A world apart?

Are there tonal differences between old Italian violins and those built at other times in other places? Can these differences be measured? In the last article (October 2003) we saw how a violin's ability to radiate sound in two particular frequency regions determined its projection. In this article we will examine the concept of frequency response – how it is measured and plotted, and how it can be used to address some of the questions that have haunted violin making for the past two centuries.

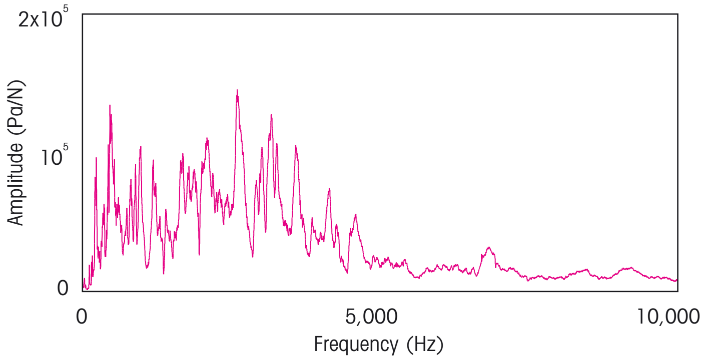
Imagine a line tracing the amount of sound made by a violin as it is swept through its frequency range in a kind of electronically induced glissando. While the typical note-to-note unevenness experienced by players suggests the line might not be straight, there is little to prepare you for the jagged landscape observed when acousticians plot the frequency response.

Frequency response is an account of how much sound is radiated at each frequency in the instrument's range, for a given input at the bridge.

Frequency response function

The frequency response function (FRF) is so fundamental to violin research that it is helpful to become familiar with its appearance. The first thing you notice about figure 1 is the multitude of jagged peaks – several hundred in all. Those to the left, at the low frequency end, are fairly distinct and well spaced, but looking to the right we can see they overlap more and more until they form a kind of spiny continuum. Note that there is almost no sound radiated at 196Hz, the fundamental of the open G string. The first significant peak occurs at 275Hz, very near to C sharp: this is the Helmholtz or f-hole resonance. The prominent peak about an octave higher, created by a resonance of the violin body, is most often responsible for wolf notes. Standing back and squinting, the strongest resonances fall in two broad clusters or formants – the first between about 250Hz and 1,000Hz, the second between about 2,000Hz and 4,000Hz. This general shape turns out to be characteristic of old Italian violins.

Figure 1



ABOVE analysing the response of the violin to a range of vibrations at the bridge is useful when comparing instruments

Photo: Clarissa Bruce

Joseph Curtin and **Martin Schleske** quantify some of the sound characteristics that distinguish classic Italian instruments from the rest of the pack

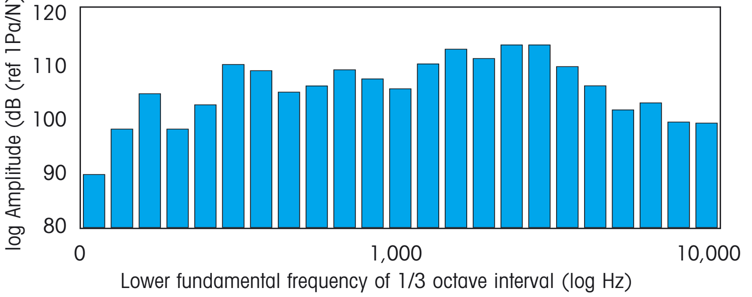
A violin's frequency response is highly complex, partly because of the hundreds of resonances that contribute to its many peaks and valleys. If we are to account for all the radiated sound, then measuring a violin's frequency response is greatly complicated by the instrument's directionality at higher frequencies. While low-frequency radiation is roughly equal in every direction, at high frequencies the sound radiates as beams whose angles shift even within a single vibrato cycle. This presents researchers with a problem: identical microphones placed in different positions will pick up different signals – suggesting different frequency responses.

