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A DIGITAL CONTROL SYSTEM FOR HIGH LEVEL ACOUSTIC NOISE GENERATION

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ABSTRACT

As part of a modernization of the Acoustic Test Facility at Lockheed Missiles and Space Company, Sunnyvale, a digital acoustic control system was designed and built by Spectral Dynamics Division of Scientific-Atlanta, Inc. [1] This paper discusses the requirements imposed by Lockheed on the control system, and the degree to which these requirements were met. Acceptance test results are discussed, as well as some of the features of the digital control system not found in traditional manual control systems.

INTRODUCTION

Lockheed's Large Vehicle Acoustic Test Facility provides the capability of subjecting space vehicles up to a size of 22 feet in diameter by 70 feet high to acoustic noise fields in excess of 150 decibels (re .00002 N/M**2). The facility has been in operation for eighteen years, using analog random noise generators and manually operated 1/3 octave filter banks to shape the sound spectrum in the test chamber. Three years ago a decision was made to modernize the facility, upgrading both the sound generation and analysis equipment. The new system would consist of two parts: a multi-channel, real-time data acquisition and analysis system and a digital acoustic noise generation and control system. There were no commercially available closed loop acoustic control systems on the market at that time, so Spectral Dynamics Division of Scientific-Atlanta was chosen to design and build one, based on their experience with building random vibration controllers for shaker tables. The result of this development, the SD1600 Acoustic Control System, is the topic of this paper. The task of building the data acquisition and analysis system was given to a group within Lockheed [2].

REQUIRED FEATURES

Lockheed's test laboratory and analytical group established a set of requirements for the acoustic control system which formed the basis for the development of the SD1600. These requirements, along with the final performance capabilities of the SD1600, will be discussed in this section. For each Lockheed requirement, a brief description of how the SD1600 meets (or fails to meet) this requirement is given.

General System Design Requirements:

1. The system should be software oriented rather than hardware oriented.

The SD1600 Acoustic Control System is based on a microprocessor. Test definition, operation, and control is software controlled.

2. An easy to use operator interface should be provided. It should be possible for less experienced workers to operate the equipment.

An interactive dialog provides an easy method for the user to enter test parameters such as the standard spectrum, pretest levels, test duration, microphone sensitivities, and graph labels. Once the test has been defined and the test definition saved on disk, the test may be run by simply pressing the start button. The SD1600 will automatically bring the test level through the user defined pretest levels up to full test. At each pretest level, the drive spectrum is automatically equalized to ensure that the response is within tolerance. In contrast, the previous manual system required a highly trained operator to equalize the spectrum by hand and provided very little protection against overtesting the specimen.

3. Built-in safety and reliability features to safeguard test specimens, test equipment and personnel.

The SD1600 has several built-in safety features to prevent accidental damage to test articles or test equipment. To protect against overtest, a hardware RMS meter is present to monitor the response signal and shut the test down very quickly if the level exceeds the abort limits. After measuring the response spectrum, the computer inside the SD1600 checks the level of each 1/3 octave band inside the frequency range of the test, and will abort the test if any band falls outside the abort limits.

Also, the operator may define a starting drive limit, which is used by the SD1600 as an upper bound to its drive signal when starting a test. If this limit is reached before sufficient response from the microphones is detected, the test is aborted, preventing overtest due to malfunctioning microphones and resulting loss of control signal.

In contrast to the automatic control system, the previous manual system relied on an operator to visually monitor a spectrum analyzer while the test was run, resulting in a less reliable and repeatable test run.

4. The new system should integrate easily with existing power amplifiers, transducers, microphones, and cables.

The SD1600 uses standard BNC cabling to connect to the existing power amplifiers and microphones. Amplifiers within the SD1600 will automatically compensate for differences in power amplifier and microphone sensitivities.

5. Acoustic controller should be able to be operated from its own front panel, or by commands sent from a host computer.

A great deal of effort was spent on the creation of a host computer interface which would allow a host computer (or remote terminal) to send commands and receive status reports from the SD1600. Using two character commands, the host computer can start or stop the test, step through the pretest levels, run the dialog, or request a graphic display of a response spectrum. The SD1600 sends status reports to the host when it changes pretest levels or stops, so that the host computer can monitor the progress of the test.

