T-2986

A PHYSICAL METHOD FOR THE FIELD MEASUREMENT OF THE ATTENUATION OF MUFF-TYPE HEARING PROTECTORS

by

Robert Roy Stein

T-2986

A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science, Mine Health and Safety.

Golden, Colorado

Date 5/19/86

Signed: Robert Roy Stein

Robert Roy Stein

Approved: Robert H. King

Robert H. King,

Thesis Advisor

Golden, Colorado

Date

Matthew J. Hrebar

Matthew J. Hrebar

Acting Head

Mining Engineering

ABSTRACT

A portable system for measuring the effectiveness of hearing protectors used in the mining industry has been developed that will improve the quality of data collected under field conditions. It has been designed to collect field data using the physical or inside-outside microphone technique and to overcome the problems of earlier systems. The new system is fully programmable through the use of a Hewlett-Packard model 71B calculator and is capable of storing full shift data samples in either full-octave or one third-octave bands. Two Larson-Davis programmable sound level meters are used for signal conditioning and measurement. The system has been qualified in the laboratory using both white noise and tape recorded tracks of actual surface mining noise. Results of noise floor tests show the system to exhibit a noise floor limit in the range from 20 to 30 dB over the frequency range of 125 to 10,000 Hz.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The National Institute for Occupational Safety and Health provided assistance for this project through tuition and stipend grants. In addition, the author would like to thank the following agencies and people for their assistance in completing this project: The U.S. Department of Interior, Bureau of Mines; Thesis Committee Members, Robert H. King, Ph. D., John U. Trefny, Ph. D., and Kenneth D. Blehm, Ph. D.; Mr. Roy C. Bartholomae, J. Alton Burks, D.Sc., and Mrs. Sandra Stein.

INTRODUCTION

This thesis details the efforts made to develop and qualify a new system that will be used to collect field data on muff-type hearing protectors used in the mining industry. This system is shown to be superior to those used in the past, thus enabling it to collect information that better describes the effectiveness of hearing protectors under conditions of actual use.

It is hypothesized that newly released programmable sound level meters produced by the Larson-Davis Company of Pleasant Grove, UT, can be used as the core of a new system that will improve data collection when using the inside-outside microphone technique for testing hearing protector effectiveness. It is also hypothesized that the sound level meters can be driven through a sampling regimen by a programmable controller that will also serve to record the data.

The Larson-Davis model 800B precision sound level meter is designed around the concept of a computer controlled sampling device that is capable of providing a wide variety of sampling modes at the command of a programmable controller. This capability has been implemented in a relatively small package weighing approximately seven pounds that is fully portable and powered by batteries. By gaining the signal conditioning ability of a sound level meter, and the flexibility of the programmable controller, improvements can be made in data collection using the inside-outside microphone technique.

Several parameters have been addressed in designing this system. Portability is of primary concern in choosing components to build a new system for the collection of field data using the physical method. It is desired that the system be developed as a unit that will be small enough to be worn by a miner as a dosimeter is; however, it is possible that fulfilling the remaining constraints may make the system to large to be used in this fashion. The other constraints are, the ability to obtain noise data in either octave, or third octave band spectra, the ability to record data for up to a full eight hour shift, the ability to examine two channels simultaneously, and a very low system noise floor. These attributes are necessary in order to improve on data collected in the past. The Larson-Davis sound level meters along with a Hewlett-Packard HP71B calculator give the new system these features in a package that is suitable for use in a mining environment.

Title 30, Code of Federal Regulations, the federal mining law, calls for the protection of miners'' hearing. Subpart F, Part 70 of Subchapter O, defines the maximum allowable noise exposure of miners.(1) These exposure limits are to be maintained primarily by engineering controls, such as designing less noisy processes or using noise controlled equipment; secondarily, through administrative controls, such as rotating workers exposed to noisy environments to quiet environments; and in the case where engineering and administrative controls have not yet been possible to implement, by personal protective equipment, such as ear muffs or ear plugs. Anyone who has spent much time in a mine can inform you that personal protective devices are used very frequently and often appear to be the first line of defense rather than the last.

In a simple example, a drill operator who is exposed to a level of 115 dBA when the drill is running may only operate the drill for fifteen minutes a day by the standards set in CFR title 30. If he were supplied with hearing protectors with a tested noise reduction of 25 dB, his exposure level would theoretically be reduced to 90 dBA thus allowing him to operate the drill for a full eight hour shift under the cited regulation.

In a typical situation; however, the noise reduction offered by the hearing protectors is substantially, though not predictably, less than the rated protection. The present policy of the Occupational Safety and Health Administration requires that the rated reduction be cut in half, and reduced further by seven dB. In the example, this would yield a noise reduction of only five and one half dB thus allowing only one half hour of operating time. It is not difficult to predict the reaction of the mine operator who has paid for hearing protectors with a rated reduction of 25 dB when he is told that he may only use them as though they are offering a five-and-one-half-dB reduction.

It has come to be accepted that hearing protectors are going to be used to protect miners' hearing in the presence of high intensity noise sources, such as pneumatic drills, until such time that engineering controls are developed. Thus, it is very important to be able to make a positive determination of the actual amount of protection they offer.

The standard method of determining a hearing protector's noise reduction rating is through the use of psychoacoustical testing. Psychoacoustical testing is performed by administering an open-ear audiogram to a subject to determine his normal threshold of hearing. The hearing protector under examination is then placed on the subject and a second audiogram is performed. The difference between the two audiograms is then stated to be the attenuation that is offered by the hearing protector.

This method of testing is obviously very subjective; however, it is repeatable, and in some aspects a good test of a hearing protector's abilities. It eliminates the need to reproduce the combined acoustics of the ear, hearing protector geometry, and material consistency, which are difficult to faithfully model. It also provides a measurement that represents an insertion loss in that the source-receiver relationship is not changed. The only difference between the two conditions is the insertion of the barrier. It is applicable to all types of hearing protectors since the test apparatus does not interfere with the protector.

The usefulness of the psychoacoustical test is limited in several aspects. It fails to take into account improper deployment, poor maintenance of hearing protectors, impulse noise, movement of wearer during normal use, and other factors that are difficult or impossible to control in actual use. Thus, it is arguable that the reduction found using the psychoacoustical method is not representative of the reduction found in the field.

Psychoacoustical testing can not be utilized in the field under actual working conditions, because the test environment must be controlled while using this method. In order to confirm the noise reduction offered by a hearing protector during actual use, a method must be used that allows testing using the work environment as the test environment.

The alternative to psychoacoustical testing is a physical test using an inside and an outside microphone. While limited to muff-type protectors because of the difficulty in mounting a microphone under a plug-type device, the physical method provides a means by which effectiveness can be checked using the work environment as the test environment. The result of the inside-outside microphone test; however, is a noise reduction not an insertion loss. The difference lies in the fact that it is not a before and after test. It simply looks at the difference between the two environments, outside the protector, and inside the protector. Therefore, the results from the two methods can not be compared directly.

It is desirable to be able to compare the results from the two methods so that a relationship can be developed that will allow the prediction of field effectiveness through the use of less expensive laboratory testing. The present body of data produced using the physical method shows little or no relationship to the body of data available from psychoacoustical tests. To restate what was said earlier, field data in general show poorer reductions than those measured in the lab, but the reductions seem to be markedly worse when the level of noise encountered in the field is in an exposure range below approximately 95 to 100 dBA. This suggests that the measurement systems being used may not possess a noise floor sufficiently low to measure low levels under the ear cup. Therefore, the new system must have a noise floor low enough to measure the levels under the ear cup.

If the body of field data collected using the physical method could be improved, it would then be possible to confirm or revise current derating policy. It would also be possible to identify criteria for the acceptable condition of hearing protectors that are in use so they can be replaced when necessary to provide full protection.

Researchers looking at the task of measuring the field effectiveness of hearing protectors worn by miners are faced with some difficult problems. Unlike factory workers, miners are highly mobile and are exposed to a wide variety of acoustic environments throughout their typical workday. The physical environment spans the extremes of temperature and humidity, and any equipment that is to be used must do little to add to the miner's level of discomfort or detract from his work performance. In addition, most mining tasks are performed within a very limited working space that hinders the attendance of sampling personnel. To this end, it has been necessary to develop a field data collection system that can reliably measure the noise reduction of a hearing protector, and that can be left with or on a miner unattended by the sampling personnel.

PROBLEMS OF MEASURING HEARING PROTECTOR EFFECTIVENESS

The standard method of measuring the effectiveness of a hearing protector, as described in ANSI S3.19-1974, "Method for the Measurement of Real-Ear Protection of Hearing Protectors and Physical Attenuation of Earmuffs", is to perform tests on human subjects in which the subject's ear is the noise receiver. In these tests, the subject is first given an open-ear audiogram in order to determine his normal hearing threshold. The audiogram is performed using selected third octave bands of white noise. The subject is then fitted with the hearing protector to be tested and given a second audiogram. The difference in hearing threshold as perceived by the test subject is recorded and when considered statistically along with the results from other subjects becomes the noise reduction rating for the device under test.(2) This difference is referred to as an insertion loss because the only alteration between the first test and the second test is the insertion of the hearing protector between the source and the receiver.

Of course, finding the level of attenuation present under laboratory conditions leaves some concerned parties with less than a total measure of confidence in how well that figure applies in the "real world." Without even questioning the level of attenuation supplied by these tests, one can argue that workers do not always wear their hearing protectors while exposed to high levels of noise, thus, reducing the amount of protection provided by the device. Beyond this argument extend the large scope of environmental differences among which are the age of the device, the condition in which it has been maintained, the tension of the head band, and cases of improper deployment. Improper deployment covers such factors as wearing a muff type protector that was designed to be worn over the head, behind the neck because of protective headware or comfort reasons. It also refers to cases in which insert type protectors such as ear plugs are not inserted correctly. In a study conducted by Lempert et.al. disposable foam earplugs provided better attenuation than custom molded types thus showing the variability in fitting techniques and the effect they have on attenuation.(3)

The concept of measuring the actual attenuation of hearing protectors in the field is not a new one. There are two basic variations on the field study of hearing protector effectiveness. In the first type of test, instrumentation is taken into the field and a test is conducted on various workers that is very similar to the standard test conducted in the laboratory. The objective is to test actual workers wearing their own personal hearing protectors rather than selected test subjects using brand new hearing protectors.(4) These tests are similar to laboratory tests because the testing environment is controlled and the real-ear method is still used. A positive feature of using the real-ear method in the field is that both insert and circumaural devices can be tested by supplying the test stimuli in either of two methods. For the testing of insert type protectors a set of audiogram earphones may be used in a portable audiometric booth since the headphones will fit over the hearing protective device and still seal properly on the external ear. For the testing of muff type devices the sound field may be introduced in a diffuse field environment that is acoustically isolated from the outside environment. The diffuse field should also be used for testing insert type protectors; however, the chamber that is required to supply the correct diffuse field is bulky, complicated to build, and less portable than the audiometric booth and, therefore, more difficult to implement.

The National Institute for Occupational Safety and Health (NIOSH) released a report in 1976 documenting their efforts in developing a method of testing the attenuation of insert type protectors in the field.(5) The objective of this study was to verify the correlation between using a diffuse field (reverberant chamber) and headphones. By providing this correlation field tests of insert type hearing protectors using the real-ear method are made easier to perform. The conclusion reached was that headphones can indeed be used and the resultant data correlated to that from a diffuse field.

Studies using the method developed by NIOSH have been published that show the variability of insert type hearing protectors in the field. The finding is that attenuation data measured in the field show far greater variability than data taken under laboratory conditions. In a study done by Lempert and Edwards (3) the NIOSH method was employed at industrial plants where workers were selected randomly from groups based on physical activity and noise exposure. Workers were pulled from their jobs at random times and taken for testing. Care was taken not to disturb the workers' hearing protectors from the way they were being worn at the time they were removed from the work environment. In general their findings reported a far greater degree of variability in the amount of attenuation provided by given models of hearing protectors than is present in the laboratory ratings of those devices.

Another interpretation of field testing of hearing protectors is given in a paper prepared by Behar detailing the results of research on the field evaluation of hearing protectors.(6) A variety of protectors was tested, including both muff-type and insert-type protectors. Workers were called away from their job assignments and instructed to sit in a quiet environment for a short time to help reduce the effects of temporary threshold shift. They were then tested in a diffuse field setting to obtain attenuation at threshold. The subjects own protective devices were used and worn in the usual manner. The researcher reports an average difference from published noise attenuation data of 14.9 dB lower.

Another concept of measuring the effectiveness of hearing protectors in the field makes use of the temporary threshold shift or TTS.(7) The TTS is the temporary increase in a person's hearing threshold after being exposed to high noise levels. This type of study has the advantage of considering most work related variables but it requires that the level under the muff is high enough to cause TTS in order to determine if the protector is performing poorly. It would seem obvious that a muff that only provides a 2 dB reduction in noise level is a poor performer but this would not be noted with the TTS technique if the worker had worn the protector in a marginal noise environment at a level in the range from 92 to 94 dB.

These and other variations of the first type of test all differ completely from the second type of test in which the hearing protectors are evaluated during actual working conditions. These tests are performed using the two microphone system. The two microphone system uses a microphone outside of the hearing protector and a microphone inside of the hearing protector. The difference between the two levels represents a measurement of noise reduction as opposed to an insertion loss and it is referred to as the physical method.

The two types of tests obviously have advantages and disadvantages when compared to one another but it would appear that the best features from both tests cannot be combined to produce a single field test that directly yields attenuation results while sampling workers under actual conditions. When using the real-ear method in the field, actual working conditions cannot be used as the test basis since the noise level must be controlled in order to determine hearing threshold. While the test data obtained using the real-ear method in the field are directly comparable to laboratory results, they fail to account for environmental effects which have a large impact on the noise attenuation provided by the hearing protectors. In contrast, the physical method measurements are not directly comparable to real-ear measurements, but they do use the actual work environment as the test environment. Thus, any factors that are influenced by job performance are taken into account by the test data.

One method of testing hearing protectors using the physical method, which has been pursued by MSHA's Technical Support Group in Denver, CO, has been to place two dosimeters on a worker and sample outside the ear muff cup and inside the ear muff cup. The Leq's obtained from these samples are then compared to determine a noise reduction. These reductions are shown to be generally lower in value that the EPA reported NR values for the muffs under test.(8) In conducting these tests, data was only recorded for 45 minute periods. The data were subsequently analyzed in the laboratory to develop the Leq's.

The problem that remains when using the physical method is that the data cannot be directly substituted for or compared to data collected using the real-ear method. Several factors have been addressed in attempting to explain and quantify the difference between real-ear method data and physical method data.

In a study performed by Stewart and Burgi, (9) the investigators worked at quantifying the difference between the real-ear, and the physical method. Their goal was to characterize the difference and subsequently develop correction factors that could be applied to physical method data to align it with real-ear method data. The result of their efforts was a set of correction factors that was to be used for adjusting physical method data to agree with real-ear method data. The study suggests that it is possible to perform physical measurements and relate them to real-ear data on the same hearing protector. This would make it possible to eliminate the artifactual differences in the two types of measurements and reveal the differences that arise between laboratory conditions and actual working conditions.

In a subsequent study by Stewart and Burgi, (10) they attempted to validate their concept by having special sound level meters built that applied their correction factors to linear levels through the use of an electronic weighting network. The results of their second study suggested to them that the correlation between the physical and psychophysical methods would not hold well except under very controlled conditions.

They experienced great difficulty with the noise floor under the muff. They had originally selected several noise samples that were representative of mine noise, and characterized them according to spectral composition and amplitude so they could be simulated for test purposes as shaped white noise introduced to the test environment via loudspeakers. Due to the problem with the noise floor under the muff, they found only one sample of test noise that they deemed suitable for running the tests. The remaining noise sample represented drill noise which is high in amplitude and also contains its major spectral components at higher frequencies; i.e. 2000 Hz. They did not; however, make a serious attempt to determine if the noise under the muff was solely a result of the physiolgical phenomenon of the occluded ear or if it was electrically induced by the particular instrumentation configuration that was being used.

Results from studies performed by Berger et.al. (11) would suggest that the high noise floor seen by Stewart and Burgi was due to electrical noise produced in the instrumentation. The Berger study was looking at the masking effect of physiological noise at low frequencies as it affects the value of REAT (real-ear attenuation at threshold). The results of the study show very low noise floors associated with the occluded ear. Levels of as low as 32 dB are reported for the physiological noise existing under a MX-41/AR audiometric test headset. In light of this information, one might feel more reassured in attempting to apply the correction factors developed by Stewart and Burgi to data collected using the inside-outside microphone technique in order to achieve attenuation data as opposed to noise reduction data.

SOFTWARE DEVELOPMENT

The Larson-Davis sound level meter was delivered with software that would drive one meter through a single spectrum analysis. It included portions that allow the user to select the range of frequencies of interest, the weighting network, the octave band width, and the integration period desired. It also included a portion that permits the SLM to be autoranging. This software provided a good basis with which to develop the program necessary to drive two SLM's through a continuous spectrum analysis. Several portions had to be modified or added in order to provide a program that would continuously run the spectrum analysis and build a data file. It also required that new logic be developed for the system to automatically range-correct two sound level meters simultaneously but independently.

In the configuration selected, the Larson-Davis system is programmed through a Hewlett-Packard HP 71B calculator, which in function is a very small microcomputer. The sound level meters are fitted with Hewlett-Packard Interface Loop decoders, and the 71B has its optional IL module installed so the entire system communicates over the HPIL loop. The software is actually a sampling program that receives its data from the SLM's. Portions of the program are set up to send the SLM configuration information that has either been input by the user or calculated by the program itself. The rest of the program takes care of the output from the SLM as it is returned.

At this point it may be useful to digress for a short explanation of the HPIL. The HPIL is a two-wire communications system used by some of the smaller Hewlett-Packard microprocessor based devices. A set of jumper wires with specially designed connectors is used to interconnect all of the devices which are to be incorporated into the system. Each device has an "in" and an "out" port. When all of the connections have been made, a loop is formed that passes through all of the devices.

The communications protocol for the loop allows for only one controller at a time. As the controller sends information, it expects to receive the information back over the other end of the loop. The process is somewhat similar to a telephone receiver feedback loop. The communication is sent out and is heard as it is sent. The controller, however, is capable of detecting the short delay between the commands and the echoes. If the response of the loop is not fast enough, the controller will break communications and display an error message. The amount of time that the controller waits for the echo can be set by the user.

The HPIL system provides a very well suited vehicle for this type of instrumentation. It allows the SLM's to be "programmable" and at the same time interfaces the small group of instruments necessary to perform the task at hand. A number of other peripheral devices are available to interface the HPIL loop with other systems using different communications protocol.

The software development evolved the original program supplied by Larson-Davis into a form that is useful for the purpose of looking at two sound level meters at once and recording enough data to fulfill the requirements of the PSLMS system. Along with the necessary ammenities of adding interactive portions for proper documentation procedures, two distinct problems had to be solved to allow the system to work properly. The first problem was range-correcting two sound level meters simultaneously, and the second problem was how to store enough data without interrupting the sampling run. The solution to the second problem was solved partly through hardware. That solution will be discussed later. The solution to the range correction problem was dealt with solely through software.

The logic that drives the single meter program through the range correction or autoranging portion of the program follows the flow chart. (figure 1) The meter is set up in a default condition and the trigger command is given which causes the meter to attempt to take a reading. A second command is then sent which puts the result of the attempt on the HPIL loop. The information is then checked for overload condition which is returned as the number "8". If the reading indicates that the meter was in overload condition, a counter is started that will reset the meter two additional times at the current range setting in order to obtain a valid reading. This feature keeps the meter from being range adjusted unnecessarily due to momentary impulses in amplitude. If the meter has not made a successful reading after three attempts, the program then passes control to a section that increases the range setting of the meter by sending a new control string. After the new control string is sent to the meter the program returns to the sample loop and three more attempts are made to read the meter. Once the reading is successful the program then

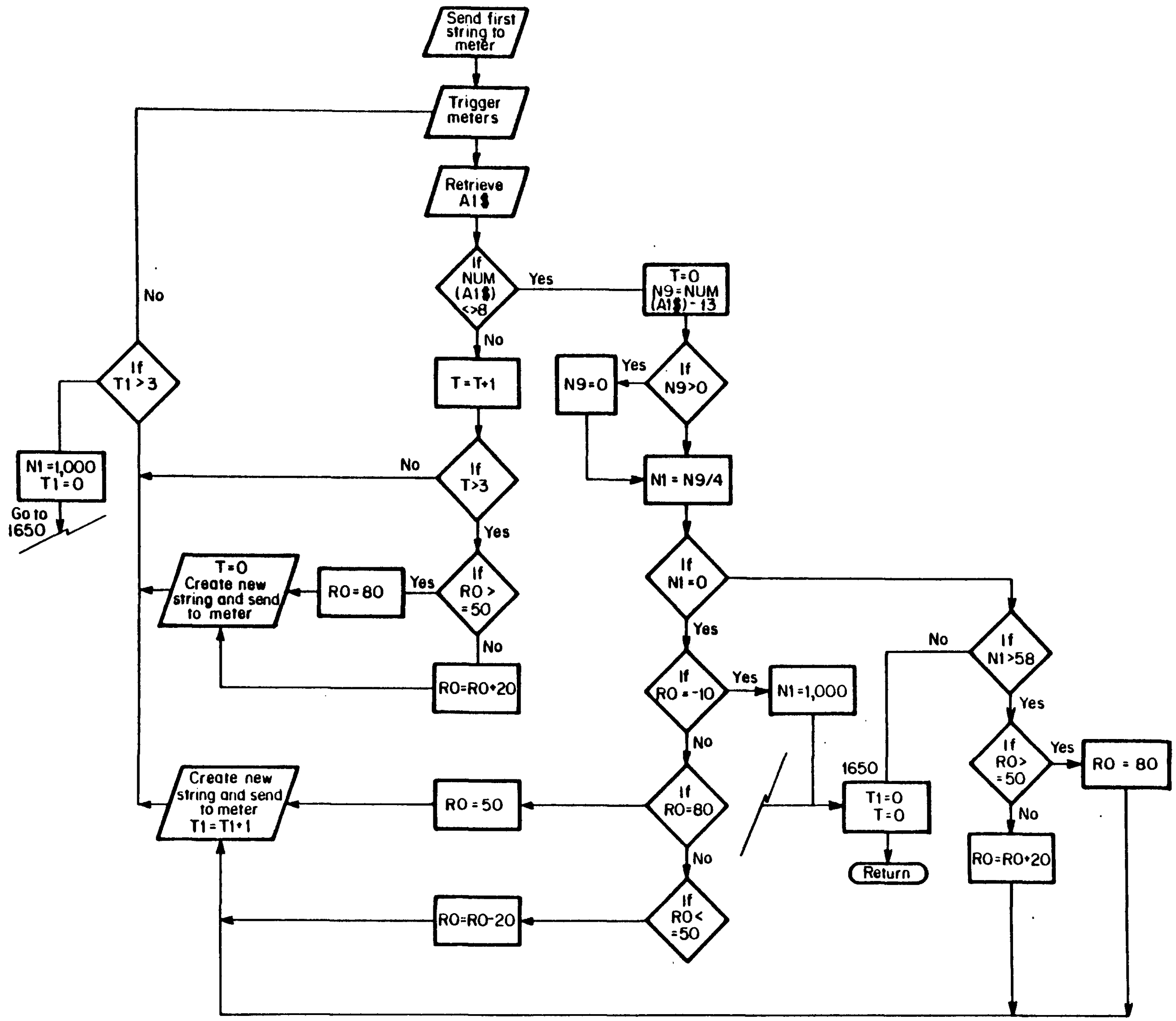

Figure 1. FLOW CHART OF ONE METER AUTORANGING ROUTINE

converts it to an index value. The offset value is then used to determine if the sample was within the accurate span of the meter. Two conditions are possible at this point that will cause the program to reject the reading and readjust the range setting for another attempt at a reading. The first condition is that the reading was below the range currently set on the meter. If this is true the program then branches to reset the range of the meter to a lower value and try again. The second possibility is that the reading was very close to the top of the currently set range. In this case, the range is increased and the meter is instructed to try to sample again. A second counter is set up to keep track of how many attempts have been made to range correct the meter. If this counter exceeds three, the program returns control to the sample recording loop with a flag value set for that reading. Once a sample has been successfully retrieved, it is passed back to the sample recording loop where the control string is sent to the meter to step to the next filter band and try to sample again. The auto ranging of the meter is complicated slightly by the necessity of keeping an offset value for the reading that corresponds to the range setting that is selected. The offset value must be added to the index value to arrive at the final sound pressure level of the sample. Every time the meter range setting is changed, the offset value must be changed in order to yield the correct level. This complicates the procedure more so when two meters are to be range corrected simultaneously, but independently of one another. The control logic for autoranging two meters, as it was developed for the PSLMS, works much in the same manner as the single meter scheme. The increase in complexity can best be observed comparing the flowchart for the single meter program to the flowchart for the two meter program. (figure 2)

The software that was delivered with the Larson-Davis products also lacked provision for data storage. The program was simply set up to record one spectrum in memory and save it for use in constructing a bar chart to be printed on the line printer. The bar chart feature was not desired for the PSLMS so it was abandoned to reduce the memory requirement of the program. The necessary changes were then made to allow the program to construct a sequential data file as it progressed through the task of sampling. At this time it was discovered that the memory capacity of the HP-71B was not large enough to store a file containing data from a full eight hour shift of work.

