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Converting Semiconductor Fabs: The Vibration Design Perspective

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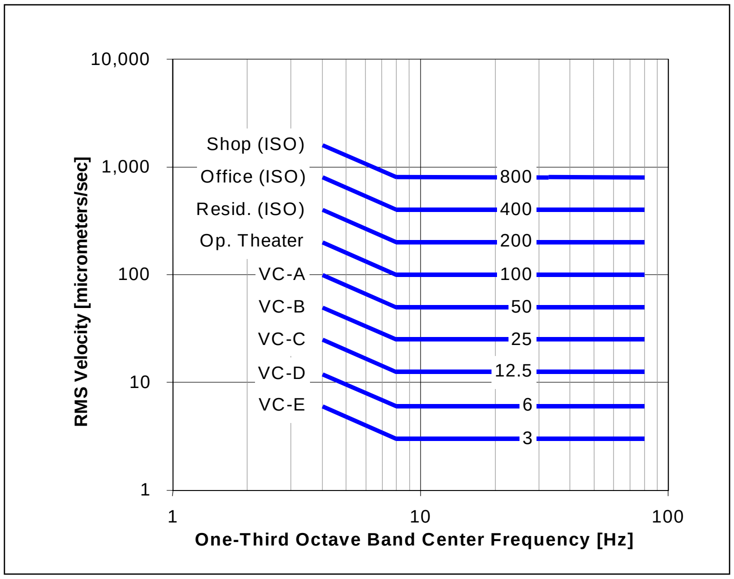
As silicon chip manufacturing technologies migrate from several micrometer to submicrometer and nanometer scales, many high-tech facilities of yesterday are becoming obsolete unless they go through a facility and process upgrade commonly called "retooling." The conversion of an old fab to a new fab involves vibration upgrade of the facility.

In the past 25 years or so, hundreds of major advanced technology facilities, commonly known as "fabs,"[†] have been built all over the world for chip manufacturing. Fabs commissioned in the early years of microelectronics manufacturing were intended for line-width technologies of several micrometers and more. The demand for faster, more powerful computers and other electronic products has been satisfied via greater transistor densities on microchips, requiring smaller IC line widths. Today, high-end manufacturing of logic and memory chips occurs at the 0.09-μm or 90-nm feature size and is rapidly migrating towards the 65-nm node.

As the facility needs of current-generation technologies have changed dramatically, so too have the microvibration needs of these facilities. A facility conversion may involve architectural, structural, mechanical, and electrical activities. The vibration upgrade includes 1) structural retrofits for increasing vertical and horizontal stiffnesses and 2) vibration source mitigation, involving systematic design implementation on existing and new facility equipment.

From a fab design point of view, vibration and noise are two contaminants that must be controlled. Since the inception of semiconductor manufacturing, Generic Vibration Criterion (VC) curves have been used in designing for microvibration in fabs. The following illustration shows a plot of a family of these curves.

[†] For simplicity, we will use the term "fab," but the discussions are equally applicable to lab buildings.



Generic Vibration Criterion (VC). VC curves are used in designing for microvibration in fabs.

The following table shows a correlation between each VC curve and the corresponding feature sizes. For example, 8-µm manufacturing requires a fab floor to meet curve VC-A or 50 µm/sec, while current devices with 0.09-µm feature sizes are produced in a curve VC-D (6 µm/sec) or VC-E (3 µm/sec) environment. The correlations in the table are only for guidance purposes; a validation of tool requirements against these curves should occur for each facility. Detailed discussions about the VC curves are documented in *IEST-RP-CC012.1, Considerations in Cleanroom Design.* A conversion of an old fab, designed to a more relaxed criterion curve such as VC-A, to high-end submicrometer manufacturing involves retrofit of the fab structure in both horizontal and vertical directions. To achieve a successful vibration upgrade in the same fab, one should evaluate the as-built condition of existing equipment that will be salvaged and ensure that acceptable vibration mitigation is possible.

Noise design issues, though not discussed here, should also be evaluated and accommodated in a fab conversion. Noise within cleanroom spaces in a fab is predominantly influenced by the recirculation systems—recirculation fans or fan filter units and make-up air fans. Since facility renovations often involve upgrading the clean class of the facility, the addition of new mechanical equipment leads to new sources of noise in the cleanroom environment. In some cases, space limitations force the installation of new machinery near quieter office and analytical laboratory areas, resulting in noise impact not only on the clean area but also on adjacent areas. The noise design of a fab conversion should include the new cleanroom configurations and the noise propagation from these air handling units.