Specific Control Requirements:

1. The control system must be capable of creating drive signals for up to 3 non-overlapping transducer frequency ranges.

The SD1600 can be configured to drive up to 4 non-overlapping frequency ranges. The overall reference spectrum as defined by the user is automatically split up according to the cutoff frequencies which the user specifies for his transducers. Separate hardware in the SD1600 is used for creation of each of the drive signals, allowing the system to adapt to different power amplifier sensitivities.

2. It should be possible to control based on the average response of up to 16 microphones.

The SD1600 can accept up to 16 microphones for power spectrum averaging. The microphones don't have to have identical sensitivities, as the user can enter individual sensitivities when defining a test. However, for best performance, microphone sensitivities should be kept to within a few dB of each other.

3. The controller should be capable of equalizing at two pretest levels, -6.0 dB and -4.5 dB relative to full test level.

During the test definition dialog, the operator may define up to four pretest levels. Pretest level transitions can be done automatically by the SD1600, or the operator may manually step through the levels by toggling a switch on the front panel of the controller. Pretest levels may be set at any value between .1 dB and 60 dB below full test level.

4. At the -6 dB pretest level, equalization to within +-3 dB should be achieved in no more than 60 seconds for each 1/3 octave band between 25 hz and 2000 hz.

The process of reading in a response spectrum, correcting the drive spectrum, and sending an equalized drive signal to the transducers is called an equalization loop. Typical equalization loop times for the SD1600 are between 12 and 18 seconds, depending on the bandwidth and number of degrees of freedom defined for the test. Thus, the 60 second requirement would allow at least 3 equalization attempts at the -6 dB level. When in the automatic mode of pretest level transitions, the SD1600 will make only 1 equalization attempt at each level. Test results show that equalization to within +-3 dB can be achieved easily with a single equalization pass.

5. At the -4.5 dB pretest level, equalization to within +-1.5 dB should be achieved in no more than 30 seconds for each 1/3 octave band between 25 hz and 2000 hz.

Again, the 30 second requirement is easily met by the SD1600, allowing up to 2 equalization loops at -4.5 dB. Experimental results at Lockheed show that the +-1.5 dB tolerances are just barely within the capability of the SD1600. A typical test will show most of the 1/3 octave bands to be in tolerance, with 1 or 2 bands (usually in the lower frequencies below 100 hz) at +-2.0 dB. The greater the nonlinearity of the transducers, the more difficult it is to achieve +-1.5 dB tolerances.

6. At full test level, equalization to within +-1.5 dB should be achieved in no more than 20 seconds for each 1/3 octave band between 50 and 2000 hz. At 25, 31.5, and 40 hz the tolerances are +3, -5 dB.

Recognizing the difficulty of equalizing the lower frequency bands at high levels, Lockheed permits a wider tolerance at 40 hz and below. The 20 second time requirement allows the SD1600 only 1 equalization attempt to get the response within tolerance. If the transducers were linear in their response to RMS changes, it would be necessary to equalize only once at the first pretest level. From then on, the response would be in tolerance at each pretest level and at full level. Unfortunately, typical transducers are not linear, especially at high levels. It is common for the transition from -4.5 dB to full test to result in a response which is about 1.0 or 1.5 dB low, if the full level is approaching the limits of the transducers and power amplifiers. The SD1600 will compensate for the undershoot in the first equalization pass, but again, due to non-linearities in the transducers, their will probably be a couple of bands out of tolerance at full level.

7. An automatic abort shall occur if the conditions specified in 4,5 and 6 cannot be achieved.

The control system will abort if any band in the measured response spectrum falls outside the specified abort limits.

8. If the response signal from any individual microphone drops below a specified number of dB below the nominal level, that microphone shall be discarded from the spectrum averaging. The test will continue, provided the number of remaining microphones is above the user defined minimum.

When gathering a response spectrum, the SD1600 multiplexes through the control microphones, adding each microphone's response to the running average. Before the response is added, however, its RMS level is compared with the reference level, and if the current microphone is too low, its response is discarded. From that point on, the test will continue (provided the number of remaining microphones is sufficient) without using the faulty microphone.