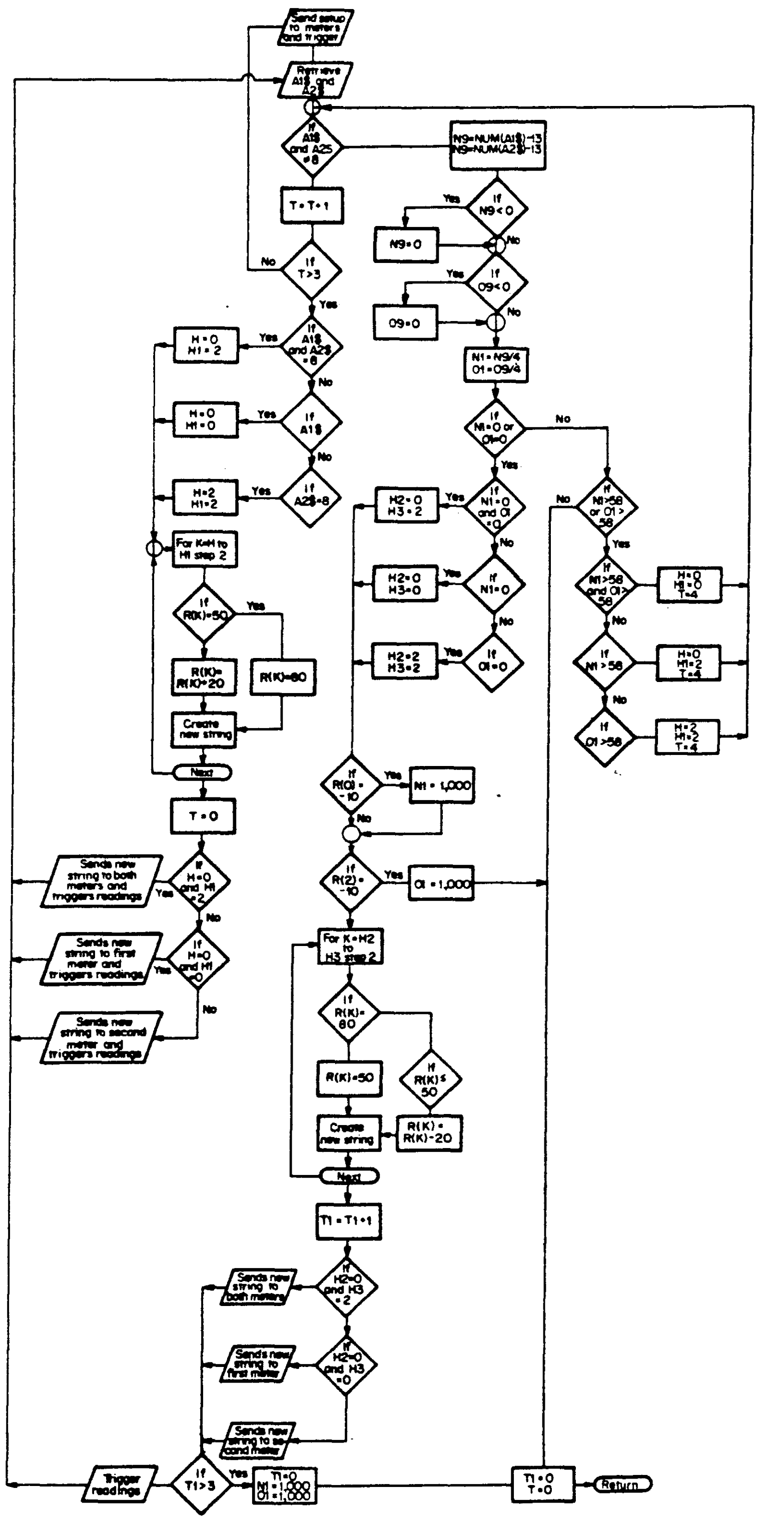

Figure 2. FLOW CHART OF TWO METER AUTORANGING ROUTINE

Additional memory modules were ordered for the machine that increased the main RAM to 33.5 K bytes of storage, but that was not enough to solve the problem. There appeared to be only two options at this point. The first option was to keep a running average of the data which would vastly reduce the memory requirement. This option was not deemed desirable because the "raw" data would be lost; thus, any post analysis attempting to look at trends over time would not be possible. The second option was to build the file in memory until the capacity was nearly reached then dump that section to tape. The first data file could then be purged from memory and a second data file could be built in the area that was freed by the purge. This option had the disadvantages of interrupting the sampling cycle because the program could not continue execution during the recording-to-tape sequence and it would decrease the reliability of the system due to the added component (the tape drive). It was calculated that approximately three data dumps would be required to record eight hours of data resulting in three gaps in sampling.

Just as this portion of the program was being written, a third alternative was found that solved the data storage problem. A 96 K byte memory module that is produced by an independent manufacturer was installed in the card reader port of the HP-71B increasing the available RAM to 127.5 K bytes. This amount of memory makes it possible to store data files that contain the information from an entire eight hour sampling period thus avoiding interruptions in sampling and the addition of another component in the system.

During the software development stage, many tests were run to simulate conditions that could potentially "hang up" the system in a circular logic loop. Initial versions sometimes failed these tests resulting in further refinements of the program. The result of the preliminary testing along with detailed planning of the program structure seems to have paid off well as the final version has not exhibited such failures.

METHODOLOGY

There are three broad areas of the system that could cause the PSLMS to collect erroneous data. They are:

1) The controller software.

2) The sound level meters, signal attenuator, and the signal adaptor.

3) The signal input section, including microphone and power supply/preamp.

These areas can be analyzed systematically as separate entities to pinpoint the source of system error. If any one area is found to be the main source of errors, remedy can then be taken to correct that area via either component changes, software changes, or both and the system reanalyzed as a unit to check the validity of the change.

Laboratory standard signal analyzers will be used to determine the accuracy of the sound level meters. Once this has been determined, different signal input sections, (i.e. microphones and preamps), can be compared to those that are to be used in order to determine if any error is being introduced at this point. The software is system dependent and will be tested under conditions that are designed to simulate field conditions in a progressively more demanding way that should help to determine where problems, if any, exist.

The test set-up for checking the sound level meters will include a Bruel and Kjaer type 2131 third octave band analyzer, a Bruel and Kjaer type 2313 graphics recorder, a Bruel and Kjaer type 1405 noise generator, and the PSLMS including the Hewlett Packard HP 71B controller, printer, and cassette data recorder.

The method by which the sound level meters and the 2131 analyzer filter the input signal is different. The sound level meter uses a single tunable filter and, therefore, can only sample one octave or third octave band at a time. The analyzer uses multiple fixed filters and can sample all filters simultaneously. The second method is more desirable from the standpoint of sampling accuracy because the portion of the signal being analyzed is all taken at the same point in time. It is comparable to being able to measure all of the color components of a picture by taking a single color photograph. This method of sampling is referred to as real-time analysis. The method using the single filter takes its sample over a longer period in time. Using the photograph analogy, it would be similar to constructing a single color photograph from several one color pictures taken over a period in time. It is easy to realize that something may change during the sampling time that would cause the overall picture to not be a true representation. This problem is most acute in situations where the noise signal is highly dynamic; however, long overall sampling periods help to "wash out" these irregularities.

The noise generator will be used to provide a readily available source of broad band noise to analyze. It is not necessary to produce an audible signal so the output from the noise generator can be connected simultaneously, via coaxial cables and a signal splitter , to the third octave band analyzer and the PSLMS. This will eliminate the microphone/preamp section from the system, thus eliminating it as a source of error. The third octave band analyzer can be controlled by the graphics recorder to continuously average the signal being produced by the noise generator thus providing a basis by which the response of the SLM can be judged.

The PSLMS will be programmed to step through the frequency bands over a range that will be picked to give the broadest test available from the noise signal being produced by the noise generator. The readings will be recorded in a sequential file in the 71B up until a prespecified stopping time. At the end of the test, a separate program that can be run on the 71B is used to extract the averages and standard deviations of the spectral data contained in the sequential file. After several test cycles, any differences in the averages obtained using the two methods can be analyzed to determine if there are errors present.

Before and after running each test, the third octave band analyzer and the 800B sound level meter will need to be calibrated to the same level by replacing the noise generator with a calibration device. The B&K type 2810 power supply/preamp connected to a one half inch microphone should provide a suitable calibration signal from a puretone type calibrator. The input sensitivity of the instruments can then be adjusted until the appropriate level is read on each one. During this operation the 800B will be controlled manually so the level can be checked in the overall mode and the appropriate full and third octave bands.

The microphone/preamp section of the system can be tested both in conjunction with the overall system and as a separate entity. Frequency response tests are the primary standard used to determine the accuracy of the microphones separate from the overall system. These tests will be used to confirm microphone selection.

An initial choice for the microphone is the Knowles Electronics model 1759. The Knowles 1759 is a miniature hearing aid microphone that readily meets the size constraints for the inside microphone. The frequency response curve supplied by the Knowles corporation shows the model 1759 to have a reasonably flat response to at least eight thousand hertz with a DC supply voltage of 1.3 volts. (figure 3) The 1759 is also credited for having a low current drain, useful when battery power is being used, high sensitivity, and high resistance to mechanical shock.

The Knowles microphone requires a polarization voltage in the range of 0.9 to 20 Vdc that cannot be supplied directly from the 800B sound level meters, so a combination preamplifier/power supply has been selected in the form of the Bruel and Kjaer type 2810 microphone power supply. The 2810 is deemed suitable because it is battery powered, small (127mm x 75mm x 37mm), supports two autonomous channels, and has a power supply voltage of five volts which is within the

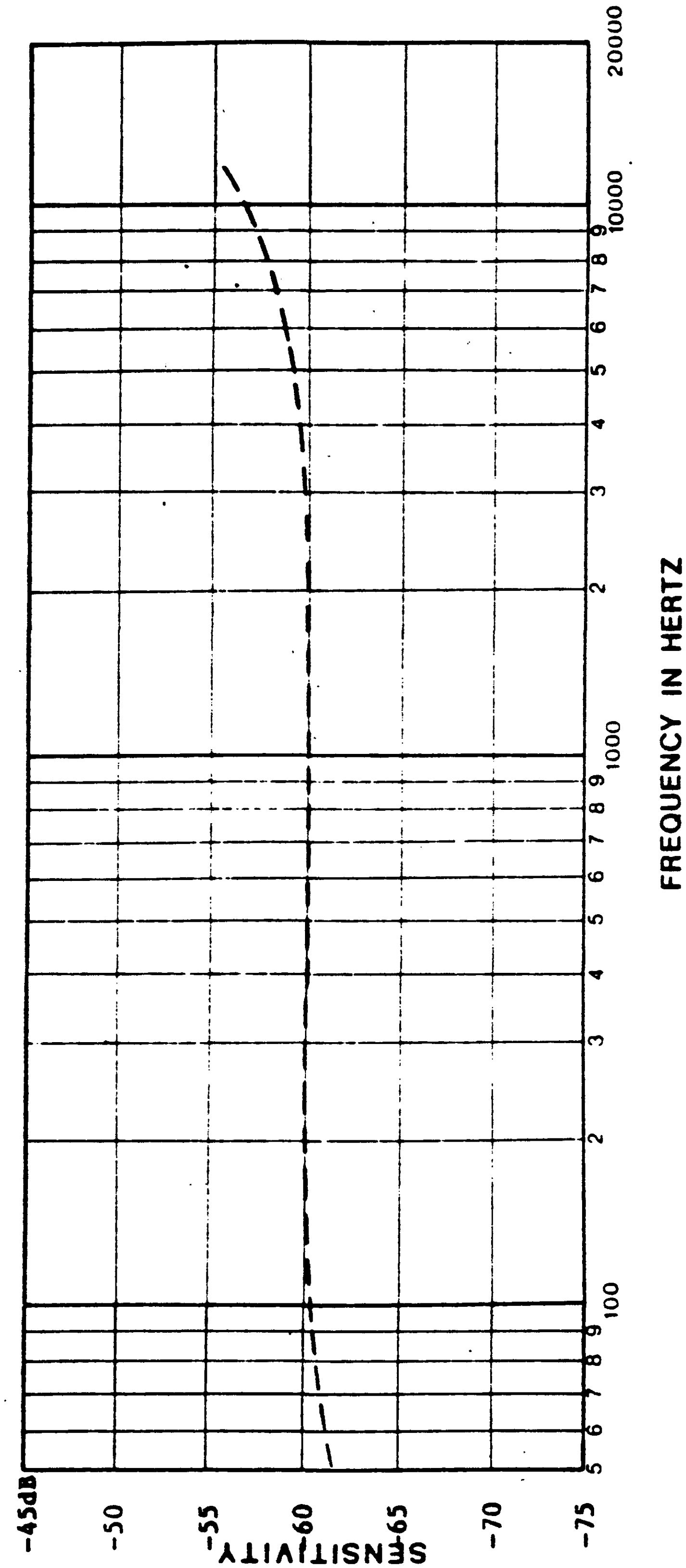

Figure 3. KNOWLES MODEL 1759 FREQUENCY RESPONSE

requirements of the Knowles microphones. The two channels are separate and each has an adjustable gain in the range from 0 to 40 dB. The 2810 also has a low distortion limit which is desirable for retaining low signal distortion before it enters the sound level meters.

The frequency response curves will be produced using the microphone and the preamp together since their interaction affects the signal being sent to the sound level meters. In addition to the microphone and preamp, the test set-up will include the following pieces of equipment which are all of Bruel and Kjaer manufacture: type 2010 hetrodyne analyzer, type 4222 anechoic test chamber, type 2307 level recorder, and type 2706 power amplifier. These pieces of equipment provide a typical arrangement for measuring and plotting the frequency response curves from various devices such as microphones and sound reproduction speakers. A hetrodyne slave filter is sometimes used with this set-up to filter the response signal, but there is not one available at this time. The lack of a hetrodyne slave filter may necessitate the use of a larger anechoic test chamber with which to isolate the 4222 test chamber.

The microphone under observation is placed within the

4222 test chamber. The chamber serves two purposes. Primarily, it serves to isolate the microphone from external noises that would contaminate the test. Secondly, it provides the test sound field by means of a sound reproduction loudspeaker which is situated so as to produce a symmetrical acoustic field on the chamber's test plane. A supporting grid of fine nylon mesh allows the user to place microphones under test on the plane. The mesh is marked in a bull's eye fashion so rings of equal intensity can easily be located. This is necessary because along with the microphone under test, a field controlling microphone is placed in the chamber so that the sound input will remain constant. Aligning the two microphones at points of equal intensity assures that the microphone under test is receiving the correct signal.

The signal for the loudspeaker is provided by the hetrodyne analyzer along with the power amplifier. The output of the controlling microphone is sent to the compressor input through the built in measuring amplifier section of the analyzer. The compressor section in turn is used to control the output of the beat frequency oscillator (BFO) which sends its output to the loudspeaker through the power amplifier where it is received by both the microphone under test and the controlling microphone. Altogether a loop is formed that will hold the sound pressure level constant over the frequency span being scanned, within the limits of the controlling microphone, at the microphone being tested.

The output of the microphone being tested is sent to the level recorder where it is recorded on specially made charts. The recorder controls the speed of the frequency scan via a mechanical linkage to the analyzer. The two instruments are synchronized so the plot of the response is already annotated as it is produced.

A perfect microphone would respond to this signal by producing a perfectly flat line across the graph; however, no microphone will produce this theoretical graph. A microphone's response curve is characteristic of its physical construction. Different microphones for different purposes are designed to have a flat response over the range that they are intended to receive. Most microphones are designed to pick up signals that are in the frequency range of human hearing. A microphone of reasonably good quality will, therefore, usually have a flat response from about 250 Hz to about 8000 Hz. Microphones for different purposes will usually have approximately the same span but in a different range.

The final testing will concentrate on proving that the software written for the PSLMS system is capable of collecting the proper data. In doing this, certain assumptions will have to be made about the typical noise signal that is to be sampled. It is known from field experience that the noise encountered by a miner during an eight hour shift can be highly variable in both level and frequency composition. The level not only varies from one activity to another, but within one activity. The software that is developed should take into consideration the fact that the noise signal will be highly dynamic.

Testing will consist of running the system while the same signal is being sent directly to both sound level meters. The signal used will be provided by a Nagra IV-SJ tape recorder. A tape will be played that contains a recording of an actual mine noise track. This test can be repeated for statistical averaging as well as for analysis by the laboratory standard equipment for comparison.

In both series of tests where the SLM's are sampling the same signal simultaneously, the standard of comparison will be a zero difference. When both SLM's are averaging the same signal, the levels should be the same thus the difference between the two levels should be zero. In addition to the zero difference, the average as recorded by the PSLMS will be compared to the average produced by laboratory standard analysis equipment. However, since the desired data point is the relative difference between the two microphones, the results of comparison to laboratory equipment will not be as critical as the zero difference tests.

RESULTS

The first series of tests performed consisted of comparing the signal analysis provided by the Larson-Davis 800B SLM against that provided by the type 2131 analyzer. As would be expected, calibration was critical in providing good results. Precalibration and postcalibration were performed for each test. The calibration procedure entailed substituting a 1000 Hz calibration tone in place of the noise generator. Sensitivity adjustments were then carried out as necessary to bring the instruments into calibration. Both instruments were checked in full octave as well as third octave band modes. Instrument drift was found to be minimal during the period of any test; however, the 2131 appeared to be more subject to warmup phenomena than the 800B. Additional warmup time was allowed to account for this.

Once the instruments were calibrated, the system was reconnected with the noise generator, and the test cycle was initiated. At this stage of testing it was deemed appropriate to test each sound level meter individually. A version of the control software was used that only controls one SLM. Test parameters were chosen to induce a scan from

8 Hz to 20000 Hz, one third octave band spectra, linear weighting, and a two second integration period. A stopping time was input that would yield a two hour sample run. Results from the sampling were stored in a temporary data file that was subsequently stored on magnetic tape and reduced by a different program on the Hewlett-Packard 71B. The type 2131 was simultaneously set up to record a two hour average of the same signal.

Averaging of the type 2131 analyzer was accomplished using the type 2313 graphics recorder with the installed BZ 7001 applications package. The analyzer and the recorder are connected through a standard IEC communications interface. Using this equipment set-up, it is possible to carry out long term averaging. Individual sample time is set on the 2131 analyzer front panel controls. The "plot spectra" function is then engaged on the recorder. The effect of these operations is that the 2313 sends a signal instructing the analyzer to take a sample. The analyzer then samples according to the parameters set via its front control panel, (i.e. one third octave band, 32 second sample period). This sample is then retrieved by the recorder and stored in a volatile memory position designated during the call of the plot spectra function. As soon as the sample is stored, a signal is sent to the analyzer for another sample. Each subsequent sample is then averaged with the prior samples in the volatile memory. The end result is one spectrum, representing the average for the sampling period, that is stored in the memory position that was designated. Overall sampling time is set by the number of samples that are to be recorded. The product of the number of samples multiplied by the sampling time set gives the approximate length of the overall sample. For example, if it is desired to attain a two hour averaging period with a 64 second sample time. One hundred twelve, sixty four second samples would yield 3584 seconds of averaging time or approximately two hours. An additional time of approximately one second is needed by the recorder for calculation time between samples adding another one hundred eleven seconds, less than two minutes. This time is usually insignificant as can be seen in the example.

The 800B was set up just as it is planned for in-field use with the signal being fed through the input signal adaptor, the B&K, 20 dB in-line attenuator, and the Larson-Davis preamplifier, all of which comprise the core of the signal analysis unit. The only difference is that the microphone-preamp section of the PSLMS was left out so the signal could be fed directly to the instruments. This was done for two reasons, the first being accuracy. The input signal is more assured to be identical by eliminating the physical characteristics of the microphones. The second reason is that the microphones must be eliminated as they are separately under investigation as a source of system error. The instrument set-up is depicted in a block diagram. (figure 4)

The data from these tests (table 1, table 2 and table 3) were analyzed using spreadsheet software on a microcomputer. The results of the multiple runs were entered into a data area where they were organized by test and by frequency. This method allows the results from individual tests to be viewed on a side-by-side basis as well as extracting overall statistical information. Results from twelve test runs were averaged together for both the PSLMS and the Bruel and Kjaer equipment. The average levels produced by the two types of equipment are plotted together in a graph. (figure 5) The standard deviation of the data is also plotted in a graph. (figure 6) As can be seen in the graph of the averages, the results from the two types of equipment compare quite well at frequencies above 200 Hz. The differences from 100 to 200 Hz are also very small.

