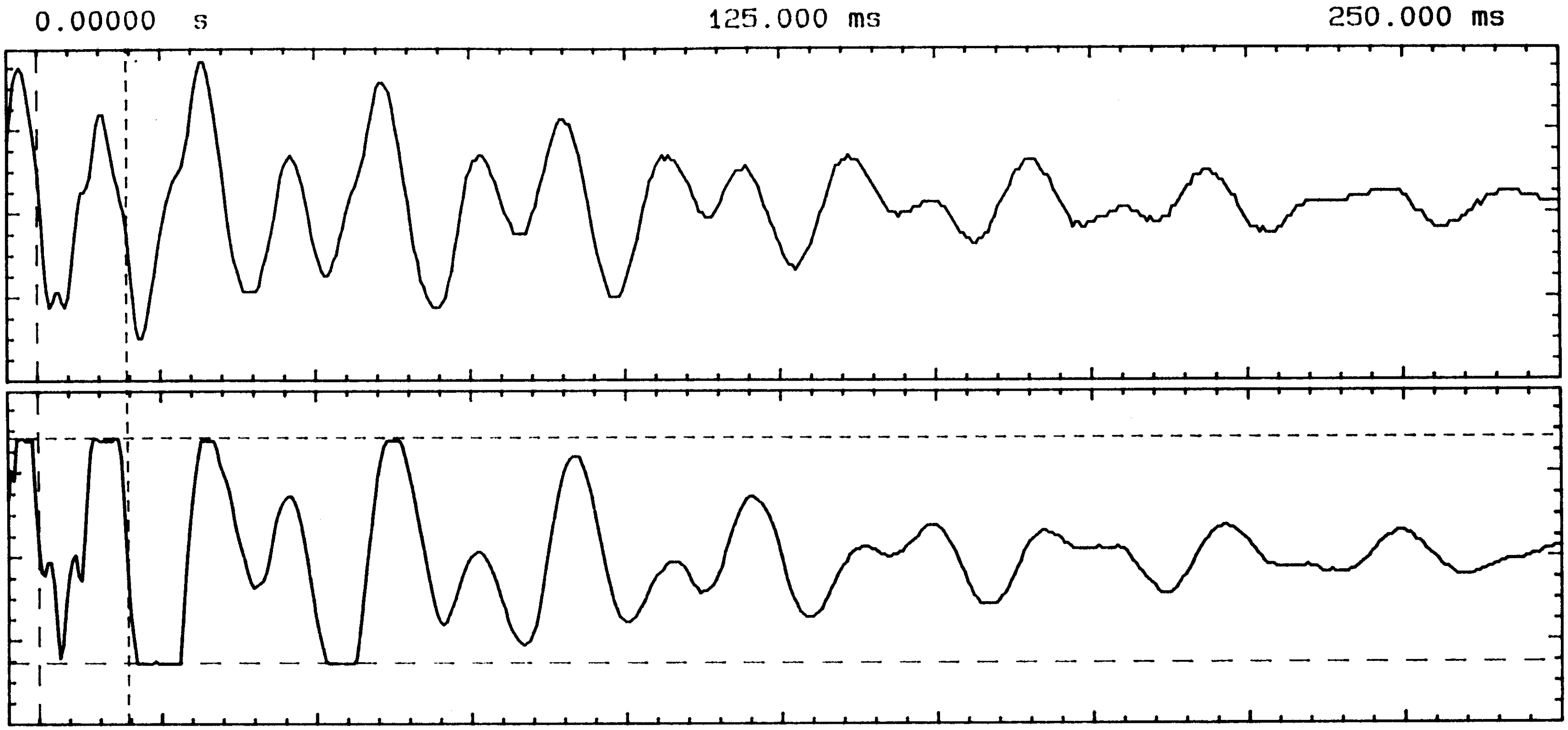
Frequency-Space



```
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Mem 1 Parameters                  Freq.      =  76.9250  Hz             Period     =  12.9997 ms
Rise Time = -10.7782 ms           + Width    =  10.6934 ms              - Width    =  2.30628 ms
Fall Time =  28.8570 ms           Preshoot   =  250.0 mvolts            Overshoot  =  0.000  volts
P-P Volts =  662.6 mvolts         RMS Volts  =  176.1 mvolts            Dutycycle  =  82.25 %
```

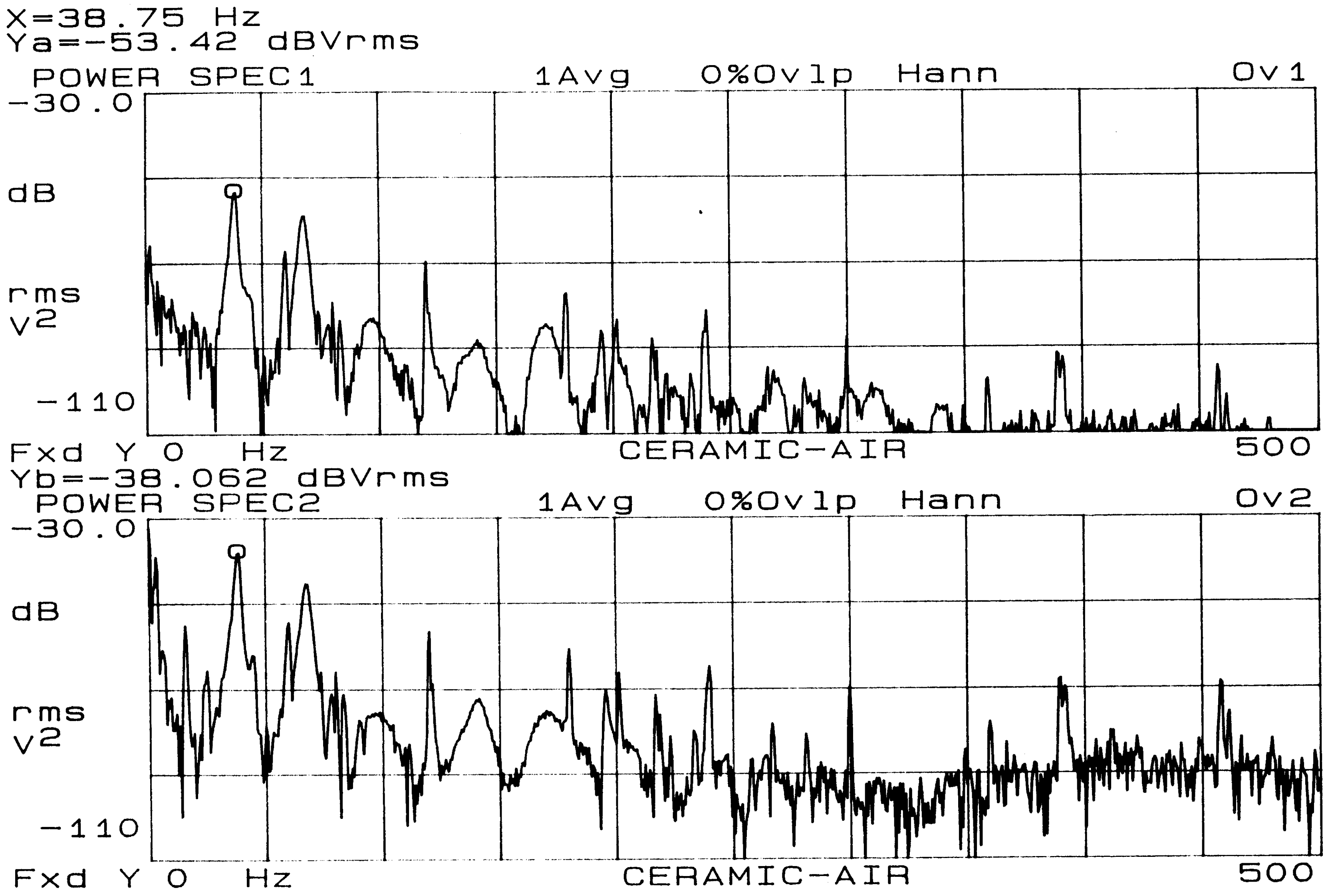
Trace: Ceramic Specimen Air Core Filtrered Input

Four Trace Overlay in Time-Space

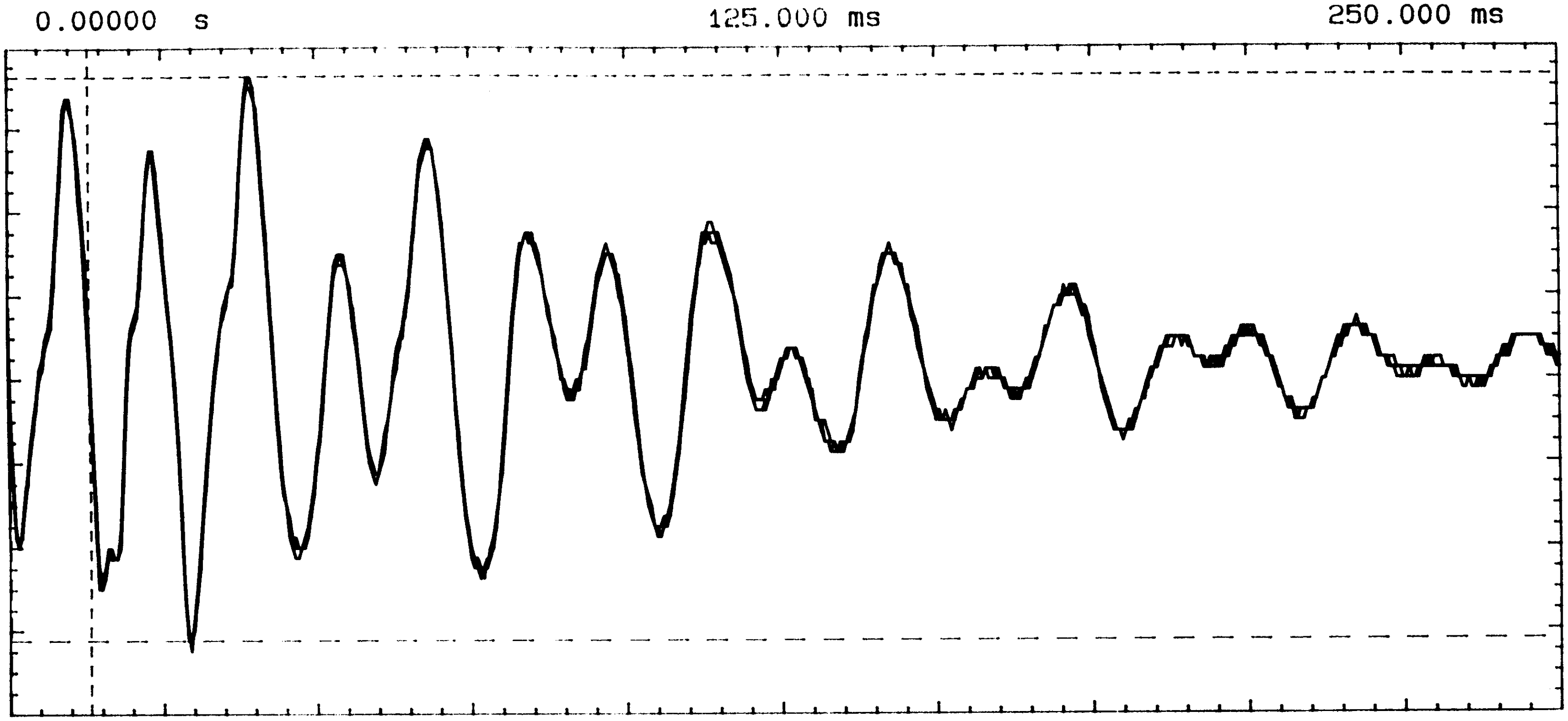


```
Ch. 1      =  200.0 mvolts/div                                     Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  70.4376  Hz       Period     =  14.1970 ms
Rise Time =  4.47829 ms           + Width     =  6.98958 ms        - Width    =  7.20739 ms
Fall Time =  4.05060 ms           Preshoot    =  0.000  volts      Overshoot  =  0.000   volts
P-P Volts =  2.687  volts         RMS Volts   =  917.4 mvolts      Dutycycle  =  49.23 %
```

Top Trace:	Ceramic Specimen	Air Core	Filtrered Input	Time-Space
Bottom Trace:	Ceramic Specimen	Air Core	Un-filtered Input	



