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A Review of Noise Issues in Semiconductor Clean Rooms

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INTRODUCTION

The production of microelectronic semiconductor products requires a facility that is environmentally controlled and virtually free from contaminants. Airborne contaminants are controlled through the use of laminar-flow clean rooms whose airhandling systems provide highly-filtered air at rates of up to 100 air changes per hour, depending upon the class.[1]

The air-handling systems in general and recirculating fans in particular are significant sources of noise, as are many items of process equipment used to fabricate the ICs. Airborne noise may induce internal vibrations in process equipment, decreasing the "yield," or productivity, of the facility.[2] The noise adds to an already uncomfortable environment in which workers must wear clean room suits. The noise interferes with speech communication, which includes heavy use of telephones, public address and paging systems, as well as person-to-person speaking.

CHARACTERISTICS OF CLEAN ROOMS

A typical, modern semiconductor clean room will have a relatively "hard" acoustical environment: raised access floor over a concrete structural floor, epoxy-coated composite walls with numerous penetrations for equipment, glass windows, and a ceiling that consists entirely of high-efficiency particle (HEPA) filters. The concern for shedding of particles generally prohibits the use of many conventional sound-absorbing treatments in the clean room or in the ducting of the air-handling systems.

Clean room noise can be attributed to three primary sources: (1) fan noise, (2) airflow turbulence, and (3) process equipment.

- The nature of fan noise is well documented and can be controlled by fairly conventional means except for the concern for cleanliness and space restrictions generally imposed by the large number of air handlers required (in the cases using modular recirculation units) or by the volume of ducting required (in side-tower recirculation systems).
- Airflow turbulence is typically generated by the introduction of discontinuities in the airstream (such as elbows or transitions). In the geometries used in clean rooms, it results in broadband low-frequency noise, sometimes peaking at frequencies well below the blade rate of the fan.
- Process equipment procedures is a mixture of tones (generally motor and transformer hum at frequencies near 30, 60, and 120 Hz as well as turbine whine) and broadband with center frequencies between 250 and 2000 Hz.

NOISE CRITERIA

All manufacturers of semiconductor production equipment provide environmental requirements (such as temperature, humidity, clean class, etc.) in the spaces where they will be installed. In some cases these include vibration criteria, but a noise criterion is seldom included. Very little work has been done regarding quantification of noise sensitivity, even though there is anecdotal evidence that some items of equipment, particularly electron microscopes, have problems in noisy environments. ASHRAE has given in very general terms some noise levels for use as guidelines for clean room design (see Ref. 1).

One manufacturer of production equipment performed laboratory experiments on two of its systems. Their work showed that noise levels above 75 dB in the 125 Hz band caused unacceptable internal motions in the systems. This corresponds approximately to the 125 Hz component of PNC-65,[3,4] NC-65,[5] RC-50,[6] and NCB-65.[7] We have elected to use PNC curves and have made a practice of using the range PNC-55 to PNC-60 as a design criterion for the air-handling systems. We prefer not to use a single-valued criterion such as dBA for clean room design purposes, although ASHRAE has given guidelines in this form for clean room design (see Ref. 1). At this time, the noise generated by process equipment and its support systems (such as vacuum pumps) is not addressed in noise-control design, as this is generally not under the control of the owner or design team.

Figure 1 shows the family of modified PNC criteria we use in the design and assessment of clean room noise. The conventional PNC curves are defined in octave bands at center frequencies between 31.5 and 8000 Hz. We have extended these curves downward to 8 Hz at the slope of the curve between 31.5 and 63 Hz, and to higher levels using the average spacing between curves.

Individual frequency components of noise may be considered alone with regard to issues not directly concerning equipment. Blazier (see Ref. 6) has published curves that relate low-frequency noise to induced vibrations in walls, windows, and other structural components. Blazier's criterion states that noise-induced vibrations are likely when octave band noise levels in and below the 31.5 Hz band exceed 65 dB and "highly probable" when they exceed 75 dB. This criterion was intended to address comfort aspects in an occupied space, but it also has an indirect effect on semiconductor production: vibration-sensitive equipment can be adversely affected if it touches a wall that is vibrating in this manner.