Even a single microphone will receive different signals if the bridge is driven from a different position – indeed, the measurements will change if you simply wait until the humidity alters. All this makes the comprehensive charting of a violin's frequency response an exhausting enterprise. Instead, researchers often rely on a more conditional, limited measurement – a frequency response function (FRF). This can be thought of as a single 'snapshot' of the instrument's acoustical characteristics – one particular view of a three-dimensional landscape. Its meaningfulness depends on how well the measurement conditions are specified; its usefulness on how much light is shed on the question at hand.

If the question is, 'How do we distinguish old Italian violins from other violins?' then it is worth looking at the work of German physicist Heinreich Duennwald. He measured a great variety of violins, from factory ones to old Italians. He measured them in an anechoic chamber, driving them with an electromagnetic transducer designed to rock the bridge from side to side, in much the same way as a bowed string does. A computer-generated signal was fed into the transducer and the resulting sounds from the instrument were picked up by a microphone and fed into a computer for comparison with the original signal. The ratio of the output signal to the input yields the frequency response function.

Instead of dealing with the fine details of several hundred curves, Duennwald divided each of them into six distinct frequency regions, then looked at the average levels in each. This is a fairly common strategy among acousticians – the ear tends to hear these ▸

Figure 2



regions independently, and the proportions of energy in each band to some extent determine tone colour. Home stereo systems with graphic equalisers take advantage of this, allowing the overall tonal balance to be adjusted by means of 1/3 octave filters. Here are Duennwald's frequency regions, along with the tonal effects he ascribed to high relative levels in each sector:

Category	Qualities
A 90–650Hz	fullness and depth
B 650–1,300Hz	nasal quality
C 1,300–1,640Hz	brilliance and projection
D 1,640–2,580Hz	brilliance and projection
E 2,580–4,200Hz	brilliance and projection
F 4,200–6,400Hz	harshness and inclarity

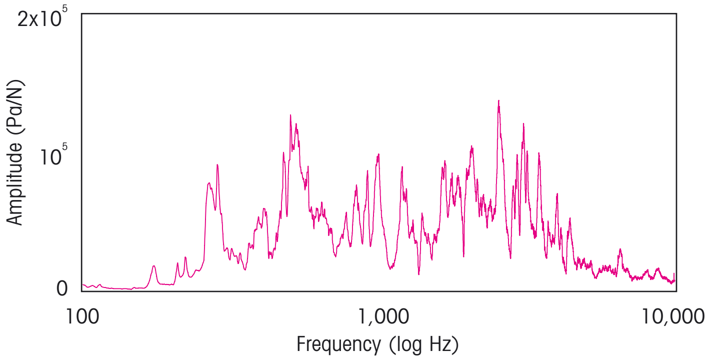
In our experience the nasal region extends from about 1,200Hz to 1,600Hz, while the region 600–1,000Hz is important for the openness of the sound, lending it an 'aaah' quality. If you want to experience this yourself you can visit www.schleske.de/hoerbeispiele/playlist10.html and listen to a single musical example, artificially modified for higher and lower values in each frequency region. Note that while a high level of B, for example, might create an unpleasantly nasal sound, too low a level can lead to an equally undesirable overcast quality. This is true for the other regions: balance is everything. Precise subjective attributes, however, are not crucial to Duennwald's results. Rather, he was concerned with comparing violins, using the measured values for each region, along with the strength of the the violin's lowest radiating resonance, the so-called Helmholtz or f-hole resonance. He first formulates the following quality parameters:

- high relative level of the Helmholtz resonance
- high percentage of un-nasal notes versus nasal notes
- high percentage of clear notes versus unclear notes.

These parameters were applied to each violin on a note-by-note basis, making allowances for some of the characteristics of the bowed string and the human ear. Violins which satisfy these parameters have a strong Helmholtz resonance and produce relatively little sound in regions B and F. Duennwald tested 700 violins, comprising 53 old Italian instruments, 75 by pre-1800 masters such as Klotz and Stainer, 42 by hobbyists, 300 by post-1800 masters and 180 factory instruments. In each category we can see the percentage of instruments showing good values for all quality parameters.