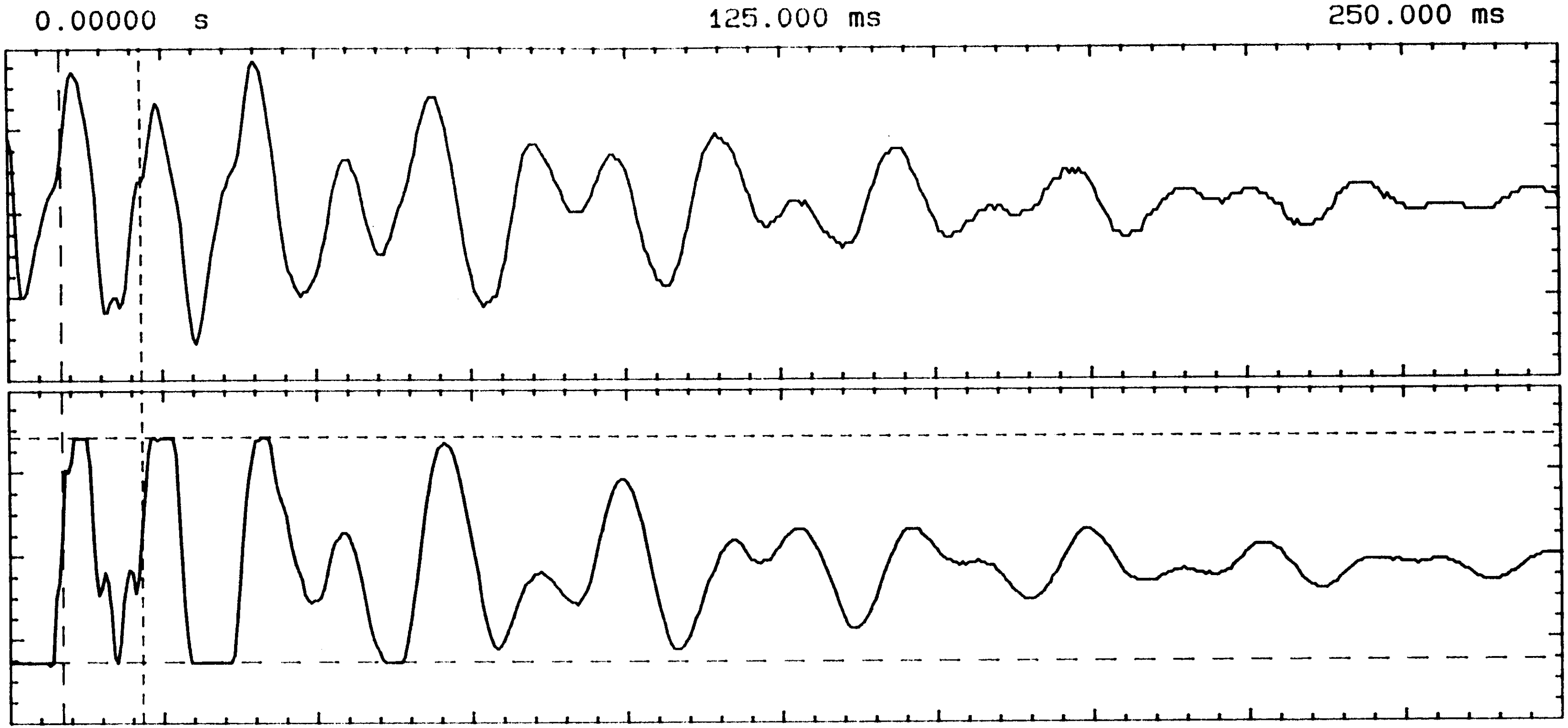
Top Trace:	Ceramic Specimen	Air Core	Filtrered Input	Frequency-Space
Bottom Trace:	Ceramic Specimen	Air Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Mem 1 Parameters                  Freq.       =  76.4814  Hz           Period     =  13.0751 ms
Rise Time =  7.52663 ms           + Width     =  7.60426 ms            - Width    =  5.47081 ms
Fall Time =  17.7435 ms           Preshoot    =  0.000  volts          Overshoot  =  0.000  volts
P-P Volts =  675.1 mvolts         RMS Volts   =  184.7 mvolts          Dutycycle  =  58.15 %
```

Trace: Ceramic Specimen Sand Core Filtrered Input

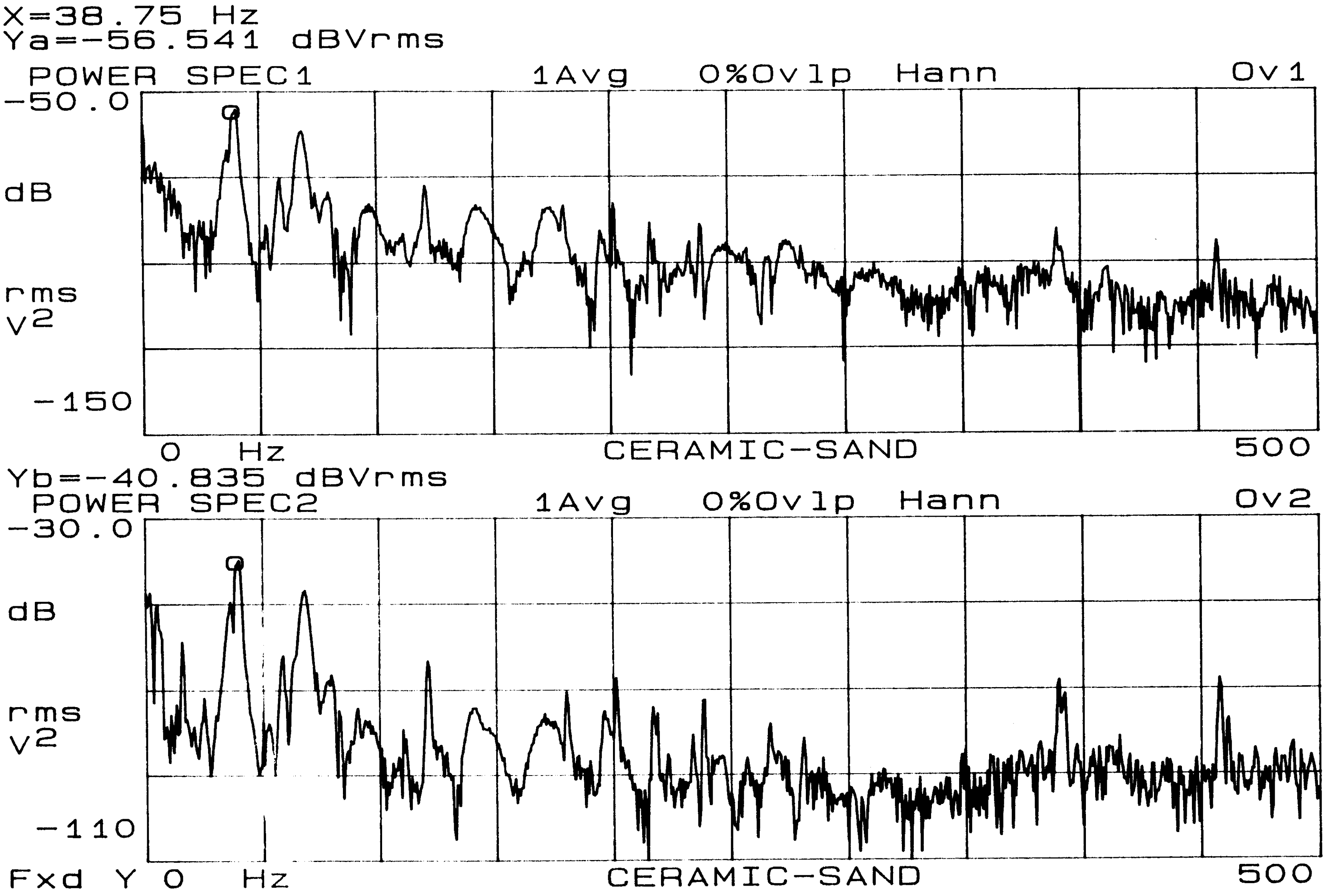
Four Trace Overlay in Time-Space



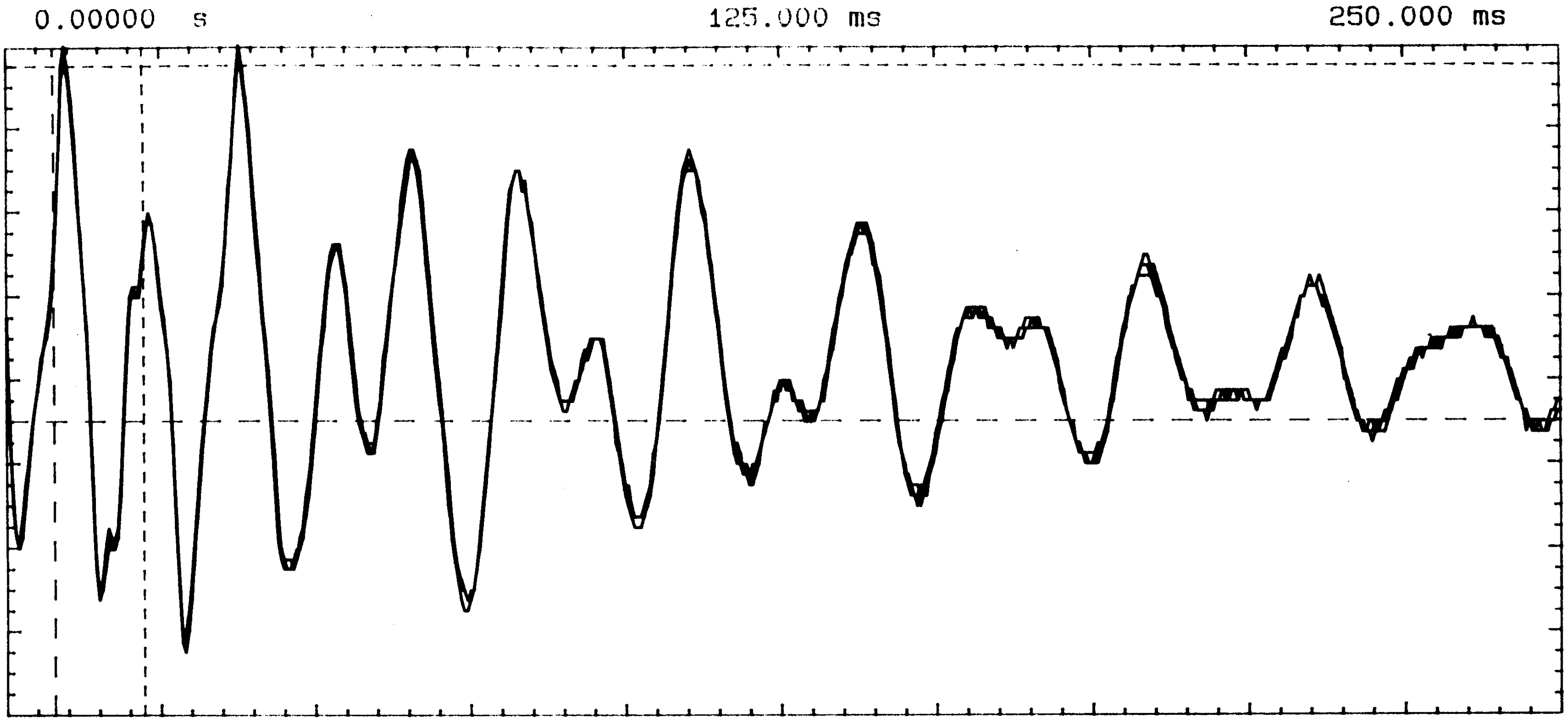
```
Ch. 1      =  200.0 mvolts/div                                             Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                             Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                  Delay      =  0.00000  s
Ch. 2 Parameters                        Freq.       =  77.2727  Hz         Period     =  12.9412 ms
Rise Time  =  2.73041 ms                + Width     =  5.42484 ms          - Width    =  7.51634 ms
Fall Time  =  3.99031 ms                Preshoot    =  31.25 mvolts        Overshoot  =  0.000   volts
P-P Volts  =  2.718   volts             RMS Volts   =  872.5 mvolts        Dutycycle  =  41.91 %
```

Top Trace: Ceramic Specimen Sand Core Filtrered Input Time-Space

Bottom Trace: Ceramic Specimen Sand Core Un-filtered Input



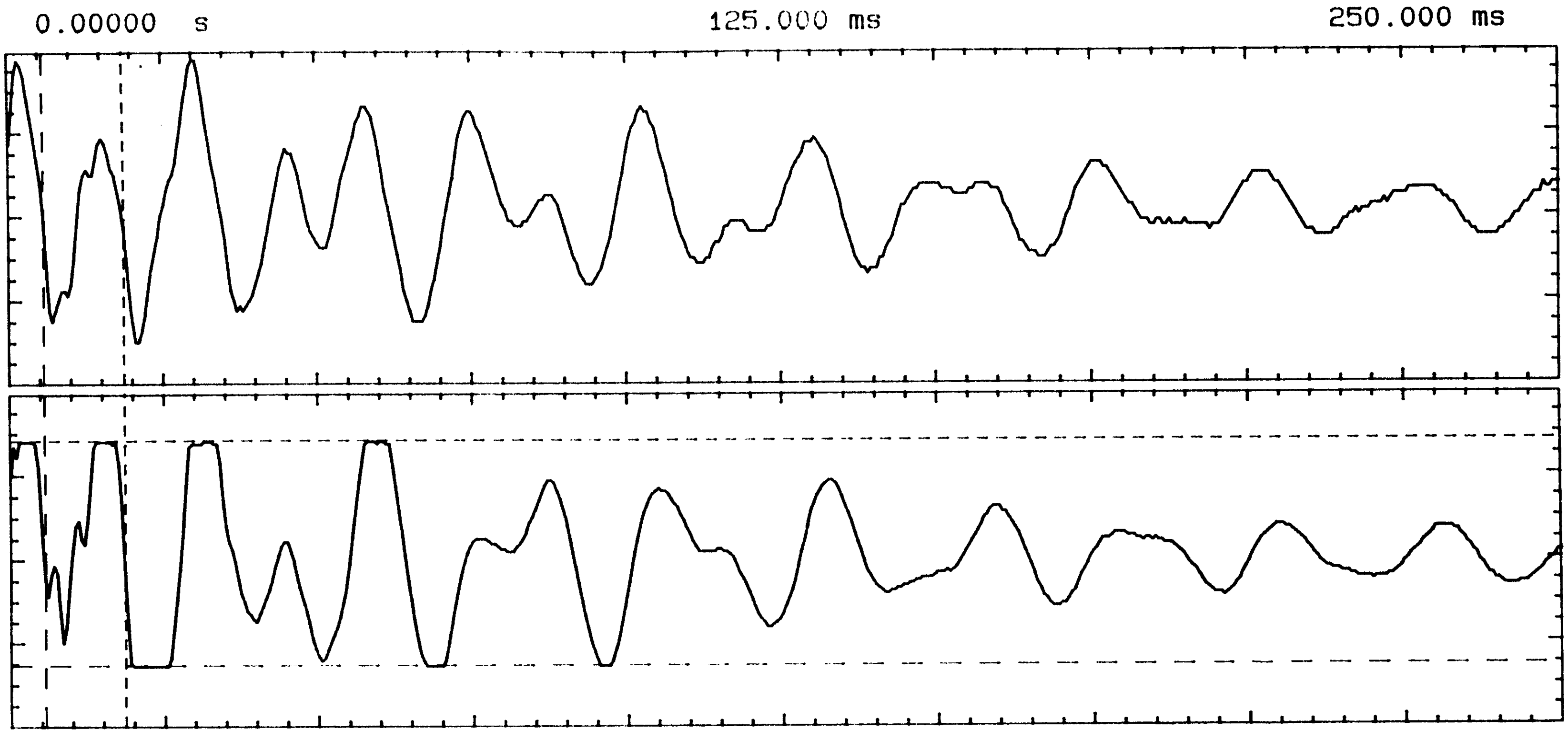
Top Trace:	Ceramic Specimen	Sand Core	Filtrered Input	Frequency-Space
Bottom Trace:	Ceramic Specimen	Sand Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Mem 1 Parameters                Freq.      =  69.1333  Hz          Period     =  14.4648 ms
Rise Time =  3.78681 ms         + Width    =  4.29836 ms           - Width    =  10.1664 ms
Fall Time =  3.01284 ms         Preshoot   =  250.0 mvolts         Overshoot =  0.000   volts
P-P Volts =  675.1 mvolts       RMS Volts =  204.1 mvolts          Dutycycle =  29.71 %
```

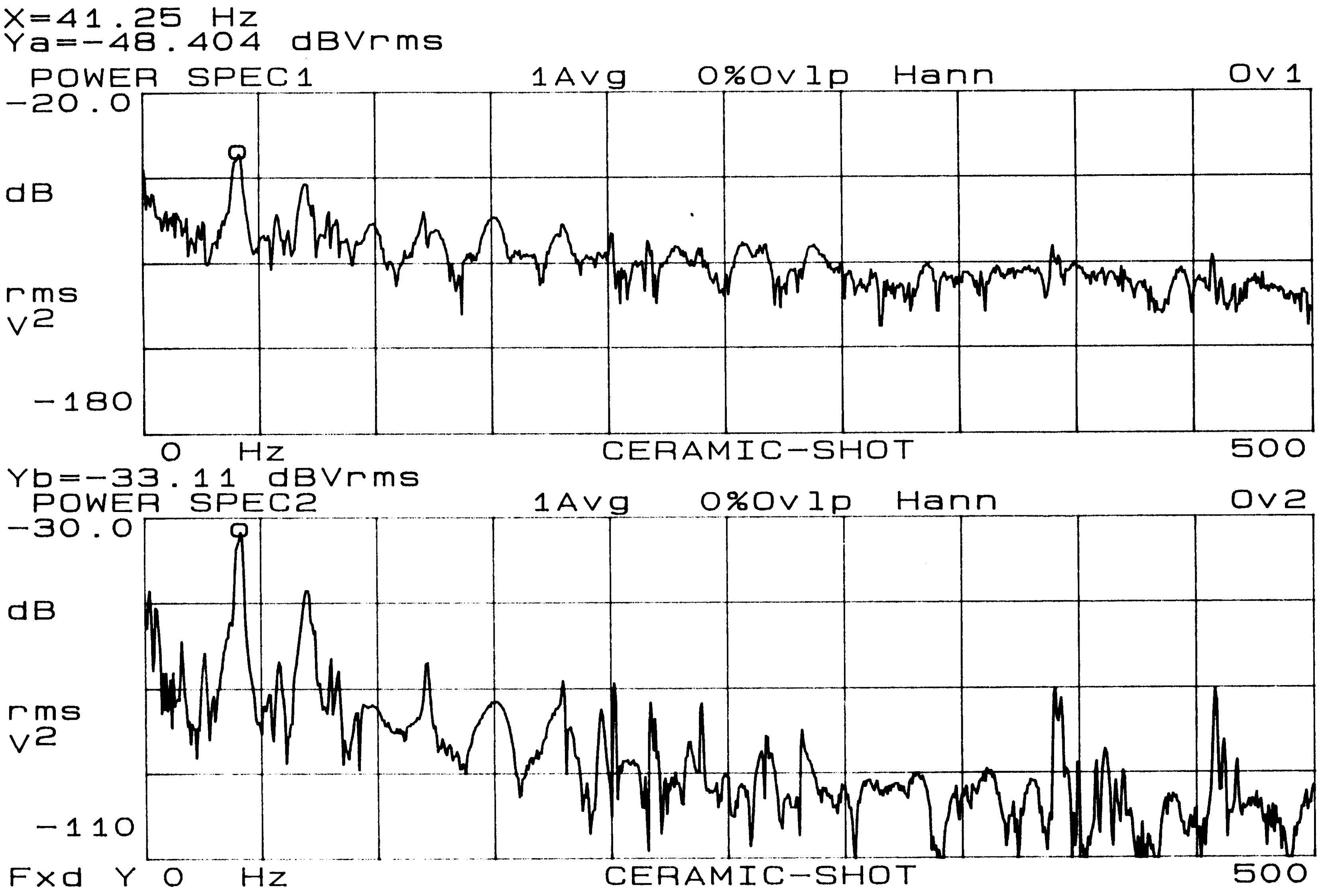
Trace: Ceramic Specimen Lead Shot Core Filtrered Input

Four Trace Overlay in Time-Space

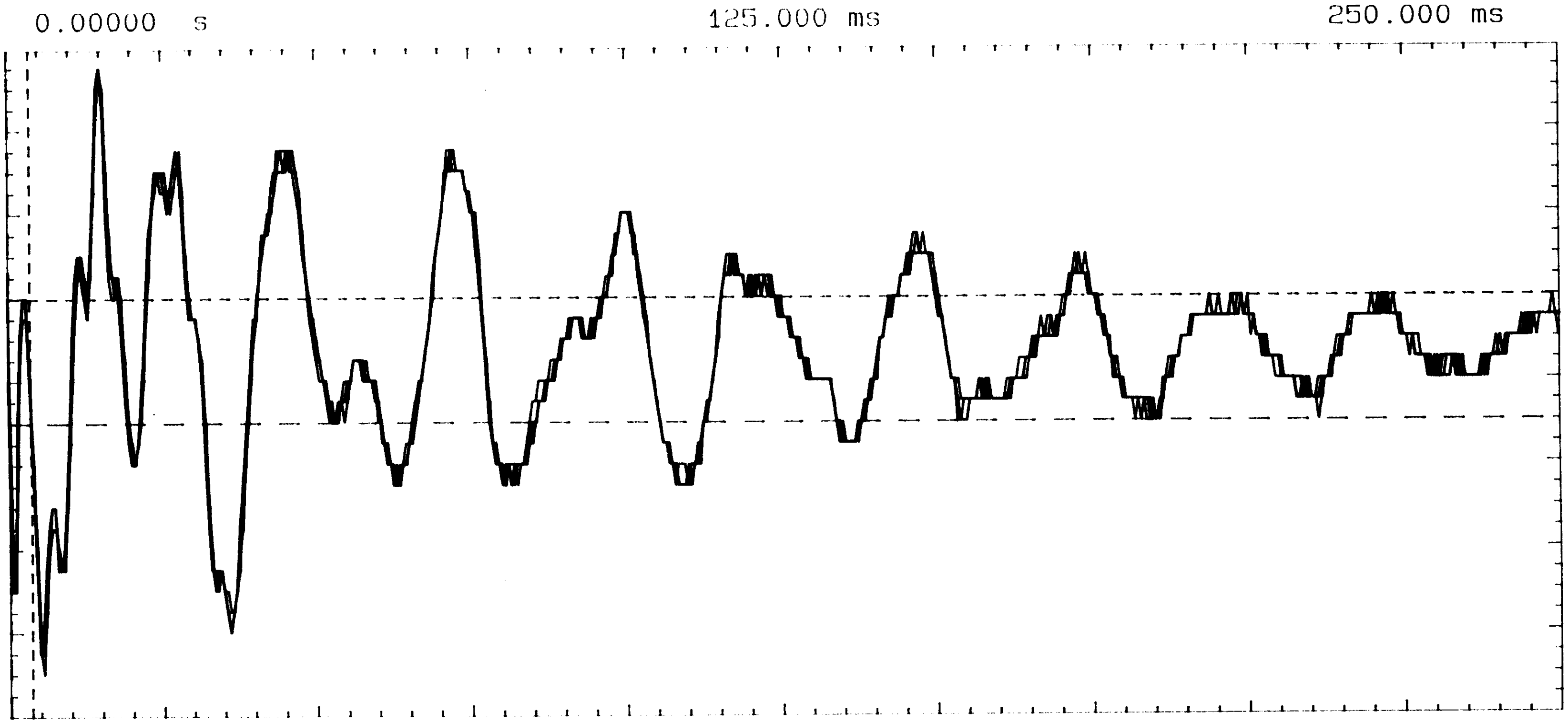


```
Ch. 1      =  200.0 mvolts/div                                      Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                      Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Ch. 2 Parameters                     Freq.        =  76.1377  Hz    Period     =  13.1341 ms
Rise Time = -13.0085 ms              + Width      =  8.40909 ms     - Width    =  4.72500 ms
Fall Time =  14.9737 ms              Preshoot     =  0.000  volts   Overshoot  =  0.000  volts
P-P Volts =  2.687  volts            RMS Volts    =  889.5 mvolts   Dutycycle  =  64.02 %
```

Top Trace:	Ceramic Specimen	Lead Shot Core	Filtrered Input	Time-Space
Bottom Trace:	Ceramic Specimen	Lead Shot Core	Un-filtered Input	