The effects of noise on speech communication may be assessed using the speech-interference level SIL,[8] which is the arithmetic average of Leq levels in the 500, 1000, 2000, and 4000 Hz octave bands. In general, SIL correlates well with A-weighted levels. Exposure limits for people are generally stated in terms of A-weighted levels, which do not include the effects of noise at very low frequencies. At low frequencies, noise can be perceived physiologically as well as being heard. Several researchers have studied this issue and have found that levels less than 85 dB at frequencies less than 160 Hz are unlikely to cause illness; levels above 95 dB may cause illness. In the presence of high levels at high frequencies (that is, high A-weighted levels), low-frequency noise appears to be of less concern.

REVIEW OF NOISE IN SEVERAL CLEAN ROOMS

Noise data measured in 17 clean room facilities were subjected to statistical analysis. Measurements in 9 of the facilities were made at startup, at which time air-circulation systems were operating but production equipment was off or only partially operational. Nine facilities were in full production. One facility (denoted A) was evaluated in both conditions. Table 1 summarizes the findings in terms of A-weighted levels, SIL, and the PNC that was met.

Table 1. Summary of Results of Measurements in 17 Semiconductor Clean Rooms

		dBA	SIL	PNC
Startup	mean, $\bar{x}$	64	57	64
	std. dev., s	5.6	5.1	7.4
	range	51-76	45-68	45-78
Production	mean, $\bar{x}$	70	65	68
	std. dev., s	4.5	5.2	4.8
	range	61-78	56-76	58-77

A statistical analysis was performed on all the production-area noise spectra obtained for the study. Figure 2 shows the results of this study as compared with the family of PNC curves we use. The mean $\bar{x}$ essentially meets the PNC-55 to -60 design range but the $\bar{x} + s$ exceeds it. At low frequencies the $x \pm s$ range falls within the range for which Blazier's criterion predicts induced vibrations in walls and windows. This supports a common complaint in many semiconductor facilities. We have seen no correlation of the observed wall vibrations with other structureborne vibrations.

The noise spectra for startup and producing facilities were separately subjected to statistical analysis. The averages are compared in Fig. 3. In the frequency bands associated with both speech communication and process equipment, the noise levels of the producing facilities are about 6-10 decibels higher than those of the startup facilities. At frequencies below 250 Hz, there is little difference between the spectra. The PNC-59 curve forms a good "fit" of the data below 250 Hz and of the startup data at higher frequencies.

The average A-weighted, SIL, and PNC levels of the producing facilities were between 4 and 8 decibels higher than those of the startup facilities. Figure 4 (see Ref. 7) shows the SIL ranges of the two operating conditions, suggesting that communication can be difficult in these environments, particularly if one must speak to a group in a producing facility, as might be the case during training.

Figure 5 shows the noise environments of several spaces within facility A, a recently-completed plant that represents the current state-of-the-art semiconductor facility. The lowest curve indicates the average noise levels measured after all air-handling systems were operating but prior to installation of any process equipment. At startup it met PNC-55. The other curves represent photolithography (Photo), chemical vapor deposition (CVD), and a support area--all with process equipment operating.

Figure 6 shows a spectrum measured in facility B—in production. The measurements were made in a process area housing a scanning electron microscope (SEM) and other equipment related to inspection and quality control as well as in the adjacent service area. The measurements were made as part of a diagnostic study of the poor performance of the SEM. (It was determined that the noise was at least part of the problem, as performance improved when the unit was clad in heavy material.) The author observed that occupants of this space often had to repeat themselves and ask telephone callers to repeat messages. Occasionally they missed hearing pages on the public address system. The SIL of 65 for this space somewhat supports these observations.

Conclusions

The noise environment in a clean room can pose problems that will interfere with speech communication and might decrease product throughout. It also diminishes worker comfort and may cause walls and windows to vibrate.

The noise is due to three sources: fans, air turbulence, and process equipment. The first two sources may be addressed by the noise-control engineer during the design of the facility. Through careful design, the air-handling noise in a semiconductor clean room can be kept to below PNC-55. This environment, however, may be masked by the noise from the equipment used to make the semiconductor products. Reduction of noise from process equipment must be handled by the manufacturers of that equipment, except for what benefits may be gained from space planning.