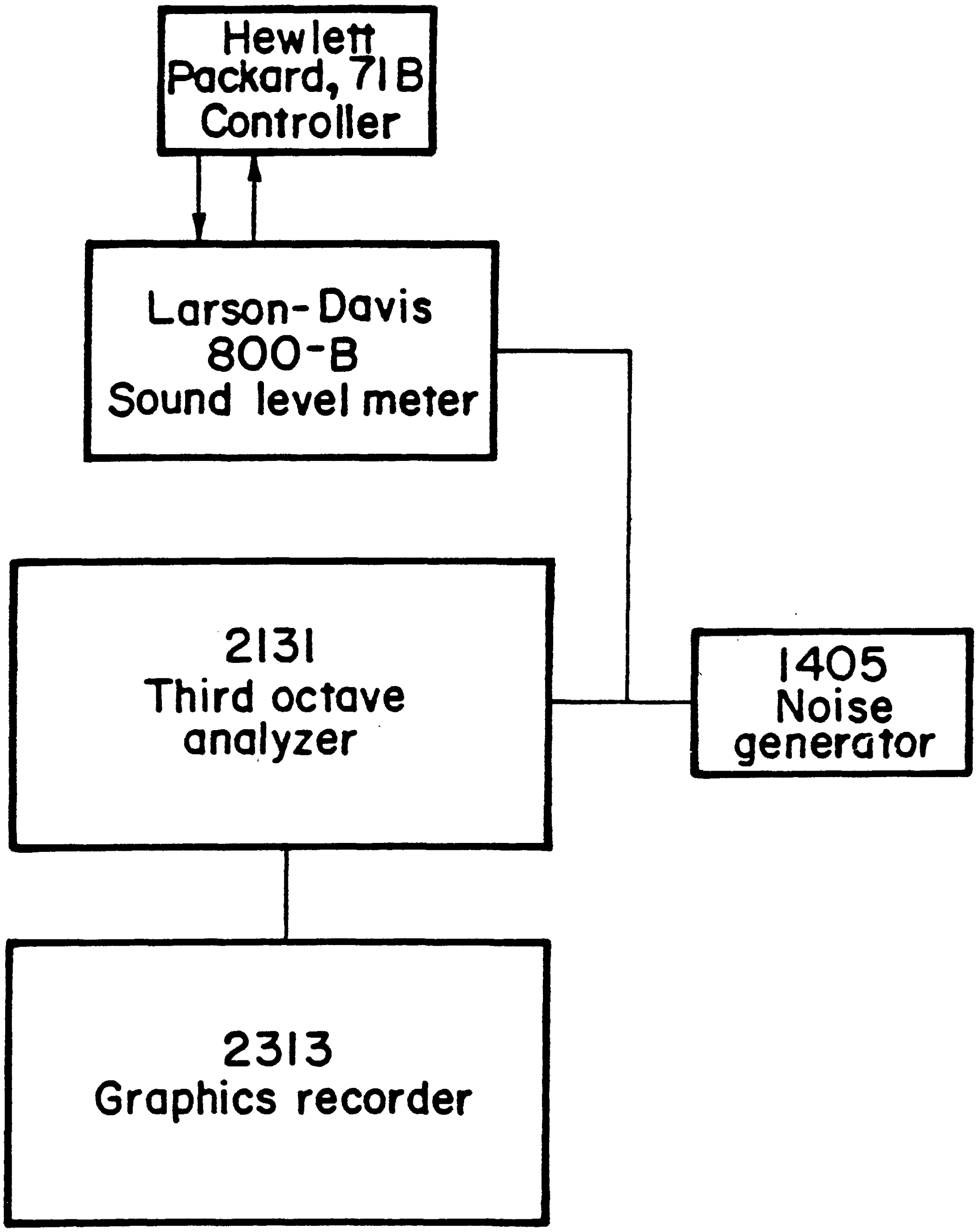

Figure 4. BLOCK DIAGRAM, TEST CONFIGURATION ONE

FREQUENCY	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	TEST 11	TEST 12	AVERAGE	STD. DEV.
8	91.7	88.8	93.6	88.3	90.0	88.0	90.8	88.0	86.5	87.5	86.5	86.7	88.9	2.14
10	84.8	82.9	87.0	84.1	85.0	83.1	83.5	82.0	81.1	82.5	84.2	84.2	83.7	1.50
12.5	83.9	84.0	86.0	84.3	84.8	83.5	83.9	83.3	82.3	83.6	85.1	84.7	84.1	0.92
16	82.2	82.9	84.2	83.4	84.2	83.9	83.5	82.9	83.2	83.3	84.7	84.9	83.6	0.76
20	81.3	82.7	82.4	83.5	82.4	82.3	79.5	79.7	81.3	81.0	83.9	85.1	82.1	1.58
25	81.4	83.4	82.3	83.9	83.4	83.4	80.7	80.9	81.7	82.0	85.3	85.4	82.8	1.51
31.5	82.1	84.2	81.6	84.9	84.2	84.1	81.3	81.6	82.6	82.7	86.6	86.6	83.5	1.79
40	86.3	88.5	85.7	89.2	88.4	87.8	86.6	87.1	87.7	87.9	89.7	90.0	87.9	1.28
50	87.7	89.6	87.1	90.4	89.6	89.4	87.6	87.8	89.0	89.2	90.5	90.8	89.1	1.17
63	89.1	90.8	87.7	91.4	90.7	90.1	88.7	88.6	89.5	89.6	91.8	91.6	90.0	1.27
80	90.1	92.0	89.4	92.1	91.5	91.3	89.8	90.1	90.7	90.8	94.6	92.6	91.2	1.40
100	93.0	94.2	92.7	94.4	93.9	93.5	93.1	93.1	93.4	93.7	95.5	94.5	93.8	0.76
125	94.2	95.2	93.6	95.4	94.9	94.5	94.6	94.1	94.6	95.0	96.7	95.7	94.9	0.80
160	95.3	96.5	94.9	96.4	95.9	95.6	95.5	95.2	95.3	96.0	97.7	96.5	95.9	0.75
200	96.5	97.0	96.1	97.4	97.0	96.6	96.5	96.3	96.7	96.9	97.7	97.3	96.8	0.46
250	98.2	99.0	98.3	99.0	98.7	98.1	98.3	98.1	98.2	98.7	98.9	99.1	98.6	0.36
315	99.3	99.9	99.4	100.0	99.7	99.1	99.5	99.3	99.3	99.7	100.0	99.9	99.6	0.31
400	100.4	101.1	100.5	101.0	100.7	100.2	100.5	100.2	100.2	100.7	100.9	101.1	100.6	0.33
500	101.4	101.8	101.4	102.0	101.7	101.3	101.6	101.4	101.3	101.7	102.0	101.9	101.6	0.25
630	102.6	103.1	102.8	103.1	102.8	102.2	102.9	102.5	102.5	102.9	103.1	102.9	102.8	0.27
800	103.8	104.1	103.8	104.2	103.9	103.4	103.9	103.5	103.6	104.0	104.1	103.9	103.9	0.24
1000	104.8	105.1	104.9	105.0	104.9	104.2	104.8	104.4	104.6	104.9	105.1	105.0	104.8	0.26
1250	105.8	106.0	105.9	106.0	105.7	105.2	105.8	105.5	105.5	105.8	106.0	105.9	105.7	0.24
1600	107.0	107.1	107.2	107.2	106.9	106.4	107.0	106.8	106.8	107.1	107.1	107.1	107.0	0.22
2000	108.0	108.2	108.1	108.2	107.8	107.4	108.0	107.8	107.8	108.1	108.1	108.0	108.0	0.23
2500	108.9	109.1	109.0	109.1	108.7	108.3	108.9	108.6	108.6	109.0	109.0	109.0	108.9	0.23
3150	109.8	110.0	110.0	110.0	109.6	109.2	109.8	109.6	109.5	110.0	110.0	109.9	109.8	0.24
4000	110.9	111.1	111.0	111.1	110.6	110.3	110.9	110.7	110.5	111.0	111.0	110.9	110.9	0.23
5000	111.9	112.1	112.1	112.0	111.7	111.3	111.9	111.7	111.6	112.0	112.0	112.0	111.8	0.23
6300	112.8	113.0	113.0	113.0	112.6	112.2	112.8	112.5	112.5	113.0	112.9	112.9	112.8	0.24
8000	113.8	113.9	113.9	113.9	113.5	113.1	113.7	113.5	113.5	113.9	113.9	113.8	113.7	0.24
10000	114.5	114.7	114.7	114.6	114.4	113.9	114.5	114.3	114.2	114.7	114.7	114.7	114.5	0.23
12500	115.5	115.7	115.7	115.6	115.3	114.9	115.5	115.3	115.2	115.6	115.6	115.6	115.5	0.23
16000	116.4	116.6	116.6	116.6	116.2	115.8	116.4	116.1	116.1	116.5	116.5	116.5	116.4	0.24
20000	117.3	117.5	117.5	117.5	117.1	116.7	117.3	117.1	117.1	117.5	117.4	117.4	117.3	0.22

Table 1. LARSON-DAVIS WHITE NOISE DATA

FREQUENCY	TEST 1	TEST 2	TEST 3	TEST 4	TEST 5	TEST 6	TEST 7	TEST 8	TEST 9	TEST 10	TEST 11	TEST 12	AVERAGE	STD DEV
8	84.1	84.1	84.2		84.0	83.9	84.1	84.6	83.9	84.7	84.6	84.4	84.2	0.28
10	85.5	85.5	85.5		85.6	85.4	85.5	85.8	85.3	86.0	85.9	86.0	85.6	0.23
12.5	86.3	86.3	86.4		86.2	86.2	86.3	86.4	86.1	86.7	86.7	86.7	86.4	0.21
16	87.1	87.1	87.1		86.8	86.9	87.0	87.0	86.8	87.4	87.3	87.0	87.0	0.18
20	88.3	88.3	88.3		88.2	88.1	88.2	88.2	88.0	88.5	88.4	88.1	88.2	0.14
25	89.2	89.2	89.2		89.0	89.0	89.2	89.1	88.9	89.4	89.3	89.3	89.2	0.14
31.5	89.9	89.9	89.9		89.7	89.7	89.9	89.7	89.6	90.0	90.0	89.9	89.8	0.13
40	91.1	91.1	91.2		90.9	90.9	91.1	90.9	90.8	91.2	91.2	91.3	91.1	0.16
50	92.0	92.0	92.1		91.9	91.8	92.0	91.8	91.7	92.1	92.1	91.7	91.9	0.15
63	92.7	92.7	92.8		92.5	92.5	92.8	92.5	92.4	92.8	92.8	92.5	92.6	0.15
80	94.0	94.0	94.0		93.8	93.8	94.0	93.8	93.7	94.1	94.0	94.1	93.9	0.13
100	95.0	95.0	95.0		94.8	94.8	95.0	94.7	94.6	95.0	95.0	95.0	94.9	0.14
125	95.7	95.7	95.7		95.5	95.5	95.7	95.4	95.4	95.7	95.7	95.7	95.6	0.12
160	96.9	96.9	97.0		96.8	96.8	96.9	96.7	96.6	97.0	96.9	96.9	96.9	0.12
200	97.9	97.9	97.9		97.8	97.7	97.9	97.7	97.6	98.0	97.9	97.9	97.8	0.12
250	98.6	98.6	98.7		98.4	98.4	98.6	98.4	98.3	98.7	98.6	98.6	98.5	0.13
315	99.9	99.9	100.0		99.7	99.7	99.9	99.7	99.6	100.0	99.9	99.9	99.8	0.13
400	100.9	100.9	100.9		100.7	100.7	100.9	100.7	100.6	101.0	100.9	100.9	100.8	0.12
500	101.6	101.6	101.7		101.4	101.4	101.6	101.4	101.3	101.6	101.6	101.5	101.5	0.12
630	102.9	102.9	102.9		102.7	102.7	102.9	102.6	102.6	102.9	102.9	102.9	102.8	0.12
800	103.9	103.9	103.9		103.7	103.7	103.9	103.7	103.6	103.9	103.9	103.9	103.8	0.11
1000	104.6	104.6	104.6		104.4	104.4	104.6	104.4	104.3	104.6	104.6	104.6	104.5	0.11
1250	105.9	105.9	105.9		105.7	105.7	105.9	105.6	105.5	105.9	105.9	105.9	105.8	0.14
1600	106.9	106.9	106.9		106.7	106.7	106.9	106.6	106.5	106.9	106.9	106.8	106.8	0.14
2000	107.5	107.5	107.6		107.4	107.4	107.5	107.3	107.2	107.6	107.5	107.5	107.5	0.12
2500	108.9	108.9	108.9		108.6	108.6	108.8	108.6	108.5	108.9	108.9	108.8	108.8	0.15
3150	109.8	109.8	109.8		109.6	109.6	109.8	109.5	109.4	109.9	109.8	109.8	109.7	0.15
4000	110.5	110.5	110.5		110.3	110.2	110.4	110.2	110.1	110.5	110.4	110.4	110.4	0.14
5000	111.7	111.7	111.7		111.5	111.4	111.7	111.4	111.3	111.7	111.7	111.6	111.6	0.15
6300	112.6	112.6	112.6		112.4	112.4	112.6	112.3	112.2	112.7	112.6	112.5	112.5	0.15
8000	113.1	113.1	113.2		112.9	112.9	113.1	112.9	112.8	113.2	113.1	113.1	113.0	0.13
10000	114.2	114.2	114.3		114.0	114.0	114.2	114.0	113.9	114.3	114.2	114.2	114.1	0.13
12500	115.4	115.4	115.5		115.3	115.2	115.5	115.2	115.1	115.5	115.4	115.4	115.4	0.13
16000	116.5	116.5	116.5		116.3	116.3	116.5	116.2	116.1	116.5	116.5	116.4	116.4	0.14
20000	117.7	117.7	117.7		117.5	117.5	117.7	117.4	117.3	117.8	117.7	117.7	117.6	0.15

Table 2. BRUEL & KJAER WHITE NOISE DATA

FREQUENCY	B&K AVERAGE	B&K STD DEV	L-D AVERAGE	L-D STD DEV	AVG DIFF
8	84.2	0.28	88.9	2.14	-4.7
10	85.6	0.23	83.7	1.50	1.9
12.5	86.4	0.21	84.1	0.92	2.3
16	87.0	0.18	83.6	0.76	3.4
20	88.2	0.14	82.1	1.58	6.1
25	89.2	0.14	82.8	1.51	6.4
31.5	89.8	0.13	83.5	1.79	6.3
40	91.1	0.16	87.9	1.28	3.2
50	91.9	0.15	89.1	1.17	2.8
63	92.6	0.15	90.0	1.27	2.6
80	93.9	0.13	91.2	1.40	2.7
100	94.9	0.14	93.8	0.76	1.1
125	95.6	0.12	94.9	0.80	0.7
160	96.9	0.12	95.9	0.75	1
200	97.8	0.12	96.8	0.46	1
250	98.5	0.13	98.6	0.36	-0.1
315	99.8	0.13	99.6	0.31	0.2
400	100.8	0.12	100.6	0.33	0.2
500	101.5	0.12	101.6	0.25	-0.1
630	102.8	0.12	102.8	0.27	0
800	103.8	0.11	103.9	0.24	-0.1
1000	104.5	0.11	104.8	0.26	-0.3
1250	105.8	0.14	105.7	0.24	0.1
1600	106.8	0.14	107.0	0.22	-0.2
2000	107.5	0.12	108.0	0.23	-0.5
2500	108.8	0.15	108.9	0.23	-0.1
3150	109.7	0.15	109.8	0.24	-0.1
4000	110.4	0.14	110.9	0.23	-0.5
5000	111.6	0.15	111.8	0.23	-0.2
6300	112.5	0.15	112.8	0.24	-0.3
8000	113.0	0.13	113.7	0.24	-0.7
10000	114.1	0.13	114.5	0.23	-0.4
12500	115.4	0.13	115.5	0.23	-0.1
16000	116.4	0.14	116.4	0.24	0
20000	117.6	0.15	117.3	0.22	0.3

Table 3. BRUEL & KJAER AND LARSON-DAVIS SUMMARY

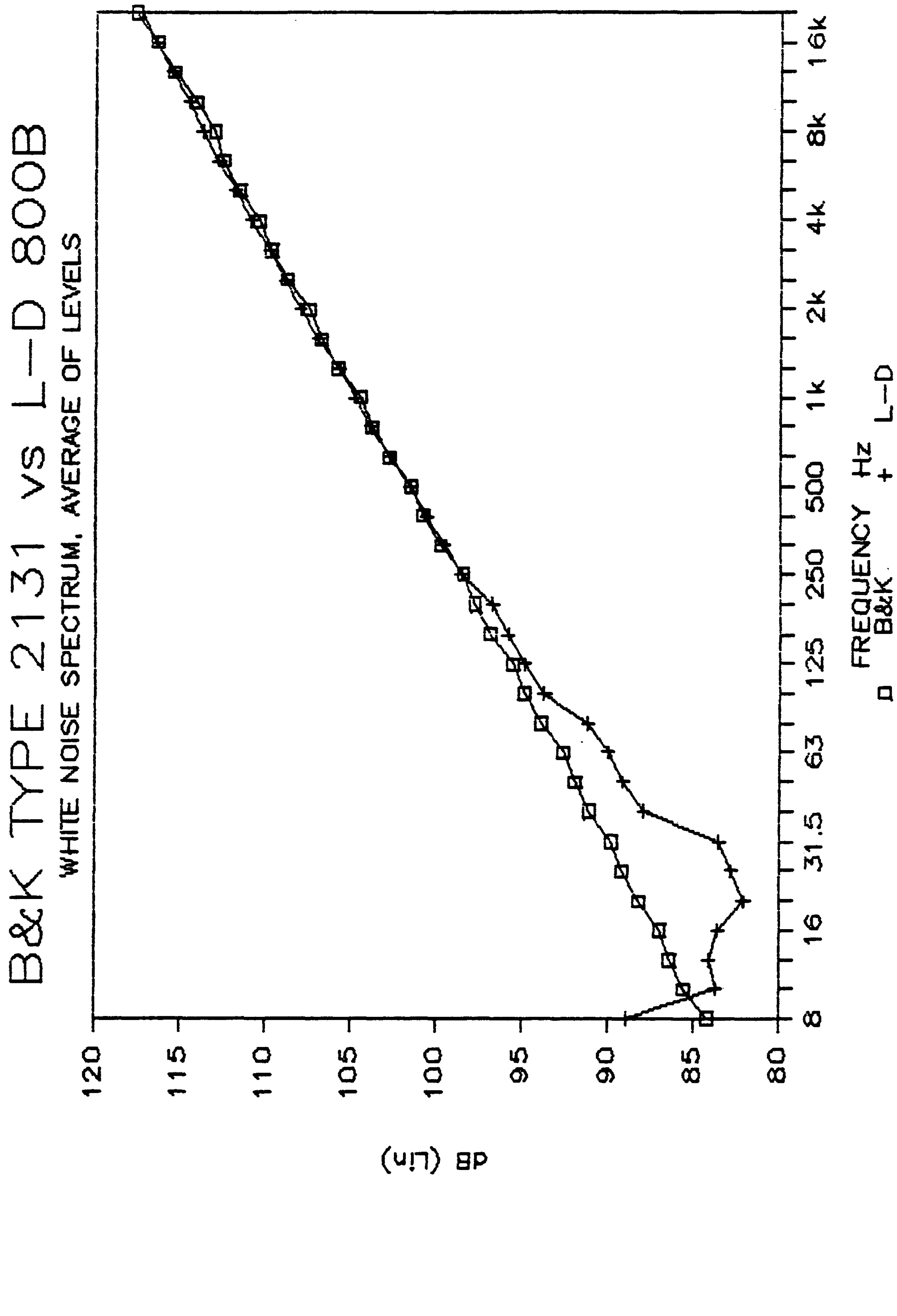

Figure 5. WHITE NOISE SPECTRUM, AVERAGE LEVELS

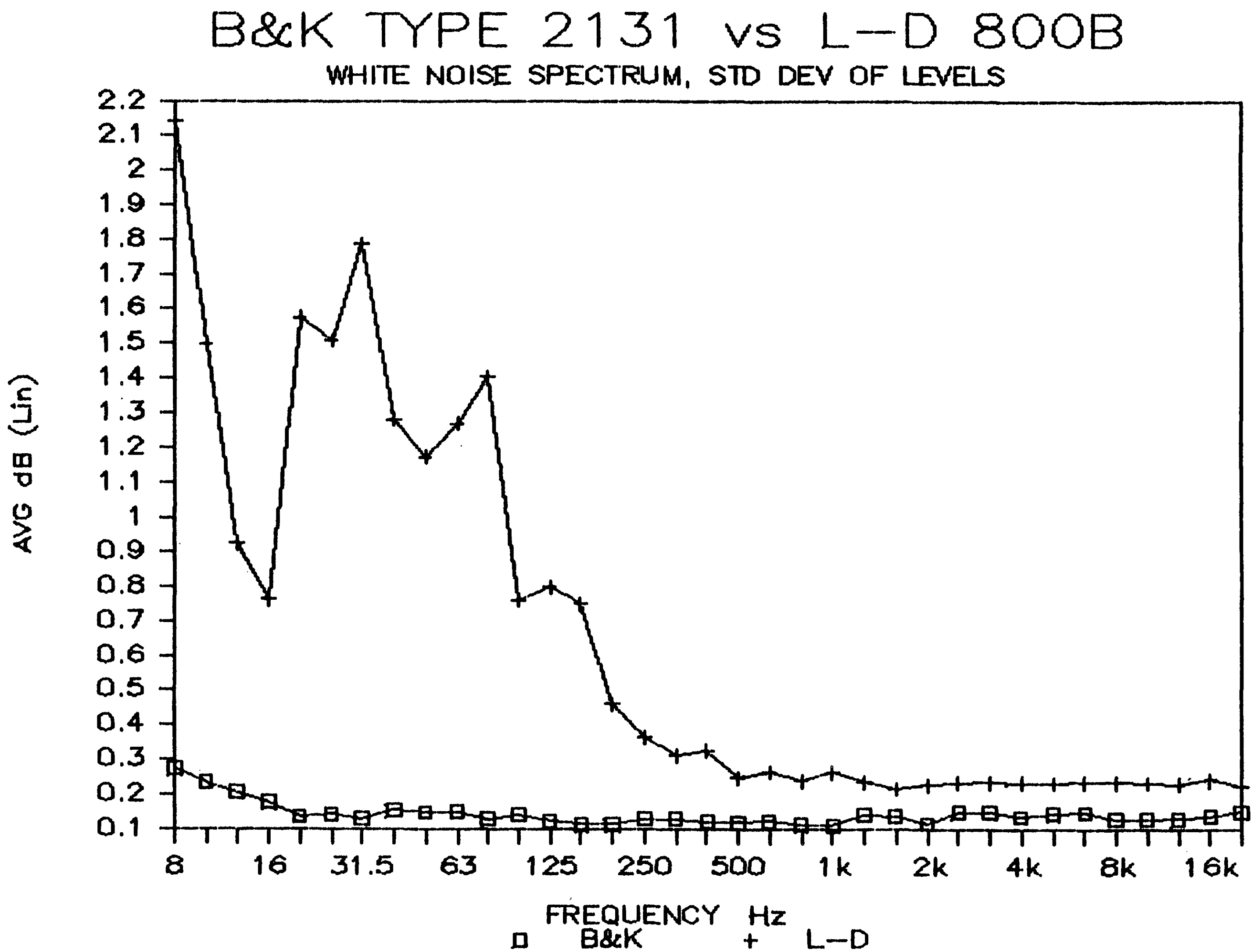

Figure 6. WHITE NOISE SPECTRUM, STANDARD DEVIATION

The larger differences at frquencies below 100 Hz can probably be accounted for by integration time errors. The 2131 system performs a true integration over a sixty four second period during the continuous averaging time while the PSLMS performs only a two second integration at any one frequency band. At the lower frequencies, the two second integration period does not allow for the sampling of enough cycles of the wave to provide results that have a great deal of statistical significance. However, it is not practical to set the integration period any longer on the PSLMS due to the method by which it samples the entire frequency range chosen. If a longer integration period is chosen, the entire sample cycle time is increased by the product of the extra integration time, times the number of bandpass filters being used. The plot of the standard deviations helps to confirm the concept of sampling time error. The larger numbers at the lower frequencies indicate that the data here are not as reliable.