ACCEPTANCE TEST RESULTS

In June of 1986, tests were run in the large acoustic test chamber at Lockheed to determine the acceptability of the Spectral Dynamics system. Five tests were defined, ranging in overall level from 139.0 dB to 151.0 dB. The 139.0 dB test used a single transducer with a 20 hz cutoff frequency. The test was defined to drive frequencies between 25 and 400 hz. The remaining 4 tests used transducers in 3 frequency ranges. In each case we used 1 transducer with a lower cutoff of 20 hz. The drive signal for this horn had energy between 25 and 40 hz, inclusive. Up to 3 transducers were used to cover the 1/3 octave bands between 50 and 315 hz, and up to 4 transducers were used from 400 to 2000 hz.

The tests were defined to have 3 pretest levels at -9.0 dB, -6.0 dB, and -4.5 dB, with a start level of -12.0 dB. Full level test duration was set at 1 minute. An independent 1/3 octave analyzer was used to monitor the response at each pretest level and at the end of 20 seconds at full level.

For some of the tests, we found that the low frequency horn's start level was too low, making it impossible for the SD1600 to pull the initial drive signal up out of the ambient noise in the chamber. The low frequency horn's start level was modified to be -10.0 dB, leaving the others at -12.0 dB, and allowing the system to achieve a start level above the ambient noise level.

Test 1, whose standard spectrum appears in Fig. 1, proved to be the most difficult to run. This test was a high level test (151.0 dB) with a lot of power required in the low end. For this test, the response was well equalized at the -4.5 dB pretest level, but the transition to full level resulted in an undershoot of about 1.5 dB in the 1/3 octave bands below 125 hz. This was due to the fact that we were approaching the maximum capability of the transducers at this level. When the SD1600 equalized at full test level, it was able to bring the low end into tolerance, but as a result, harmonic distortion caused the high frequency portion of the spectrum to rise about 1.0 dB. After 1 minute at full level, the response spectrum was as shown in Fig. 2. For the most part, the response meets the +- 1.5 dB tolerance, with the exception of a couple of bands around 1250 hz, where the distortion caused by overdriving the low frequency horns resulted in exceeding the tolerances by 0.5 dB or so.

Test 3 proved to be more successful. Fig. 3 shows the response spectrum for the 144.2 dB test 3. All bands between 31 and 2000 hz are equalized to within +-1.5 dB. The transition to full level from the -4.5 dB pretest level went smoothly, with no undershoot as was observed with Test 1.

As an illustration of the powerful display features of the SD1600, Fig. 4 shows a table of 1/3 octave bands, along with the response level and deviation from standard for each band for one of the stored responses from Test 3.

Another feature available with the SD1600 which is not generally available with manual control systems is the ability of the SD1600 to control and display spectrums in narrowband format. Using the narrowband format allows the operator to view the response spectrum calculated at up to 800 equally spaced frequencies across the bandwidth of the test. Fig. 5 shows a response spectrum displayed in narrowband format for test 3.

The other spectrums used for the acceptance test ran much like test 3. The SD1600 has about a 16 second equalization loop time, so the time constraints were met. Control accuracy was generally +-1.5 dB for the tests with overall level below 150 dB. The tests above 150 dB controlled to +-2.5 dB, although there were usually only one or two 1/3 octave bands outside the +-1.5 dB tolerances. In subsequent testing, we have found that by adjusting the crossover frequencies and the number of horns used for the test we can improve the performance of the high level tests.

CONCLUSIONS

The requirements for a digital control system for the Lockheed Acoustic Test Facility have, for the most part, been met by the Spectral Dynamics SD1600 Acoustic Control System. The system has proven to be easy to operate and reliable. It is estimated that at least $50,000 per year savings in nitrogen gas and payroll will result because of the speed and ease of use of the SD1600. The ability to control spectrums above 150 dB to +-1.5 dB tolerances remains questionable for the Lockheed facility at this time. Adjusting horn cutoff frequencies did result in improved control for the high level tests, so we hope that as experience in running the new control system increases, the performance at high test levels can be enhanced.

AUTHORS' BIOGRAPHIES

John Lee is a Principal Engineer at ORINCON Corporation. Before joining ORINCON, he was with Spectral Dynamics Division of Scientific-Atlanta in San Diego, where he participated in the development of the SD1600 Acoustic Control System. He received his M.S. degree in Electrical Engineering from Oregon State University in 1983 and his M.S. degree in Mathematics from University of Oregon in 1979.