In the production areas of an "average' facility, the noise at frequencies of 500 Hz and higher is mainly attributable to process equipment; at lower frequencies, it is due to the air-handling systems. In support areas, the process-support equipment dominates at even lower frequencies.

References

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, *1987 ASHRAE Handbook*, Chap. 32.
2. E. Ungar, D. H. Sturz, and C. H. Amick, "Vibration Control Design of High Technology Facilities," to be published in *Sound & Vibration*, July 1990.
3. L. Beranek, W. E. Blazier, and J. J. Figwer, "Preferred Noise Criteria (PNC) Curves and Their Applications," presented at the 81st Meeting of the Acoustical Society of America, Washington, D.C., April 20, 1967.
4. L. Beranek, editor, *Noise and Vibration Control*, McGraw-Hill (1971).
5. L. L. Beranek, "Revised Criteria for Noise Control in Buildings," *Noise Control*, 3, 19-27 (1957).
6. W. E Blazier, Jr., "Revised Noise Criteria for Application in the Acoustical Design and Rating of HVAC Systems," *Noise Control Engineering Journal*, 16, 64-73 (1981).
7. L. L. Beranek, "Balanced Noise Criterion Curves, NCB," *J. Acous. Soc. Am.*, August 1989.
8. American National Standard, "Rating Noise with Respect to Speech Interference," S3.14-1977 R-1986). Purchase from Acoustical Society of America, 500 Sunnyside Blvd., Woodbury, NY 11797.

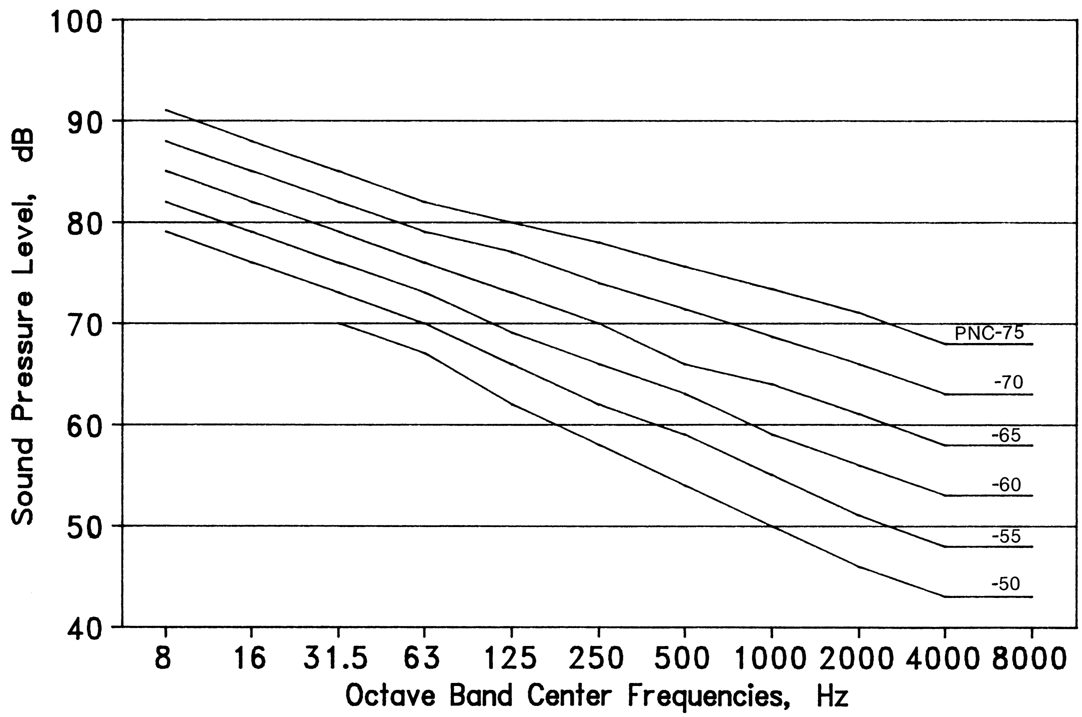

Figure 1. Modified PNC Criteria used in clean rooms.