Category	%
Old Italian	92.5
Pre-1800 masters	30.7
Hobbyists	26.2
Post-1800 masters	19.1
Factory	8.4

Figure 3



Plotting a frequency response function

Amplitude is plotted on the vertical or y-axis, using either a linear or logarithmic scale. Plotted linearly, as in figure 1, a doubling of the signal doubles the height of the curve. In figure 2, amplitude is plotted logarithmically using the decibel scale (see October 2003, p.1107) and this produces a more compact graph that roughly mimics our subjective sense of loudness. Linear scales, by contrast, highlight small differences in amplitude. Frequency is plotted horizontally, on the x-axis. Again, a linear scale can be used, where each 1,000Hz increment is given equal space, or a logarithmic one (see figure 3), where each octave is given equal space – as it is on the piano keyboard. The many ups and downs of an FRF can be smoothed to emphasise the overall shape of the curve rather than individual details. It can also be plotted as a bar chart, where the height of the bar is the average amplitude across, say, each 1/3 octave band (see figure 2).

Clearly, violins from all categories make the grade, though none so consistently as the old Italians. In terms of actual numbers, and given the enormous quantity of them in existence, factory violins satisfying all the parameters far outnumber old Italians, assuming Duennwald's instruments are representative. And it is hard to know what to make of the violins built by hobbyists. Who are these makers who do so significantly better than the masters after 1800? Duennwald, sadly, does not say.

What conclusions may be drawn from his results? If one can extrapolate from the quality parameters back to perceived tone, old Italian sound seems to combine fullness and depth along with brilliance, clarity and projection. In terms of frequency response, this implies a broad peak below 1,000Hz and another centred at about 3,000Hz. This nicely satisfies the two paradigms for projection we looked at in our last article.

There is a need for caution, however. Duennwald does not compare the total amount of sound each instrument produces. This information is lost when he normalises the curves to an arbitrary value (raising or lowering the entire curve until the highest peak in band B reaches 25dB). For this reason, a violin could satisfy all Duennwald's quality criteria and yet be almost inaudible!

The concept of old Italian sound is necessarily an abstraction from generations of playing and listening ▸

Phase difference

A comparison of two oscillating signals, in this case the input and the output, phase difference measures the difference between their respective positions on the peak–trough–peak cycle, as a proportion of the whole cycle. This lag or lead is expressed as an angle between -180° and 180°, where the midpoint, zero, is perfectly in phase and 180° or -180° is completely out of phase.

Imagine two identical pendulums one behind the other. When they are moving as one, they are said to be in phase. If they are both at the vertical and one pendulum swings to the right while the other swings left, they are 180° out of phase. If, however, one pendulum reaches the top of its swing just as the other reaches its lowest position, there is a difference of 90°.

For violin measurements, you can compare the side-to-side oscillation of the bridge with the in-and-out motion of the microphone diaphragm. Phase difference requires a separate graph, usually placed directly beneath the FRF, as in figure 4. The angle is plotted on the y-axis and the frequency on the x-axis. This data can be displayed on a single chart (see figure 5).