Jerry Bosco heads the Engineering Operations Group of the Large

Vehicle Acoustic Test Facility at Lockheed Missiles and Space Company, Space Systems Division, Sunnyvale, California. He is a Group Engineer with a background of 30 years of acoustic test experience. For the past two years, Mr. Bosco has worked on the updating of two acoustic test facilities, the most recent one being the large and sophisticated facility described in the present paper. His BSEE degree was from Heald Engineering College of San Francisco and was followed by graduate study at the University of California extension in Southern California. Mr. Bosco has just completed chairing an acoustic seminar for the Annual Technical Meeting if the IES, and is a Senior Member of the IES and a member of the Acoustical Society of America.

REFERENCES

[1] Lee, John P., "High Intensity Acoustic Noise Generation Closed Loop System", Proceedings of the Institute of Environmental Sciences, 1986, pp 170-180.

[2] Smith, Strether, "Data Acquisition/Control/Analysis Systems for Large-Scale Acoustic Testing Facilities", Proceedings of the Institute of Environmental Sciences, 1986, pp 163-169.

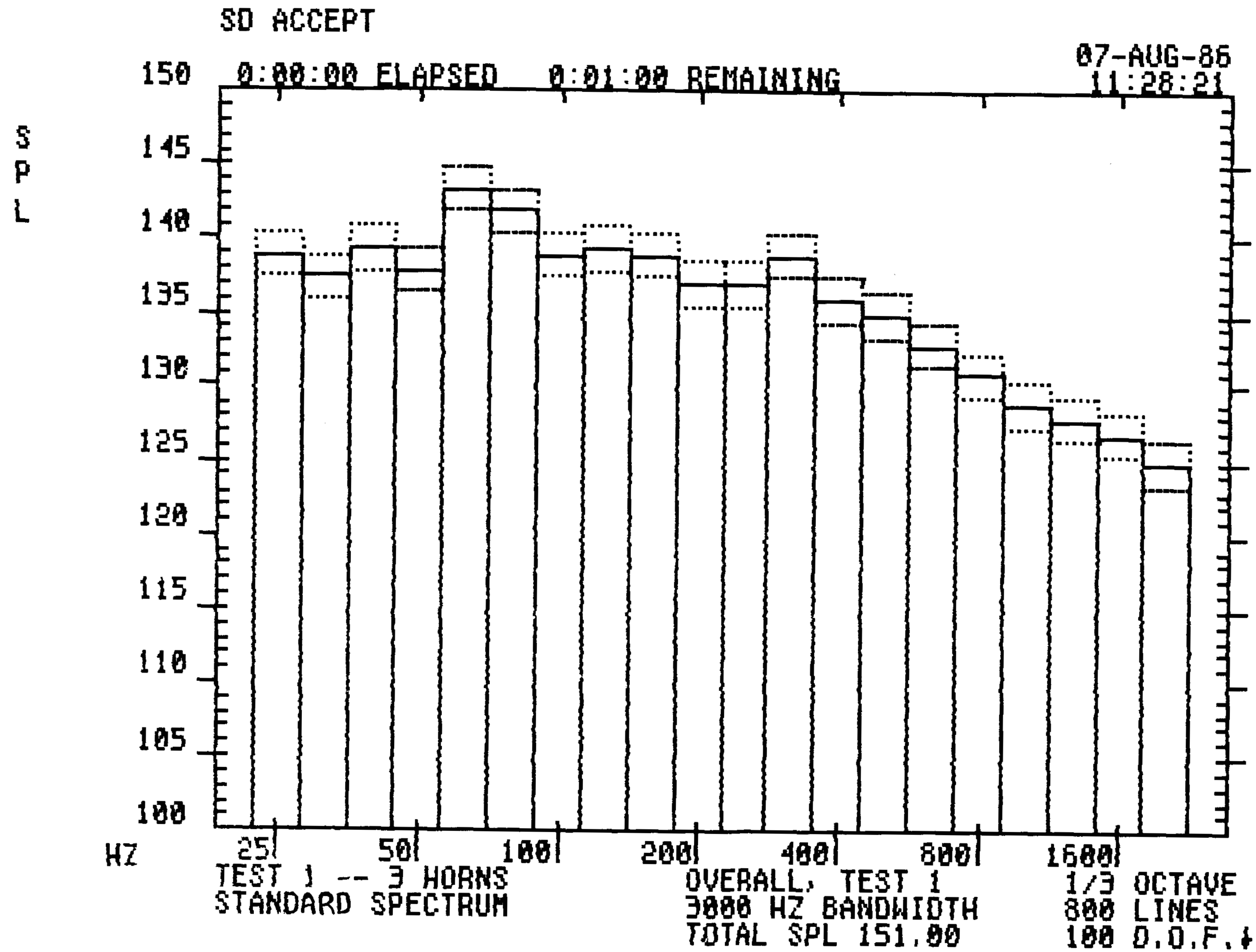

