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Meeting The Vibration Challenges Of Next-Generation Photolithography Tools

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ABSTRACT

In the past, the vibration design process has been driven by the requirements for an acceptable ambient vibration environment for tools. However, the newest generation of photolithography tools, the "scanners" or "step-and-scan" systems, impose an additional requirement for the dynamic resistance properties of the tool's support points. This paper discusses the current scanner support criteria in terms of receptance spectra, and compares them with receptance measurements carried out in several fabs. Design philosophies are discussed for both floor structures and tool support pedestals.

INTRODUCTION

Traditionally, the manufacturers of vibration-sensitive semiconductor production tools have imposed vibration limits on the environment in order to protect those tools from vibrations. In the traditional definition, the tool is the "receiver" of vibration and everything exciting the environment such as human activities, machinery, traffic, etc., are the "sources" of vibrations. Vibration criterion (VC) curves have been developed to address the needs of vibration-vulnerable tools. Facility designers go to great lengths to minimize the sources of vibrations.

Many modern tools involve positioning mechanisms, so that a wafer can be positioned at predetermined locations for photolithographic exposure or inspection. However, the wafer is usually stationary during the important operation, with settling time allowed after each positioning. These tools may be categorized as "passive," and include step-and-repeat tools (*steppers*) and virtually all metrology tools. Even though they generate internal vibrations by their own internal positioning systems, they come to rest and are thus dependent only upon the ambient vibration environment.

The newest generation of photolithography tools, called step-and-scan systems (or *scanners*), increase throughput and resolution (i.e. smaller line widths) by carrying out the critical lithography operation "on the fly," while both reticle and stage are moving. This introduces a new control variable: the motion during exposure must be exquisitely smooth. In order to achieve this, the control system must guarantee coordination between the reticle and stage, necessitating the use of dynamic positioning forces. Those forces must be resisted by the structure supporting the tool. As a consequence, toolmakers are now specifying "resistance" characteristics in addition to ambient vibration requirements. Those resistance characteristics must be accommodated by the structural designers of floors and tool pedestals.

BASIS FOR TOOL VIBRATION REQUIREMENTS

The purposes of steppers and scanners are essentially the same: to produce a precisely positioned photographic image on a silicon wafer. The primary difference between the two technologies arises from the machine state during photographic exposure. The differences are shown schematically in Figure 1 in terms of time histories of relative position, velocity, acceleration, and exposure. Both systems involve relatively large masses, and the acceleration (and deceleration) of those masses generates forces which are carried by the floor and tool pedestal.

Step-and-Repeat Systems

Figure 1(a) shows schematically the time histories associated with steppers. The key feature to note is that the system comes to a complete stop prior to the commencement of each exposure. At a given moment, the exposure pattern is relatively large, most likely the entire chip pattern. Because the system is motionless during exposure, the vibration environment is completely determined by the ambient state.

Step-and-Scan Systems

Figure 1(b) shows the schematic time histories associated with scanners. The primary difference may be observed with regard to the velocity, which remains constant. It is important that the actual velocity be as smooth as possible during exposure (i.e., zero acceleration and zero jerk). The exposure pattern is a narrow rectangle, a small fraction of its width in the direction of travel and the width of the chip in the direction perpendicular to travel. The control system must be able to generate reactive forces to maintain the precision of motion during exposure, so the vibration environment during exposure results from <u>*both*</u> ambient conditions and the response to dynamic loads. In order to keep the overall motion within prescribed parameters, the system response to the dynamic positioning forces during exposure must itself be kept within limits. This requires that the resistive support conditions themselves must meet certain limits.

VIBRATION CRITERIA

Steady-state vibrations (in the case of tonal vibrations) and stationary vibrations (in the case of random or broadband vibrations) can be represented by *vibration spectra*, graphs of amplitude as a function of frequency. Spectra can have the units of displacement, velocity or acceleration. It is a relatively simple matter to convert from one set of units to another. These conversions, as well as the issue of bandwidth, are discussed at length in Amick (1997).

Tool-Specific Vibration Criteria

Most modern tools used for semiconductor photolithography and metrology provide some sort of requirement in terms of allowable vibration environment. In many cases, it is mandatory for a facility to meet tool-specific criteria at the locations where those tools are to be installed.

