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A Study of Low-Frequency Ground Vibration in Widely Differing Geographic Areas

Colin G. Gordon

BBN Laboratories Incorporated
21120 Vanowen Street
Canoga Park, California 91303

The low-frequency ambient vibration existing on the ground is an important parameter in the siting of buildings that will contain equipment and processes that are sensitive to vibration. Such equipment is commonly used in "wafer fabrication plants" in which integrated circuit "micro-chips" are manufactured. Ground vibration can be an important factor also in the siting of research laboratories and hospitals.

Over the past 10 years or so, BBN Laboratories has undertaken ambient vibration studies at more than 60 sites spread throughout the United States and in some overseas countries also. The frequency range of interest in these studies has typically covered 5 Hz through 100 Hz. It is within this range that most sensitive equipment--microaligners, steppers, E-Beam systems, probe test systems, etc.--exhibits vibration-related problems. These problems, typically, are caused by low-order resonances that cause relative motion within the equipment.

In this paper, let me present a brief overview and discussion of some of these data. First of all, however, let me discuss the topic of vibration criteria, since it is against these that the results of site surveys must be judged.

VIBRATION CRITERIA

Figure 1 shows the criterion curves that we use currently in our Microelectronics Facilities design studies. These curves include the guidelines of the International Standards Organization (ISO) for human occupancy of buildings. The threshold of vibration detection or "feelability" lies at a velocity of about

5000 microinches/sec--between the ISO "Operating Theater" and "Residential Day" curves.

The criterion curves demonstrate two general principles that we have found to be applicable in our microelectronics facilities studies and that others (including the ISO) have found, or presumed, to be applicable in others areas also. Very simply stated, these are:

1. Velocity, as opposed to acceleration or displacement, is the best measure of vibration in the sense that, when velocity is used to describe an environment, the response is independent of the frequency. This principle appears to be valid, in a general sense, in describing the damaging effects of vibration on buildings, the annoyance effects of vibration on people, and the operational effects of vibration on sensitive equipment.
2. The combined effects of broadband (random) and tonal vibrational energy can best be quantified using a one-third octave proportional bandwidth, as opposed to the constant bandwidth used by many analyzers. The one-third octave band provides a good measure of the broadband energy that may effectively excite a lightly damped resonant system at damage threshold, a person at detectability threshold, or a microscope at the limits of its usability.

GROUND VIBRATION MEASUREMENTS

The technique that we use in measuring ground vibration, as a prelude to site selection for vibration-sensitive buildings, can be summarized as follows:

Typically, we concentrate our attention on vertical, as opposed to horizontal, vibration. On most sites that we have encountered, the horizontal components lie below the vertical components by a factor of 3 to 10 (10 to 20 dB).

In order to measure the "quietest" sites--those carrying very low levels of ambient vibration--we use a "seismic" accelerometer with a sensitivity approaching 10 volts/g. The accelerometer output is amplified by a low-noise high-gain charge amplifier and then recorded on magnetic tape. Typically, at each location we record data over a period of about 30 minutes. The data are generally acquired during the day--7 a.m. to 7 p.m.--when ambient vibration levels will generally be at their highest, assuming that these are dominated by traffic and industrial activity in the survey area.

In data reduction, the recorded signals are integrated to convert the acceleration signal to velocity. The signal is then fed through a one-third octave band digitizing spectrometer, the output of which is fed to a digital computer. The computer then analyzes the time-varying statistics of the data in each band.

It is our usual practice to examine the data at the 10-percent level--being that level in each band that is exceeded for 10 percent of the total time covered by the recorded data.

We generally look for the ambient vibration conditions on a site to lie 10 dB or more below the vibration criterion for the completed building, because the building itself--the mechanical systems that "power" it and the people that occupy it--will introduce many new sources of vibration, the sum total of which must comply with the criterion.

DATA SUMMARY AND DISCUSSION

Over the past 8 years the Los Angeles office of BBN Laboratories has carried out site vibration studies at upwards of 60 sites. The data from 51 of these sites have been examined in preparing this paper.

The geographic disposition of these sites reflects in many respects the disposition of the microelectronics industry as it has spread nationally and internationally from its beginnings in the "Silicon Valley" of Northern California.

Area (States)	Number of Sites
West (CA, OR, WA)	27
Desert/Mountain (AZ, UT, ID, CO, NM)	7
Midwest (IN, OH, MN)	4
East (MA, VT, FL)	3

Data have been acquired also at sites in Scotland, Italy, and Singapore.