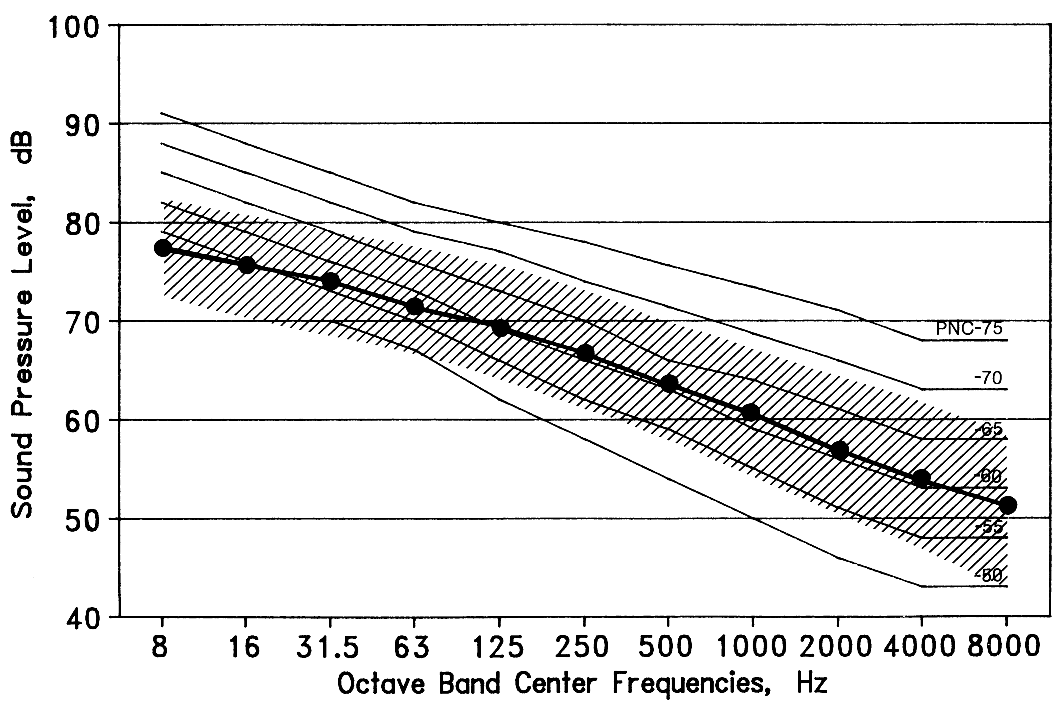

Figure 2. Average noise levels in clean rooms.