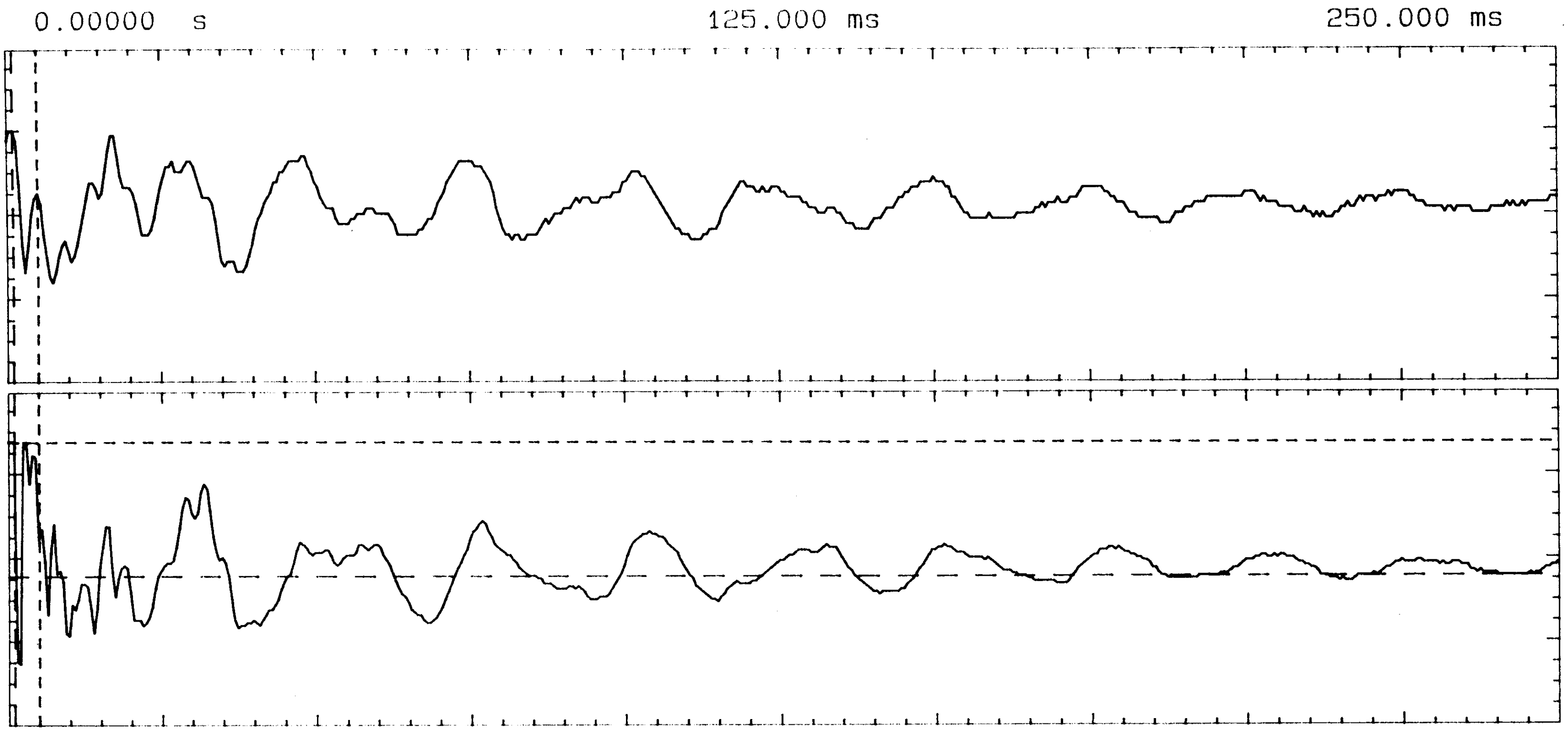
Top Trace:	Ceramic Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Ceramic Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 1   =  50.00 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 2   =  50.00 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 3   =  50.00 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Memory 4   =  50.00 mvolts/div                                              Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                   Delay      =  0.00000  s
Mem 3 Parameters              Freq.       =  310.757  Hz                    Period     =  3.21795 ms
Rise Time =  9.38678 ms       + Width     =  1.19048 ms                     - Width    =  2.02747 ms
Fall Time =  184.645 us       Preshoot    =  137.5 mvolts                   Overshoot  =  137.5 mvolts
P-P Volts =  350.0 mvolts     RMS Volts   =  67.31 mvolts                   Dutycycle  =  36.99 %
```

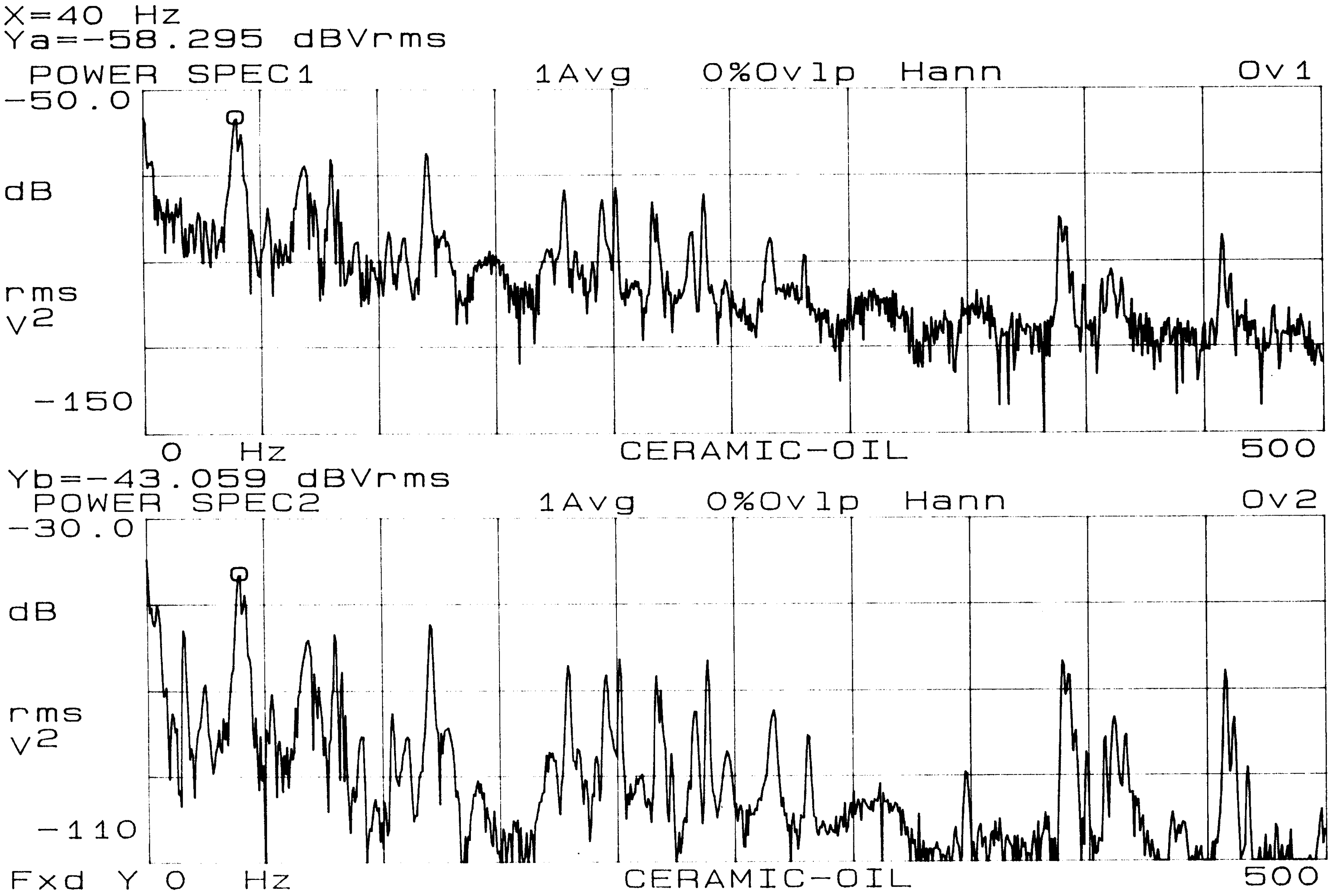
Trace: Ceramic Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                     Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                     Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                          Delay      =  0.00000  s
Ch. 2 Parameters                  Freq.       =  273.020  Hz       Period     =  3.66273 ms
Rise Time =  239.982 us           + Width     =  2.46452 ms         - Width    =  1.19821 ms
Fall Time =  242.839 us           Preshoot    =  0.000   volts      Overshoot =  1.062   volts
P-P Volts =  2.656   volts        RMS Volts =  1.182   volts        Dutycycle =  67.28 %
```

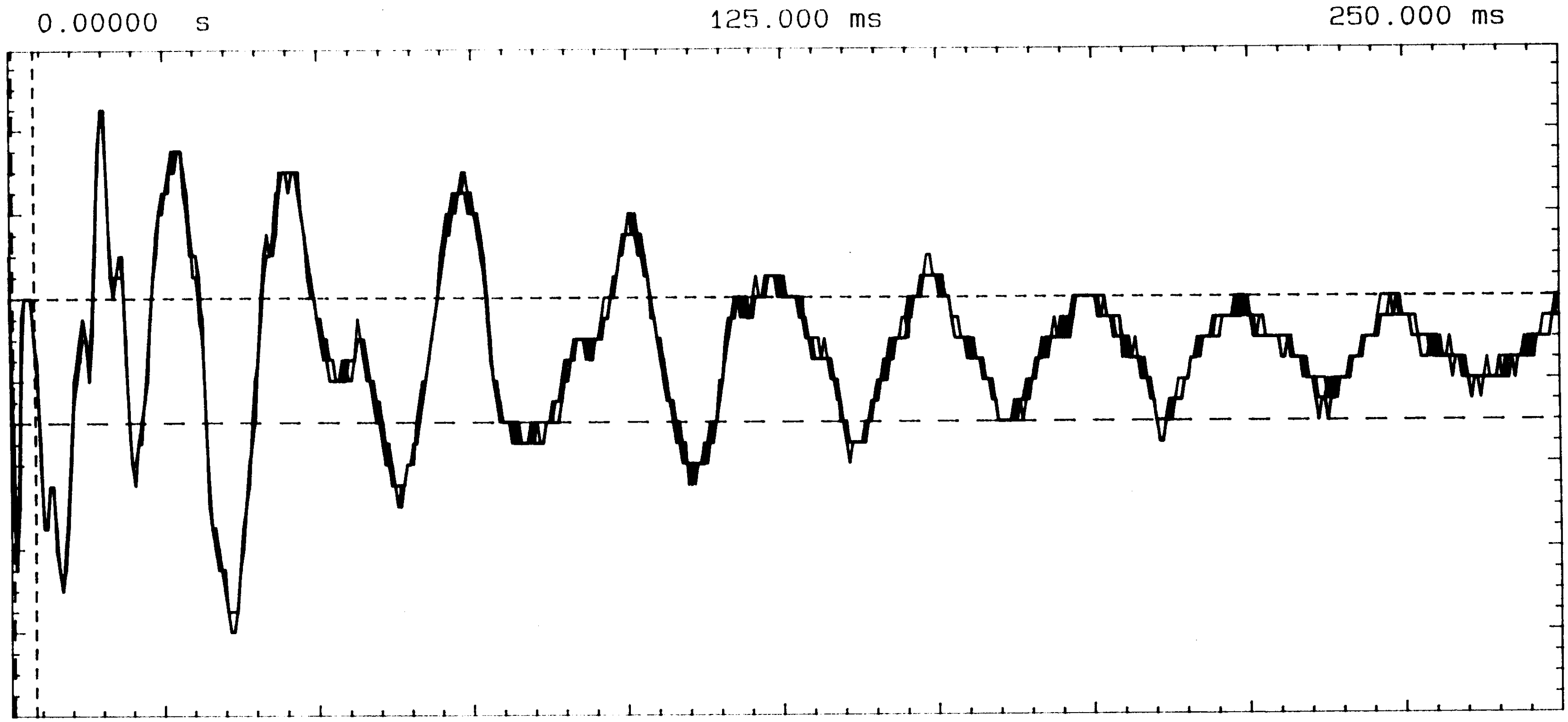
Top Trace:	Ceramic Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Ceramic Specimen	Oil Core	Un-filtered Input	



Top Trace: Ceramic Specimen Oil Core Filtrered Input

Bottom Trace: Ceramic Specimen Oil Core Un-filtered Input

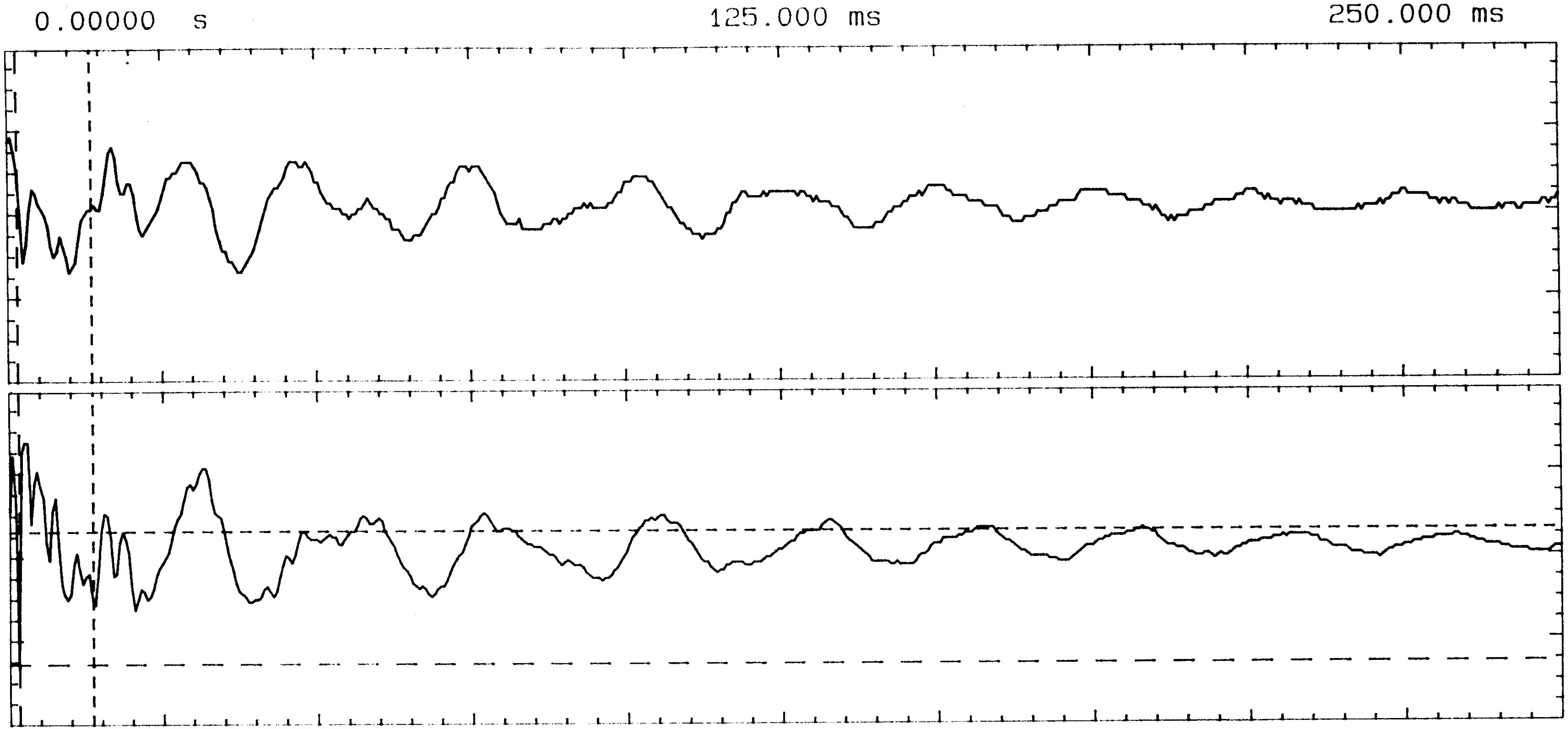
Frequency-Space



```
Ch. 1      =  50.00 mvolts/div                                            Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay     =  0.00000  s
Memory 1   =  50.00 mvolts/div                                            Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay     =  0.00000  s
Memory 2   =  50.00 mvolts/div                                            Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay     =  0.00000  s
Memory 3   =  50.00 mvolts/div                                            Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay     =  0.00000  s
Memory 4   =  50.00 mvolts/div                                            Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                                 Delay     =  0.00000  s
Ch. 1 Parameters                Freq.      =  260.325  Hz                 Period    =  3.84135 ms
Rise Time =  11.7939 ms         + Width    =  2.02051 ms                  - Width   =  1.82083 ms
Fall Time =  319.765 us         Preshoot   =  112.5 mvolts                Overshoot =  112.5 mvolts
P-P Volts =  300.0 mvolts       RMS Volts  =  58.30 mvolts                Dutycycle =  52.59 %
```