Generic Criteria

Many fabs have been designed to generic vibration criteria originally proposed by Gordon and Ungar (1983). These criteria were developed from conservative interpretation of the individual criteria of families of tools operating within a particular range of geometries. They consist of spectral limits on rms velocity amplitude as stated in one-third octave bands, at frequencies up to 80 Hz. In their original form, they were relaxed at frequencies less than 8 Hz and undefined at frequencies below 4 Hz. Ungar, *et al*. (1990) proposed elimination of the relaxation and extension of the curves down to 1 Hz to accommodate the requirements of pneumatically-supported tools. The amplitudes of the generic criteria are given in Table 1. Current fabs are being designed to VC-D and VC-E. [For greater detail, see Gordon (1991), IEST (1993), Amick (1997).]

Table 1. Amplitudes associated with generic vibration criteria.

Criterion	**1/3 Octave Band rms Velocity**	
	(μm/s)	**(μin/sec)**
VC-A	50	2000
VC-B	25	1000
VC-C	12.5	500
VC-D	6	250
VC-E	3	125

Gordon (1987) observed that vertical broadband stationary ambient vibrations in an operating fab tend to be inversely proportional to midbay point stiffness of the floor, and that walker-generated vibrations are inversely proportional to the product of the point stiffness and fundamental resonance frequency of the floor. The design of many fab floors has been based on these relationships. [For greater detail, see Amick and Bayat (1998).]

RESISTANCE CRITERIA

Response and Resistance Metrics

Response may be represented in terms of displacement, velocity, or acceleration, each divided by the excitation force spectrum, in which case the resulting normalized spectra are known as *receptance*, *mobility* or *accelerance*, respectively. The inverse of response is *resistance*. Table 2 summarizes the common response and resistance terminology and the relevant definitions, in which F is force, and d, v and a are displacement, velocity and acceleration, respectively. [For greater detail, see McConnell (1995).]

Table 2. Summary of response and resistance definitions.

Metric	Response Term	Resistance Term
Displacement	Receptance = d / F	Apparent Stiffness = F / d
Velocity	Mobility = v / F	Mechanical Impedance = F / v
Acceleration	Accelerance = a / F	Apparent Mass = F / a

The response and/or resistance of a point on a structure are straightforward to measure with a force source, a vibration sensor, and a two-channel spectrum analyzer. The two common force sources are instrumented hammers and electrodynamic shakers. The "static" stiffness at a point is the value of apparent stiffness to which that spectrum appears to be asymptotic at low frequencies.

Manufacturers' Resistance Criteria

Several manufacturers of step-and-scan systems provide resistance criteria that must be met at the support points of the tool in order for the tool to be warranted. There are no industry standards for the form in which the criteria are to be stated, and the current criteria are stated in quite different ways. These criteria have been converted to a "neutral" form (i.e., one not used by any of the three) and are shown in Figure 2. The curves represent the *maximum* receptance that is allowed at a support point. Each curve has what might be considered a constant *limiting value* over some frequency range typical for the resonance frequencies of fab floors. These limiting values and corresponding frequency ranges are summarized in Table 3.

Table 3. Limiting values of receptance and apparent stiffness for three scanners.

Tool	**Maximum Receptance**		**Min. Apparent Stiffness**		**Frequency Range**
	(μm/N)	(μin/lb)	(N/m)	(lb/in)	(Hz)
A (Max)[1]	0.0076	1.32	1.3×10^8	0.75×10^6	$10 \le f \le 250$
A (Min)	0.0038	0.66	2.6×10^8	1.5×10^6	$10 \le f \le 80$
B	0.0025	0.44	4×10^8	2.3×10^6	$30 \le f \le 70$
C	0.011	1.9	1×10^8	5×10^5	$1 \le f \le 100$
D (Vert)	0.00067	0.12	14.9×10^8	8.5×10^6	$10 \le f \le 100$
D (Horiz)	0.0016	0.29	6.12×10^8	3.5×10^6	$10 \le f \le 100$

[1] Manufacturer A provides two criterion curves. The one denoted here as "Min" identifies a state in which the tool's performance will always be acceptable. Receptance values exceeding this curve may identify a "gray area" in which problems might be possible. The curve denoted here as "Max" identifies a state in which problems are likely. Receptance values exceeding the "Max" curve are deemed unacceptable.