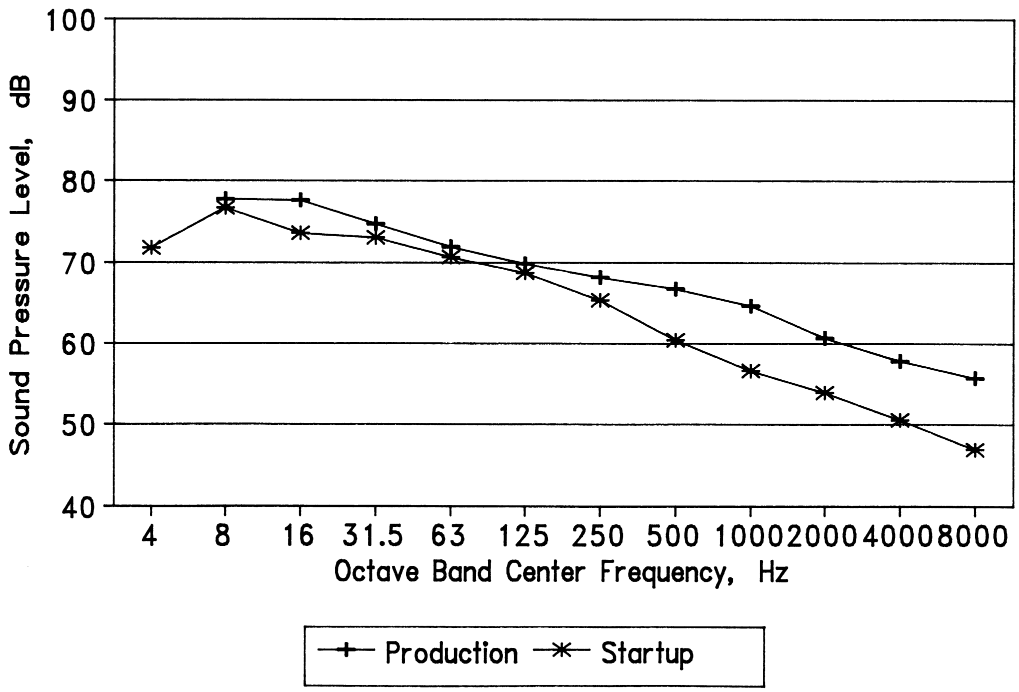

Figure 3. Comparison of average clean room noise at startup and in production.

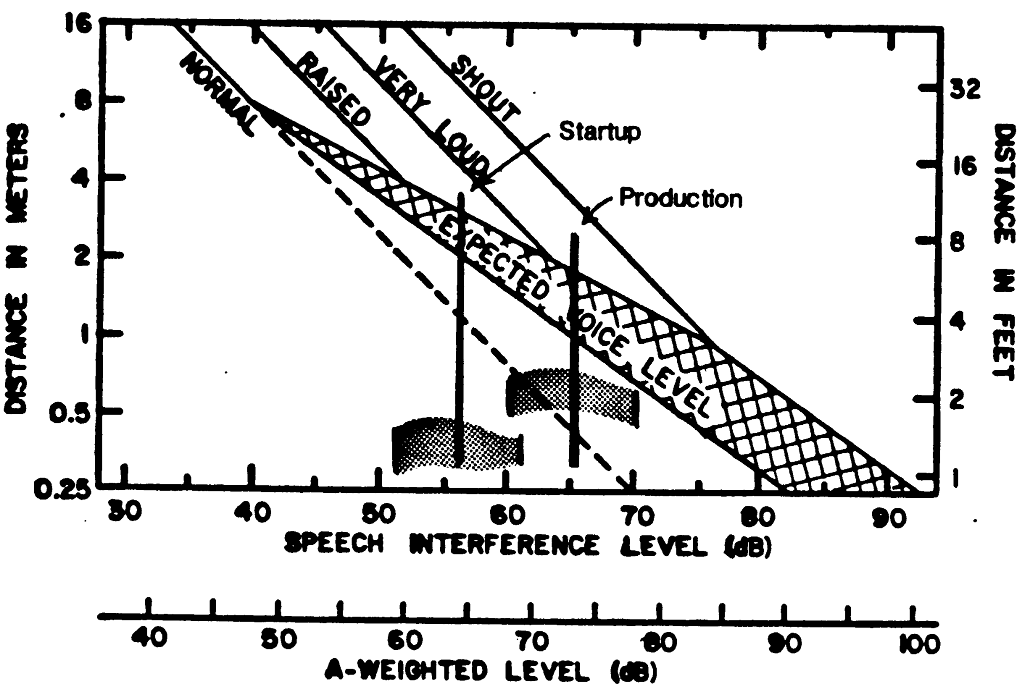

Figure 4. Speech-interference levels at startup and in production.