During the test period, the B&K equipment began producing errors. It was felt that enough information had been collected up to that point to enable the first series of tests to conclude. In order to continue, a slightly new test set-up was conceived in which the sound level meter was connected to the noise generator alone and allowed to sample the noise during different test runs. The object of these tests was to hold the noise source as steady as possible and determine how well the sound level meter system would reproduce results over several tests. This method of examination was only meant to serve as a test of accuracy. Data from this set of tests are displayed in a table. (table 4) The standard deviation of this set of data is better than that in the first series of tests. This is explained by the fact that the main objective during the calibration phase of this series was to maintain the identical level being output by the noise generator as opposed to making certain that both types of equipment were receiving the same level. The equipment set-up for this series of tests is shown in a block diagram. (figure 7)

Once the results of the first two sets of tests had been analyzed and found to meet the expectations of the instruments, the PSLMS was configured as a system and allowed to sample the white noise signal from the type 1405 noise generator for the zero-difference test. Eight test segments were run representing a full shift of data collection. The data from these tests are presented in a table. (table 5) The data represents the difference between

FREQUENCY	TEST 15	TEST 16	TEST 17	TEST 18	TEST 19	TEST 20	TEST 21	TEST 22	TEST 23	TEST 24	TEST 25	TEST 26	TEST 27	AVERAGE	STD DEV
8	83.6	83.8	84.5	83.5	83.5	85.0	84.2	83.5	83.5	83.6	84.4	83.5	83.7	83.9	0.46
10	84.7	83.8	85.0	84.8	84.4	85.8	84.7	85.1	84.2	84.6	84.9	84.6	84.1	84.7	0.48
12.5	85.6	85.5	86.5	86.1	85.2	85.7	85.7	85.5	85.6	85.5	84.9	85.3	85.2	85.6	0.40
16	86.8	86.5	86.8	86.5	86.7	86.7	86.6	86.8	86.7	86.8	86.5	86.4	86.7	86.6	0.15
20	87.7	87.8	87.4	87.9	87.8	87.9	88.1	88.0	87.5	87.8	87.0	87.7	87.7	87.7	0.27
25	88.8	88.0	88.5	88.8	88.5	88.1	88.3	88.4	88.4	88.5	88.4	88.2	88.6	88.4	0.23
31.5	89.5	89.2	89.6	89.4	89.6	89.6	89.2	89.5	89.9	89.5	89.3	89.8	89.3	89.5	0.21
40	90.8	90.6	90.8	90.8	90.6	91.2	90.8	90.6	90.6	90.5	90.7	90.8	90.5	90.7	0.18
50	91.6	91.5	91.7	91.5	91.9	91.9	91.6	92.0	91.7	91.6	91.6	91.7	91.8	91.7	0.14
63	92.8	92.5	92.8	92.5	92.5	93.2	92.8	92.6	92.9	92.8	92.5	92.7	92.6	92.7	0.19
80	93.7	93.2	93.8	93.9	93.5	93.5	93.5	93.6	93.5	93.7	93.8	93.3	93.4	93.6	0.20
100	94.7	94.9	94.8	94.7	94.7	95.0	94.9	94.8	94.5	94.7	94.7	94.7	94.7	94.8	0.12
125	95.8	95.8	95.9	95.7	95.8	95.9	96.0	96.2	95.9	95.8	95.8	95.8	95.7	95.8	0.12
160	96.9	96.6	96.8	96.8	96.6	96.9	96.6	96.6	96.6	96.7	96.7	96.8	96.7	96.7	0.11
200	97.6	97.4	97.6	97.6	97.8	97.8	97.7	97.8	97.6	97.8	97.6	97.6	97.8	97.7	0.11
250	98.9	98.7	99.0	99.0	98.8	99.0	98.8	99.0	98.8	99.0	98.8	98.8	98.9	98.9	0.10
315	99.8	99.7	100.0	100.0	99.9	99.8	99.9	99.9	99.9	99.9	99.8	100.0	99.8	99.9	0.08
400	100.9	100.7	100.8	100.9	100.9	100.8	100.8	100.8	101.0	100.8	100.7	101.0	100.7	100.8	0.09
500	101.7	101.6	101.8	101.9	101.8	102.0	101.7	101.8	101.7	102.0	101.6	102.1	101.7	101.8	0.15
630	103.0	102.9	103.0	103.0	103.1	103.0	103.0	103.0	102.9	103.0	102.9	103.2	103.0	103.0	0.08
800	104.0	103.8	104.1	104.0	104.0	104.1	104.0	104.1	103.9	104.0	104.0	104.1	104.0	104.0	0.09
1000	104.9	104.8	105.0	105.1	104.9	105.0	105.0	105.1	104.9	104.9	104.9	105.0	105.0	104.9	0.08
1250	105.9	105.8	105.9	106.0	105.8	106.0	105.9	105.9	105.9	106.0	106.0	105.9	105.8	105.9	0.07
1600	107.1	106.9	107.1	107.2	107.0	107.1	107.1	107.1	107.1	107.1	107.1	107.1	107.0	107.1	0.06
2000	108.0	107.8	108.1	108.1	108.0	108.0	108.0	108.0	108.0	108.1	108.0	108.1	108.0	108.0	0.06
2500	108.8	108.7	108.9	109.0	108.9	108.9	108.9	108.9	108.8	108.9	108.9	108.9	108.9	108.9	0.07
3150	109.8	109.7	109.9	109.9	109.8	109.9	109.8	109.9	109.8	109.9	109.8	109.9	109.9	109.8	0.06
4000	110.9	110.7	110.9	111.0	110.9	110.9	110.9	110.9	110.9	110.9	110.9	111.0	110.8	110.9	0.06
5000	111.9	111.8	112.0	112.0	112.0	111.9	112.0	112.0	111.9	112.0	111.9	112.0	111.9	111.9	0.06
6300	112.9	112.8	112.9	113.0	112.9	113.0	112.9	113.0	112.9	112.9	112.9	112.9	112.9	112.9	0.06
8000	113.9	113.8	114.0	114.0	113.9	114.0	113.9	114.0	113.9	114.0	113.9	114.0	113.9	114.0	0.05
10000	114.7	114.6	114.8	114.8	114.7	114.7	114.8	114.8	114.7	114.8	114.7	114.8	114.7	114.7	0.06
12500	115.8	115.7	115.8	115.8	115.8	115.8	115.8	115.8	115.7	115.8	115.8	115.8	115.7	115.8	0.04
16000	116.8	116.7	116.9	116.9	116.9	116.8	116.8	116.9	116.8	116.9	116.8	116.8	116.8	116.8	0.05
20000	117.9	117.8	118.0	118.0	118.0	117.9	118.0	118.0	117.9	118.0	117.9	118.0	117.9	117.9	0.04

Table 4. LARSON-DAVIS ACCURACY DATA

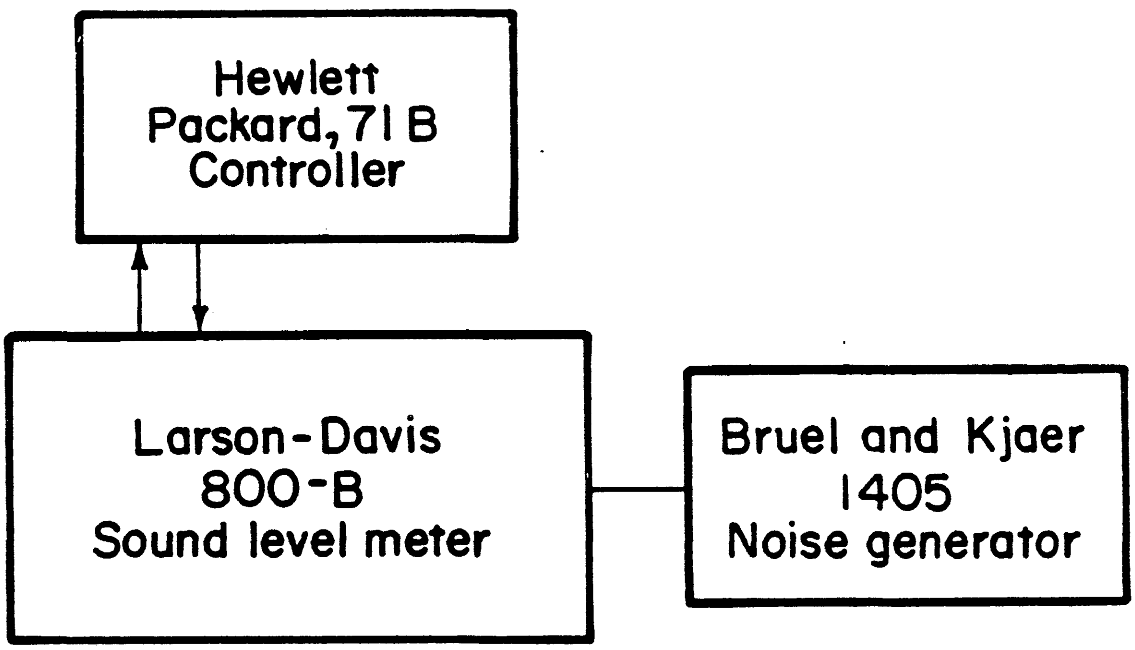

Figure 7. BLOCK DIAGRAM, TEST CONFIGURATION TWO

FREQUENCY	WCOMP1	WCOMP2	WCOMP3	WCOMP4	WCOMP5	WCOMP6	WCOMP7	WCOMP8	AVERAGE	STD DEV
100	0.2716	0.2902	-0.1124	0.0555	0.2881	-0.1292	-0.0114	0.1016	0.1	0.16
125	0.0618	0.0780	0.1962	-0.2426	-0.0242	0.1960	0.1831	0.1572	0.1	0.14
160	-0.0544	-0.1574	0.1855	0.0339	0.0022	0.1361	-0.1138	0.0727	0.0	0.11
200	-0.0514	-0.0486	0.0507	0.1613	-0.0084	0.0322	0.0777	0.1342	0.0	0.07
250	0.1094	0.0053	0.1637	-0.0171	0.2923	0.0365	-0.0058	-0.2155	0.1	0.14
315	0.1027	-0.0163	-0.0911	-0.0431	0.0665	-0.0816	-0.0258	0.0380	0.0	0.07
400	0.3303	0.1067	0.0432	0.0992	0.1527	0.0029	0.0400	0.1115	0.1	0.09
500	0.0155	0.1727	0.0542	-0.0296	-0.2100	0.1845	0.0487	0.0435	0.0	0.13
630	-0.1366	0.0229	-0.2126	0.0920	-0.1170	0.0730	-0.1941	0.1147	0.0	0.11
800	-0.0136	0.0891	-0.0941	0.0892	-0.0824	0.1039	-0.0504	0.1584	0.0	0.11
1000	-0.0584	0.1146	-0.1731	0.0174	-0.1346	0.0669	-0.1742	0.1557	0.0	0.15
1250	-0.0758	0.1772	-0.1460	0.1686	0.0132	0.2047	-0.2615	0.1280	0.0	0.16
1600	-0.1350	0.1712	-0.2145	0.1403	-0.1578	0.1242	-0.0947	0.1530	0.0	0.15
2000	-0.0942	0.1851	-0.1707	0.0588	-0.0214	0.1648	-0.1497	0.1978	0.0	0.13
2500	-0.0667	0.0573	-0.1900	0.0765	-0.1204	0.1525	-0.0410	0.1346	0.0	0.12
3150	-0.0861	0.2089	-0.1822	0.0648	-0.0608	0.0958	-0.0521	0.1520	0.0	0.15
4000	-0.1001	0.1815	-0.1811	0.1904	-0.1130	0.1784	-0.1816	0.1983	0.0	0.18
5000	-0.1645	0.1727	-0.1717	0.1991	-0.1687	0.2063	-0.1443	0.2716	0.0	0.21
6300	-0.2088	0.2530	-0.1921	0.2444	-0.2089	0.2716	-0.2104	0.2611	0.0	0.28
8000	-0.3032	0.3143	-0.3398	0.3409	-0.2858	0.3732	-0.3392	0.3073	0.0	0.33

Table 5. ZERO DIFFERENCE DATA, WHITE NOISE

the levels recorded by the individual meters while they were both receiving the same signal. The meters were calibrated before and after each test segment to insure that both were responding to the signal at the same level. The average difference is plotted in a graph. (figure 8)

The tests of microphone frequency response yielded favorable results. In the initial stages, problems were encountered with the isolation of the test system. The type 4222 anechoic test chamber, as located in the noise laboratory, was picking up spurious signals from its surroundings. Jumps in response were noted when personnel passed by in the hallway or when doors could be heard being shut in other parts of the building. To overcome this problem, the small test chamber was isolated further by enclosing it within a walk-in anechoic chamber. This was done in lieu of obtaining a hetrodyne slave filter which can be operated synchronously with the sweep of the input signal to eliminate outside noise. The instrumentation test set-up that was used is shown in a block diagram. (figure 9) The results of the double isolation were good. The subsequent testing showed no signs of the spurious noise except at very low frequencies.

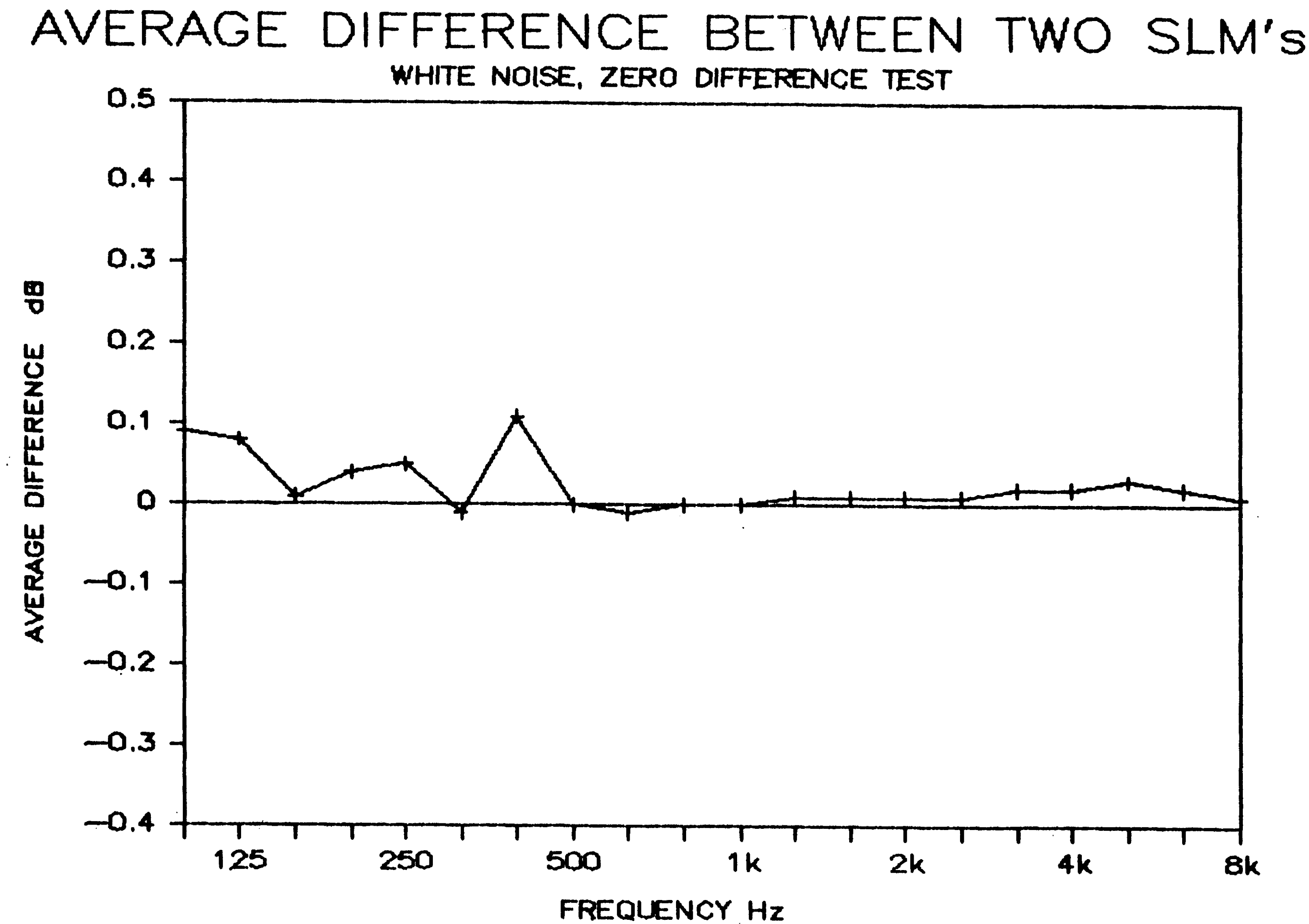

Figure 8. ZERO DIFFERENCE TEST, WHITE NOISE

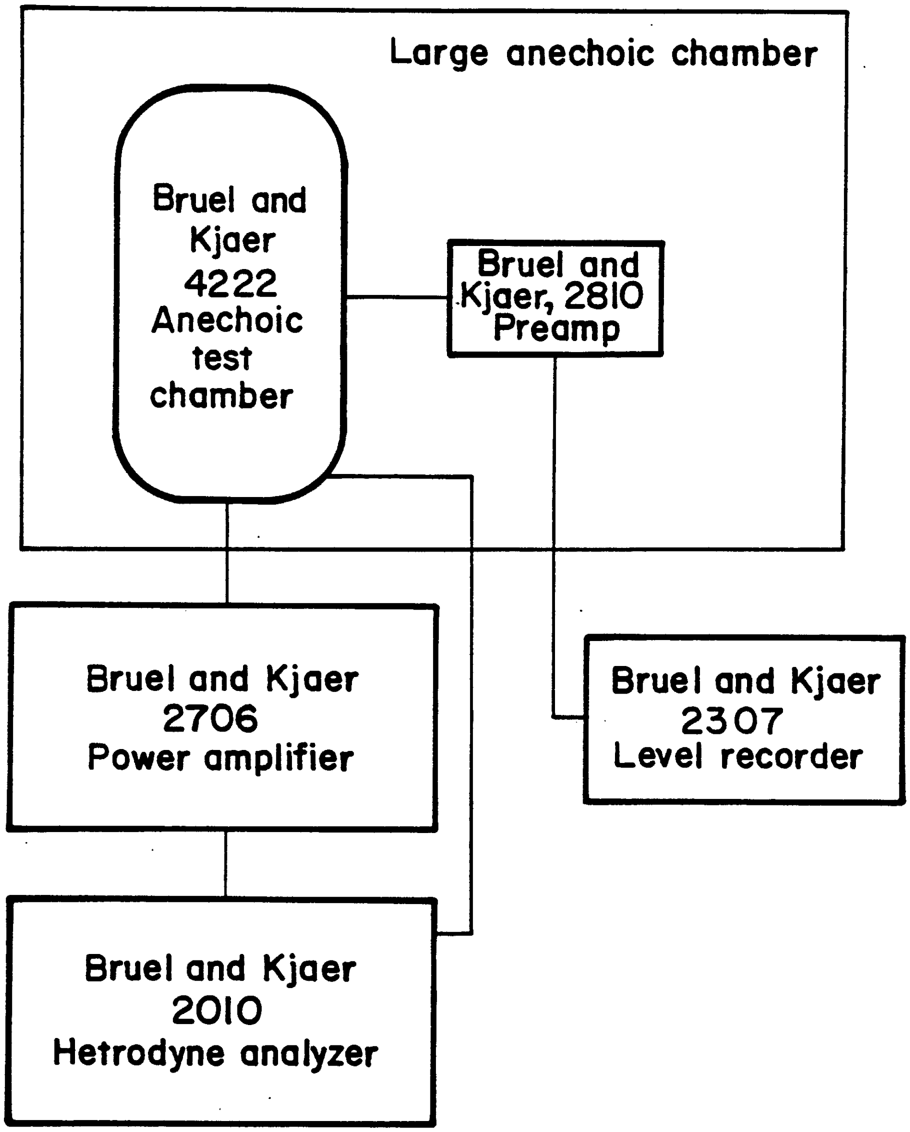

Figure 9. BLOCK DIAGRAM, TEST CONFIGURATION THREE

The data from the frequency response tests is produced in the form of paper strip charts that are written on the strip chart recorder. The plots on the charts are analyzed visually to reveal the characteristics of the microphone. The sample strip charts (figure 10 and figure 11) reveal the information on the two microphones. Traces that are the same shape but exhibit a vertical offset show a difference in overall sensitivity and are more favorable than traces that are different in shape even if the overall level is the same. Differences in overall sensitivity can be overcome easily by calibrating the two individual meter units together at any one frequency. They will then yield similar data at all frequencies. If, however, the two traces were not parallel, calibrating at any one frequency would only yield good agreement at that frequency. The swept frequency spectra from the Knowles microphones shows them to be parallel in their linear range between the pair of microphones selected.