Application and interpretation of the generic vibration criterion (VC) curves‡			
Criterion Curve (see VC illustration)	**Max Level[1] µm/sec**	**Detail Size[2] µm**	**Description of Use**
Workshop (ISO)	800	N/A	Distinctly feelable vibration. Appropriate for workshops and nonsensitive areas.
Office (ISO)	400	N/A	Feelable vibration. Appropriate for offices and nonsensitive areas.
Residential Day (ISO)	200	75	Barely feelable vibration. Appropriate for sleep areas in most instances. Probably adequate for computer equipment, probe test equipment and low-power (to 20×) microscopes.
Operating Theatre (ISO)	100	25	Vibration not feelable. Suitable for sensitive sleep areas. Suitable in most instances for microscopes to 100× and for other equipment of low sensitivity.
VC-A	50	8	Adequate in most instances for optical microscopes to 400×, microbalances, optical balances, proximity and projection aligners, etc.
VC-B	25	3	An appropriate standard for optical microscopes to 1000×, inspection and lithography equipment (including steppers) to 3-µm line widths.
VC-C	12.5	1	A good standard for most lithography and inspection equipment to 1-µm detail size.
VC-D	6	0.3	Suitable in most instances for the most demanding equipment, including electron microscopes (TEMs and SEMs) and E-Beam systems, operating to the limits of their capability.
VC-E	3	0.1	A difficult criterion to achieve in most instances. Assumed to be adequate for the most demanding sensitive systems, including long path, laser-based, small target systems and other systems requiring extraordinary dynamic stability.

[1]As measured in one-third octave bands of frequency over the range of 8 Hz to 100Hz.
[2]The detail size refers to the line widths for microelectronics fabrication, the particle (cell) size for medical and pharmaceutical research, etc. The values given take into account the observation that the vibration requirements of many items depend upon the detail size of the process.

Structural Considerations

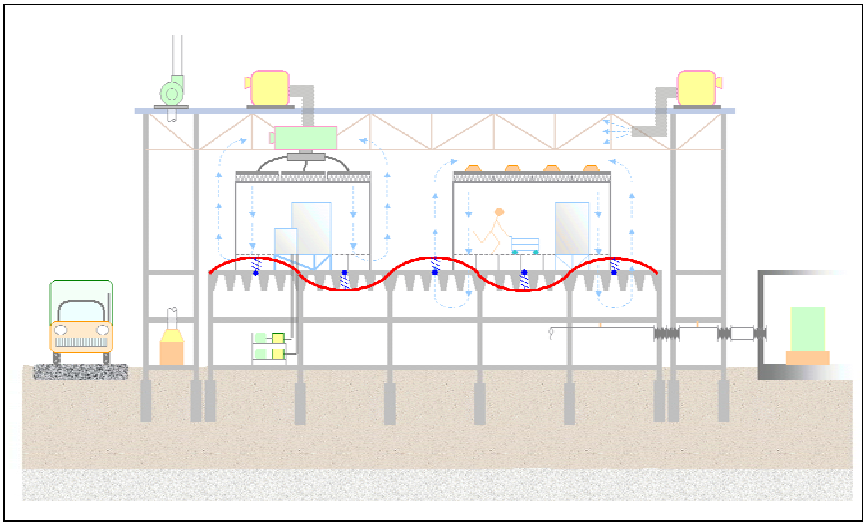
The conversion of an old fab to a new fab involves vibration upgrade of the facility. The extent of the upgrade depends on the degree of transformation of the fab from its original design to the new one. For instance, the structural and other vibration considerations can be extensive in converting a fab originally designed to the VC-A curve into a VC-E fab geared towards 0.10-µm manufacturing or R&D. A VC-A fab may have bay sizes exceeding 30 ft while a VC-E fab may require bay sizes of 12 ft or smaller depending on the existing floor configuration. Similarly, the horizontal vibration upgrade may involve extensive retrofit of the lateral stiffening of the fab structure.