The sites studied have varied from remote locations, far distant from significant traffic and industrial sources, to busy urban locations, close to major highways. Soil conditions have varied from those typical of dry desert sites, composed largely of hard packed soils of mainly silty-sand content, to wet sites composed of clays and uncompacted silts, with water tables lying close to the ground surface.

In preparing this paper, I have not attempted to correlate the data in detail with the many site parameters that might have an influence on the vibration conditions. Such detailed analyses would require much more information and data than we have readily available just now. The analysis I present here will be very general.

The collected spectra can be divided into three types as illustrated in Figs. 2, 3, and 4. In these figures I show the average vibration velocity spectrum associated with each type. I show also the range covering 68 percent (± one standard deviation) of the spectra within each spectrum type.

In Spectrum Type (a), Fig. 2, the predominant energy lies at or close to the 5 Hz one-third octave band. At higher frequencies, the spectrum drops off at a rate of about 9 dB per octave. A similar rate of falloff appears to occur at lower frequencies also. This spectrum shape is typically encountered at sites that are remote from significant sources of vibration or at sites that are quite wet and on which low-frequency energy propagates very efficiently. Some 20 percent of the sites analyzed had this spectrum shape.

Spectrum Type (b), Fig. 3, shows low-frequency energy in much the same form and at much the same levels as Spectrum (a). A second "hump," however, appears on the spectrum at a frequency of about 12.5 Hz. This second peak is associated with closer sources--typically traffic on a local road. The level of the second peak is lower than the level of the 5 Hz peak. Some 20 percent of the sites analyzed had this spectrum shape.

In Spectrum Type (c), Fig. 4, the relative importance of the 5 Hz and the 12.5 Hz peaks is reversed. The vibration on these sites tends to be dominated by local traffic or by nearby highways. About 60 percent of the sites studied had this spectrum shape.

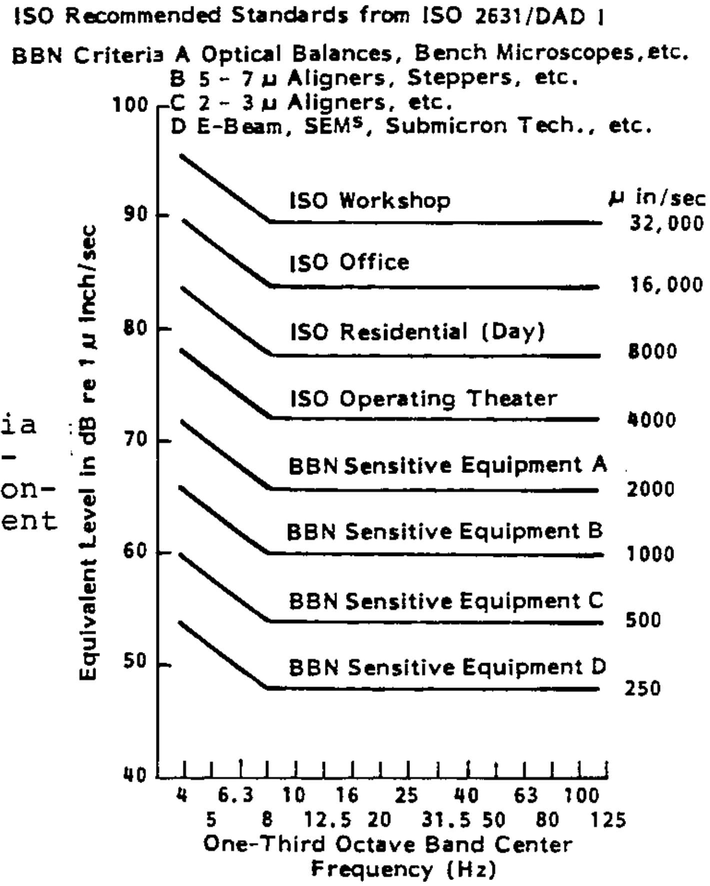
COMMENTS AND NOTES

One or two other comments are in order. Of the 51 sites covered by this analysis, 9 were found to have levels in excess of 38 dB, 80 microinches/sec. These sites, therefore, were judged as marginally acceptable or as unacceptable for a building designed to BBN Criterion Curve D in Fig. 1. On many other sites, as a result of the site survey, we have defined minimum "setback distances" from roadways.

I close this paper with a cautionary note. The analyses presented here are quite preliminary and cursory, based on limited data relating to mechanisms that are quite complex and improperly understood at the present time. Hopefully this presentation will prove useful. Perhaps it will form a basis for the collection, dissemination, and discussion of similar data by others.

Fig. 1.