Figure 4

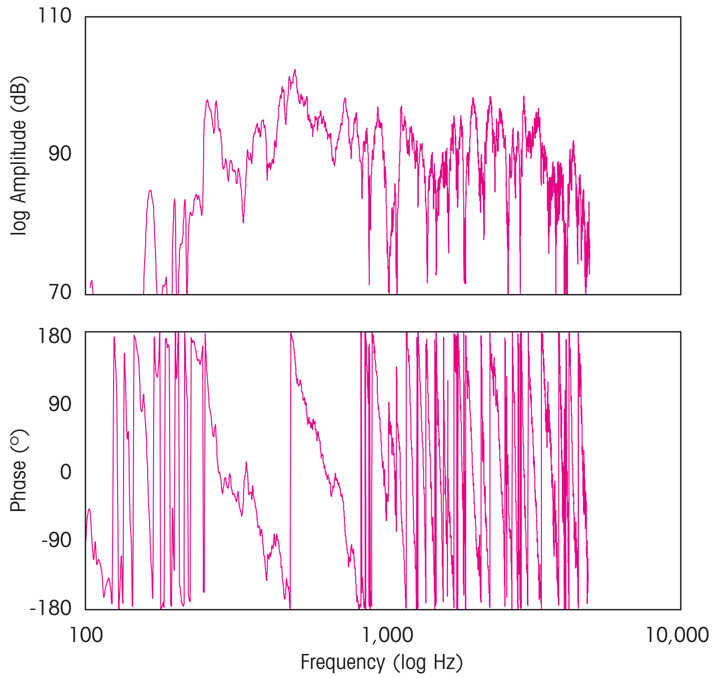
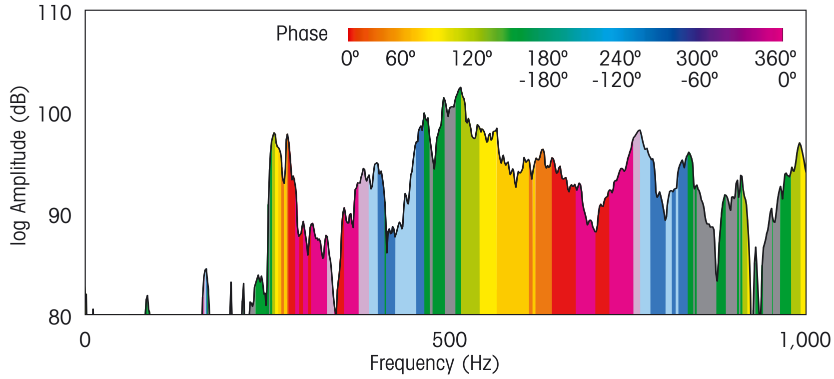


Figure 5



Anechoic chambers

Heinreich Duennwald, like many acousticians, performed his experiments in an anechoic chamber – literally, a room without echoes. Sophisticated sound-absorption techniques eliminate almost all reflection off the interior surfaces, thus creating an acoustically 'dead' space, whereas all normal listening environments are reverberant to some extent. This reverberation adds to the sound emanating from the instrument, leaving researchers with the problem of disentangling the two.

Yet banishing reverberation creates its own complications. The directional patterns of the sound radiating from the violin vary sharply with frequency, at least above 1,500Hz or so. In typical listening environments the portions of the sound that travel away from the listener are effectively 'gathered and sent back' by the surface reflection, thus providing the listener with a fairly complete tonal effect. In anechoic chambers, however, sound not heading directly towards the microphone is not heard. Thus, for any given microphone placement, some of the radiated sound is lost. At high frequencies even a 50mm shift in microphone position can a produce dramatically different FRF curve. This problem can be solved by surrounding the violin with numerous microphones or by rotating the instrument in relation to a single microphone and averaging the readings.

experience. It is complicated by the vast differences in quality among the old Italian instruments themselves, which range from the barely playable to the sublimely expressive. And if there is such a thing as old Italian sound, can we assume it is measurable in an empirical fashion? Can the beauty of a Matisse painting be understood by studying the way light bounces off the canvas? Research like Duennwald's is valuable precisely because these questions are so difficult to answer or even formulate in meaningful ways. Duennwald demonstrates the existence of a statistical community of violins linked by specific, measurable parameters. These are at best only partial definitions of old Italian sound – still, if one is building violins today and the violins happen to show high levels in regions B and F, and they are proving difficult to sell, then Duennwald's parameters seem a useful point of reference.

With this in mind, we will next consider practicable ways in which frequency response can be measured in the workshop. S