Trace: Ceramic Specimen Sand/Oil Core Filtrered Input

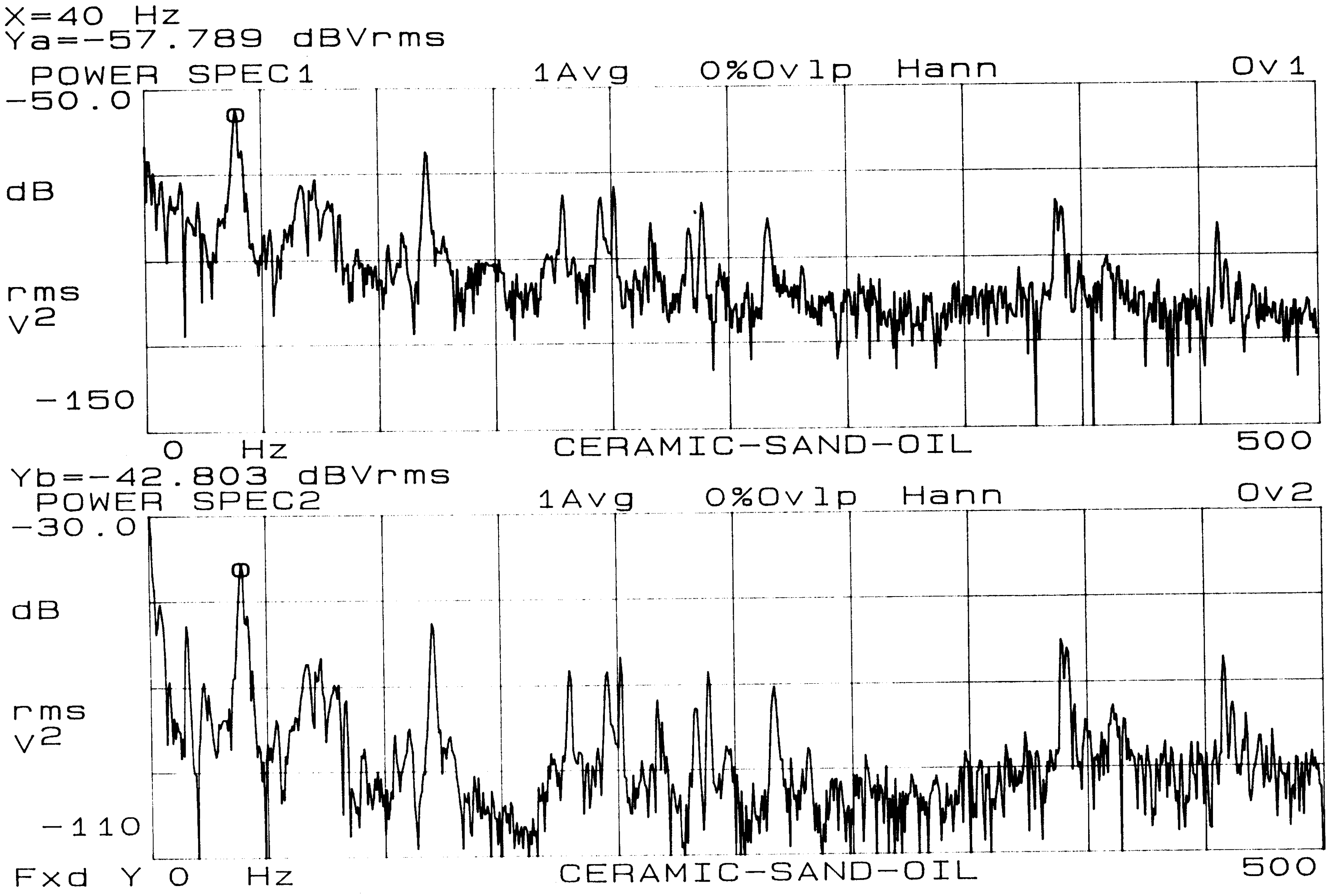
Four Trace Overlay in Time-Space



```
Ch. 1     =  200.0 mvolts/div                                            Offset    =  0.000  volts
Ch. 2     =  1.000  volts/div                                            Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                                 Delay     =  0.00000  s
Ch. 2 Parameters                    Freq.      =  80.5544  Hz            Period    =  12.4140 ms
Rise Time =  251.832 us             + Width    =  12.0509 ms             - Width   =  363.053 us
Fall Time =  329.007 us             Preshoot   =  1.062  volts           Overshoot =  0.000  volts
P-P Volts =  2.656  volts           RMS Volts  =  700.5 mvolts           Dutycycle =  97.07 %
```

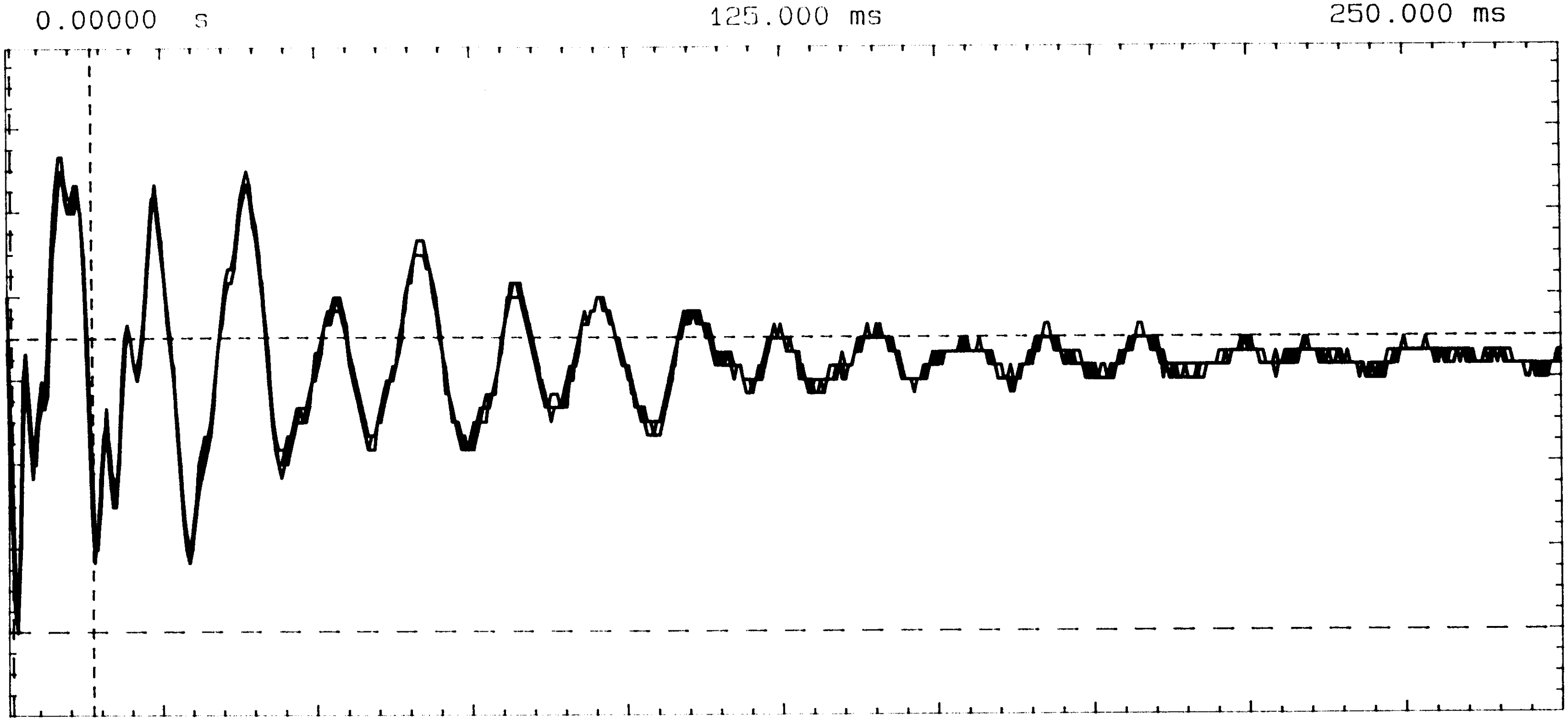
Top Trace: Ceramic Specimen Sand/Oil Core Filtrered Input Time-Space

Bottom Trace: Ceramic Specimen Sand/Oil Core Un-filtered Input



Top Trace: Ceramic Specimen Sand/Oil Core Filtrered Input Frequency-Space

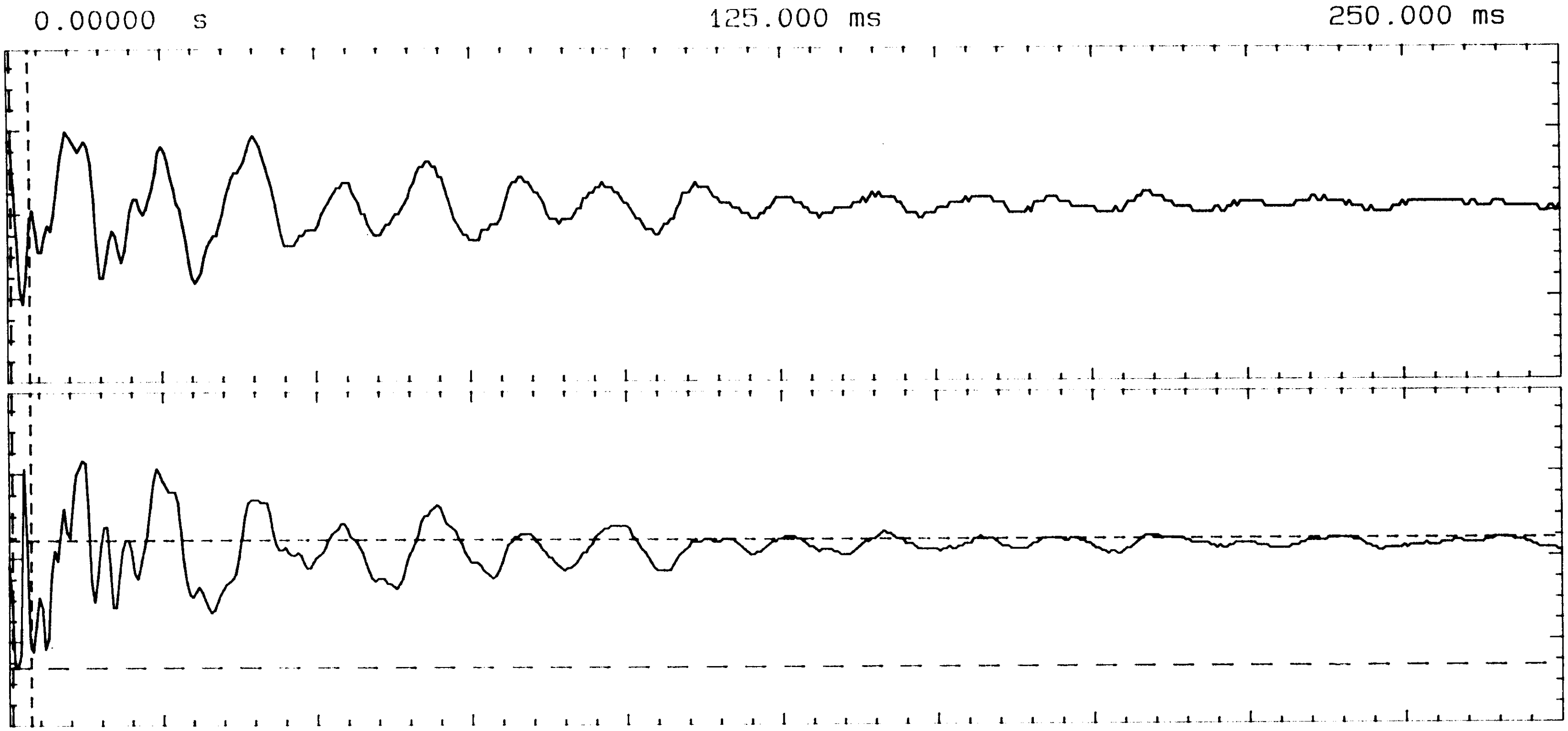
Bottom Trace: Ceramic Specimen Sand/Oil Core Un-filtered Input



```
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 1   =  75.00 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 2   =  75.00 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 3   =  75.00 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 4   =  75.00 mvolts/div                                               Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                    Delay      =  0.00000  s
Mem 1 Parameters                      Freq.       =  78.6676  Hz             Period     =  12.7117 ms
Rise Time =  4.64185 ms               + Width     =  11.1558 ms              - Width    =  1.55595 ms
Fall Time =  1.03479 ms               Preshoot    =  161.7 mvolts            Overshoot  =  0.000  volts
P-P Volts =  424.2 mvolts             RMS Volts   =  124.2 mvolts            Dutycycle  =  87.75 %
```

Trace: Ceramic Specimen Lead Shot/Oil Core Filtrered Input

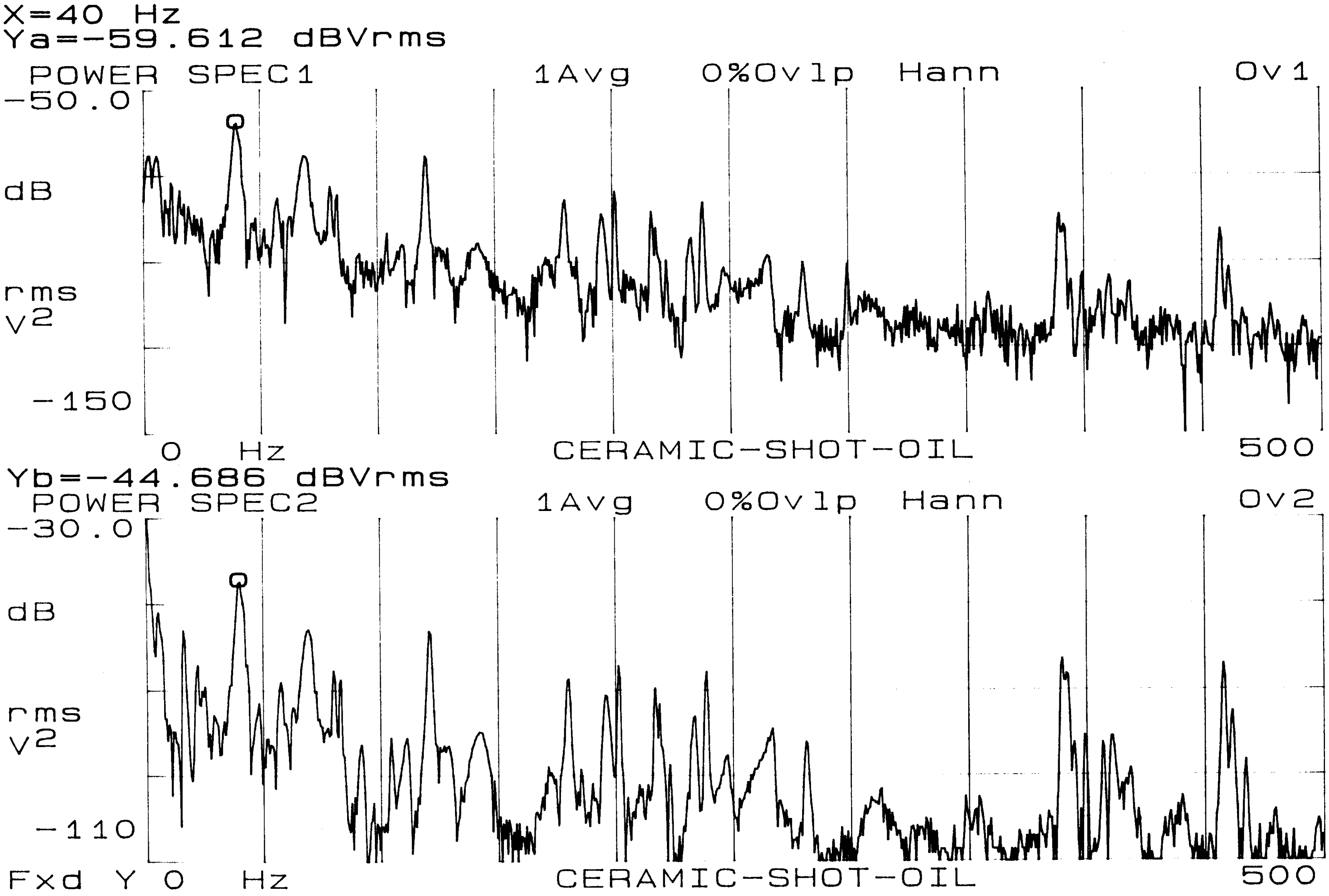
Four Trace Overlay in Time-Space



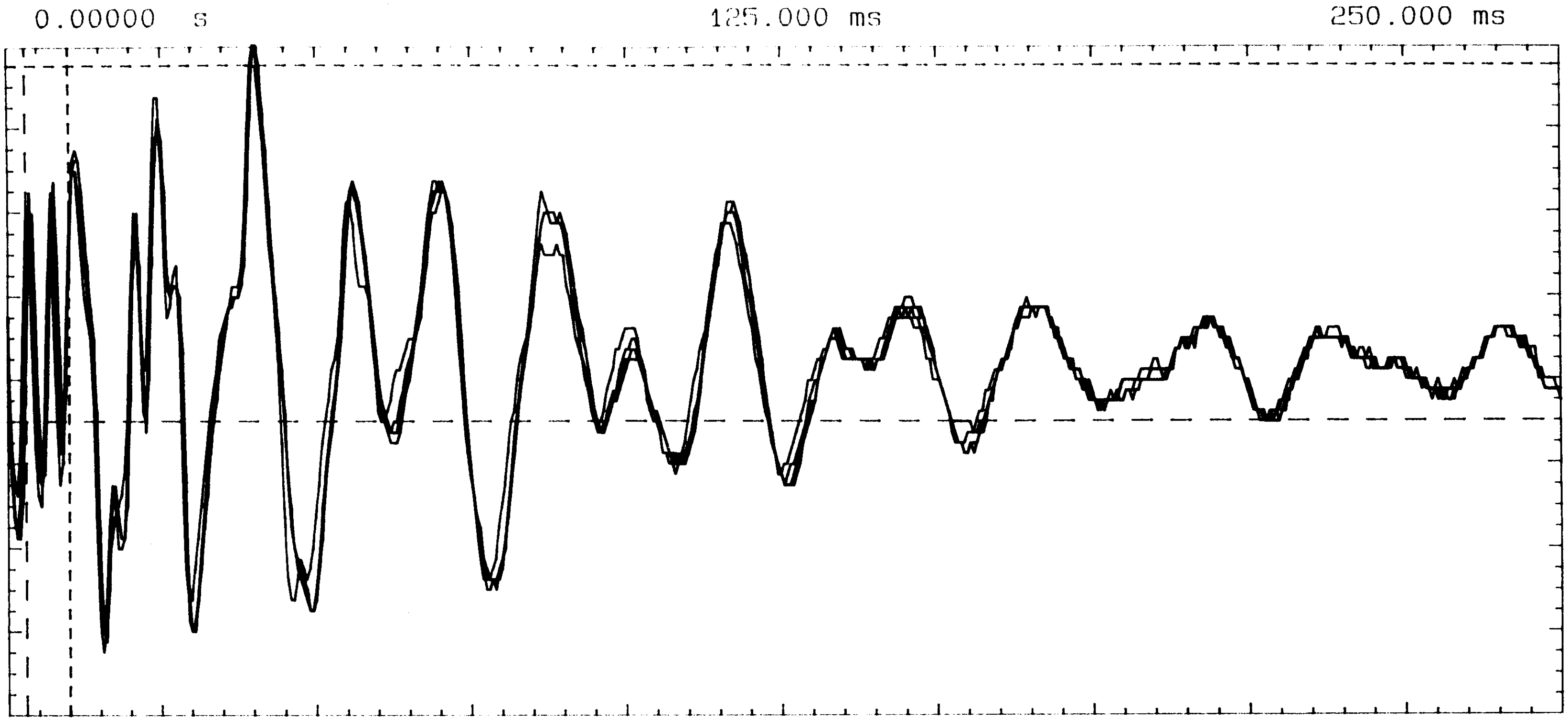
```
Ch. 1     =  200.0 mvolts/div                                          Offset     =  0.000  volts
Ch. 2     =  1.000  volts/div                                          Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                               Delay      =  0.00000  s
Ch. 2 Parameters                       Freq.       =  365.799  Hz      Period     =  2.73375 ms
Rise Time =  566.173 us                + Width     =  1.17678 ms        - Width   =  1.55697 ms
Preshoot  =  937.5 mvolts              Overshoot =  0.000  volts       P-P Volts  =  2.468  volts
RMS Volts =  1.003  volts              Dutycycle =  43.04 %
```