Vertical Vibration

Vertical vibration performance of fab floors is associated with the fundamental bending modes of a fab structure. These bending modes, in turn, are directly proportional to the size of fab bays and floor depth and configuration. Regression analyses have confirmed that vertical vibration is

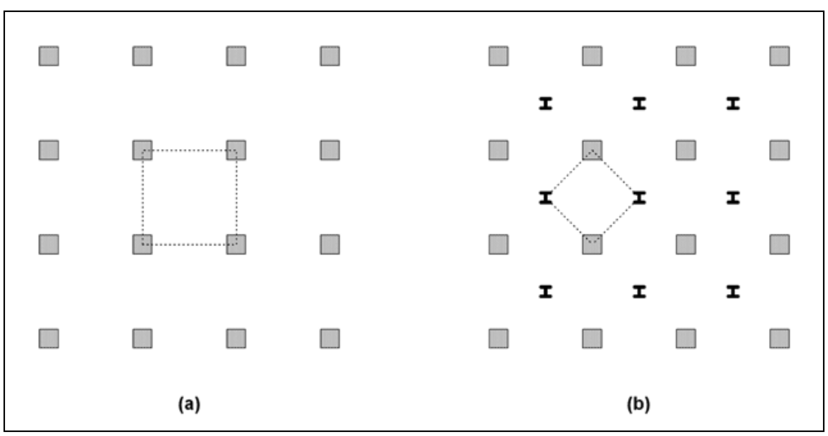
‡ The information given in this table is for guidance only. In most instances, it is recommended that the advice of someone knowledgeable about applications and vibration requirements of the equipment and process be sought.

inversely proportional to vertical stiffness. Hence, the objective is to increase the stiffness of the old fab floors. Many structural retrofit options can be considered. Three of these options are considered here in the order of their effectiveness and desirability in terms of constructability and cost.



Vertical vibration. Bending modes of the sensitive floor controls the vibration environment.

Column Stiffening Option. The structural retrofit of a fab conversion usually involves reducing bay sizes and possibly also stiffening the fab floor by adding steel members underneath the fab floor. To reduce bay sizes, the easiest approach is to introduce additional columns, such as columns at midbays or in column lines. Depending on the existing fab floor configuration, midbay column additions can be very effective. If the fab floor has a two-way symmetric configuration (e.g., uniform waffle system), the new midbay columns and existing fab columns can create “diamond” bays, as shown in the following illustration. Even if the floor system is not symmetric (e.g., pan-joist floors), the column option can be combined with additional steel beams between columns and the existing floor to improve vibration performance.



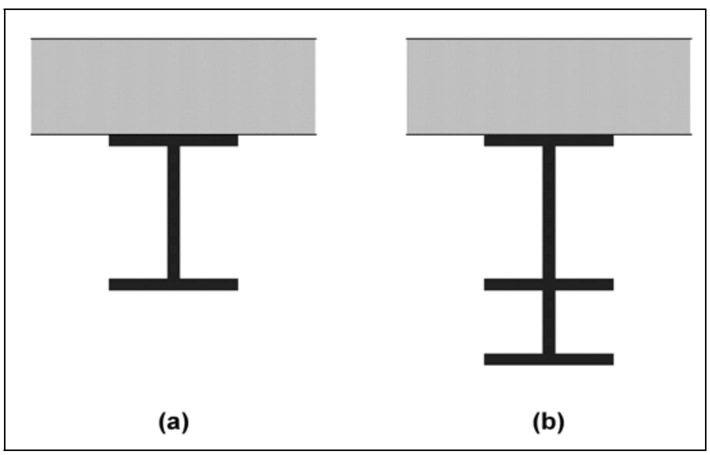
Column stiffening option. Original concrete column grid shown in (a); added steel I-beam columns shown in (b). Note the smaller effective bay size.

There are two drawbacks to adding columns. First, new columns require new foundations. In a facility that enjoys a good soil condition that allows for a shallow foundation such as mat or spread footings, this concern is trivial. However, on sites with poor soil, a pile foundation may be needed. The addition of such deep foundations in a retrofit situation is not a trivial matter. Also, in sites with poor soil, settlement of the new foundation can disengage the new columns from supporting and stiffening the fab floor. The other significant drawback to adding columns is the potential interference with existing subfab components such as utilities and equipment.