Vibration Criteria for Human Occupation and Vibration-Sensitive Equipment in Buildings



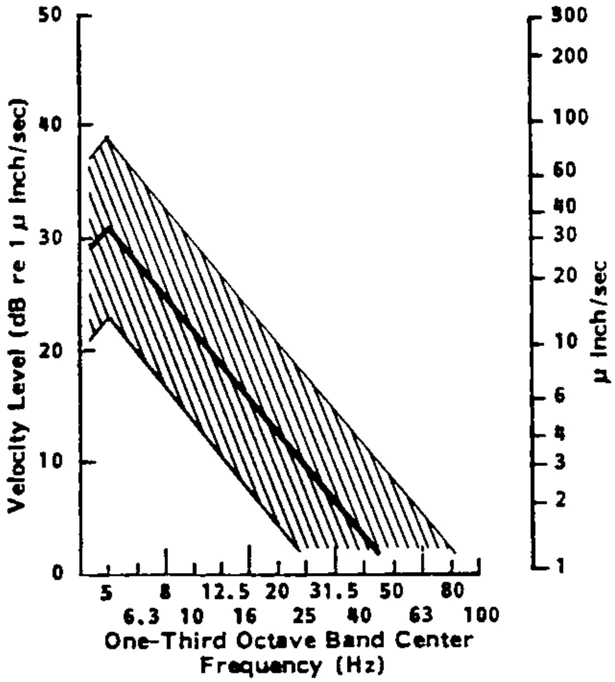


Fig. 2.

Summarized Results of Field Measurements - Spectrum Type (a)

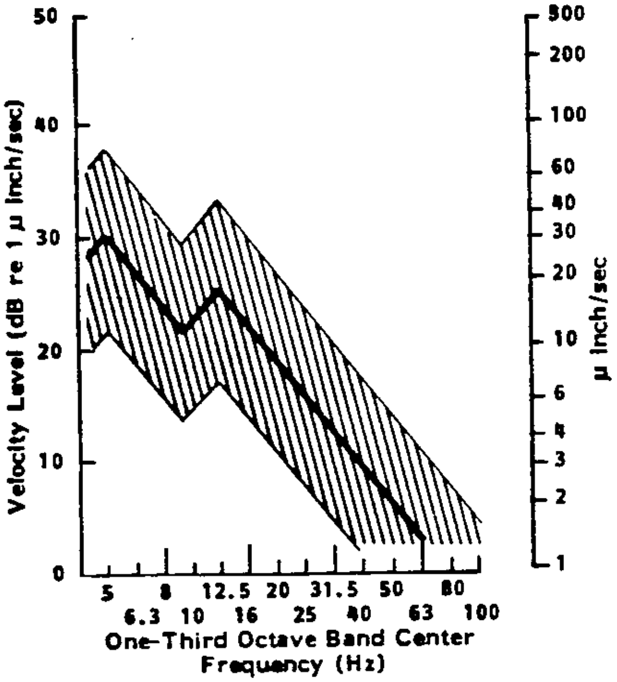


Fig. 3. Summarized Results of Field Measurements - Spectrum Type (b)

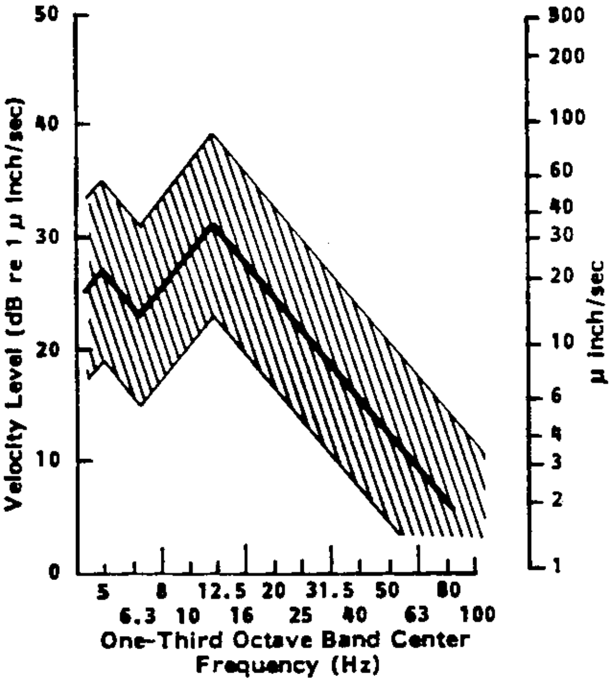


Fig. 4. Summarized Results of Field Measurements - Spectrum Type (c)