Top Trace: Ceramic Specimen Lead Shot/Oil Core Filtrered Input Time-Space

Bottom Trace: Ceramic Specimen Lead Shot/Oil Core Un-filtered Input



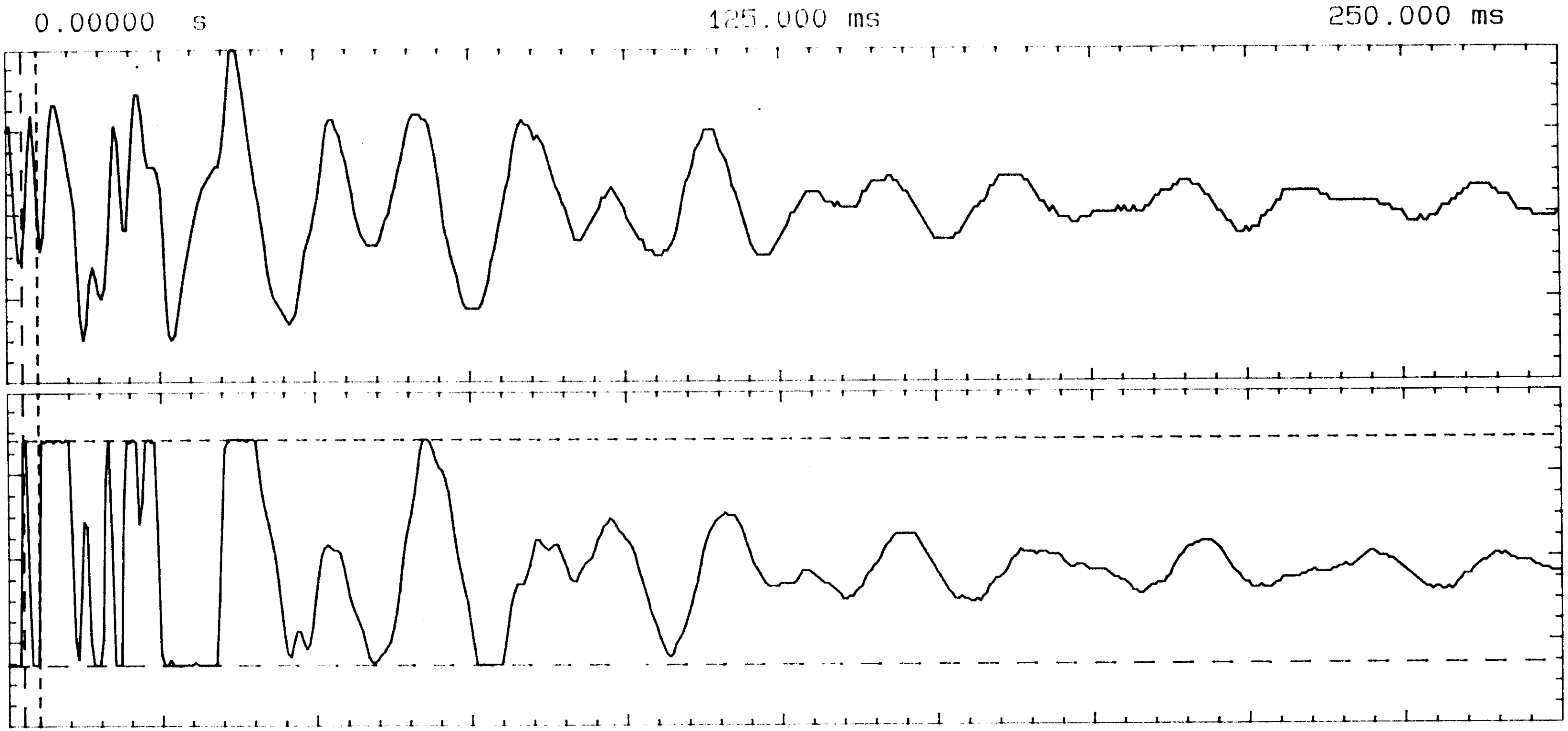
Top Trace:	**Ceramic Specimen**	**Lead Shot/Oil Core**	**Filtrered Input**	**Frequency-Space**
Bottom Trace:	**Ceramic Specimen**	**Lead Shot/Oil Core**	**Un-filtered Input**	



```
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 1  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 2  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 3  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Memory 4  =  100.0 mvolts/div                                     Offset    =  0.000  volts
Timebase  =  25.0 ms/div                                          Delay     =  0.00000  s
Mem 1 Parameters                  Freq.      =  139.718  Hz       Period    =  7.15729 ms
Rise Time =  37.1352 ms           + Width    =  455.826 us        - Width   =  6.70147 ms
Fall Time = -36.7623 ms           Preshoot   =  275.0 mvolts      Overshoot =  0.000  volts
P-P Volts =  700.1 mvolts         RMS Volts  =  121.7 mvolts      Dutycycle =  6.368 %
```

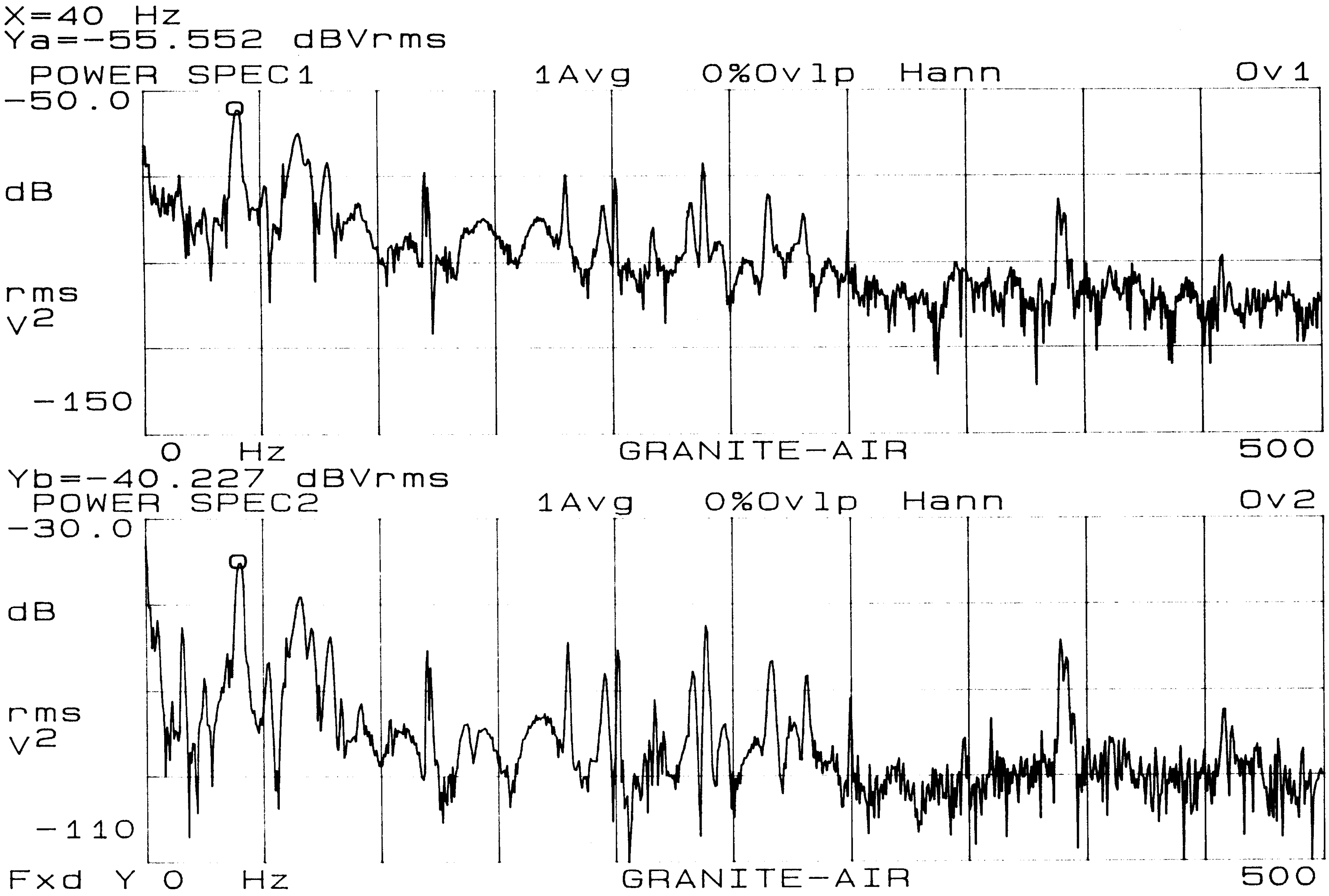
Trace: Granite Specimen Air Core Filtrered Input

Four Trace Overlay in Time-Space

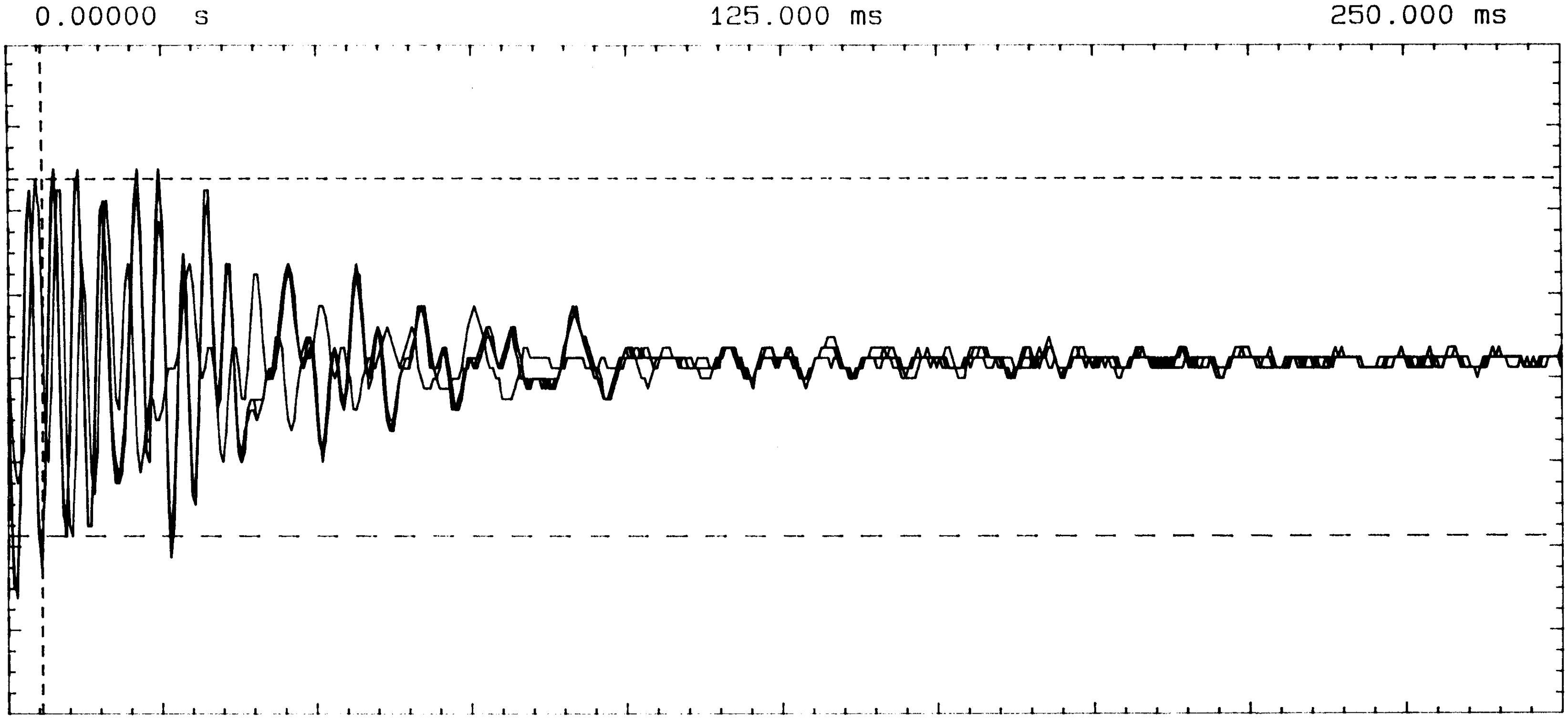


```
Ch. 1      =  200.0 mvolts/div                                        Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                        Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                             Delay      =  0.00000  s
Ch. 2 Parameters                          Freq.        =  333.660  Hz     Period     =  2.99706 ms
Rise Time =  404.687 us                   + Width      =  1.13797 ms      - Width    =  1.85909 ms
Fall Time =  783.070 us                   Preshoot     =  0.000  volts    Overshoot  =  0.000  volts
P-P Volts =  2.687  volts                 RMS Volts    =  1.217  volts    Dutycycle  =  37.96 %
```

Top Trace:	Granite Specimen	Air Core	Filtrered Input	Time-Space
Bottom Trace:	Granite Specimen	Air Core	Un-filtered Input	



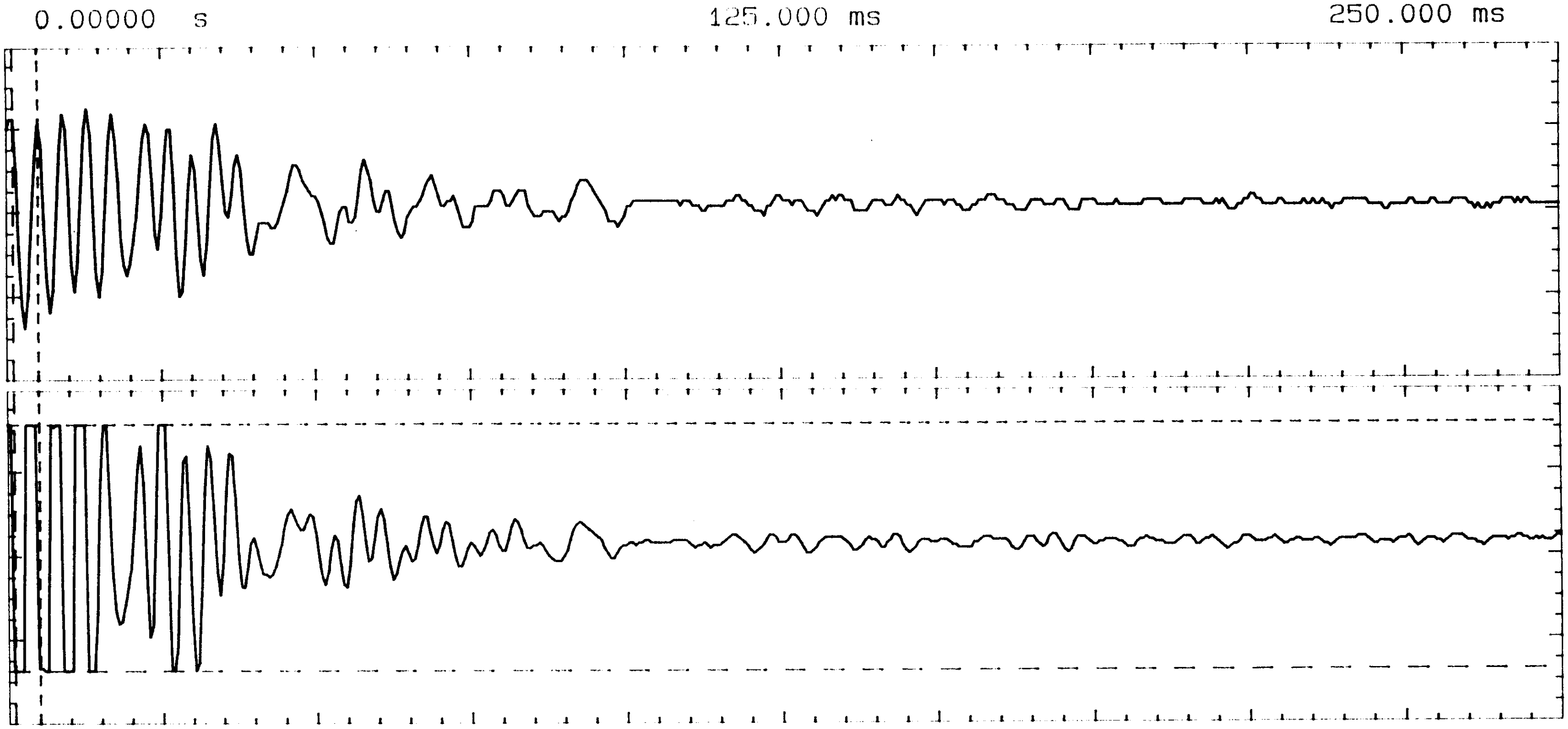
Top Trace:	Granite Specimen	Air Core	Filtrered Input	Frequency-Space
Bottom Trace:	Granite Specimen	Air Core	Un-filtered Input	



```
Timebase  =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 1  =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 2  =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 3  =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                    Delay      =  0.00000  s
Memory 4  =  100.0 mvolts/div                                               Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                                    Delay      =  0.00000  s
Mem 3 Parameters                      Freq.      =  179.370  Hz             Period     =  5.57508 ms
Rise Time = -2.86227 ms               + Width    =  2.44944 ms              - Width    =  3.12564 ms
Fall Time =  4.99932 ms               Preshoot   =  0.000  volts            Overshoot  =  0.000  volts
P-P Volts =  425.0 mvolts             RMS Volts  =  127.2 mvolts            Dutycycle  =  43.93 %
```