The final phase of testing was performed using a tape recorded noise track of a diesel powered front end loader. The noise was recorded from within the cab on the machine during a typical work day. The tape provides approximately forty minutes of noise. The test set-up consisted of the

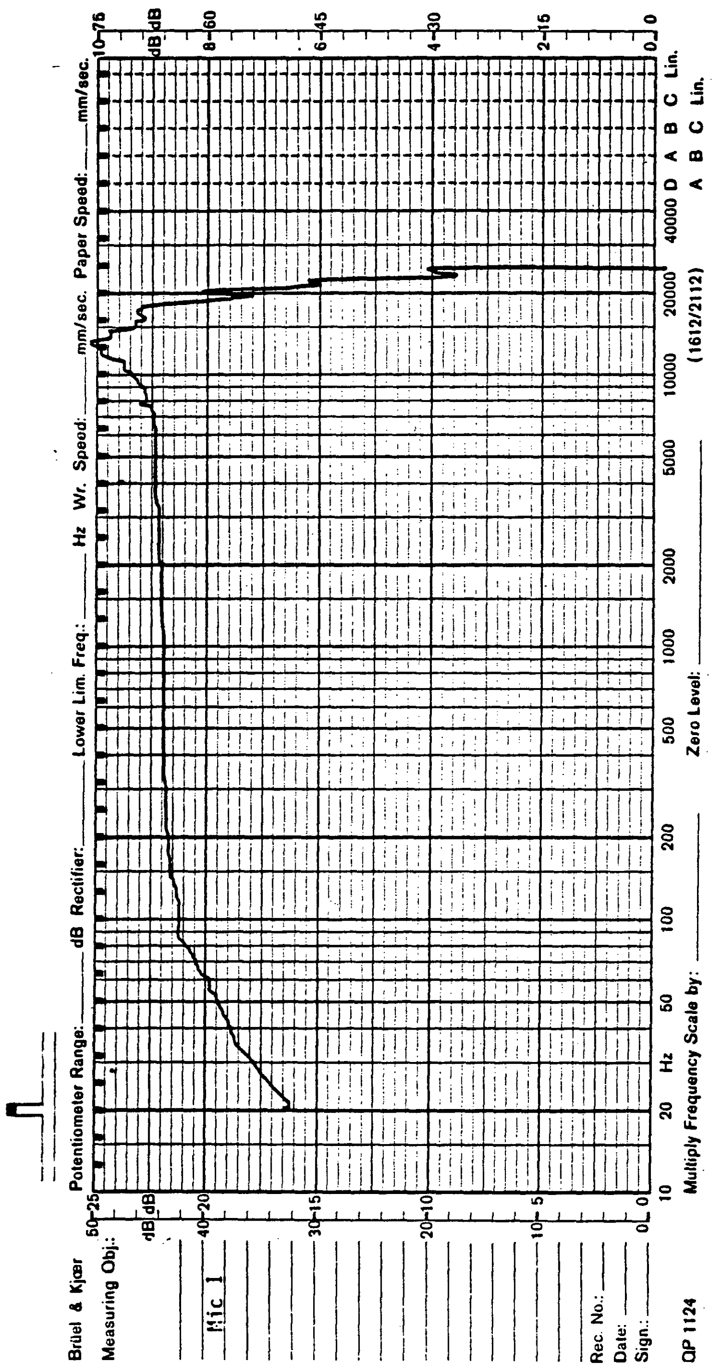

Figure 10. FREQUENCY RESPONSE, MICROPHONE ONE

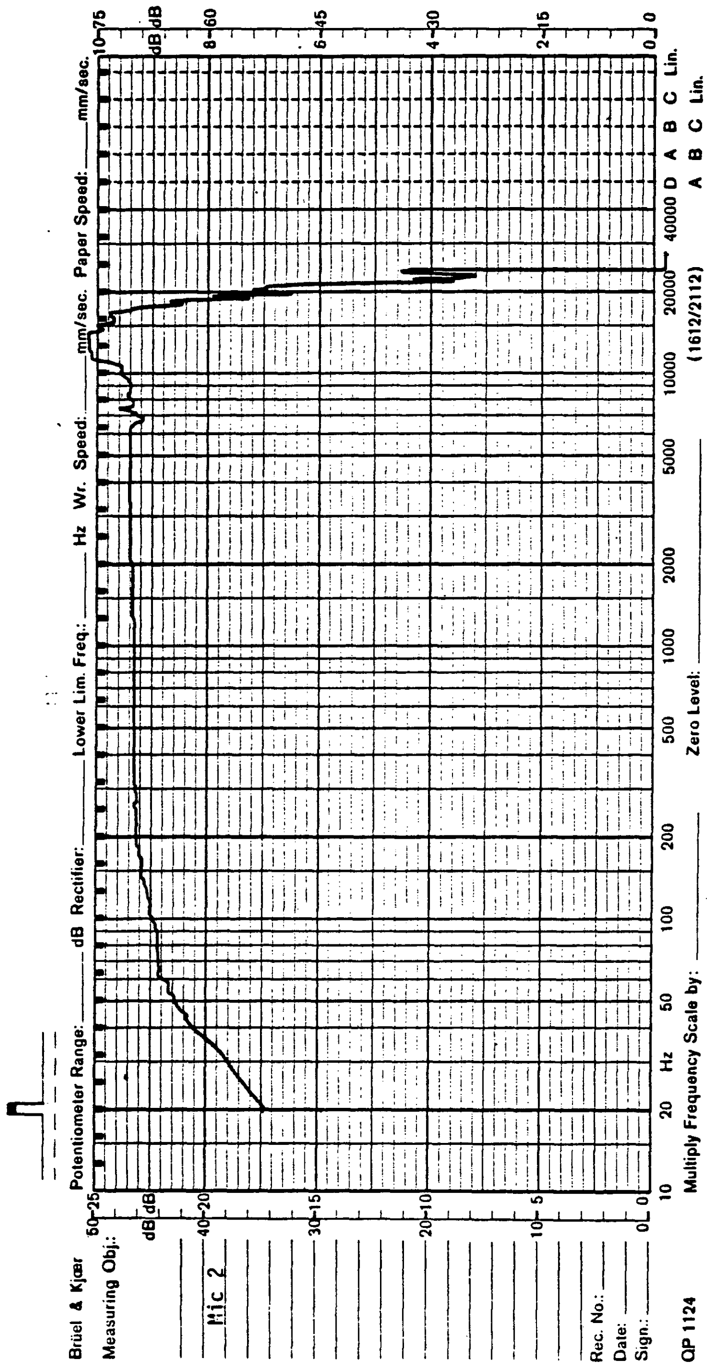

Figure 11. FREQUENCY RESPONSE, MICROPHONE TWO

tape mounted on a Nagra Kudelski IV-SJ two track tape recorder, the Bruel & Kjaer type 2131 third octave band analyzer, the Bruel & Kjaer type 2313 graphics recorder, and the PSLMS system. The Bruel & Kjaer type 1405 noise generator was also employed to provide a different signal to the meter not currently under scrutiny. This provided a further test of the system software to deal with signals of two differing amplitudes.

The signal from the tape recorder was fed to both meters via electrical means and the PSLMS was set to a calibration mode. The tape was recorded with a 1000 Hz calibration tone at the beginning of the noise track. This signal was used to calibrate both sound level meters to the same reading. The tape was then stopped and the PSLMS was set to record data for approximately thirty minutes using third-octave band filtering in the range from 100 to 8000 Hz, linear weighting factor, and a two second integration period. The tape was then restarted and sampling commenced with the beginning of the noise track. This allowed the same section of the tape to be sampled repeatedly. When the sampling was completed, the system controller was disconnected from the PSLMS and the data were recorded on magnetic tape and reduced using a second program on the

HP-71B. The instrumentation arrangement for testing is shown in a block diagram. (figure 12) Data from this series of tests are shown in tables. (table 6 and table 7) As with the white noise tests, the average levels produced by the two types of instrumentation are plotted on one graph for comparison. (figure 13) The standard deviation of the data is also plotted in a graph. (figure 14) It can be observed from these two plots that the average from the two systems still compares quite well, while the standard deviation exhibits a greater degree of randomness than with the white noise data.

The zero-difference test was also run again to examine the ability of the system to sample a more variable noise than that of the white noise generator. The instrument set-up for the zero-difference test is shown in a block diagram. (figure 15) Calibration for this test was done using the 1000 Hz tone that had been recorded on the noise tape for this purpose. Once the data from the PSLMS had been collected and reduced it was placed in tabular form. (figure 8) The averages of the data were calculated and are plotted in a graph. (figure 16) The results show the difference of the two meters once again to be roughly zero. It should be noted that the differences from the white noise

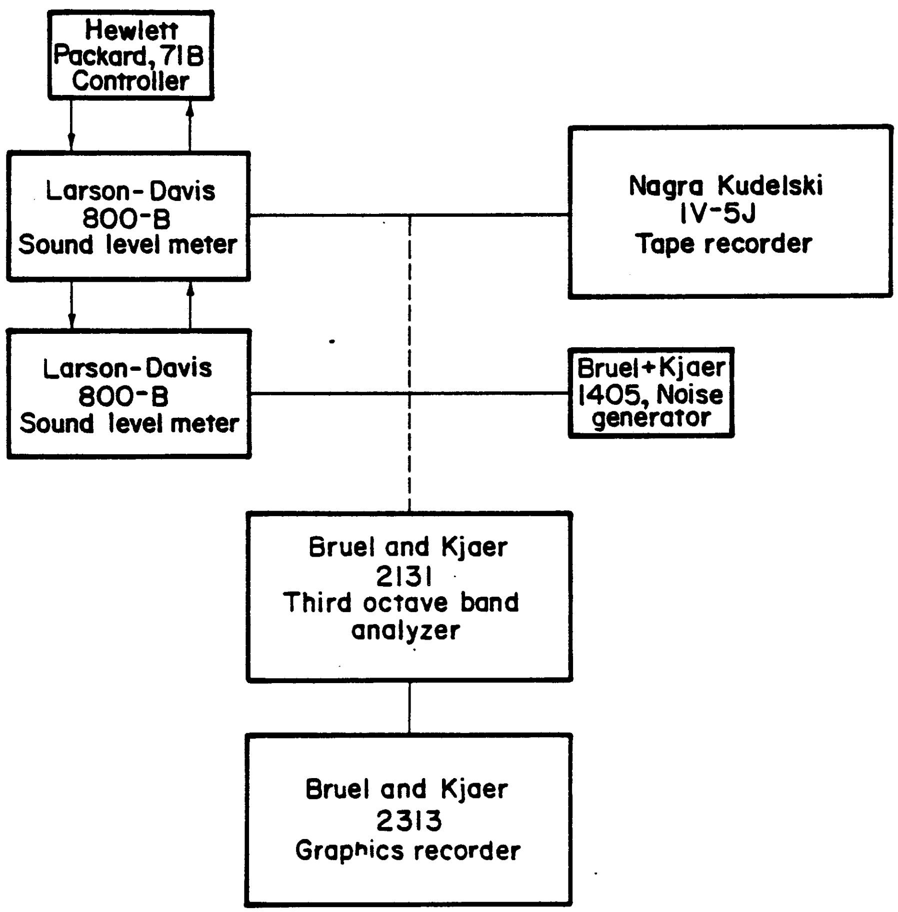

Figure 12. BLOCK DIAGRAM, TEST CONFIGURATION FOUR

FREQUENCY	B&K 1	B&K 2	B&K 3	B&K 4	B&K 5	B&K 6	B&K 7	B&K 8	AVERAGE	STD DEV
100	93.4	92.1	93.4	93.4	93.5	93.4	93.5	93.5	93.3	0.45
125	91.9	90.1	91.2	91.2	91.2	91.2	91.2	91.3	91.2	0.46
160	91.0	91.0	91.0	91.1	91.1	91.1	91.1	91.1	91.1	0.05
200	89.5	89.3	89.6	89.6	89.6	89.6	89.6	89.6	89.6	0.10
250	88.4	88.4	88.4	88.4	88.5	88.5	88.4	88.5	88.4	0.05
315	84.0	83.3	84.1	84.1	84.2	84.1	84.1	84.2	84.0	0.28
400	85.1	84.4	85.1	85.1	85.2	85.1	85.2	85.2	85.1	0.25
500	82.8	82.2	82.9	82.9	82.9	82.9	82.9	82.9	82.8	0.23
630	83.6	83.4	83.7	83.7	83.7	83.7	83.7	83.7	83.7	0.10
800	82.7	82.3	82.7	82.7	82.8	82.8	82.8	82.8	82.7	0.16
1000	78.1	77.4	78.1	78.1	78.1	78.2	78.2	78.1	78.0	0.24
1250	77.8	77.5	77.9	77.9	77.9	77.9	77.9	77.9	77.8	0.13
1600	74.4	73.7	74.4	74.4	74.5	74.5	74.4	74.5	74.4	0.25
2000	73.2	72.0	73.3	73.3	73.3	73.3	73.3	73.3	73.1	0.43
2500	71.0	69.3	71.0	71.0	71.1	71.1	71.0	71.1	70.8	0.58
3150	69.3	67.2	69.3	69.3	69.3	69.3	69.3	69.3	69.0	0.69
4000	69.5	68.1	69.5	69.5	69.6	69.6	69.5	69.6	69.4	0.48
5000	70.3	68.0	70.3	70.3	70.3	70.4	70.3	70.4	70.0	0.77
6300	68.3	65.0	68.3	68.3	68.4	68.3	68.3	68.4	67.9	1.10
8000	67.5	63.7	67.5	67.5	67.6	67.6	67.5	67.6	67.1	1.27

FREQUENCY	L-D 1	L-D 2	L-D 3	L-D 4	L-D 5	L-D 6	L-D 7	L-D 8	AVERAGE	STD DEV
100	93.0	89.9	93.5	93.3	92.5	93.0	92.8	89.8	92.2	1.39
125	91.0	91.0	91.4	90.6	92.8	91.4	90.3	91.0	91.2	0.70
160	90.4	90.5	90.4	90.7	90.7	88.4	90.9	90.4	90.3	0.73
200	88.1	87.6	88.8	88.3	89.2	90.8	87.9	87.9	88.6	0.98
250	88.3	88.3	87.5	88.7	88.5	88.6	88.7	88.8	88.4	0.38
315	84.0	83.9	84.9	83.1	82.8	84.5	84.2	83.9	83.9	0.65
400	84.8	83.8	84.5	84.0	82.5	83.2	84.8	83.6	83.9	0.75
500	83.2	82.6	83.2	82.7	81.7	82.1	82.5	82.3	82.5	0.48
630	82.7	82.6	82.2	83.3	82.2	83.0	82.5	82.2	82.6	0.37
800	82.7	82.1	82.5	83.0	82.7	83.2	82.7	82.1	82.6	0.34
1000	77.8	78.0	77.8	77.8	76.8	77.9	77.9	78.1	77.8	0.38
1250	77.6	77.2	77.6	77.6	75.8	76.2	77.2	77.0	77.0	0.63
1600	74.3	74.3	75.0	74.5	74.1	73.3	75.1	74.2	74.3	0.51
2000	72.5	73.9	73.1	72.6	74.1	72.9	73.1	74.0	73.3	0.61
2500	70.8	70.8	71.1	70.3	70.2	70.4	71.1	70.7	70.7	0.32
3150	67.9	68.9	69.0	67.7	67.6	67.2	68.3	69.8	68.3	0.81
4000	67.9	68.9	69.0	68.4	68.5	67.4	67.8	68.9	68.3	0.55
5000	69.3	66.2	70.0	68.0	68.5	68.2	67.3	67.5	68.1	1.11
6300	65.8	67.0	65.1	67.1	68.3	65.8	64.6	65.8	66.2	1.11
8000	63.9	64.8	63.4	65.9	65.8	65.5	66.9	64.8	65.1	1.06

Table 6. LARSON-DAVIS AND BRUEL & KJAER FEL NOISE DATA

FREQUENCY	B&K AVERAGE	B&K STD DEV	L-D AVERAGE	L-D STD DEV	AVG DIFF
100	93.3	0.45	92.2	1.39	1.04
125	91.2	0.46	91.2	0.70	-0.03
160	91.1	0.05	90.3	0.73	0.73
200	89.6	0.10	88.6	0.98	0.96
250	88.4	0.05	88.4	0.38	0.01
315	84.0	0.28	83.9	0.65	0.1
400	85.1	0.25	83.9	0.75	1.15
500	82.8	0.23	82.5	0.48	0.27
630	83.7	0.10	82.6	0.37	1.08
800	82.7	0.16	82.6	0.34	0.07
1000	78.0	0.24	77.8	0.38	0.28
1250	77.8	0.13	77.0	0.63	0.82
1600	74.4	0.25	74.3	0.51	0.01
2000	73.1	0.43	73.3	0.61	-0.15
2500	70.8	0.58	70.7	0.32	0.15
3150	69.0	0.69	68.3	0.81	0.76
4000	69.4	0.48	68.3	0.55	1.02
5000	70.0	0.77	68.1	1.11	1.92
6300	67.9	1.10	66.2	1.11	1.71
8000	67.1	1.27	65.1	1.06	1.92