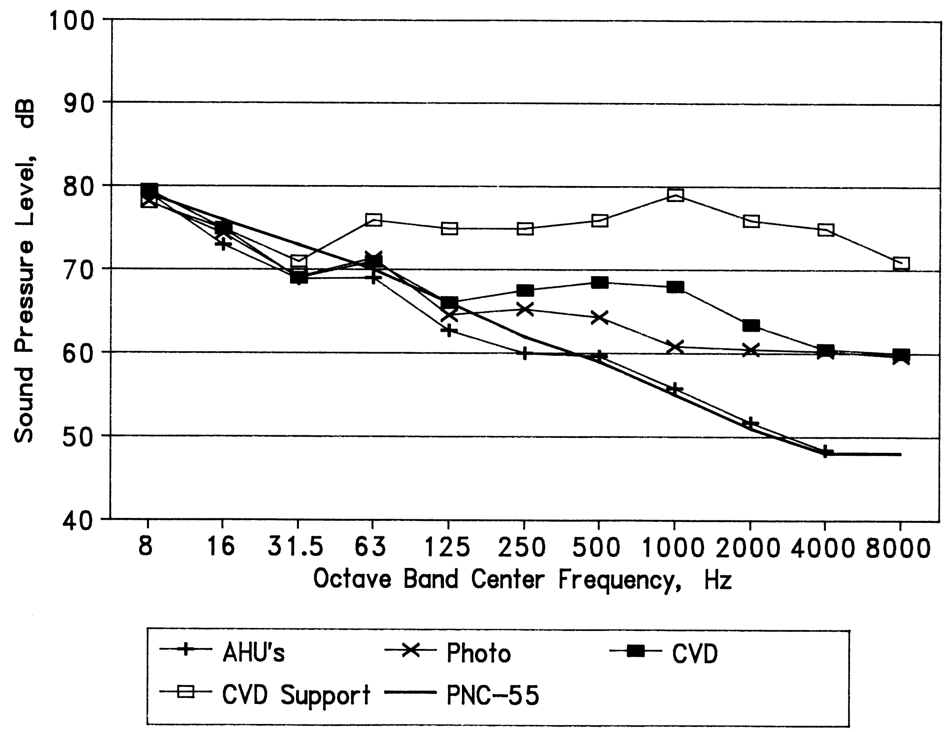

Figure 5. Noise in several spaces in Facility A.

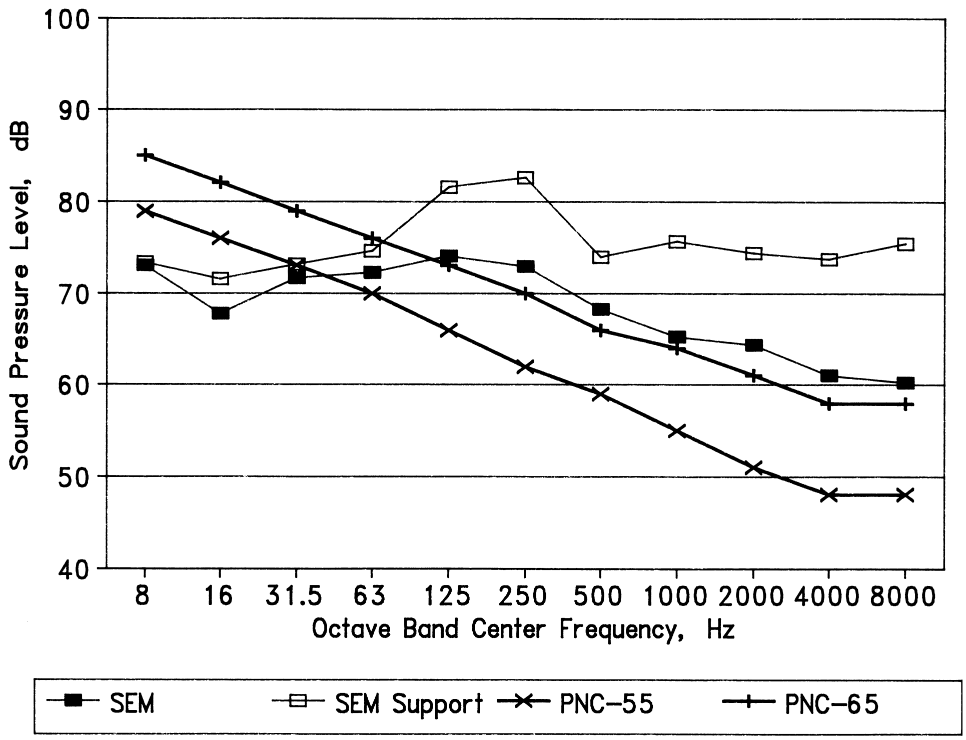

Figure 6. Troublesome noise in a production area and its support area, Facility B.