PERFORMANCE OF TYPICAL FLOORS

Typical 50 and 25 μm/sec Floors

It is not uncommon for the floors of some non-critical areas in a fab to be designed to meet less stringent vibration criteria, such as VC-A (50 μm/sec, or 2000 μin/sec) or VC-B (25 μm/sec, or 1000 μin/sec). Figure 3 shows measured receptance spectra for two floors, one meeting each vibration criterion. The maximum receptance of the VC-A floor exceeds the most stringent of the receptance criteria by a factor of over 200 times. The maximum receptance of the VC-B floor exceeds the Tool B criterion by a factor of about 9 times, and that of Tool D by about 230 times.

The "static" receptance (the value at very low frequencies) of both floors meets the low-frequency requirements for Tools B and C, but exceeds those of Tool A (Min) (assuming that criterion is extended to low frequencies) and Tool D.

Typical 6 μm/sec Floors:

The majority of fab floors over the last decade have been designed to VC-D (6 μm/sec, or 250 μin/sec). The measured receptance spectra for five floors designed for VC-D are shown in Figure 4. The static receptance values all fall within a fairly narrow range (about 0.001 to 0.0025 μm/N)—in all cases less than the criteria—but the maximum mobility values cover a range from 0.002 to 0.011 μm/N. Some of the floors meet some of the criteria, but none meets all of them.[2]

Typical 3 μm/sec Floors

Some of the more demanding fabs have been designed to VC-E (3 μm/sec, or 125 μin/sec). The measured receptance spectra for two VC-E floors are shown in Figure 5. Both of them lie completely below all but one of the receptance criteria.

DESIGN PHILOSOPHY – FLOORS

A trend may be observed in Figure 3 through Figure 5. A more stringent ambient design criterion appears to be more likely to lead to an acceptable receptance. Floors designed to VC-E appear consistently to meet the receptance requirements of most of the tools, but floors designed to VC-D are on a "borderline," some meeting the receptance requirements and some failing. Thus, stiffness alone cannot be used as a design basis. We should note that the measured receptance spectra reported here are for the vertical direction at the midbay of the fab floors. The horizontal receptance of the fab floors should also meet the same scanner limits. Although not discussed here, the horizontal receptance should readily meet most of these limits (one exception being Tool D, for which a separate horizontal criterion is given).
Closer examination of the nature of the receptance curves at and near the fundamental resonance frequency suggests a relationship between frequency and peak receptance at

[2] It should be noted that VC-D fabs have generally been found to be adequate for the current generation of submicron manufacturing (about 0.15 micron line widths).

resonance. If the receptance curves are normalized by dividing them by the static receptance (the same thing as multiplying by static stiffness), the result is a response magnification curve. The upper bound of the normalized receptance peaks (at resonance) may be given by a curve defined by g in Equation (1), which is non-dimensional.

$$g = \frac{740}{f^{1.6}} \quad (1)$$

Thus, the minimum midbay design stiffness should be based on allowable receptance at the resonance frequency and take into account the magnification that occurs at resonance. Since the floor's static stiffness is the inverse of the static receptance, the required static stiffness $k_{\min}$ is given by Equation (2).

$$k_{\min} = \frac{g}{R_{\max}} = \frac{740}{R_{\max} f^{1.6}} \quad (2)$$

where $R_{\max}$ is the maximum spectral receptance.

The behavior exhibited by this relationship is not completely understood at this time, and is the subject of ongoing parametric studies. The change in shape of the receptance curves as the resonance frequency increases bears some similarity to the family of curves one might obtain if damping was varied, but structural damping of the structures in question should be more uniform than has been exhibited (all are cast-in-place concrete waffles or grillages) and it should not have the apparent dependence on resonance frequency.

In summary, we can conclude that the receptance requirements of scanners control the design of a fab floor. This differs considerably from the traditional design approach, in which we wish simply to control the tool's ambient vibration environment. For instance, a VC-D floor may be adequately addressing the ambient vibration requirements of scanners and other tools, but it does not necessarily address the receptance limits. To design for the latter, the floor would need to be further stiffened as discussed above.

DESIGN PHILOSOPHY – PEDESTALS

Manufacturers' resistance requirements are defined at the locations at which tool feet will rest. Most modern fabs employ raised access floors some distance above the elevation of the structural floor, so tool pedestals are used to create a bearing surface for the tool at the elevation of the access floor. Most pedestals are fabricated from steel, but some are built from concrete.