Table 7. BRUEL & KJAER AND LARSON-DAVIS SUMMARY

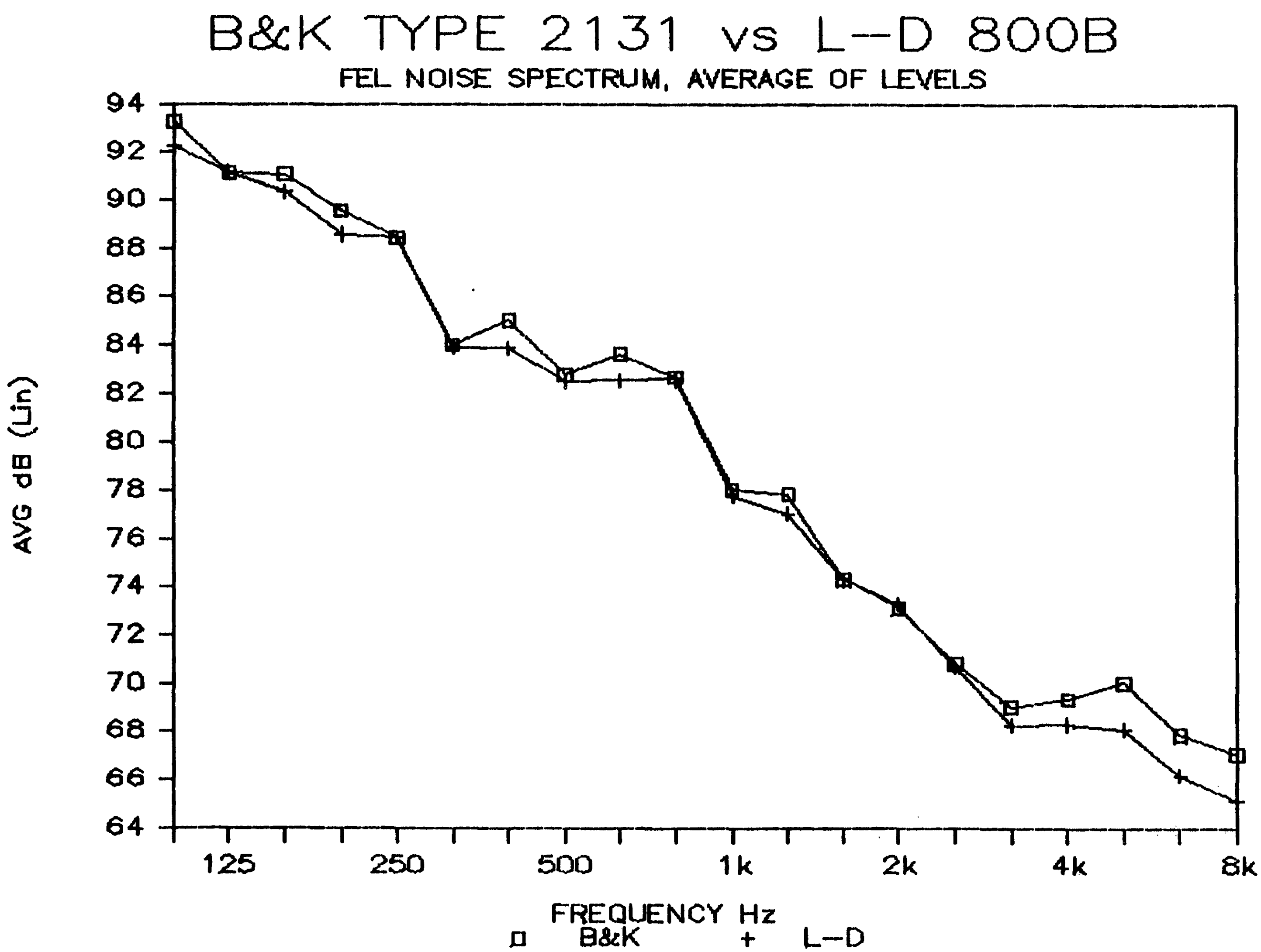

Figure 13. FEL NOISE SPECTRUM, AVERAGE LEVELS

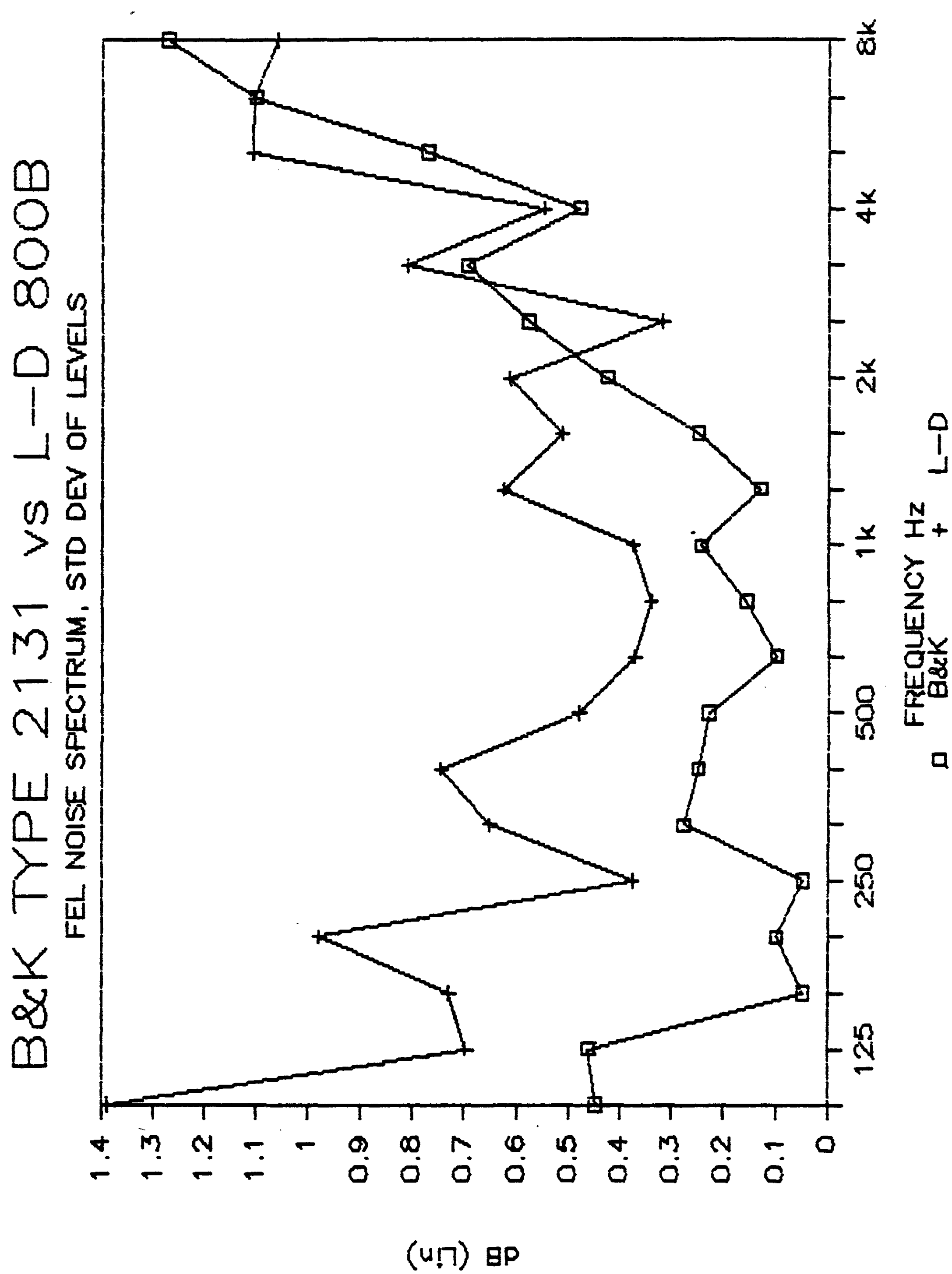

Figure 14. FEL NOISE SPECTRUM, STANDARD DEVIATION

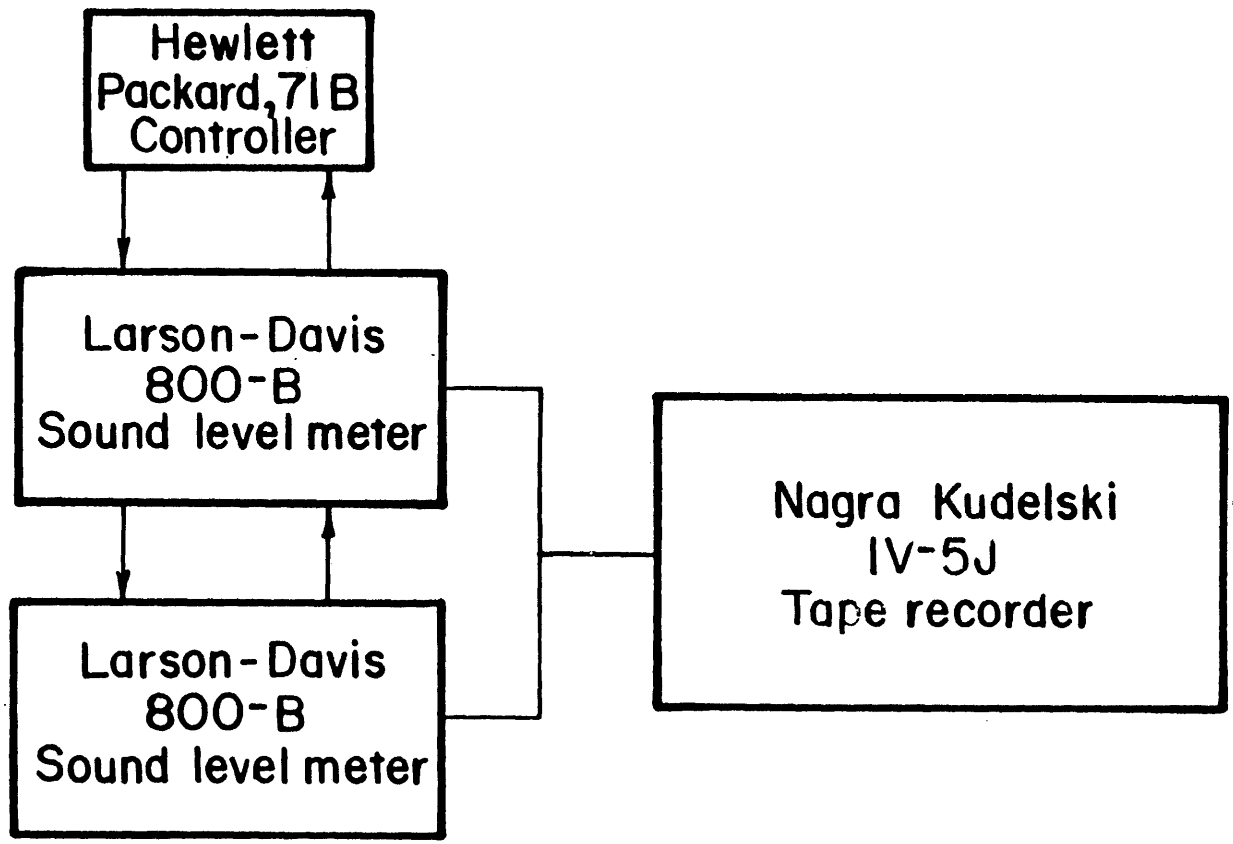

Figure 15. BLOCK DIAGRAM, TEST CONFIGURATION FIVE

FREQUENCY	COMP1	COMP2	COMP3	COMP4	COMP5	COMP6	COMP7	COMP8	AVERAGE	STD DEV
100	0.3052	-0.0806	0.4582	0.4292	0.1575	0.1580	-0.1609	0.2942	0.20	0.21
125	-0.0525	0.1299	0.0971	0.1188	-0.0690	0.1480	0.1912	0.1161	0.08	0.09
160	0.2175	0.0238	0.0353	0.3131	0.1787	0.2088	0.3759	0.0344	0.17	0.12
200	0.3125	0.3700	0.2769	0.0840	0.6660	0.0515	0.2962	0.3595	0.30	0.18
250	-0.1797	0.1699	-0.2496	0.2963	-0.1075	0.1631	0.2127	0.1072	0.05	0.19
315	0.3135	0.2691	0.3701	0.2941	0.0455	0.0200	0.2203	0.0547	0.20	0.13
400	0.1128	-0.0870	-0.1586	-0.0143	-0.1733	-0.0404	0.2149	-0.2214	-0.05	0.14
500	0.1445	0.4809	0.2945	0.2557	0.4623	0.5697	0.4195	0.2322	0.36	0.14
630	-0.4206	-0.4275	-0.3510	-0.4114	-0.3604	-0.3320	-0.4296	-0.3700	-0.39	0.04
800	0.3901	0.5669	0.6416	0.4432	0.4538	0.2266	0.6603	0.5906	0.50	0.14
1000	0.0731	0.1520	-0.0456	0.1930	0.0947	0.3291	0.3895	0.2137	0.17	0.13
1250	0.0376	0.0728	0.0351	-0.0626	0.2313	0.0993	0.1081	0.0504	0.07	0.08
1600	-0.0097	0.0262	0.0704	0.0617	0.4925	0.0011	0.2537	0.1986	0.14	0.16
2000	-0.2249	-0.9105	-0.0575	-0.0141	0.0705	-0.0907	0.1062	-0.0941	-0.15	0.30
2500	0.1033	0.3932	0.0670	-0.0347	0.2299	0.1867	0.5567	0.0379	0.19	0.18
3150	-0.1444	-0.1814	-0.2984	-0.3010	-0.1941	-0.2654	0.1714	-0.5120	-0.22	0.18
4000	-0.1793	-0.1305	-0.1602	-0.2672	0.3735	0.2058	0.0254	0.3250	0.02	0.23
5000	-0.2388	-0.1967	-0.0549	0.0889	-0.1878	-0.1224	-0.0289	-0.1547	-0.11	0.10
6300	-0.3101	-0.3903	-0.1376	-0.1989	-0.4001	-0.2526	0.0389	-0.2857	-0.24	0.13
8000	0.9951	0.1027	-0.1032	-0.0676	-0.2759	0.5233	-0.1456	-0.2192	0.10	0.41

Table 8. ZERO DIFFERENCE DATA, FEL NOISE

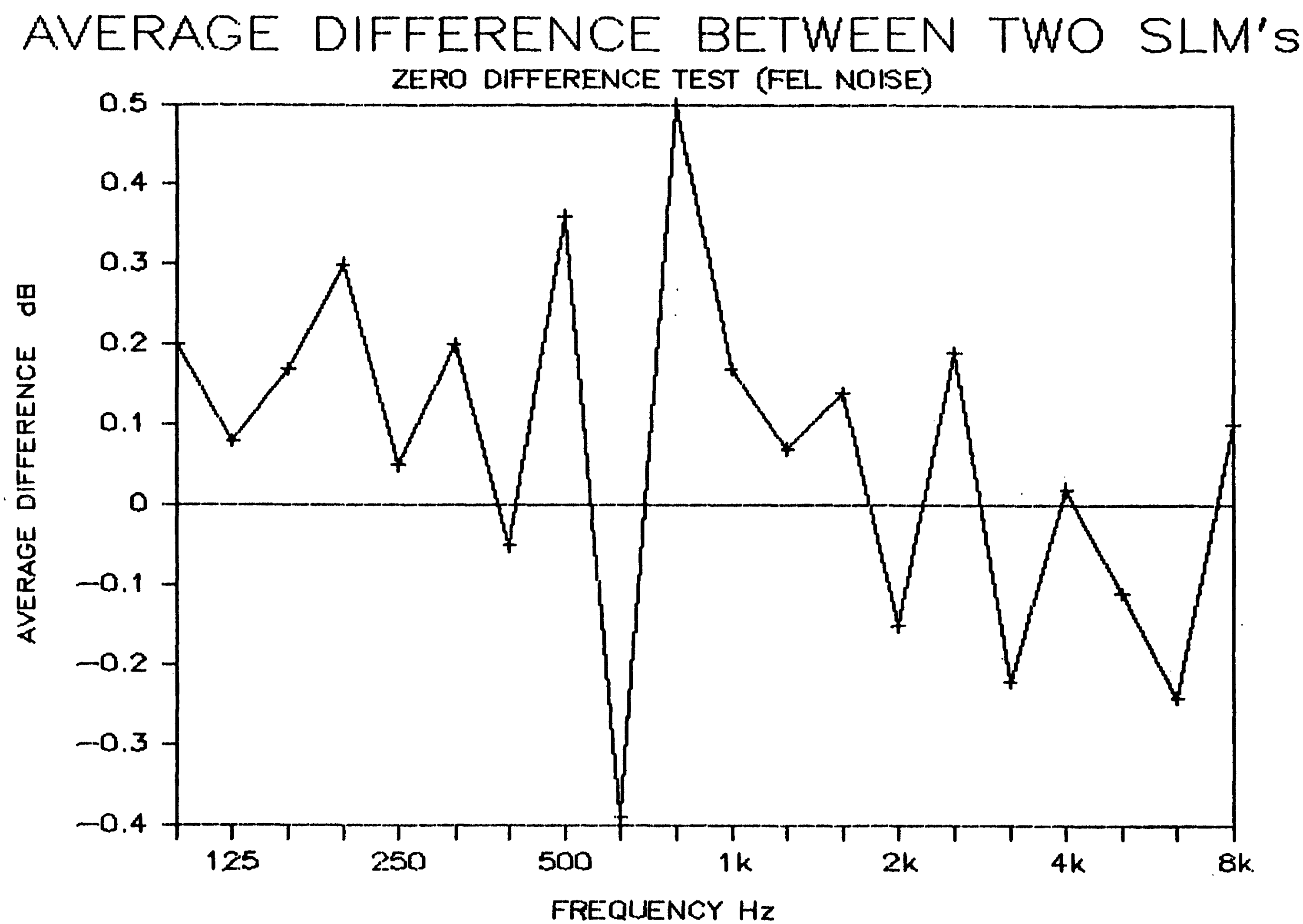

Figure 16. ZERO DIFFERENCE TEST, FEL NOISE

test and the FEL noise test when compared support the concept of a variable difference. They to not seem to show any general instrument bias.

Overall, the tests of the PSLMS instruments show the system to be capable of producing reliable data that are accurate from the standpoint of measurements with laboratory standard equipment, such as the B&K third octave band analyzer; however, the question of the noise floor under the muff remained as a barrier to the collection of reliable physical-method data (10). In order to address this issue, the PSLMS was retested with the microphones attached to make a determination of the system noise floor. The large anechoic chamber was employed again to provide a test environment. The chamber is isolated against outside noise and exhibits a very low noise floor especially at frequencies above 200 Hz. The PSLMS was placed inside the chamber and the microphones were placed on an acoustical mannequin that is designed to simulate a human torso and head. The microphones were placed just as they would be in an actual test on a human with one microphone mounted in the ear of the mannequin and the other microphone taped to the outside of the same earcup that contains the inner microphone. The system was then set to sample while the chamber was left unoccupied by human presence. Data from this test (table 9) show the noise floor of the system while mounted on the mannequin to be in the range of 12 to 24 dB. An odd phenomenon occurred at the 100 and 125 Hz frequencies wherein the level under the earcup on the mannequin appeared to be substantially higher than that outside the cup. Upon further investigation, this was found to be due to vibrational noise induced directly into the mannequin either through the structure of the chamber or airborne noise incident on the mannequin.

A nearly consistent two-dB difference was present at almost all frequencies tested. This was found to be reversible depending on which meter was selected for inside and which one was selected for outside, but it does not appear at higher noise levels. This is apparently due to a differential reduction in the sensitivity of the microphones at low signal levels. A test was performed in which the two microphones were simply placed in close proximity of each other within the large anechoic chamber. The results of this test are in close agreement with the mannequin test except at frequencies below 160 Hz where the level under the cup was higher on the mannequin. (table 10)

FREQUENCY	OPEN AIR TEST		MANNEQUIN TEST		HUMAN TEST (STILL)		HUMAN TEST (MOVING)	
	OUTSIDE	INSIDE	OUTSIDE	INSIDE	OUTSIDE	INSIDE	OUTSIDE	INSIDE
100	24.8	24.1	24.1	42.6	23.1	31.9	29.5	44.6
125	21.1	20.1	23.0	23.8	22.4	24.6	53.0	49.2
160	19.4	17.4	20.7	20.7	20.3	23.1	27.7	34.5
200	18.5	16.3	19.7	18.6	18.8	17.5	22.9	31.9
250	18.1	15.8	18.7	20.2	17.7	16.0	20.5	26.7
315	16.9	14.6	17.9	16.7	17.3	15.3	23.8	20.8
400	16.4	14.2	16.9	14.5	16.4	14.2	22.6	16.4
500	15.7	13.5	16.3	13.6	15.7	13.8	22.8	17.3
630	15.1	13.4	15.8	13.4	15.5	13.1	22.0	15.3
800	15.0	12.9	15.6	13.2	15.0	13.1	22.6	14.7
1000	14.7	12.7	15.4	12.9	14.9	12.9	28.5	15.5
1250	14.6	12.8	15.3	12.9	14.8	12.8	14.8	13.0
1600	14.9	13.6	15.7	13.5	15.2	13.5	15.9	13.8
2000	15.3	13.8	16.0	13.9	15.5	13.8	26.7	14.1
2500	15.7	14.3	16.4	14.3	15.8	14.4	19.2	14.3
3150	16.4	14.8	17.0	14.9	16.4	14.9	20.4	15.1
4000	17.2	15.8	18.1	15.8	17.4	15.8	17.7	15.7
5000	18.1	16.5	18.8	16.5	18.3	16.6	18.4	16.6
6300	19.0	17.3	19.7	17.3	19.2	17.4	19.2	16.9
8000	20.0	18.1	20.7	18.1	20.1	18.2	20.3	18.3
10000	20.8	18.9	21.5	18.9	20.8	18.9	20.8	19.0

Table 9. NOISE FLOOR DATA

FREQUENCY	OPEN AIR TEST		MANNEQUIN TEST		HUMAN TEST (STILL)		HUMAN TEST (MOVING)	
	OUT-IN	AVG	OUT-IN	CORRECTED	OUT-IN	CORRECTED	OUT-IN	CORRECTED
100	0.8	24.4	-5.1	-4	-8.8	-8	-15.1	-14
125	1.0	20.6	-4.0	-3	-2.2	-1	3.8	3
160	2.0	18.4	0.1	-2	-2.8	-1	-6.8	-5
200	2.2	17.4	-0.6	2	1.3	-1	-9.0	-7
250	2.3	17.0	-2.0	0	1.7	-1	-6.2	-4
315	2.2	15.7	1.9	0	2.0	0	2.9	1
400	2.3	15.3	2.8	1	2.2	0	6.2	4
500	2.2	14.6	2.7	1	1.9	0	5.5	3
630	1.8	14.2	2.8	1	2.4	1	6.7	5
800	2.2	14.0	2.8	1	1.9	0	7.9	6
1000	2.0	13.7	2.7	1	2.0	0	13.0	11
1250	1.7	13.7	2.6	1	2.1	0	1.8	0
1600	1.4	14.2	2.6	1	1.7	0	2.1	1
2000	1.5	14.5	2.5	1	1.7	0	12.7	11
2500	1.5	15.0	2.5	1	1.4	0	5.0	4
3150	1.5	15.6	2.5	1	1.5	0	5.3	4
4000	1.4	16.5	2.3	1	1.6	0	2.0	1
5000	1.6	17.3	2.7	1	1.6	0	1.9	0
6300	1.8	18.1	2.9	1	1.9	0	2.2	0
8000	1.9	19.0	2.9	1	1.9	0	2.1	0
10000	1.9	19.8	2.6	1	1.9	0	1.8	0

Table 10. NOISE FLOOR RESULTS

The final check was to test the system noise floor on a human subject. Two versions of this test were performed. The first version had the subject sitting as motionless as possible in the anechoic test chamber while the PSLMS sampled the noise level under the hearing protector cup and outside of the hearing protector cup. The results from this test are very similar to the mannequin tests indicating that the levels shown are indeed the noise floor of the instruments and that the physiological noise floor is below the 12 to 24 dB range at the frequencies tested. The second version of this test required that the subject move around on the basis that the physiological noise floor would be increased over that of a stationary subject along with other motion induced noise sources such as the noise of the system cables hitting the ear cup and the noise that can be induced by relative motion between the inside microphone and the test subject. The motion test did show slightly increased levels at most frequencies with significant increases below 250 Hz. There appears to be an amplification of low frequency noise under the ear cup but it is difficult to determine if the levels are actually amplified or if the level of the noise under the cup is higher and the outside microphone is being shielded by the presence of the hearing protector. The noise levels observed still do not represent an impediment to the collection of data. The corrected levels (figure 10) were arrived at by reducing the difference in level between the two microphones by the amount of difference from the open air test. As stated earlier, the apparent deviation between the two microphones is not seen at higher levels; however, since it does appear at low noise levels, the difference in levels from inside to outside was corrected by this amount.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

This new system should be a valuable tool to use in increasing the body af data available on the field attenuation of muff-type hearing protectors. If the data collected by this system can be correlated with laboratory data in some predictable manner the results will yield two highly useful bench marks for hearing protectors. First, the current policy of derating hearing protectors can either be confirmed or modified to a more realistic level. Second, the amount of protection offered by new hearing protective devices in the field will be predictable using laboratory tests.

The results of testing performed on the PSLMS have shown it to be a credible data collection tool for the inside-outside microphone procedure of testing muff-type hearing protectors under the conditions proposed for studies on surface mining equipment. All system components work well together to perform the task of data collection in a manner that appears to be superior to those used to date. All design goals for the PSLMS have been met as follows:

1. Continuous data collection for periods extending up to and beyond a full shift (eight hours).

2. Data collection in full or third-octave bands.
3. Portability sufficient to allow placement on mobile surface mining equipment with the potential for placement on personnel.
4. Microphones small enough to be placed under ear muff cups without interfering with the mass of the protective device.
5. Ability to sample two channels simultaneously but independently.
6. Noise floor sufficiently low to help prevent masking or clipping of the measured effectiveness.
7. High dynamic range to compliment low noise floor.
8. Remote operation.

Preliminary data will have to be rechecked to insure that masking is not occuring at low frequency, low signal portions of records. If masking appears to be a problem, the PSLMS will allow for on line data conditioning to help overcome this problem. One possibility would be to "flag" data that fall under a certain predetermined cutoff range so they can be scrutinized separately during analysis. This is only one example of the flexibility allowed by using a fully programmable system controller.

The increase in the standard deviation of the Larson-Davis data at low frequencies is probably best explained by the shorter integration period used by the sound level meters. This averaging period, which is shorter than that used by the laboratory equipment, does not allow the time to sample as many cycles of a low frequency component as it does of a high frequency component. This results in reduced statistical confidence at low frequencies. While it is generally agreed that this phenomenon occurs, more work would be necessary to actually prove that this is the case regarding the difference in the two sets of data presented here.

Suggestions for improving the present instrumentation would lie mostly in the area of size reduction. The ultimate desire at the present time would be a similar system that would be easily wearable by a miner while he is working. This is not impossible with the present system, but a very willing subject would be needed to wear the present system weighing in at approximately seven pounds.

Future research regarding any system for testing hearing protectors using the inside-outside microphone method should look at the phenomenon of higher levels under the ear cup at low frequencies. This noise would certainly mask the measured effectiveness of the hearing protectors at low signal amplitude.

One method by which the problem of masking can be overcome is to test the hearing protectors on workers that are exposed to very high noise levels. In mining the ideal candidates for extremely high noise levels are percussion drill operators. Following the testing on surface mobile equipment operators, a possible selection for subsequent testing will be drill jumbo operators in underground metal-non-metal mines and quarries who are often exposed to levels exceeding 115 dBA.