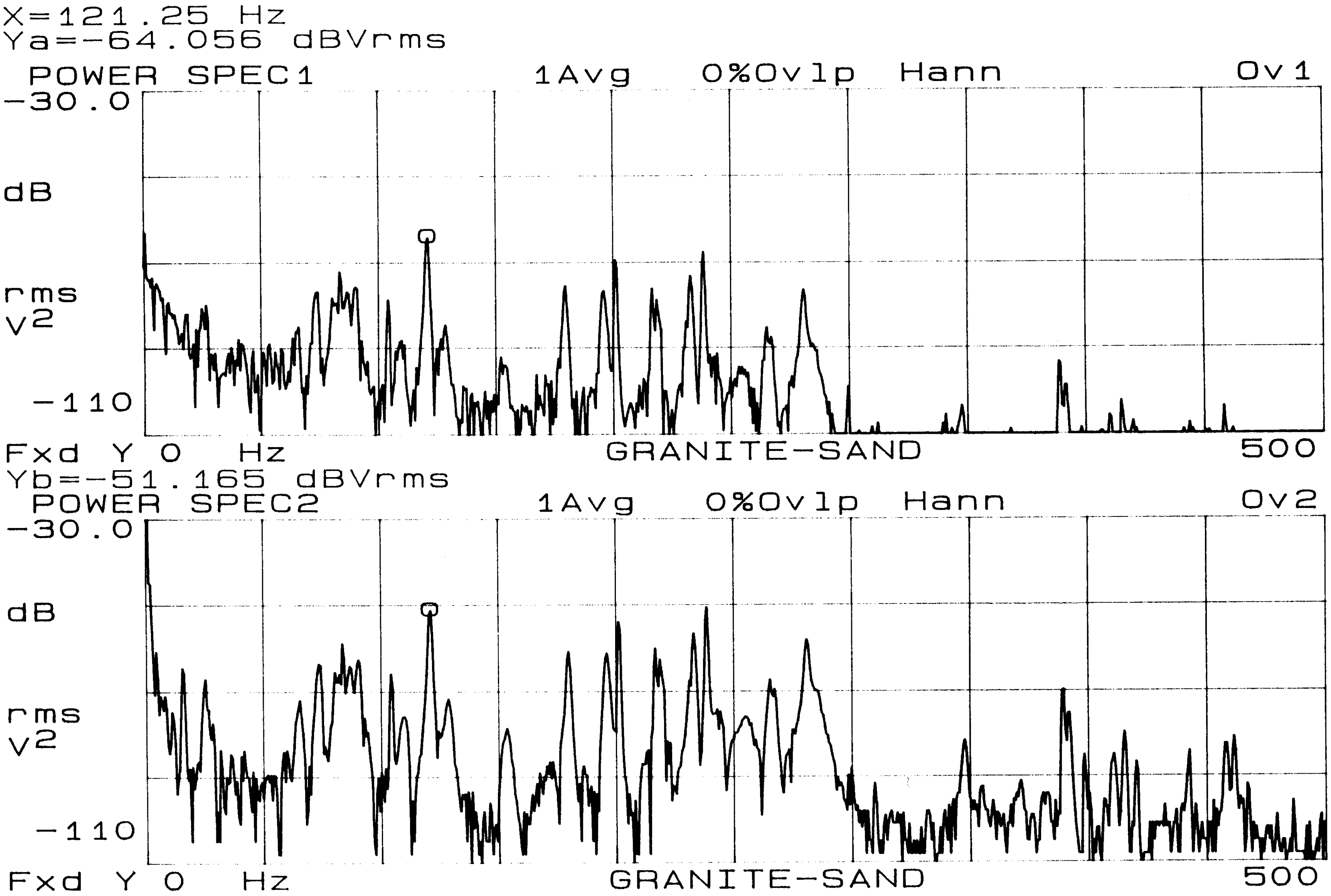
Trace: Granite Specimen Sand Core Filtrered Input

Four Trace Overlay in Time-Space



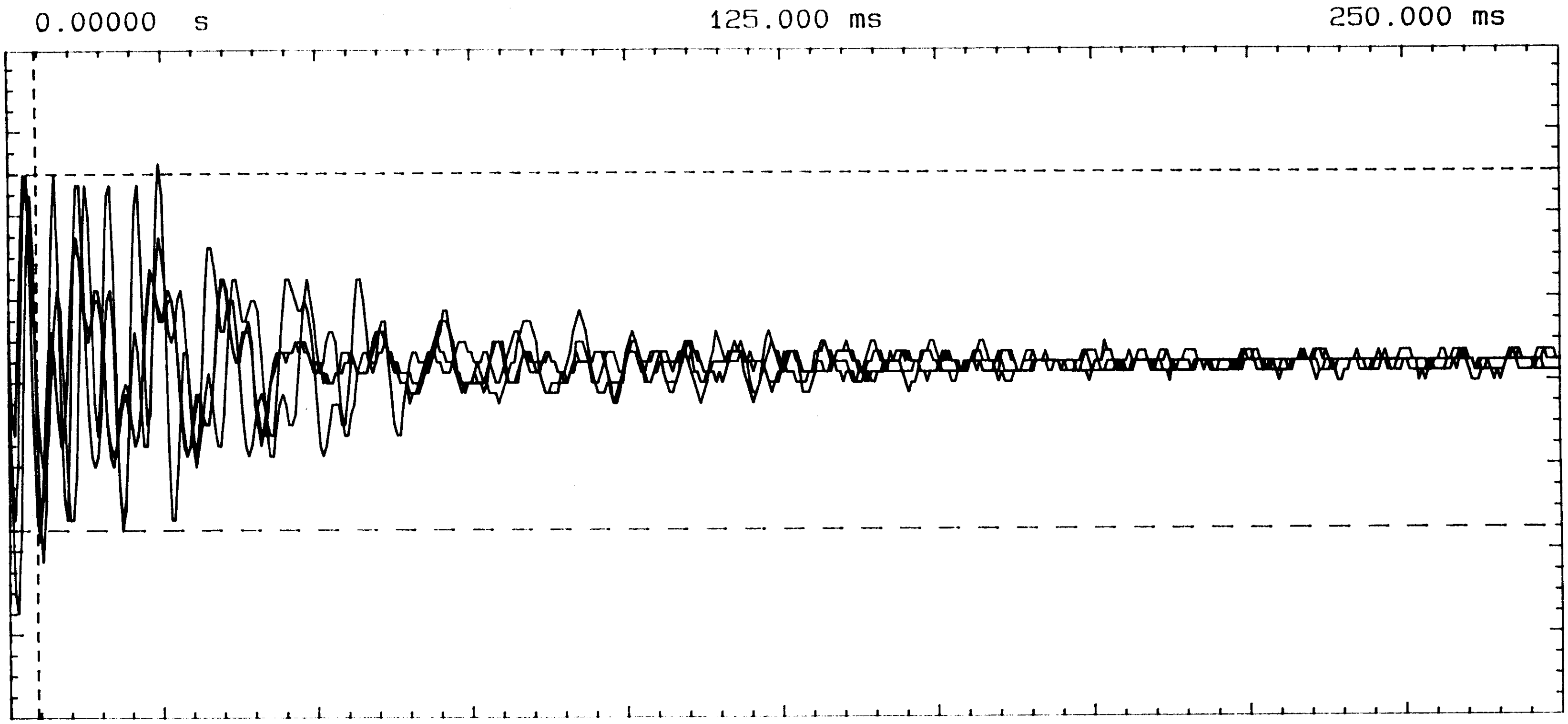
```
Ch. 1      =  200.0 mvolts/div                                  Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                  Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                       Delay      =  0.00000  s
Ch. 2 Parameters               Freq.      =  249.832  Hz        Period     =  4.00269 ms
Rise Time =  400.017 us        + Width    =  2.00269 ms         - Width    =  2.00000 ms
Fall Time =  400.017 us        Preshoot   =  0.000   volts      Overshoot =  0.000  volts
P-P Volts =  2.937   volts     RMS Volts  =  1.458   volts      Dutycycle =  50.03 %
```

Top Trace:	Granite Specimen	Sand Core	Filtrered Input	Time-Space
Bottom Trace:	Granite Specimen	Sand Core	Un-filtered Input	



Top Trace:	Granite Specimen	Sand Core	Filtrered Input
Bottom Trace:	Granite Specimen	Sand Core	Un-filtered Input

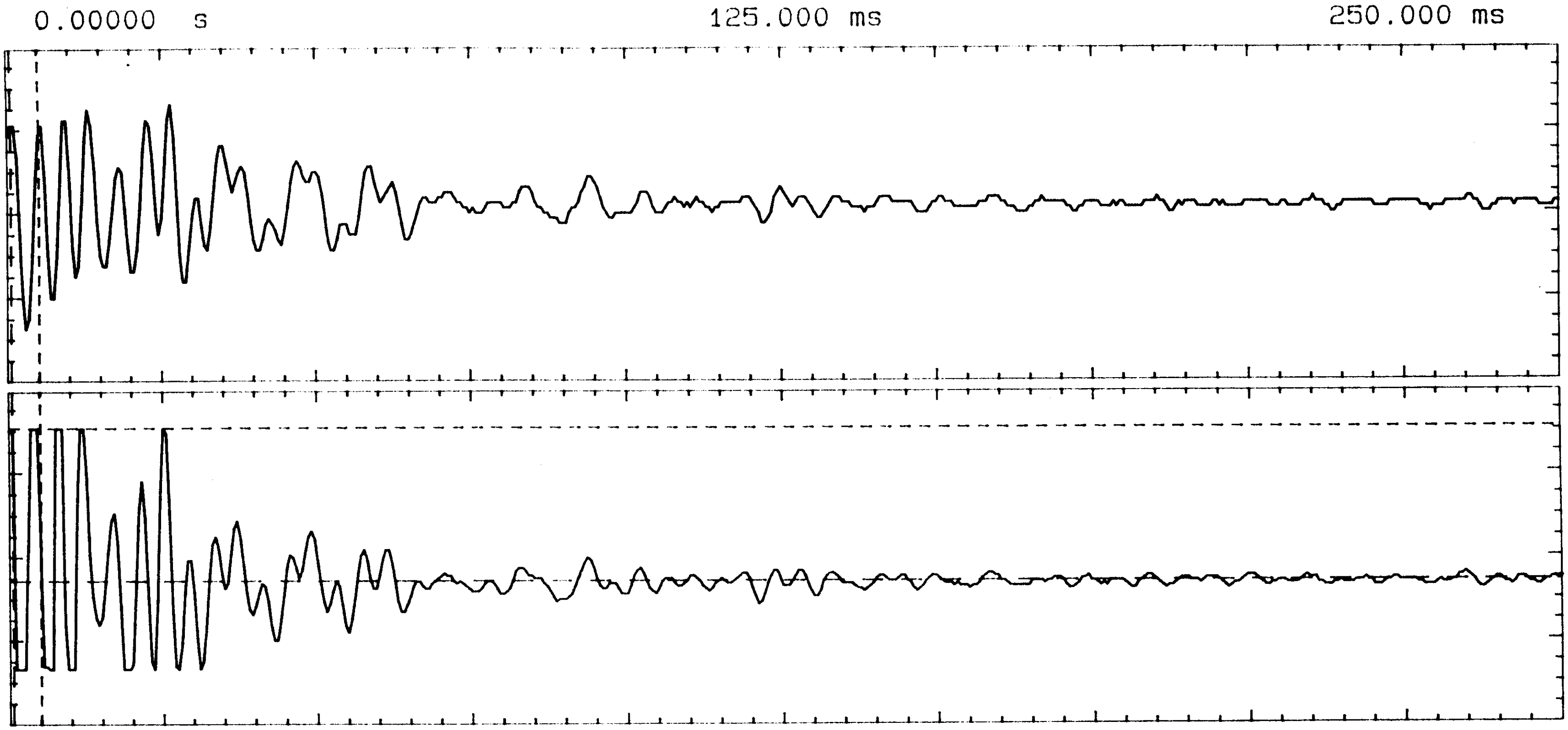
Frequency-Space



```
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                           Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                                Delay      =  0.00000  s
Mem 1 Parameters                        Freq.       =  233.646  Hz       Period     =  4.27998 ms
Rise Time =  1.43359 ms                 + Width     =  2.43339 ms         - Width   =  1.84658 ms
Fall Time =  6.42154 ms                 Preshoot    =  0.000  volts      Overshoot  =  0.000  volts
P-P Volts =  425.0 mvolts               RMS Volts   =  145.6 mvolts      Dutycycle  =  56.85 %
```

Trace: Granite Specimen Lead Shot Core Filtrered Input

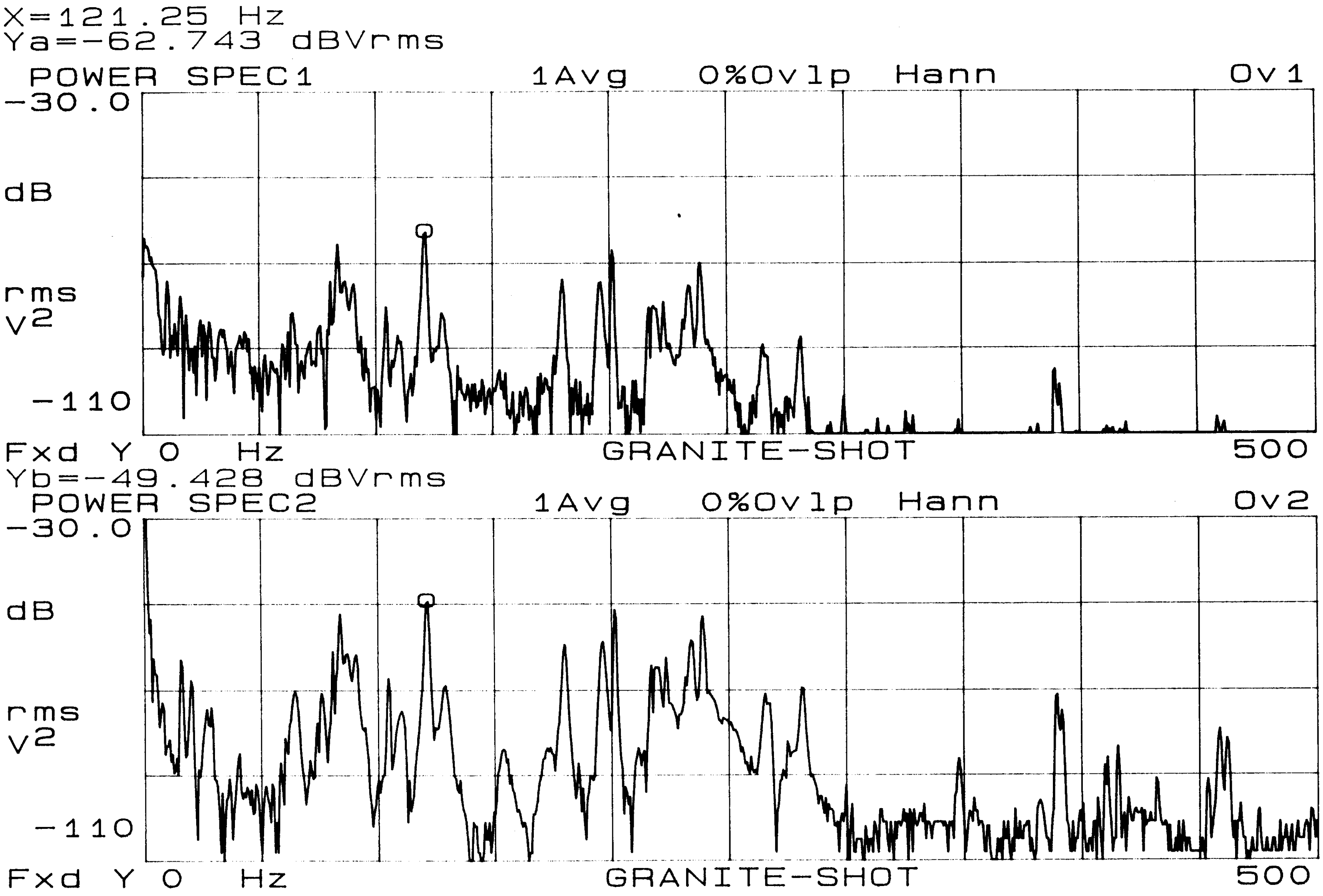
Four Trace Overlay in Time-Space



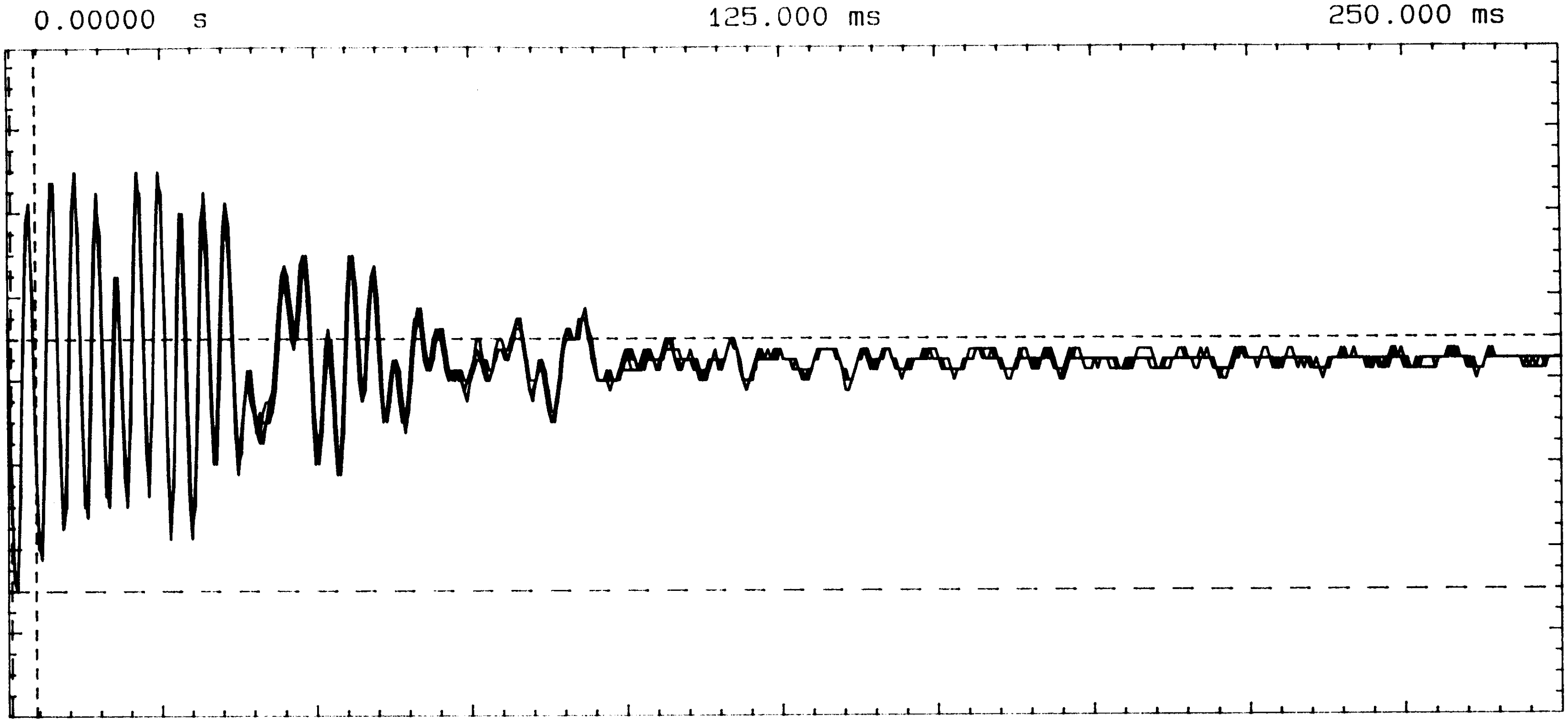
```
Ch. 1      =  200.0 mvolts/div                                       Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                       Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                            Delay      =  0.00000  s
Ch. 2 Parameters                   Freq.      =  238.799  Hz         Period     =  4.18763 ms
Rise Time =  487.294 us            + Width    =  1.64732 ms          - Width    =  2.54031 ms
Fall Time =  252.165 us            Preshoot   =  0.000   volts       Overshoot  =  1.062  volts
P-P Volts =  2.875  volts          RMS Volts  =  1.290   volts       Dutycycle  =  39.33 %
```