A common practice is to design a steel pedestal with members and geometries that produce resonance frequencies no lower than 100 Hz. The intent is to force the resonances to frequencies higher than those at which significant ambient vibrations occur. This approach will address the ambient vibration requirements of a scanner, but in order to meet the resistance requirements, the designer must design the pedestal such that the combined resistance of floor and pedestal meets the resistance requirements of the given scanner.

CONCLUSIONS

Scanners make up the newest suite of photolithography tools that present new challenges for designers of fabs. Although their ambient vibration requirements can be met by conventional design approaches, they also require minimum dynamic resistance properties at the support locations. Conventional design approaches may—in many cases—provide structures of adequate stiffness, but compliance with manufacturers' requirements at resonance frequencies (were there may be amplification) may require additional effort. A methodology has been presented which will lead to floors of adequate stiffness for the current generation of scanners.

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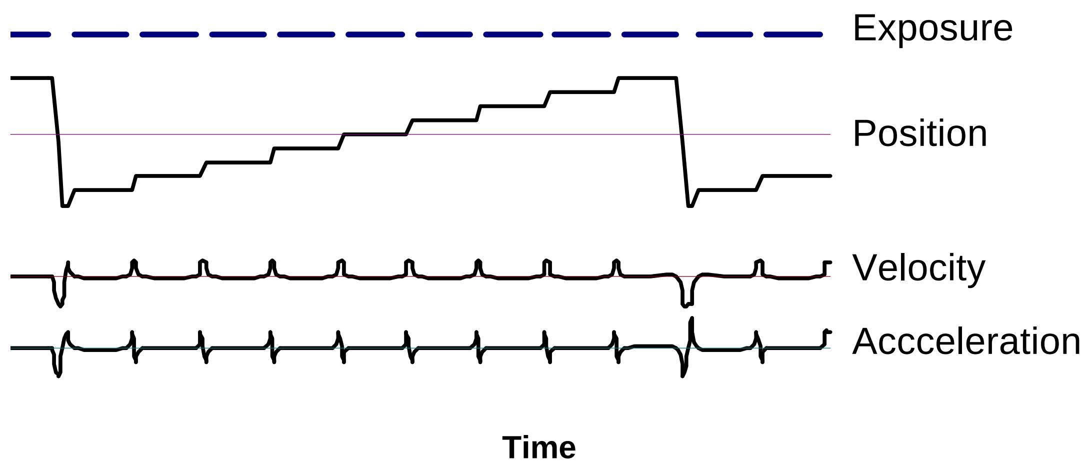

Figure 1(a). Dynamic parameters of a *stepper*.

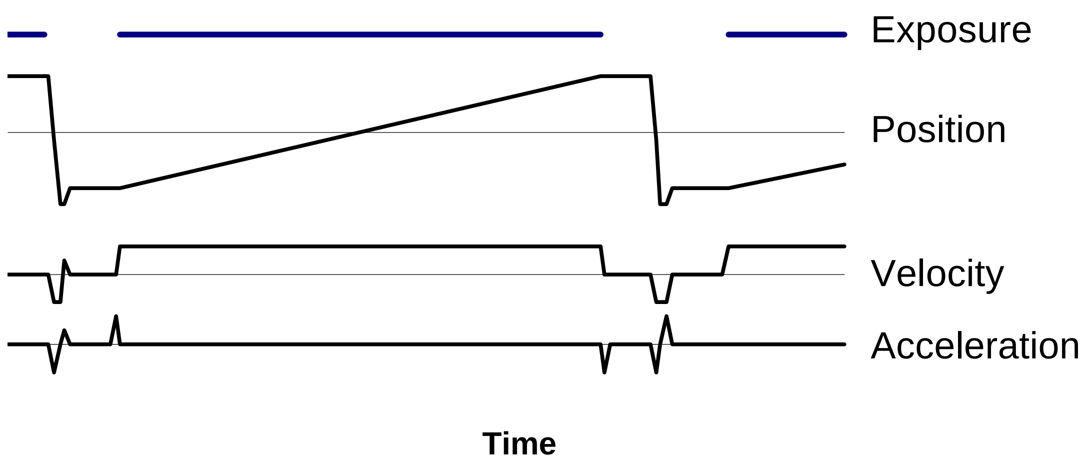

Figure 1(b). Dynamic parameters of a *scanner*.