Figure 1. Standard spectrum

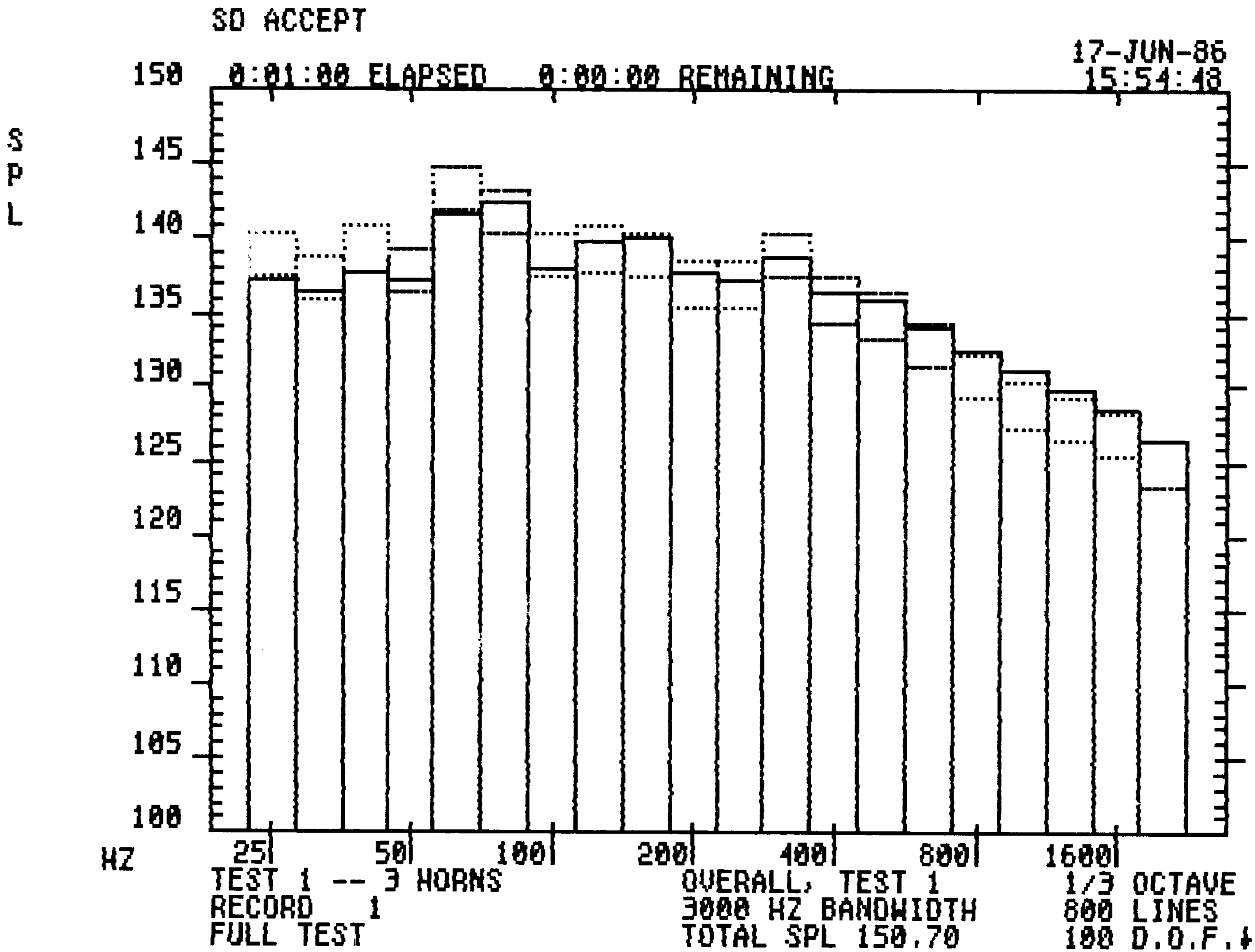

Figure 2. Response spectrum

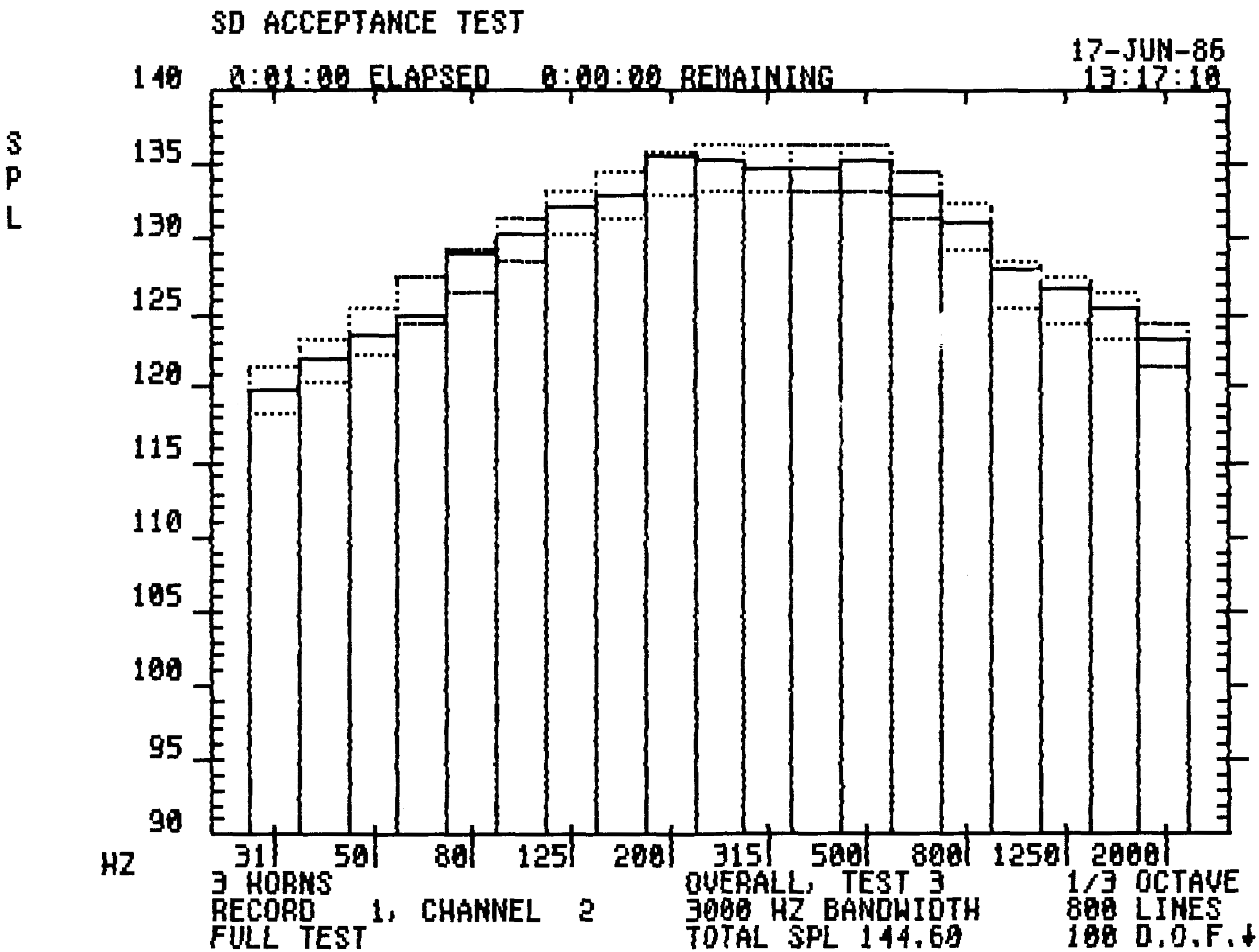

Figure 3. Response spectrum

TEST NUMBER 3 UNIT NUMBER 0 STORED RECORD # 1
OVERALL SPL 144.6 OVERALL RMS PASCALS 338.8 1/3 OCTAVE

FREQ	SPL	ERROR	FREQ	SPL	ERROR	FREQ	SPL	ERROR
31	119.9	-0.1	160	133.1	0.1	800	131.4	0.4
40	122.0	0.0	200	135.7	1.2	1000	128.2	1.2
50	123.6	-0.4	250	135.4	0.4	1250	126.9	0.9
63	124.9	-1.1	315	135.0	0.0	1600	125.5	0.5
80	129.2	1.2	400	135.0	0.0	2000	123.4	0.4
100	130.4	0.4	500	135.4	0.4			
125	132.4	0.4	630	133.2	0.2			