Top Trace: Granite Specimen Lead Shot Core Filtrered Input Time-Space

Bottom Trace: Granite Specimen Lead Shot Core Un-filtered Input



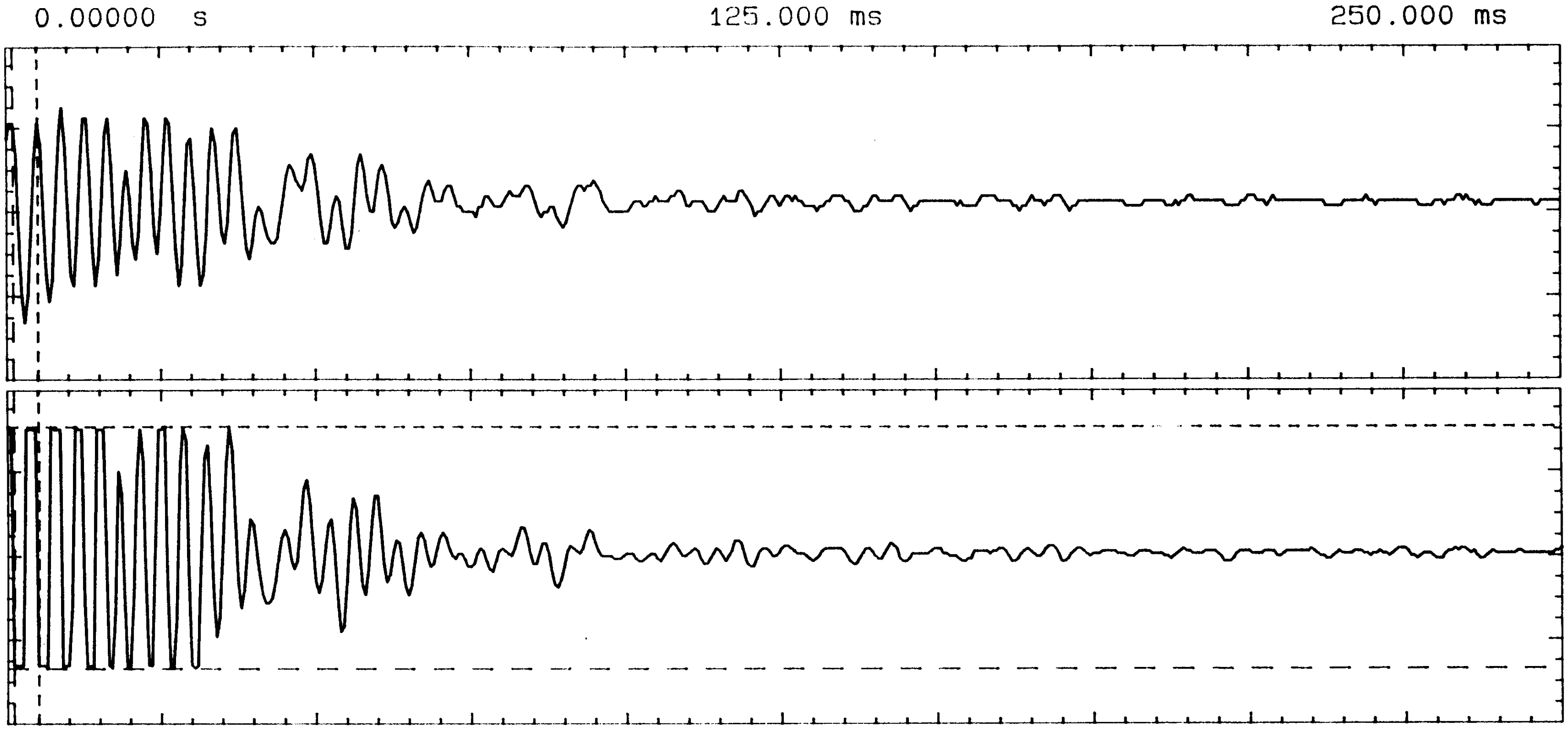
Top Trace:	Granite Specimen	Lead Shot Core	Filtrered Input	Frequency-Space
Bottom Trace:	Granite Specimen	Lead Shot Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 1   =  100.0 mvolts/div                                                 Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 2   =  100.0 mvolts/div                                                 Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 3   =  100.0 mvolts/div                                                 Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Memory 4   =  100.0 mvolts/div                                                 Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                                      Delay      =  0.00000  s
Mem 2 Parameters                  Freq.       =  237.929  Hz                   Period     =  4.20294  ms
Rise Time  =  794.414 us          + Width     =  2.56467  ms                   - Width    =  1.63827  ms
Fall Time  =  809.003 us          Preshoot    =  200.0 mvolts                  Overshoot  =  0.000   volts
P-P Volts  =  500.0 mvolts        RMS Volts   =  164.5 mvolts                  Dutycycle  =  61.02 %
```

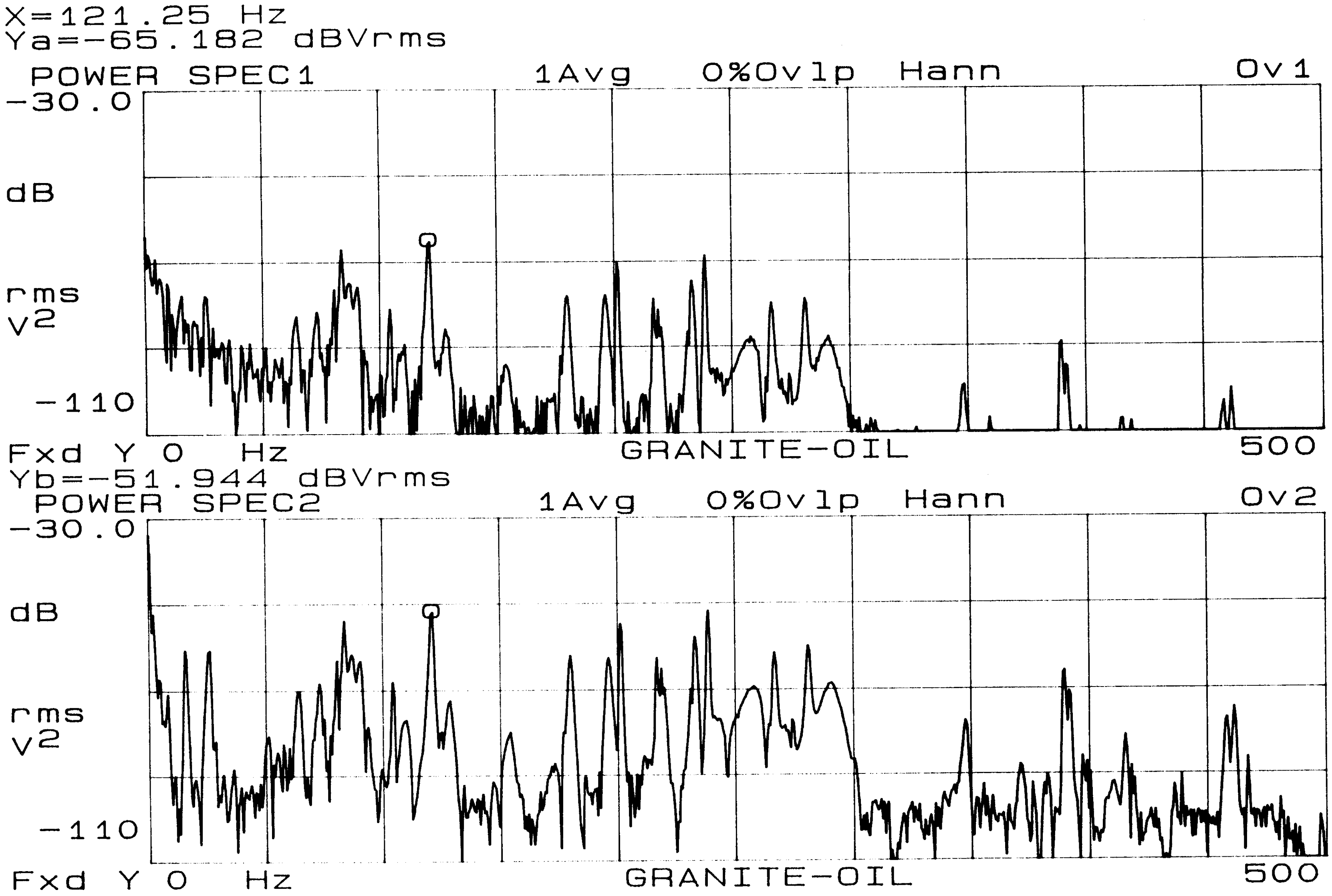
Trace: Granite Specimen Oil Core Filtrered Input

Four Trace Overlay in Time-Space

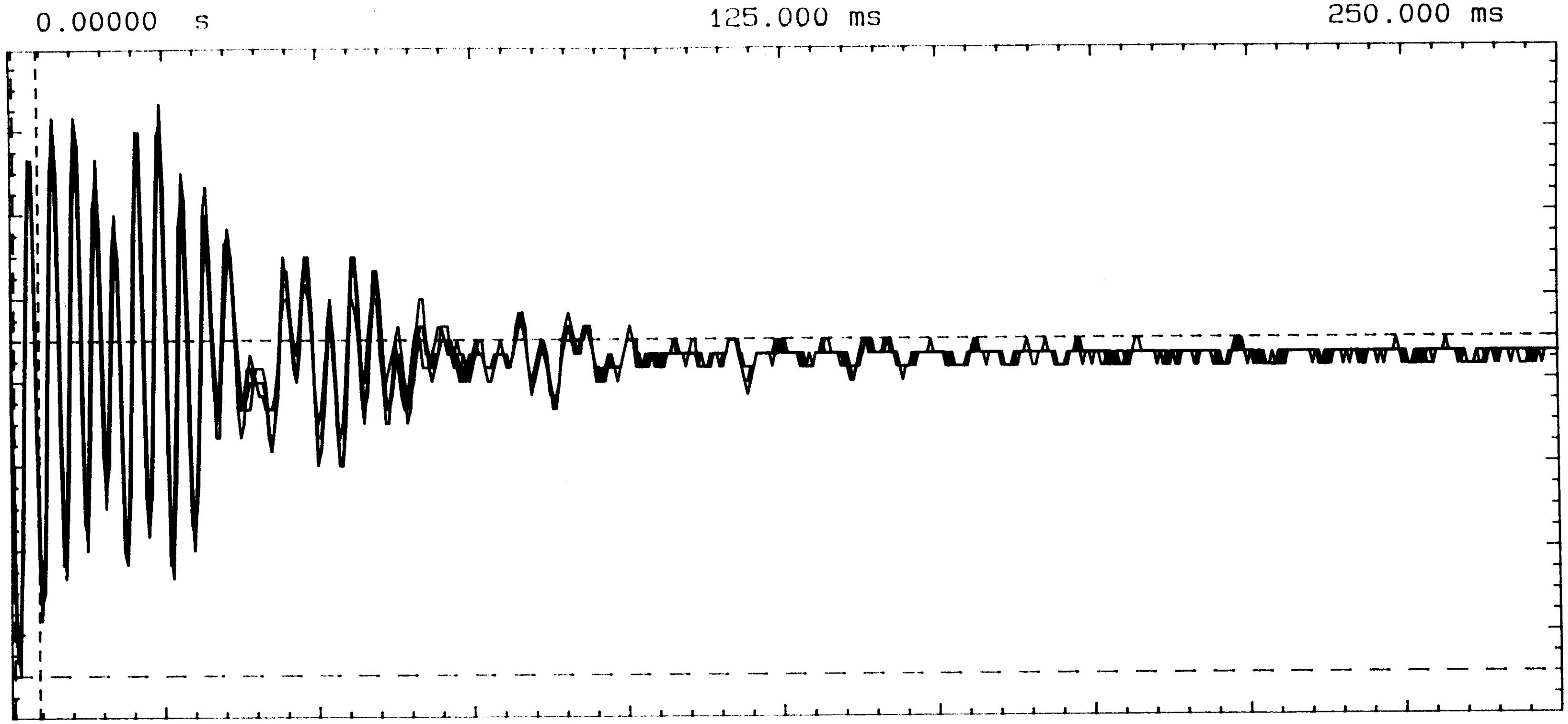


```
Ch. 1      =  200.0 mvolts/div                                      Offset     =  0.000   volts
Ch. 2      =  1.000  volts/div                                      Offset     =  0.000   volts
Timebase   =  25.0 ms/div                                           Delay      =  0.00000  s
Ch. 2 Parameters                      Freq.      =  250.000  Hz     Period     =  4.00000 ms
Rise Time =  408.898 us               + Width    =  2.00000 ms      - Width    =  2.00000 ms
Fall Time =  408.898 us               Preshoot   =  0.000   volts   Overshoot =  0.000   volts
P-P Volts =  2.875  volts             RMS Volts =  1.398   volts    Dutycycle =  50.00 %
```

Top Trace:	Granite Specimen	Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Granite Specimen	Oil Core	Un-filtered Input	



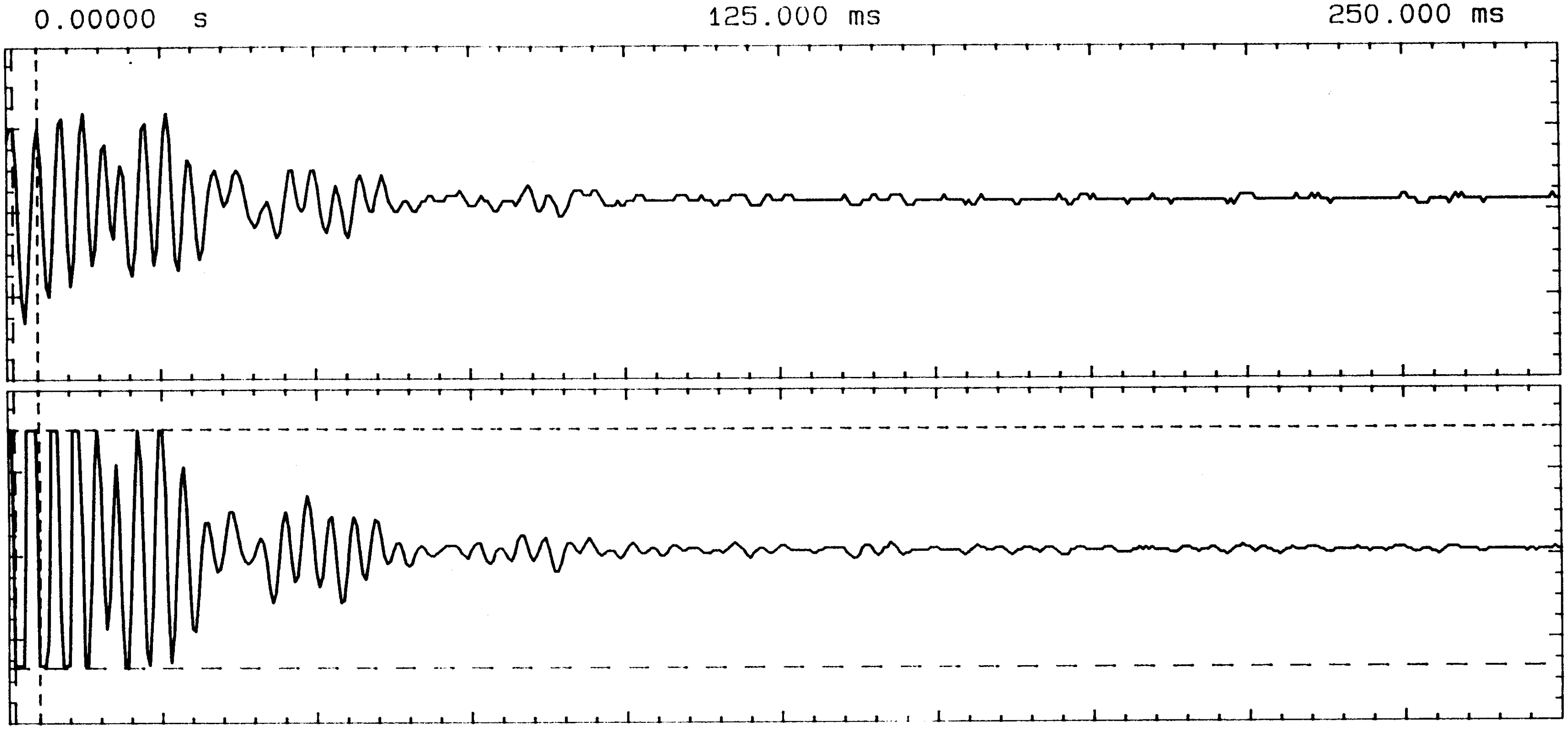
Top Trace:	Granite Specimen	Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Granite Specimen	Oil Core	Un-filtered Input	