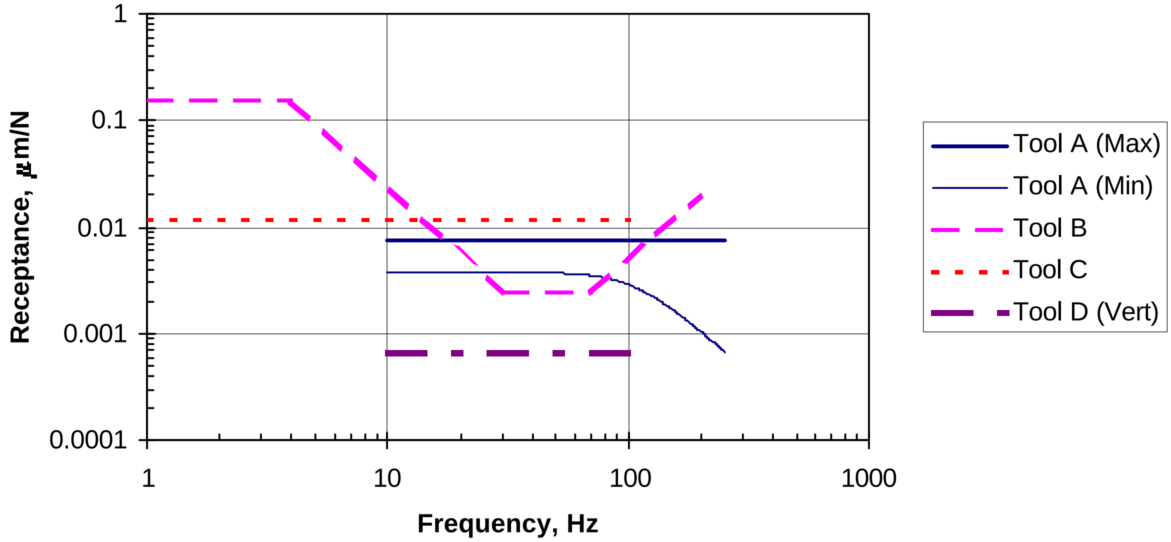

Figure 2. Resistance criteria for four scanners, given as maximum allowable receptance.

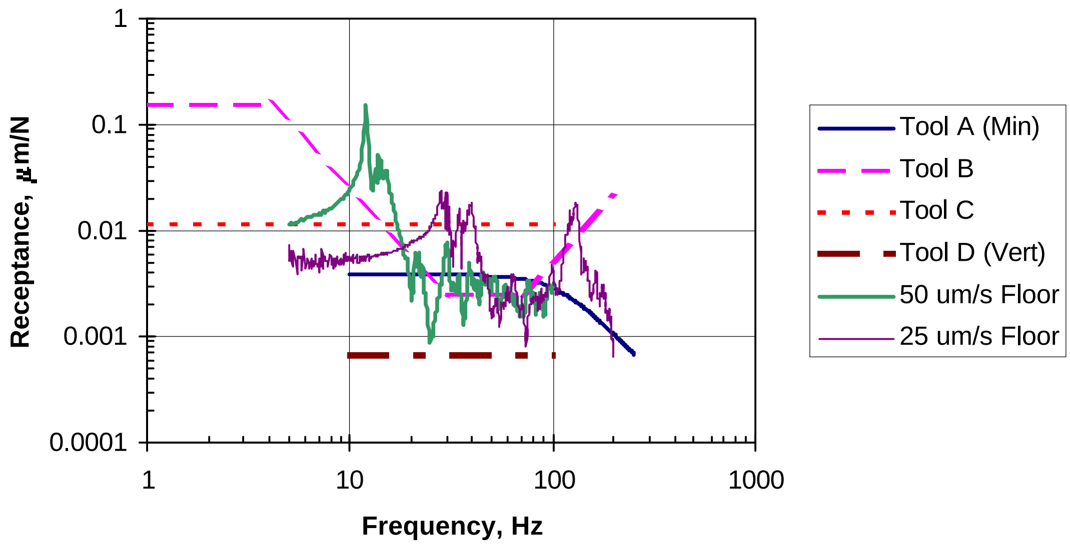

Figure 3. Measured receptance of typical VC-A (50 µm/s) and VC-B (25 µm/s) floors.