Another aspect of physical testing that should be addressed is the use of the inside-outside microphone test on insert type protectors. The size of the microphones becomes much more critical when used on earplugs. The obvious problem lies in mounting the inside microphone under the ear plug, inside the ear canal. Although there are microphones available that are small enough to be placed in the ear canal, there are still safety problems when placing the microphone in the ear canal during physical activity. Less obvious is the problem of microphone mass. When using the microphone under an earmuff, the proportion of the microphone mass to the protector mass is small enough to prevent the microphone from adding to or detracting from the performance of the device under test but this is not so with earplugs. In most cases the microphone can be up to fifty percent of the mass of the earplug. Advances in electronic technology will probably solve this problem in the near future.

REFERENCES CITED

1. Title 30, Code of Federal Regulations; Washington, D.C.; Office of the Federal Register National Archives and Records Administration; Special Edition of the Federal Register; 444-596 (1985)

2. Standard S3.19-1974; New York, NY; American Institute of Physics for the Acoustical Society of America; 2-5 (1974)

3. Lempert, Barry L. and Edwards, Richard G.; Field Investigations of Noise Reduction Afforded by Insert-Type Hearing Protectors; American Industrial Hygiene Association J. 44:12; 894-902 (1983)

4. Alberti,P. W. and Riko, K., et.al.; The Effectiveness of Hearing Protectors in Practice; Toronto, Canada; The Journal of Otolaryngology 8:4; 354-359 (1979)

5. Michael, P. L., Kerlin, R. L., et.al.; A Real Ear Method for the Measurement of the Noise Attenuation of Insert-Type Hearing Protectors; Cincinnati, OH; National Institute for Occupational Safety and Health; Report on contract No. CDC-99-74-63; 7-48 (1976)

6. Behar, Alberto; Field Evaluation of Hearing Protectors; Ontario, Canada; Noise Control Engineering J.; 24:1; 13-18 (1985)

7. Royster, Larry H., Royster, Julia D., and Cecich, Thomas F.; An Evaluation of the Effectiveness of Three Hearing Protection Devices at an Industrial Facility with a TWA of 107 dB; J. Acoustical Society of America; 76:2; 485-497 (1984)

8. Goff, Richard J. and Blank, William J.; A Field Evaluation of Muff-Type Hearing Protection Devices; Bay Village, OH; Sound and Vibration; 18:10; 16-22 (1984)

9. Stewart, Kenneth C. and Burgi, Ernest J.; Noise Attenuating Properties of Earmuffs Worn by Miners Volume 1: Comparison of Earmuff Attenuation as Measured by Psychophysical Methods and Physical Methods;

Pittsburgh, PA; U. S. Bureau of Mines; Final report on contract No. J0188018 (1979)

10. Stewart, Kenneth C. and Burgi, Ernest J.; Noise Attenuating Properties of Earmuffs Worn by Miners Volume 2: Development of a Laboratory Procedure for the Physical Measurement of Earmuff Attenuation; Pittsburgh, PA; U. S. Bureau of Mines; Final report on contract No. J0188018 (1980)

11. Berger, E. H. and Kerivan, J. E.; Influence of Physiological Noise and the Occlusion Effect on the Measurement of Real-Ear Attenuation at Threshold; J. Acoustical Society of America; 74:1; 81-94 (1983)

APPENDIX A

PROGRAM LISTING

This appendix provides a program listing of the HP-71B software developed to drive two programmable sound level meters through continuous spectrum analysis.

```
10 REM ***PSLMSPRG***
20 DISP USING 180;TIME$
30 A$=KEY$ @ IF A$='Y' OR A$='y' THEN 70
40 IF A$='N' OR  A$='n' THEN 50 ELSE 30
50 INPUT "ENTER TIME ","00:00:00";C9$
60 SETTIME C9$
70 DISP USING 190;TIME$
80 FOR I=1 TO 250
90 NEXT I
100 DISP USING 200;DATE$
110 K$=KEY$ @ IF K$='Y' OR K$='y' THEN 150
120 IF K$='N' OR K$='n' THEN 130 ELSE 110
130 INPUT "ENTER DATE ","YY/MM/DD";C8$
140 SETDATE C8$
150 DISP USING 210;DATE$
160 FOR I=1 TO 300
170 NEXT I
180 IMAGE "IS TIME? " XK" Y/N"
190 IMAGE "SYS. TIME IS"XK
200 IMAGE "IS DATE?"XK"  Y/N"
210 IMAGE "SYS. DATE IS"XK
220 CFLAG -23
230 RESET HPIL
240 ASSIGN IO ':LI,:LO,:CA'
```

```
250 CLEAR :LOOP
260 SEND LISTEN 1,2 DDL 2
270 OPTION BASE 0
280 DESTROY ALL
290 STD
300 SHORT N(44),C(44),E(44)
310 SHORT F(44),D(44),O(44),V(44)
330 ON ERROR GOTO 340
340 OFF ERROR
350 D2=210 @ D3=231
360 SEND UNT UNL LISTEN 1,2 MTA DDL 0,DATA 0,0 UNL
370 REM *********************
380 REM 'THIS SECTION SETS UP SAMPLING PARAMETERS
INTERACTIVLY'
390 REM *********************
400 INPUT 'FILE NAME? ';E$
410 IF E$="" THEN BEEP @ GOTO 400
460 INPUT 'STOP TIME ?`,'00:00:00';J3$
470 IF J3$<TIME$ THEN BEEP @ GOTO 460
480 INPUT 'F WT:A(1) C(2) LIN(3)','3';W
490 IF W<1 OR W>3 THEN 480
500 ON W GOSUB 940,950,960
510 INPUT 'START FREQ(HZ) ?','100';F0
520 IF F0>=1 AND F0<=20000 THEN 540
```

```
530 BEEP @ GOTO 510
540 INPUT 'STOP FREQ(HZ) ?','5000';F1
550 IF F1>=F0 AND F1<=20000 THEN 570
560 BEEP @ GOTO 540
570 INPUT '1/1 (0) OR 1/3 (1) ?'.'1';B
580 IF B=1 OR B=0 THEN 600
590 BEEP @ GOTO 570
600 IF B=0 THEN DISP '1/1 OCTAVE BW'
610 IF B=1 THEN DISP '1/3 OCTAVE BW'
620 GOSUB 1200
630 C0$=C$
640 IF B=0 THEN B0=157 ELSE B0=153
650 C3$=CHR$(142)&CHR$(B0)&CHR$(207)
660 C4$=CHR$(102)&CHR$(100)
670 C$=C0$&CHR(63+W)&CHR$(144)&C3$
680 GOSUB 1060
690 INPUT 'INT TIME IN SEC','1';T3
700 IF T3<.25 THEN T3=.25
710 IF T>64 THEN T3=64
720 IF T3>1 THEN P=42-IP(3.33*LOG10(T3)+.5)
730 IF T3<=1 THEN P=42-IP(3.33*LOG10(T3))
740 C5$=CHR$(P)
750 T9=2^(42-P)
760 DISP 'INT TIME';T9;'SEC'
```

```
770 R(0)=30 @ R(2)=30
780 T=0 @ T1=0
790 DISP 'PRESS G TO START.'
800 K$=KEY$ @ IF K$='' THEN 800
810 IF K$='G' OR K$='g' THEN 1390
840 REM *********************
850 REM 'PROGRAM DATA
860 REM *********************
870 DATA 102,100,50,85,120,66,16,40,300
880 DATA 1,1.25,1.6,2,2.5,3.15,4,5,6.3,8,10,12.5,
16,20,25,31.5,40 ,50,63,80
890 DATA 100,125,160,200,250,315,400,500,630,800
1000,1250,1600,2 000,2500,3150,4000,5000
900 DATA 6300,8000,10000,12500,16000,20000
910 REM *********************
920 REM 'DISPLAY SUBROUTINES
930 REM *********************
940 DISP 'A WEIGHT' @ RETURN
950 DISP 'C WEIGHT' @ RETURN
960 DISP 'LINEAR WEIGHT' @ RETURN
970 REM *********************
980 REM 'DEVICE INTERFACE SUBROUTINES
990 REM *********************
1000 OUTPUT ':LI' ;C$
```

```
1010 RETURN
1020 REM ********************
1030 OUTPUT ':LO' ;C$
1040 RETURN
1050 REM ********************
1060 OUTPUT ':LI' ;C$
1070 OUTPUT ':LO' ;C$
1080 RETURN
1090 REM ********************
1100 TRIGGER ':LI'
1110 TRIGGER ':LO'
1120 RETURN
1130 REM ********************
1140 ENTER ':LI' ;A1$
1150 ENTER ':LO' ;A2$
1160 RETURN
1170 REM *********************
1180 REM 'ROUTINE TO INITIALIZE C$ CONTROL CODE FROM
PROGRAM DATA
1190 REM *********************
1200 C$="" @ RESTORE 870
1210 FOR I=1 TO 10
1220 READ D9
1230 IF D9=1 THEN I=10 @ GOTO 1250
```

```
1240 C$=C$&CHR$(D9)
1250 NEXT I
1260 RETURN
1270 REM *********************
1280 REM 'ROUTINE TO DETERMINE L-D CONTROL CODES FOR THE
FREQUENCIES CHOSEN
1290 REM *********************
1300 IF B=0 THEN B0=4 ELSE B0=0
1310 C9=INT(10*LOG10(F9)+.5)
1320 F9=128+MOD(C9,16)
1330 B0=B0+152+C9 DIV 16
1340 RETURN
1350 REM *********************
1360 REM 'THIS SECTION PERFORMS THE SPECTRUM
1370 REM 'ANALYSIS BY STEPPING THE 800B THROUGH THE
SELECTED FREQUENCIES
1380 REM *********************
1390 ASSIGN #1 TO E$
1400 DISP  'SPECTRUM ANALYSIS'
1410 IF B=1 THEN J=1 ELSE J=3
1420 T2=0 @ RESTORE 880
1440 FOR I=1 TO 44
1450 READ F9
1460 F(I)=F9
```

```
1480 IF T2=1 THEN 1510
1480 IF F9<F0 THEN I2=I @ GOTO 1540 ELSE T2=1
1490 I3=I2+1
1500 IF MOD(F(I2),F0)<MOD(F(I3),F0) THEN M0=I2 ELSE
M0=13
1510 IF F9>=F0 AND F9<F1 THEN I4=I @ GOTO 1540
1520 I5=I4+1
1530 IF MOD(F(I4),F1)<MOD(F(I5),F1) THEN M1=I4 ELSE
M1=I5
1540 NEXT I
1550 PRINT #1;1+(M1-M0)/J,DATE$
1560 K$=KEY$ @ IF K$='P' OR K$='p' THEN GOSUB 2340
1570 FOR I=M0 TO M1 STEP J
1580 F9=F(I)
1590 T0=10/F9
1600 IF T0<T3 THEN T0=T3
1610 GOSUB 1300
1620 C$=CHR$(144)&CHR$(F9)&CHR$(B0)&C5$ @ GOSUB 1060
1630 WAIT 30/F(I)+.5
1640 T=0 @ GOSUB 1810
1650 IF N1=1000 AND O1=1000 THEN N2=0 @ O2=0 @ GOTO 1690
1660 N2=N1+R(0)
1670 O2=O1+R(2)
1680 V0=O2-N2
```

```
1690 DISP F(I);'HZ ';N2;O2;V0
1700 PRINT #1;V0
1710 NEXT I
1720 PRINT #1;TIME$
1730 IF MEM<355 THEN GOTO 2290
1750 IF TIME$>J3$ THEN GOTO 2290 ELSE 1560
1770 REM *********************
1780 REM 'AUTORANGING PORTION'
1800 REM *********************
1810 C$=C4$ @ GOSUB 1060
1820 WAIT 10/F(I)+.5 @ GOSUB 1100
1830 GOSUB 1140
1840 IF NUM(A1$)<>8 AND NUM(A2$)<>8 THEN T=0 @ GOTO 1990
ELSE T=T+1
1850 IF NUM(A1$)=8 AND NUM(A2$)=8 THEN H=0 @ H1=2 @ GOTO
1870
1860 IF NUM(A1$=8 THEN H=0 @ H1==0 @ GOTO 1870 ELSE IF
NUM(A2$)=8 THEN H=2 @ H1=2
1870 FOR K=H TO H1 STEP 2
1880 IF T>6 THEN 1890 1720 ELSE 1910
1890 IF R(K)>=50 THEN R(K)=80 ELSE R(K)=R(K)+20
1900 T=0 @ GOTO 1920
1910 BEEP @ GOTO 1810
1920 R(K+1)=INT(R(K)/20+.5) @ C$=C4$&CHR$(52-R(K+1))
```

```
1930 NEXT K
1940 IF H=0 AND H1=2 THEN GOTO 1950 ELSE GOTO 1960
1950 GOSUB 1060 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
1960 IF H=0 AND H1=0 THEN GOTO 1970 ELSE GOTO 1980
1970 GOSUB 1000 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
1980 GOSUB 1030 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
1990 N9=NUM(A1$)-13 @ O9=NUM(A2$)-13
2000 IF N9<0 THEN N9=0
2010 IF O9<0 THEN O9=0
2020 N1=N9/4 @ O1=O9/4
2030 IF N1=0 OR O1=0 THEN 2040 ELSE 2060
2040 IF N1=0 AND O1=0 THEN H2=0 @ H3=2 @ GOTO 2100
2050 IF N1-0 THEN H2=0 @ H3=0 @ GOTO 2100 ELSE IF O1=0
THEN H2=2 @ H3=2 @ GOTO 2100
2060 IF N1>58 OR O1>58 THEN 2070 ELSE 2250
2070 IF N1>58 AND O1>58 THEN H=0 @ H1=0 @ T=7 @ GOTO
1870
2080 IF N1>58 THEN H=0 @ H1=0 @ T=7 @ GOTO 1870
2090 IF O1>58 THEN H=2 @ H1=2 @ T=7 @ GOTO 1870
2100 FOR K=H2 TO H3 STEP 2
2110 IF R(0)=-10 THEN N1=1000
```

```
2120 IF R(2)=-10 THEN O1=1000 @ GOTO 2250
2130 IF R(K)=80 THEN R(K)=50 @ GOTO 2150
2140 IF R(K)<=50 THEN R(K)=R(K)-20 @ GOTO 2150
2150 R(K+1)=INT(R(K)/20+.5) @ C$=C4$&CHR$(52-R(K+1))
2160 NEXT K
2170 T1=T1+1
2180 IF H2=0 AND H3=2 THEN GOTO 2190 ELSE GOTO 2200
2190 GOSUB 1060 @ WAIT 30/F(I)+5 @ GOTO 2230
2200 IF H2=0 AND H3=0 THEN GOTO 2210 ELSE GOTO 2220
2210 GOSUB 1000 @ WAIT 30/F(I)+5 @ GOTO 2230
2220 GOSUB 1030 @ WAIT 30/F(I)+5 @ GOTO 2230
2230 IF T1>6 THEN T1=0 @ N1+1000 @ O1=1000 @ GOTO 2250
2240 GOSUB 1100 @ GOTO 1830
2250 T1=0 @ T=0 @ RETURN
2260 REM *********************
2270 REM 'END ROUTINE
2280 REM *********************
2290 ASSIGN #1 TO *
2300 COPY E$ TO ':CA'
2310 DISP 'JOB COMPLETED @ ';TIME$
2320 K$=KEY$ @ IF K$='' THEN 2320
2330 END
2335 REM *********************
2337 REM 'WAIT ROUTINE
```

```
2340 DISP 'PRESS ANY KEY TO CONT'
2350 K$=KEY$ @ IF K$='' THEN 2320
2360 RETURN
```

APPENDIX B

PROGRAM DOCUMENTATION

The first section of the program offers the user a chance to check the controller's internal clock and calendar and correct them if they are not set properly. Since the program needs the correct date to properly document files, this is a prudent if not entirely necessary check. The correct time; however, is necessary in order to enable the termination of sampling at a point in time that does not have to be calculated by the user. The time of day that sampling is to end is all that is needed by the program.

```
10 REM ***PSLMSPRG***
```

Remark line naming program file.

```
20 DISP USING 180;TIME$
```

At the beginning of execution this line causes the question, " IS TIME? 00:00:00 Y/N ", to be displayed where 00:00:00 is the current time known to the system.

```
30 A$=KEY$ @ IF A$='Y' OR A$='y' THEN 70
```

Retrieves user response from keyboard and passes control to line 70 on a positive response, line 40 on any other response.

```
40 IF A$='N' OR A$='n' THEN 50 ELSE 30
```

Passes control to line 50 on a negative response or back to line 30 on a null response.

```
50 INPUT "ENTER TIME ","00:00:00";C9$
```

On a negative response in line 40, displays prompt, " ENTER TIME 00:00:00 ", and places cursor under the first zero.

```
60 SETTIME C9$
```

Employs input time from line 50 to set system time.

```
70 DISP USING 190;TIME$
```

Displays, " SYS. TIME IS 00:00:00 ", as a final confirmation that the correct time is placed in the system.

```
80 FOR I=1 TO 250
90 NEXT I
```

This loop causes a short delay so the user has time to read the statement in line 70.

```
100 DISP USING 200;DATE$
```

Displays, " IS DATE? YY/MM/DD Y/N ", showing the date currently known to the system.

```
110 K$=KEY$ @ IF K$='Y' OR K$='y' THEN 150
```

Retrieves response from keyboard and passes control to line 140 on a positive response, line 120 on any other response.

```
120 IF K$='N' OR K$='n' THEN 130 ELSE 110
```

Passes control to line 130 on a negative response, line 110 on a null response.

```
130 INPUT "ENTER DATE ","YY/MM/DD";C8$
```

Displays the prompt, " ENTER DATE YY/MM/DD ", placing the cursor under the first `Y' in the date.

```
140 SETDATE C8$
```

Uses input date from line 130 to set system date.

```
150 DISP USING 210;DATE$
```

Displays, " SYS. DATE IS YY/MM/DD ", confirming the current system date.

```
160 FOR I=1 TO 300
170 NEXT I
```

Loop causes a short delay so the user has time to read the display from line 150.

```
180 IMAGE "IS TIME? " XK" Y/N"
```

Image for line 20.

```
190 IMAGE "SYS. TIME IS"XK
```

Image for line 70.

200 IMAGE "IS DATE?"XK" Y/N"

Image for line 100.

210 IMAGE "SYS. DATE IS"XK

Image for line 150.

The above section causes a short discourse wherein the user is shown the current system time and is asked whether or not it is correct. If it is not correct, a "no" response, the user is prompted for the correct time, and this time is set as the system time. If the time is deemed correct, the system reconfirms the time then moves on to the date. The yes/no response causes the same reactions as in the time section. From here, control is automatically passed on to the next section of the program.

****

The next section of commands sets the system operating parameters to an initialized state:

220 CFLAG -23

Clear flag -23, defeats overflow warning indicator. If this flag were to remain set, a confusing warning message could possibly appear in the display.

230 RESET HPIL

Resets all addresses on the HP Interface Loop. If system was previously used with a different set of loop addresses, this command restores continuity over the loop.

240 ASSIGN IO ':LI,:LO,:CA'

Assigns addresses to the devices on the HP Interface Loop. While the address labels can be arbitrarily chosen, these are intended to be descriptive so the user can determine which device occupies which physical location in the loop. IM, stands for Inside Microphone; OM, stands for Outside Microphone; CA, stands for Cassette recorder.

250 CLEAR :LOOP

Clears input/output buffers on all devices connected on the HPIL loop.

260 SEND LISTEN 1,2 DDL 2

Sets up devices at addresses one and two, the sound level meters, as listeners so the 71B can send them messages over the loop by simply using the "output" statement. The DDL 2 sequence is a device dependent message indicated by the byte number 2.

270 OPTION BASE 0

Sets array base to zero, as opposed to one, and sets display to instantly scroll completely to the right.

280 DESTROY ALL

Resets all variables.

290 STD

Selects standard display format for numbers.

```
300 SHORT N(44),C(44),E(44)
310 SHORT F(44),D(44),O(44),V(44)
```

Dimensions arrays N,C,E,F,D,O, and V. It also sets the values as having a five decimal digit precision.

```
330 ON ERROR GOTO 340
340 OFF ERROR
```

Turns off any error flag occuring as a result of line 340.

```
350 D2=210 @ D3=231
```

Initialize D2 and D3.

```
360 SEND UNT UNL LISTEN 1,2 MTA DDL 0,DATA 0,0 UNL
```

The UNT UNL sequence clears all devices on the loop from talker and listener status. The LISTEN 1,2 MTA sequence sets up the devices at addresses 1 and 2, the sound level meters, as listeners and makes the 71B the only talker. The DDL 0, DATA 0,0 sequence sends device dependent listener message 0 and the data message 0,0. The UNL then takes all devices off of listener status.

****

The next section of the program is an interactive section using the keyboard as the input device. It allows the user to select sampling parameters with default values set at each stage. It also guides the user through the steps necessary to include enough file identifiers to be able to recall what information is stored in a particular file.

```
370 REM *********************
380 REM 'THIS SECTION SETS UP SAMPLING PARAMETERS
INTERACTIVLY'
390 REM *********************
```

Title block.

```
400 INPUT 'FILE NAME? ';E$
```

Prompts user for a data file name.

```
410 IF E$="" THEN BEEP @ GOTO 400
```

Returns control to line 400 if a null string response is indicated for the filename.

```
460 INPUT 'STOP TIME ?`,'00:00:00';J3$
```

Prompts user for time that sampling is to cease.

```
470 IF J3$&lt;TIME$ THEN BEEP @ GOTO 460
```

Returns control to line 460 if a null string response is indicated for the stop time.

```
480 INPUT 'F WT:A(1) C(2) LIN(3)','3';W
```

Prompts user for weighting factor. A default factor of `3' is displayed that can be passed directly to the program by simply pressing the return key during execution.

```
490 IF W<1 OR W>3 THEN 480
```

Passes control back to line 480 if the response is not correct.

```
500 ON W GOSUB 940,950,960
```

This line calls the proper subroutine to display which weighting factor has been chosen.

```
510 INPUT 'START FREQ(HZ) ?','100';F0
```

Prompts user for starting frequency. A default of 100 is displayed and can be passed directly to the program by simply pressing the return key during execution.

```
520 IF F0>=1 AND F0<=20000 THEN 540
```

Checks input for F0 to be sure that it falls within the allowable range.

```
530 BEEP @ GOTO 510
```

If the logical AND returns a false value in line 520, this statement causes the controller to beep and return control to line 510 for another attempt at a correct value.

```
540 INPUT 'STOP FREQ(HZ) ?','5000';F1
```

Prompts user for stop frequency. A default value of 5000 is displayed and can be passed directly to the program by simply pressing the return key during execution.

```
550 IF F1>=F0 AND F1<=20000 THEN 570
```

Checks input for F1 to be sure that a value has been selected that falls between the starting frequency and the highest possible stopping frequency.

```
560 BEEP @ GOTO 540
```

If the logical AND returns a false value in line 550, this statement causes the controller to beep and return control to line 540 for another attempt at a correct value.

```
570 INPUT '1/1 (0) OR 1/3 (1) ?'.'1';B
```

Prompts user to select full, or one third octave bands. A default of `1' is displayed and can be chosen by pressing the return key during execution.

```
580 IF B=1 OR B=0 THEN 600
```

Checks for proper input from line 570, and passes control to line 590 on false or line 600 on true.