```
Timebase   =  25.0 ms/div                                         Delay     =  0.00000  s
Memory 1   =  75.00 mvolts/div                                    Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                         Delay     =  0.00000  s
Memory 2   =  75.00 mvolts/div                                    Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                         Delay     =  0.00000  s
Memory 3   =  75.00 mvolts/div                                    Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                         Delay     =  0.00000  s
Memory 4   =  75.00 mvolts/div                                    Offset    =  0.000  volts
Timebase   =  25.0 ms/div                                         Delay     =  0.00000  s
Mem 4 Parameters                 Freq.      =  263.292  Hz        Period    =  3.79807 ms
Rise Time =  816.678 us          + Width    =  2.26761 ms         - Width   =  1.53046 ms
Fall Time =  988.808 us          Preshoot   =  199.2 mvolts       Overshoot =  0.000  volts
P-P Volts =  499.2 mvolts        RMS Volts  =  161.7 mvolts       Dutycycle =  59.70 %
```

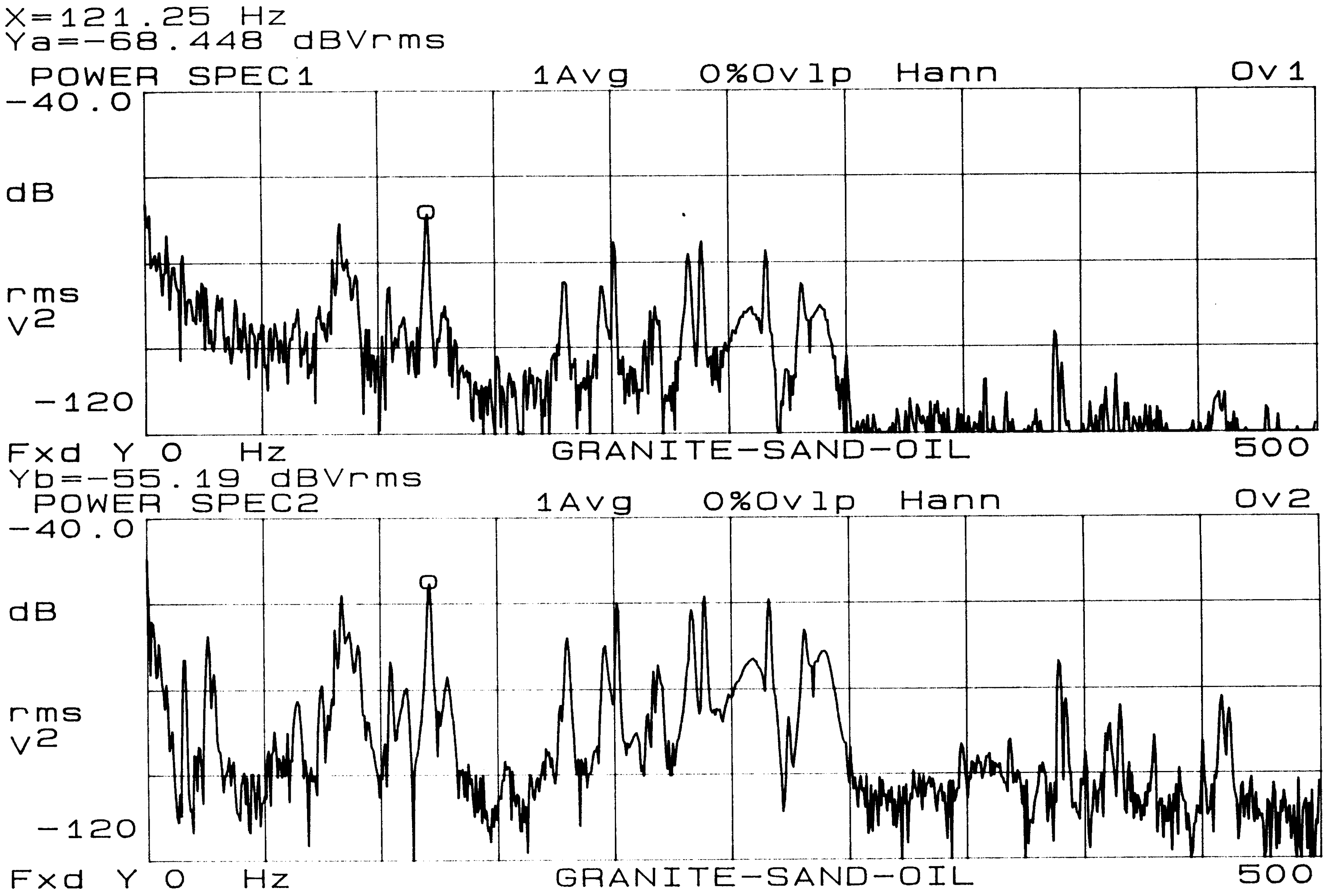
Trace: Granite Specimen Sand/Oil Core Filtrered Input

Four Trace Overlay in Time-Space

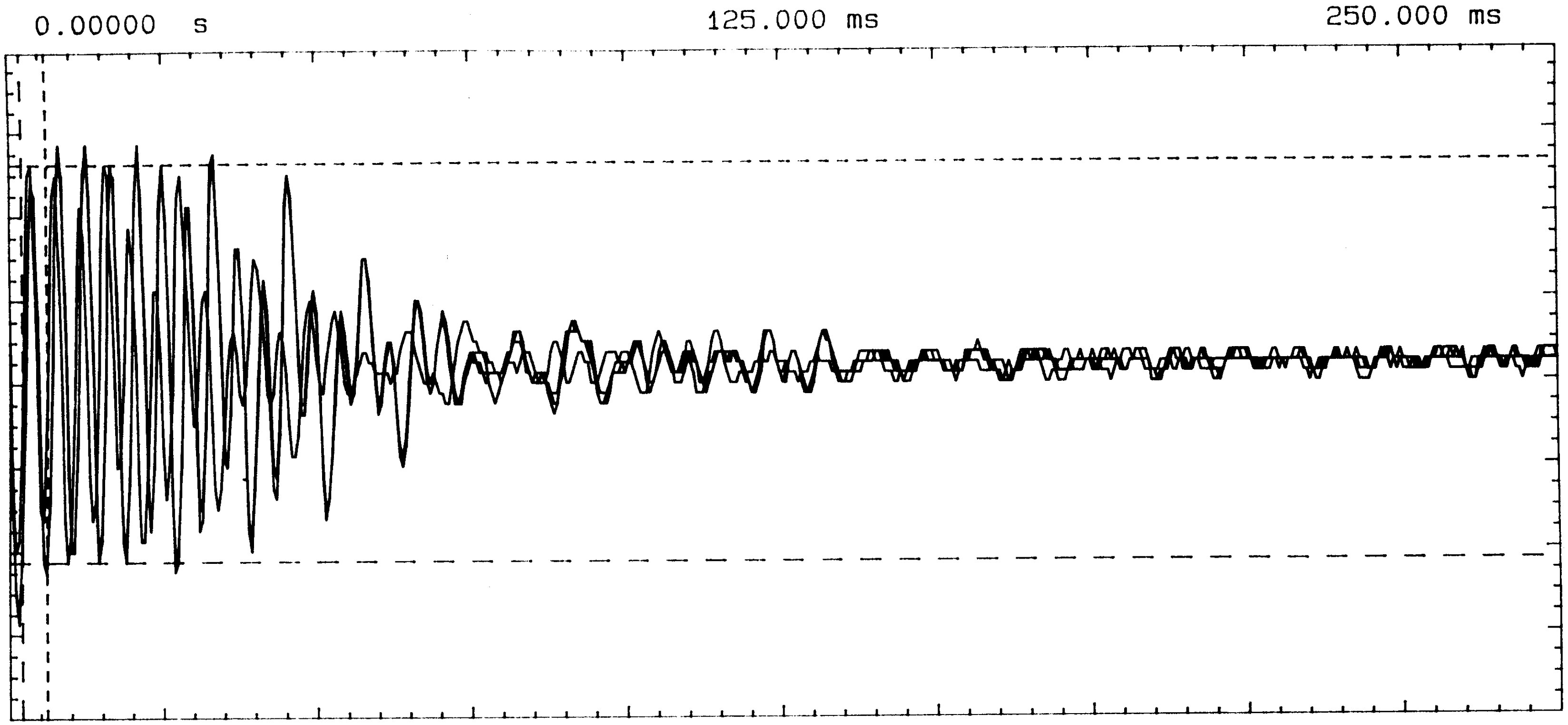


```
Ch. 1     =  200.0 mvolts/div                                                   Offset     =  0.000   volts
Ch. 2     =  1.000  volts/div                                                   Offset     =  0.000   volts
Timebase  =  25.0 ms/div                                                        Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.      =  250.000  Hz                  Period     =  4.00000 ms
Rise Time =  404.427 us             + Width    =  2.00556 ms                   - Width    =  1.99444 ms
Fall Time =  404.427 us             Preshoot   =  0.000   volts                Overshoot  =  0.000   volts
P-P Volts =  2.843   volts          RMS Volts  =  1.398   volts                Dutycycle  =  50.13 %
```

Top Trace:	Granite Specimen	Sand/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Granite Specimen	Sand/Oil Core	Un-filtered Input	



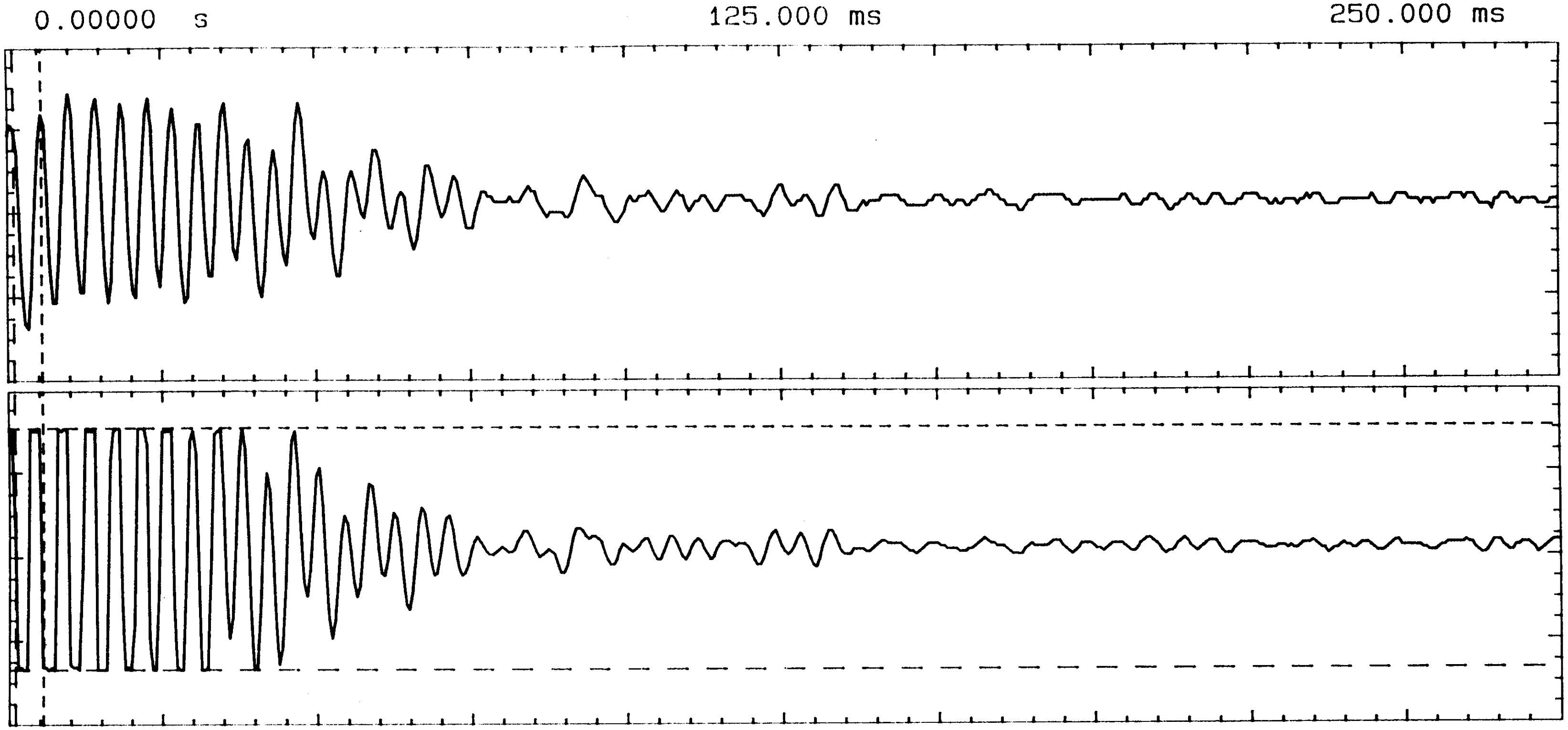
Top Trace:	Granite Specimen	Sand/Oil Core	Filtrered Input	Frequency-Space
Bottom Trace:	Granite Specimen	Sand/Oil Core	Un-filtered Input	



```
Timebase  =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 1  =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 2  =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 3  =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                            Delay      =  0.00000  s
Memory 4  =  100.0 mvolts/div                                       Offset     =  0.000  volts
Timebase  =  25.0 ms/div                                            Delay      =  0.00000  s
Mem 4 Parameters                 Freq.      =  250.159  Hz          Period     =  3.99746 ms
Rise Time =  1.27027 ms          + Width    =  2.15911 ms           - Width    =  1.83836 ms
Fall Time =  5.43169 ms          Preshoot   =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  475.0 mvolts        RMS Volts  =  159.5 mvolts         Dutycycle  =  54.01 %
```

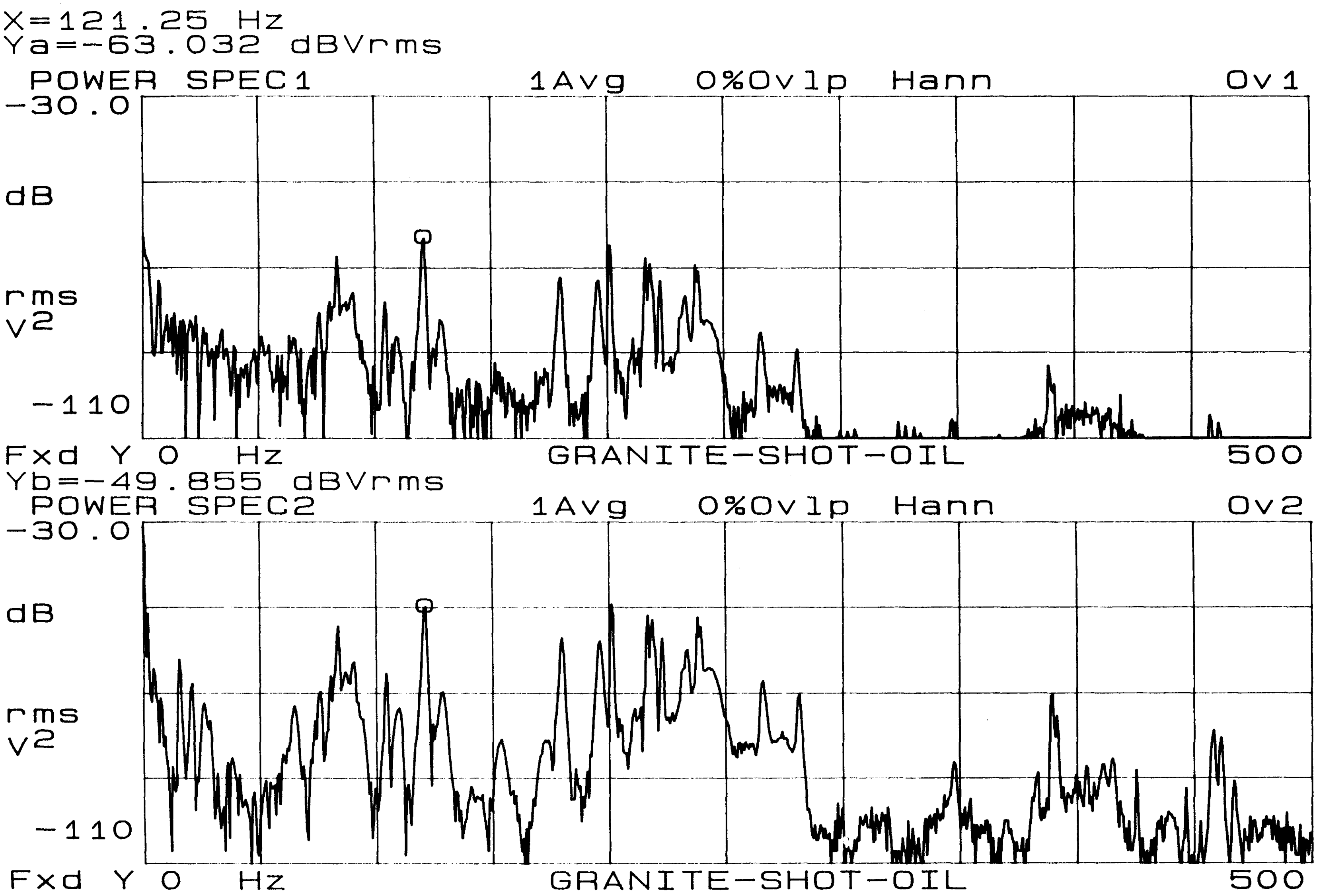
Trace: Granite Specimen Lead Shot/Oil Core Filtrered Input

Four Trace Overlay in Time-Space



```
Ch. 1      =  200.0 mvolts/div                                          Offset     =  0.000  volts
Ch. 2      =  1.000  volts/div                                          Offset     =  0.000  volts
Timebase   =  25.0 ms/div                                               Delay      =  0.00000  s
Ch. 2 Parameters                    Freq.       =  239.842  Hz          Period     =  4.16941 ms
Rise Time =  404.404 us             + Width     =  2.00000 ms           - Width    =  2.16941 ms
Fall Time =  810.203 us             Preshoot    =  0.000  volts         Overshoot  =  0.000  volts
P-P Volts =  2.875  volts           RMS Volts   =  1.342  volts         Dutycycle  =  47.96 %
```

Top Trace:	Granite Specimen	Lead Shot/Oil Core	Filtrered Input	Time-Space
Bottom Trace:	Granite Specimen	Lead Shot/Oil Core	Un-filtered Input	



Top Trace:	Granite Specimen	Lead Shot/Oil Core	Filtrered Input
Bottom Trace:	Granite Specimen	Lead Shot/Oil Core	Un-filtered Input

Frequency-Space

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