Column addition is attractive in instances where stiffening the fab floor is necessary for only one or two tools. In this scenario, affected bays may be retrofitted, thus minimizing cost, interference with subfab components, and disruptions to ongoing activities. Again, given the right soil type, this option is considered to be the most effective and easy-to-accomplish retrofit. The new columns are designed and fabricated with jacking screw mechanisms at top and bottom to allow for loading the new columns once they are in place. The jacking mechanism can also be used to compensate for foundation settlement.

The size of the column must be based on vertical stiffness value of the column, not its structural load capacity. The stiffness requirement will most likely result in much heavier columns, such as W14x257 for a 24-foot-long column. The stiffness requirement is intended to create nodal points at the column locations such that the new bays (between existing and new columns) produce new bending modes. In seismic zones, it may be necessary to reevaluate the seismic performance of the fab structure when adding columns, depending on the extent of their application.

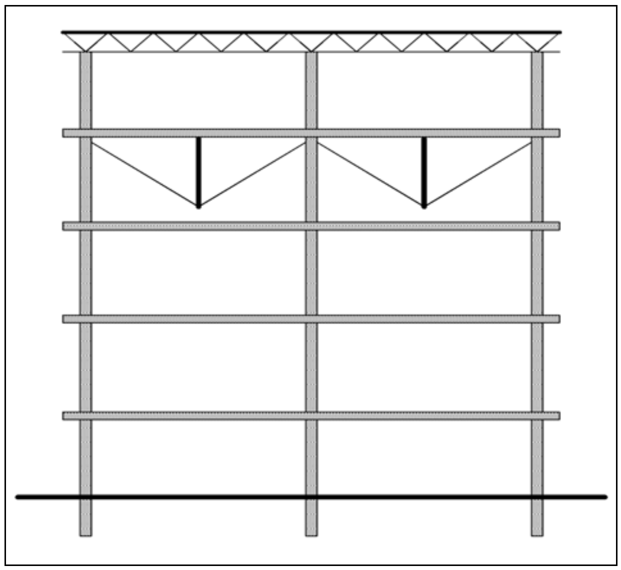
Beam Stiffening Option. If adding columns is not feasible for a particular old fab, the floor can be stiffened by adding steel beam members underneath the bays. If the floor is already supported with steel beams, additional material may be welded to the bottoms of these beams to create deeper structures.



Beam stiffening option. Original steel I-beam shown in (a); retrofitted beam with T-section welded to the bottom shown in (b). Note the deeper beam structure.

The key to this option is that new beams and the fab floor should behave as a composite structure (i.e., resist vertical and horizontal loads through composite action) rather than as simple parallel structures. To achieve this composite behavior, structural detailing is required, such as adding dowels from steel beams to the fab floor and using straps to wrap the existing concrete beams to steel beams (to create a composite condition for vertical load carrying). Even the use of thin layers of epoxy between steel and concrete beams in combination with other retrofit detailing can result in shear transfer between the new and existing structural elements and hence the desired composite action. From the examples given here, one can appreciate the multiplicity of options available for each existing fab configuration.

King Post Option. Another alternative to adding columns is to stiffen the floor via "king posts." This option involves adding vertical posts at floor midbays. The length of the vertical posts is based on the required stiffening of the bays. Cables brace and pull the ends of the posts in different directions. This option may be the least desirable since it takes up more of the subfab space underneath the fab floor and also provides a smaller stiffness improvement. However, this option is useful in instances where columns cannot be added due to the foundation design, or on upper floors where carrying new columns down through several stories to the foundation will disrupt the space allocation in too many areas.



King post option. The posts are inserted at the midbays, with cabling running to adjacent columns. Since additional columns are not needed, there is no concern regarding foundation type and space allocation on lower floors.

All of the options discussed should be modeled using finite element modeling software, performing both static and dynamic analysis of the retrofitted structures. One should pay close attention to natural frequencies of different structural elements such as the fab floor bays, columns, and subfab to ensure that unwanted tuning of these frequencies does not occur. Also, it is essential to separate these structural modes from rotating frequencies of equipment directly mounted on them. Finally, the retrofitted structure should be field-tested under ambient, walker, and excitation sources such as an instrumented hammer to verify the performance of the modified structure. In fabs where there exists some potential for foundation settlement and unloading of the new columns, field-testing can identify these conditions and additional adjustment of the jacking screws may be needed.