Figure 4. Response table

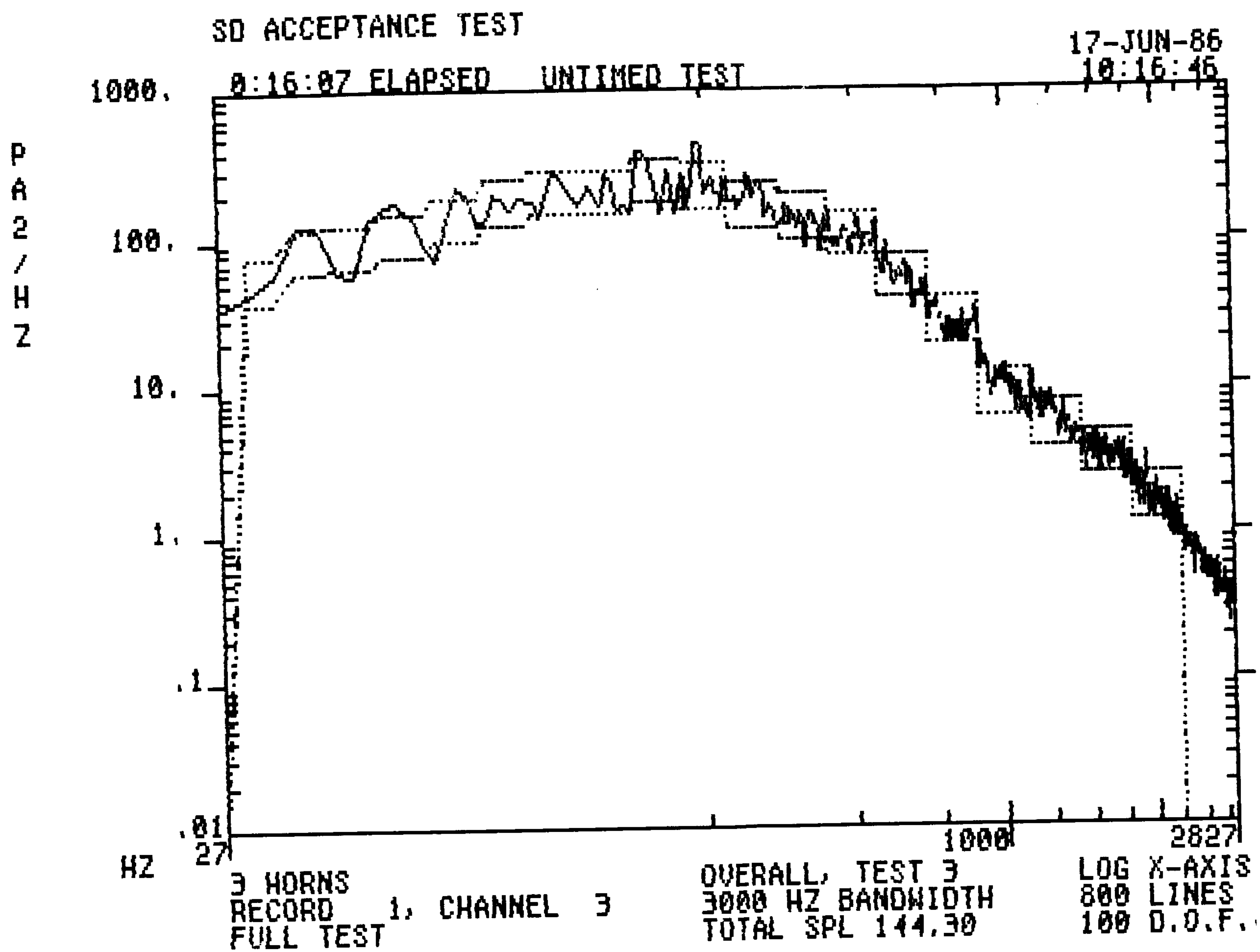

Figure 5. Narrowband response spectrum