590 BEEP @ GOTO 570

Causes controller to beep and passes control back to line 570 for another attempt at a correct value.

600 IF B=0 THEN DISP '1/1 OCTAVE BW'

610 IF B=1 THEN DISP '1/3 OCTAVE BW'

Displays which band width has been chosen.

620 GOSUB 1200

Passes control to subroutine beginning on line 1200.

630 C0$=C$

Upon return of control from the subroutine beginning on line 1200, this line substitutes the string value of C0$ for the value of C$ and holds it for use in line 670.

640 IF B=0 THEN B0=157 ELSE B0=153

Utilizes input value from line 570 to set correct the control code value for B0.

```
650 C3$=CHR$(142)&CHR$(B0)&CHR$(207)
```

C3$ is a string value which is used to pass control codes to the Larson-Davis sound level meter in this case, 142 followed by B0, set in the line above, is the code to set up the band pass filters.

```
660 C4$=CHR$(102)&CHR$(100)
```

The string value C4$ is set up as a reset code.

```
670 C$=C0$&CHR(63+W)&CHR$(144)&C3$
```

This line gathers the values of all of the control codes that have been set in the previous two lines and the in subroutine that begins on line 1200, and prepares them as one string suitable for output to the SLM by the subroutine at line 1060. This string is the initialization code and it has the following values when it is first sent to the SLM's.

Value:	Meaning:
102	
100	102 followed by 100 is the reset code.
50	Range setting of 30-90
85	Sample mode, Multiple sample mode with initial reset and reset after each sample.
120	Integrate mode.
66	Linear weighting.
16	Number of samples set to one.
40	Sample interval set to two seconds.
63+W	Where W was the input value for filter weighting, (i.e. 1,2, or 3) and 63 is the offset. Yields 64 for A weighting, 65 for C weighting, or 66 for Linear weighting.
144	Turns off the band pass filters.
142	Along with the next number, selects 1000 Hz center frequency in full band or third band depending on the code for B0.
B0	Selects the band pass filter centered around one kiloHertz at full or one third octave band width depending on the input value for B.
207	

```
680 GOSUB 1060
```

Passes control to subroutine at line 1060 which sends the control code initialization string.

```
690 INPUT 'INT TIME IN SEC','1';T3
```

Prompts user for integration period and assigns input to T3.

```
700 IF T3<.25 THEN T3=.25
```

Sets minimum integration period.

```
710 IF T>64 THEN T3=64
```

Sets maximum integration period.

```
720 IF T3>1 THEN P=42-IP(3.33*LOG10(T3)+.5)
```

Derives proper Larson-Davis code for integration period based on numeric value of integration time.

```
730 IF T3<=1 THEN P=42-IP(3.33*LOG10(T3))
```

Same as line 720 for values of time less than or equal to one second.

```
740 C5$=CHR$(P)
```

Sets up the string value C5$ as the code for the integration time.

```
750 T9=2^(42-P)
```

Recalculates integration time that is being used from P and holds it for display.

```
760 DISP 'INT TIME';T9;'SEC'
```

Displays integration period that has been calculated so the user knows what integration time is actually being used.

```
770 R(0)=30 @ R(2)=30
```

Initializes R(0) and R(2) which will be used later as a range selection basis.

```
780 T=0 @ T1=0
```

Initializes T and T1 which are used later as counters.

```
790 DISP 'PRESS G TO START.'
800 K$=KEY$ @ IF K$='' THEN 800
810 IF K$='G' OR K$='g' THEN 1390
```

At this point in the program all of the sampling parameters have been selected and the data collection portion can be started. Lines 790 through 810 holds program execution until the user is ready to start at which point touching one key will start the data collection cycle.

```
840 REM *********************
850 REM 'PROGRAM DATA
860 REM *********************
```

This short section of lines contains data statements that are used elsewhere throughout the program.

```
870 DATA 102,100,50,85,120,66,16,40,300
```

Control codes which are read by the subroutine at line 1020. They in turn are fed to the SLM as the initial set-up.

```
880 DATA 1,1.25,1.6,2,2.5,3.15,4,5,6.3,8,10,12.5,
16,20,25,31.5,40,50,63,80
890 DATA 100,125,160,200,250,315,400,500,630,800
1000,1250,1600,2 000,2500,3150,4000,5000
900 DATA 6300,8000,10000,12500,16000,20000
```

These three data statements contain the list of possible center frequencies for the band pass filters. They are read from line 1450 and used to document which center frequncies are being used.

```
910 REM *********************
920 REM 'DISPLAY SUBROUTINES
930 REM *********************
```

Title block.

```
940 DISP 'A WEIGHT' @ RETURN
950 DISP 'C WEIGHT' @ RETURN
960 DISP 'LINEAR WEIGHT' @ RETURN
```

Lines 940 through 960 simply display the weighting network chosen in line 480. Control is passed from line 500 and returns to line 510 upon completion.

****

The next section contains the interface subroutines which are used to pass information over the HPIL between the controller and the SLM's.

```
970 REM *********************
980 REM 'DEVICE INTERFACE SUBROUTINES
990 REM *********************
```

Title block.

```
1000 OUTPUT ':LI' ;C$
1010 RETURN
1020 REM ********************
```

Sends the control string variable C$ to the device labeled LI only.

```
1030 OUTPUT ':LO' ;C$
1040 RETURN
1050 REM ********************
```

Sends the control string variable C$ to the device labeled LO only.

```
1060 OUTPUT ':LI' ;C$
1070 OUTPUT ':LO' ;C$
1080 RETURN
1090 REM ********************
```

Sends the control string variable C$ to the device labeled LI and the device labeled LO.

```
1100 TRIGGER ':LI'
1110 TRIGGER ':LO'
1120 RETURN
1130 REM ********************
```

Causes the devices labeled LI and LO, the SLM's, to take a reading according to their present settings.

```
1140 ENTER ':LI' ;A1$
1150 ENTER ':LO' ;A2$
1160 RETURN
```

Causes the devices labeled LI and LO, the SLM's, to put the present reading on the loop.

```
1170 REM *********************
1180 REM 'ROUTINE TO INITIALIZE C$ CONTROL CODE FROM
PROGRAM DATA
1190 REM *********************
```

Title block.

```
1200 C$="" @ RESTORE 870
```

Initializes C$ to the null string and resets data pointer to line 870.

```
1210 FOR I=1 TO 10
1220 READ D9
1230 IF D9=1 THEN I=10 @ GOTO 1250
1240 C$=C$&CHR$(D9)
1250 NEXT I
1260 RETURN
```

This loop reads the data from the data statement in line 1070 and sets up the initial control code string for the

SLM's. The "1" at the end of the data statement is a dummy code that will allow the user to add control codes easily at that point and still assure that the codes are read correctly without having to change the loop counter.

```
1270 REM *********************
1280 REM 'ROUTINE TO DETERMINE L-D CONTROL CODES FOR THE
FREQUENCIES CHOSEN
1290 REM *********************
```

Title block.

The following subroutine is used to calculate the correct control codes that are needed to set up the band pass filters. It is used every time the SLM,s are changed from one filter to the next in line 1610.

```
1300 IF B=0 THEN B0=4 ELSE B0=0
```

Checks the input value for B and sets the offset value B0 accordingly.

```
1310 C9=INT(10*LOG10(F9)+.5)
```

This formula calculates the value C9 using the current center frequency.

```
1320 F9=128+MOD(C9,16)
```

This formula calculates the value F9 using C9. The MOD function simply returns the remainder of the division of the first argument by the second argument.

```
1330 B0=B0+152+C9 DIV 16
```

This formula calculates the control code B0 by adding the offset value from line 1300, 152,(which is a fixed offset), and the value returned by the expression; C9 DIV 16, which is simply the integer result of the division of the first argument by the second.

```
1340 RETURN
```

Returns control to line 1620.

****

The next section is at the core of the entire program. It is the section that steps the SLM's through the frequency range and builds the data file that is used for later analysis.

```
1350 REM *********************
1360 REM 'THIS SECTION PERFORMS THE SPECTRUM
1370 REM 'ANALYSIS BY STEPPING THE 800B THROUGH THE
SELECTED FREQUENCIES
1380 REM *********************
```

Title block.

```
1390 ASSIGN #1 TO E$
```

Opens file with the name given by the user in line 400.

```
1400 DISP  'SPECTRUM ANALYSIS'
```

Causes the words SPECTRUM ANALYSIS to be displayed so the user can confirm that execution has commenced.

```
1410 IF B=1 THEN J=1 ELSE J=3
```

Sets loop counter J according to band width chosen.

```
1420 T2=0 @ RESTORE 880
```

Sets event index T2 to 0 and resets the data pointer to the proper point.

```
1440 FOR I=1 TO 44
```

Initializes loop.

```
1450 READ F9
```

Reads center frequencies from data statements.

```
1460 F(I)=F9
```

Stores center frequencies in array "F".

```
1480 IF T2=1 THEN 1510
```

Passes program control to the indicated line when T2=1. This occurs when the center frequency is equal to the starting frequency that has been selected by the user.

```
1480 IF F9<F0 THEN I2=I @ GOTO 1540 ELSE T2=1
```

Checks if starting frequency has been reached and indexes the value I2. Also indexes the value T2 when the starting frequency has been reached.

```
1490 I3=I2+1
```

Sets I3 equal to the last count plus one.

```
1500 IF MOD(F(I2),F0)<MOD(F(I3),F0) THEN M0=I2 ELSE
M0=I3
```

In this line, a calculation is made to determine which of the fixed center frequencies is closest to the starting frequency that has been chosen by the user and sets the index value, M0 accordingly. For example, if the frequency 700 Hz had been input as the starting frequency, the previous two lines would have set the following values: F(I2)=630, F(I3)=800, I2=29, I3=30 and, of course, F0 would be equal to 700. The MOD function would return the value 70 on the left side of the inequality and 100 on the right side thus setting M0 to 29.

1510 IF F9>=F0 AND F9<F1 THEN I4=I @ GOTO 1540

Checks for a frequency greater than the ending frequency and sets the value I4 accordingly.

1520 I5=I4+1

Sets the value of I5.

1530 IF MOD(F(I4),F1)<MOD(F(I5),F1) THEN M1=I4 ELSE M1=I5

This line functions the same as the line that sets M0 and sets the value for M1.

1540 NEXT I

Closes the loop.

1550 PRINT #1;1+(M1-M0)/J,DATE$

Prints the number of octave or third octave bands and the date to the data file.

```
1560 K$=KEY$ @ IF K$='P' OR K$='p' THEN GOSUB 2340
```

This line allows the user to interrupt execution of the program during the sampling cycle. It is looking for input from the keyboard at which point it will pass control to the subroutine indicated. This action assures that there are no partial data cycles included in the data file by interrupting the program.

```
1570 FOR I=M0 TO M1 STEP J
```

Sets up the frequency indexing loop according to the values of M0 and M1 set previously.

```
1580 F9=F(I)
```

Selects the center frequency to be used according to the itteration counter.

```
1590 T0=10/F9
1600 IF T0<T3 THEN T0=T3
```

These two lines set up a minimum waiting time of [10 divided by the frequency] seconds based on chosen integration period.

1610 GOSUB 1300

Utilizes the subroutine that determines the band pass filter codes.

1620 C$=CHR$(144)&CHR$(F9)&CHR$(B0)&C5$ @ GOSUB 1060

Resets the string value C$ that will be sent to the SLM's by the subroutine. The code 144 turns the band pass filters off or resets them, then the two character code of F9 and B0 turns on the proper filter. Finally, the integration period code C5$ is sent.

1630 WAIT 30/F(I)+.5

Tells the controller to suspend the execution for a time of 30/F(I)+.5 seconds. This gives the SLM's time to respond before the next command is sent.

1640 T=0 @ GOSUB 1810

Sets the value of T, a counter, to 0 and passes control to the autoranging subroutine.

```
1650 IF N1=1000 AND O1=1000 THEN N2=0 @ O2=0 @ GOTO 1690
```

Checks for "No data" condition and sets values to 1000 as a flag.

```
1660 N2=N1+R(0)
1670 O2=O1+R(2)
```

These two lines add the index values returned from the SLM's to the presently held offset values, R(0), and R(2).

```
1680 V0=O2-N2
```

Calculates the difference between the inside and the outside levels.

```
1690 DISP F(I);'HZ ';N2;O2;V0
```

Displays the output of the SLM's to be displayed so the progress of the system may be monitored.

1700 PRINT #1;V0

Prints the difference between the inside and the outside levels to the data file.

1710 NEXT I

Ends loop.

1720 PRINT #1;TIME$

Prints the time of the system clock to the data file between completed passes through the frequency spectrum acting as a delimiter.

1730 IF MEM<355 THEN GOTO 2290

Checks memory capacity. If memory capacity is less than 355 bytes, program control is passed to line 2290 which is the end routine.

1750 IF TIME$>J3$ THEN GOTO 2290 ELSE 1560

Checks to see if the stopping time has been reached. If the stopping time has been reached, control is passed to the end routine, if not, control is passed back to the beginning of a new sample cycle.

```
1770 REM *********************
1780 REM 'AUTORANGING PORTION'
1800 REM *********************
```

Title block.

```
1810 C$=C4$ @ GOSUB 1060
```

Sends both of the SLM's a reset code.

```
1820 WAIT 10/F(I)+.5 @ GOSUB 1100
```

Causes the controller to wait to give time for response then sends both SLM's the command to take a reading.

---------------------- OVERLOAD PORTION ------------------

```
1830 GOSUB 1140
```

Sends the SLM's the signal to send back their respective readings.

```
1840 IF NUM(A1$)<>8 AND NUM(A2$)<>8 THEN T=0 @ GOTO 1990
ELSE T=T+1
```

The readings from the SLM's are sent to the controller as string values which are assigned by the program as A1$ and A2$. This line determines if the numeric values of the strings are 8 indicating that the readings were out of the range presently set on the SLM's.

```
1850 IF T>3 THEN 1870
1860 BEEP @ GOTO 1810
```

These two lines have the effect of giving the SLM's three chances to return a readable value. This is done in case the overload condition was caused by some transient effect. A counter is set up and control is passed back to line 1810 which sends a reset command and tries to make a reading again.

```
1870 IF NUM(A1$)=8 AND NUM(A2$)=8 THEN H=0 @ H1=2 @ GOTO
```

1890

```
1880 IF NUM(A1$)=8 THEN H=0 @ H1=0 @ GOTO 1890 ELSE IF
NUM(A2$)=8 THEN H=2 @ H1=2
```

Once the controller has determined the system needs to be readjusted to take a reading, it is necessary to determine which SLM is out of range. Line 1870 takes affect if both SLM's are out of range and sets the index values H and H1 so that both SLM's will be reset to a higher range in the subsequent loop. Line 1880 is called upon if one or the other SLM needs readjusted and sets H and H1 accordingly.

```
1890 FOR K=H TO H1 STEP 2
1900 IF R(K)>=50 THEN R(K)=80 ELSE R(K)=R(K)+20
1910 R(K+1)=INT(R(K)/20+.5) @ C$=C4$&CHR$(52-R(K+1))
1920 NEXT K
```

This loop makes use of the index values H and H1 to adjust the range of the SLM's upward. In the case where both SLM's are under-range, "H" will have been set to 0, and "H1" will have been set to 2. These values will cause two iterations of the loop and will calculate four values. R(0) and R(2) are the range offsets. They are used to correct the readings from the SLM's. R(1) and R(3) are the code values used to set the SLM's to the desired range. They are added to the code offset, 52, to derive the proper code to be sent to the SLM's.

```
1930 T=0
```

Resets the counter "T".

```
1940 IF H=0 AND H1=2 THEN GOTO 1950 ELSE GOTO 1960
```

At this point, the settings of the index values H and H1 indicate which SLM (or both) needs to be readjusted. This line sends the control to the proper line below that in turn selects the proper subroutine.

```
1950 GOSUB 1060 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
```

Calls subroutine to adjust both SLM's, has the controller wait a specified period for instrument response, then calls the subroutine that causes the SLM's to take a reading. Control is then passed to the beginning of the autoranging routine so that the new input can be checked.

```
1960 IF H=0 AND H1=0 THEN GOTO 1970 ELSE GOTO 1980
```

Similar to line 1940.

```
1970 GOSUB 1000 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
```

Calls subroutine to adjust only the first SLM in the loop.

```
1980 GOSUB 1030 @ WAIT 30/F(I)+5 @ GOSUB 1100 @ GOTO
1830
```

Calls subroutine to adjust only the second SLM in the loop.

------------------- UNDER-RANGE PORTION -----------------

```
1990 N9=NUM(A1$)-13 @ O9=NUM(A2$)-13
```

Once the overload portion returns a value other than 8 for NUM(A1$) and NUM(A2$), control is passed to this line which calculates the significant portion of the level.

```
2000 IF N9<0 THEN N9=0
2010 IF O9<0 THEN O9=0
2020 N1=N9/4 @ O1=O9/4
```

Since the under-range condition has not been checked for yet, it is possible that the value for N9 and O9 will be negative. These lines correct for this condition until further checks are made.

```
2030 IF N1=0 OR O1=0 THEN 2040 ELSE 2060
```

This marks the first point where the under-range condition is tested for. If both N1 and O1 are not under-range, control is passed to the line that makes the final check for data continuity.

```
2040 IF N1=0 AND O1=0 THEN H2=0 @ H3=2 @ GOTO 2100
```

Checks for both values being under-range in which case the index values H2 and H3 are set and control is passed on to the point where the range can be lowered.

```
2050 IF N1=0 THEN H2=0 @ H3=0 @ GOTO 2100 ELSE IF O1=0
THEN H2=2 @ H3=2 @ GOTO 2100
```

Checks for one or the other value being under-range and sets the index values accordingly.

```
2060 IF N1>58 OR O1>58 THEN 2070 ELSE 2250
```

The last error condition that is checked is a high reading. If N1 or O1 is greater than 58, it is an indication that the range selected is lower than desirable. The solution is to increase the range level. This line passes control to the end of the autoranging routine if both values are found to be less than or equal to 58.

```
2070 IF N1>58 AND O1>58 THEN H=0 @ H1=0 @ T=7 @ GOTO
1870
```

Determines if both values are greater than 58 and sets the index values H and H0 to the appropriate values. It then passes control to the range adjustment portion.

```
2080 IF N1>58 THEN H=0 @ H1=0 @ T=7 @ GOTO 1870
2090 IF O1>58 THEN H=2 @ H1=2 @ T=7 @ GOTO 1870
```

If both of the values are not greater than 58 then one or the other must be at this point. These two lines determine which one, and set H and H1 to the corresponding values.

```
2100 IF R(0)=-10 THEN N1=1000
```

This line checks the value of R(0). If it is already set to -10, the first SLM is in its lowest range, so it is of no use to try another reading. The value of N1 is set to the flag value of 1000 and the next code is checked.

```
2110 IF R(2)=-10 THEN O1=1000 @ GOTO 2250
```

Finishes the job started in the previous line by checking R(2), the code for the second meter and passing control to the end of the subroutine.

```
2120 FOR K=H2 TO H3 STEP 2
2130 IF R(K)=80 THEN R(K)=50 @ GOTO 2150
2140 IF R(K)<=50 THEN R(K)=R(K)-20 @ GOTO 2150
2150 R(K+1)=INT(R(K)/20+.5) @ C$=C4$&CHR$(52-R(K+1))
2160 NEXT K
```

This loop makes use of the index values H2 and H3 to adjust the range of the SLM's downward. The values of R(0), R(1), R(2), and R(3) are recalculated for a lower range setting than the present one.

2170 T1=T1+1

Increments the counter, T1.

2180 IF H2=0 AND H3=2 THEN GOTO 2190 ELSE GOTO 2200

If the result of the logical AND is true, then both SLM's were range corrected so the appropriate subroutine is selected to send both SLM's a new set up code.

2190 GOSUB 1060 @ WAIT 30/F(I)+5 @ GOTO 2230

Sends control string to both SLM's, has controller wait for response time then passes control to the line that checks for number of trys.

2200 IF H2=0 AND H3=0 THEN GOTO 2210 ELSE GOTO 2220

If both SLM's were not under-range, this line determines which one and passes control accordingly.

2210 GOSUB 1000 @ WAIT 30/F(I)+5 @ GOTO 2230

Selects subroutine for first SLM only.

2220 GOSUB 1030 @ WAIT 30/F(I)+5 @ GOTO 2230

Selects subroutine for second SLM only.

2230 IF T1>3 THEN T1=0 @ N1+1000 @ O1=1000 @ GOTO 2250

If more than three attempts are made to take a reading in the same condition, the values for N1 and O1 are set to the flag value, and control is passed out of the autoranging subroutine.

2240 GOSUB 1100 @ GOTO 1830

This line is a common receiver of control from the point where the controller has sent a new set-up string. It passes control to the subroutine that causes the SLM's to take a reading then sends the control back to the beginning of this subroutine to check for a valid reading.

2250 T1=0 @ T=0 @ RETURN

Resets the counters T1 and T to 0, and passes control back to the stepping routine.

```
2260 REM ********************
2270 REM 'END ROUTINE
2280 REM ********************
```

Title block.

```
2290 ASSIGN #1 TO *
```

Closes the data file.

```
2300 COPY E$ TO ':CA'
```

Writes the data file to cassette storage.

```
2305 C$=C4$&CHR$(96) @ GOSUB 1060
```

Sends the SLM's a reset command and the command to return control of the instruments to their local switches.

```
2310 DISP 'JOB COMPLETED @ ';TIME$
```

Displays "JOB COMPLETED @ xx:xx:xx". This allows the user to confirm that all functions have been performed and at what time they were completed.

```
2320 K$=KEY$ @ IF K$='' THEN 2320
```

Causes the above line to be held in the display until the user presses a key to halt execution.

```
2330 END
```

Ends program execution.

```
2335 REM ********************
2337 REM 'WAIT ROUTINE
2338 REM ********************
```

Title block.

```
2340 DISP 'PRESS ANY KEY TO CONT'
2350 K$=KEY$ @ IF K$='' THEN 2320
2360 RETURN
```

This subroutine displays the message "PRESS ANY KEY TO CONT." in response to pressing the "P" during execution. Since execution continues, it allows a very easy way to halt the progress of the sampling.