Horizontal Vibration

The horizontal vibration performance of a fab is associated with global cantilevered modes of the fab structure. These modes generally reside in the range of 2 Hz to 6 Hz. The lateral stiffening elements of fab structures control the amplitude of horizontal vibration. The floor rigidity in the horizontal plane is equally important because the floor is responsible for the load transfer from the floor to lateral stiffening elements such as shearwalls and diagonals. In the structural world, this phenomenon is referred to as diaphragm shear deformation, or rigidity. In most fabs with grillage floors perforated with many holes, the horizontal floor rigidity is very poor, requiring closer spacing of lateral stiffening elements such as shear walls. To further complicate the problem, an old fab with relaxed criterion such as VC-A or VC-B may not have needed any shear walls or other stiffening elements (assuming it is located in a non-seismic zone). Therefore, a difficult task lies ahead in improving the horizontal vibration performance of a VC-A or VC-B fab to criteria such as VC-D or VC-E. In some older fabs, the fab floor is divided into several fab structures with complete structural isolation breaks around each. In one instance, an old fab had eight individual fab floors, each supported on approximately 60 columns. This was especially complicated because it was necessary to design a method of connecting these individual fab floors into one monolithic floor before proceeding with lateral stiffening retrofits.

In combining individual fab segments into one monolithic structure, the objective is to achieve horizontal shear transfer between the segments. Therefore, depending on the waffle type, one can employ simple structures such as discrete steel plates (adequately sized to have equivalent shear stiffness to that of the concrete floor bays). An easy, straightforward solution is to bolt solid steel plates to each floor segment at each bay along the boundaries of the fab segments. The solid plates can be applied only at the top of the waffle because, in most cases, the waffle topping is the primary shear transfer element.

Source Mitigation

Stiffening the structure is only one part of the solution for improving the vibration environment of a facility. The need for high throughput and extremely clean environments places intense demands on building mechanical systems. These rotating mechanical systems are sources of vibration, both tonal (deterministic sine waves at single frequencies, with specific amplitudes and frequencies) and broadband random (broad-spectrum energy at many frequencies, with no deterministic component) vibrations. The tonal vibration is due to dynamic unbalanced forces generated by the rotating assembly of each piece of equipment; the broadband random vibration is due, among other things, to turbulent flow in piping and ducting driven by these systems. Our design philosophy assumes that the force inputs to the structure are broadband random vibration in nature, and that tones due to rotating equipment are minimized through good selection of vendors, tight dynamic balance requirements, and adequate vibration isolation systems design for each piece of equipment.

In facilities originally designed to operate under less restrictive vibration criteria, mechanical equipment often was procured without much thought to dynamic balance, vibration isolation, and location relative to sensitive floors. Even in those cases where vibration impact was considered, it is not uncommon for existing mechanical equipment to be in poor condition, with worn-out bearings, highly unbalanced rotating assemblies, misaligned shafts, and belt-driven systems, all of which contribute greatly to the vibration spectrum. Where present, vibration isolation systems frequently either are poorly designed or have degraded over time. Since the structure cannot reasonably resist the tonal forces generated by poorly fabricated, poorly maintained, and unisolated equipment, simply upgrading the structure without addressing the existing mechanical equipment can result in failure to meet the desired vibration criterion.

In most retrofits, a number of mechanical systems are kept in place. These systems should be inspected for condition, dynamic balance, and the presence and effectiveness of vibration isolation systems. Similarly, specifications for new systems should be written to insure good dynamic balance and appropriate vibration isolation systems. In some cases, new systems can be located away from sensitive floors, thereby reducing their vibration impact. Similarly, attention should be given to piping and ductwork, and isolation systems should be introduced into these systems based on their location, size, and attachment type. A pipe or duct directly below the fab floor receives more mitigation measure than those located farther away in a central utility building.

Ahmad Bayat, president and founder of Vibro-Acoustic Consultants, San Francisco, has more than 20 years of design experience, 12 in vibration and acoustic design of advanced technology facilities. Prior to founding VACC, Bayat was senior consultant at Colin Gordon & Associates. He has held various positions with ABB Impell and Sargent & Lundy designing nuclear power plants. Bayat received a BS in civil engineering and an MS in soil and structural dynamics from the University of Houston, Houston, TX. He is a registered professional engineer and a member of ASCE, SEONC, and a senior member of IEST.

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