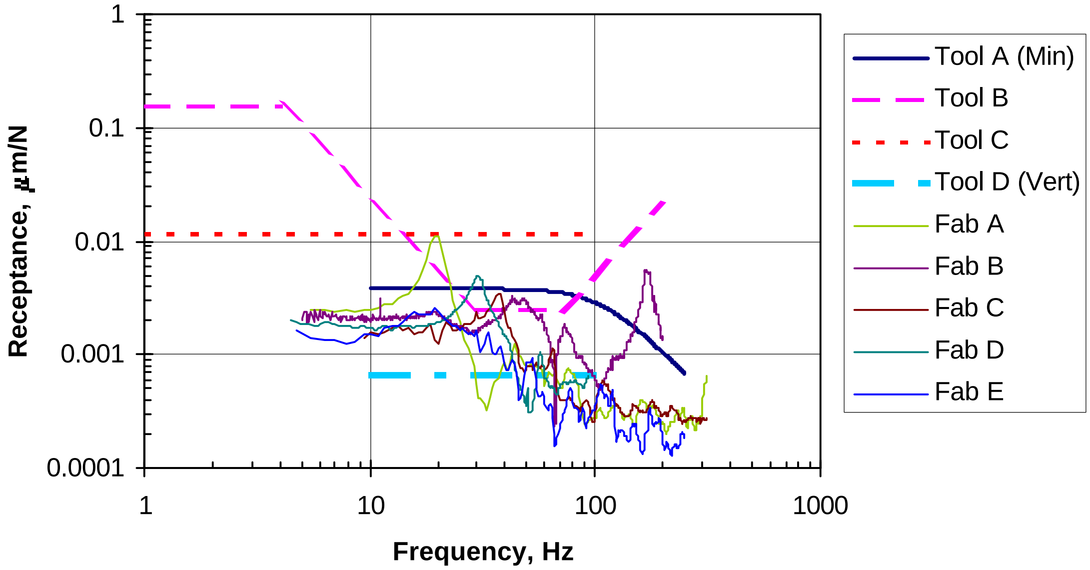

Figure 4. Measured receptance of several floors for which stiffness was selected to yield VC-D (6 µm/s) performance.

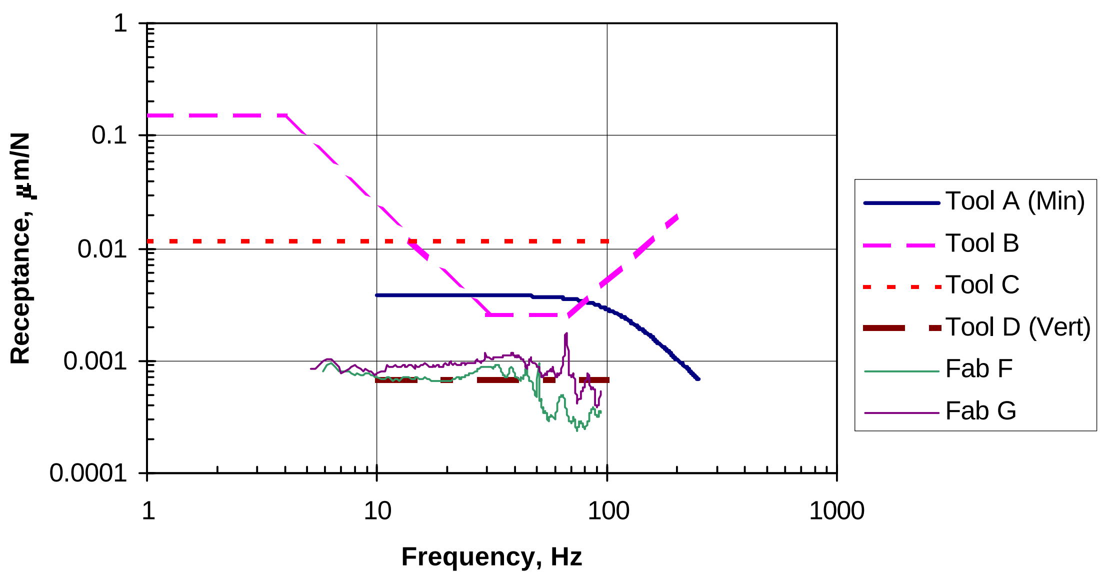

Figure 5. Measured receptance of two VC-E (3 µm/s) floors.