Man and the machine

Your office computer can be easily transformed into a vital sound-analysis tool. By **Joseph Curtin** and **Martin Schleske**

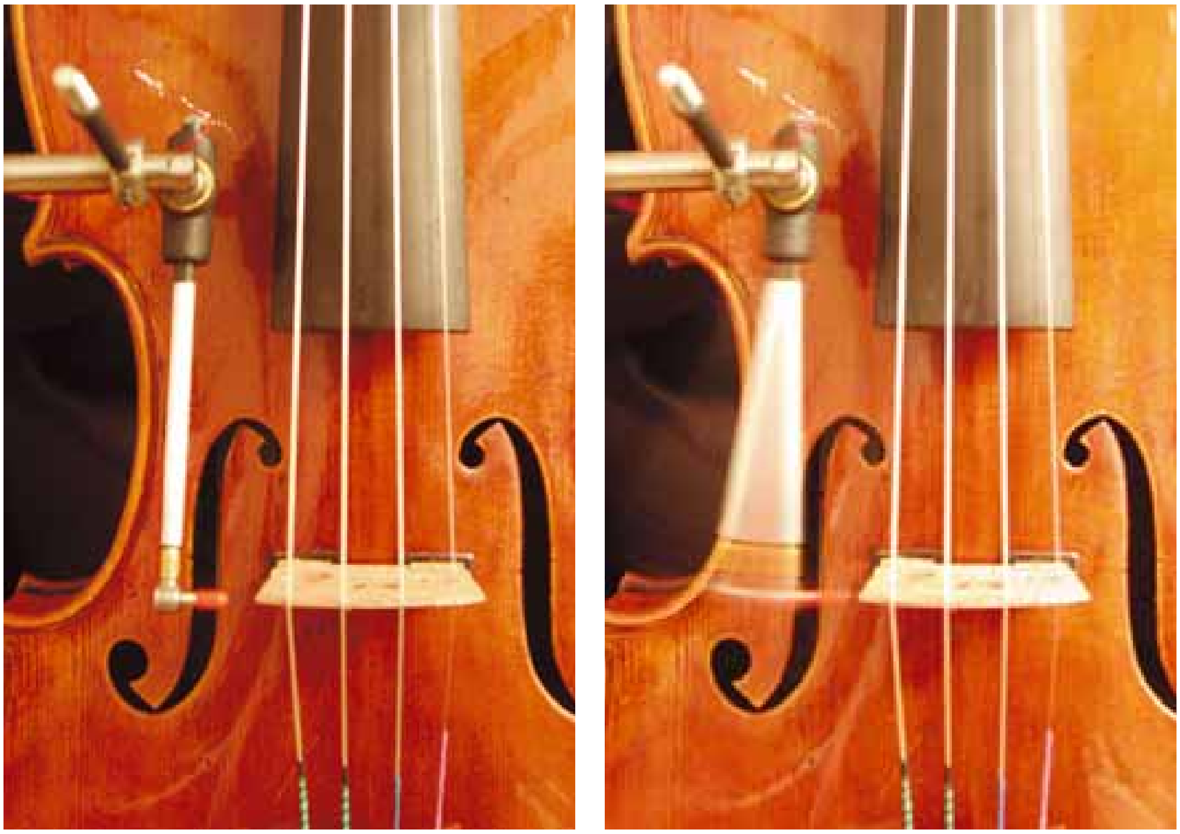
Most violin shops have a computer in their office. Can it double as a workshop tool?

As most computers have soundcards they stand ready to process audio signals. With the addition of a microphone and about around €100 of sound-analysis software we now have a piece of workshop equipment of the same day-to-day usefulness as a thickness caliper. Violin makers interested in plate tuning can determine the tap-tones of a free plate by holding it near the microphone and tapping the appropriate antinodes; after a few keystrokes or cursor movements, the frequencies can be read off the monitor. This method does not show the mode shapes – the Chladni patterns made visible by the loudspeaker-and-glitter method – but it is considerably faster and requires neither ear protection nor a broom to sweep up glitter.

It is equally simple to assess the fingerboard and Helmholtz resonances, with a view to matching them – you just hold the instrument near the microphone and tap the back with your knuckle. The Helmholtz resonance – the lowest air mode, also known as A1 – is the broad peak on the chart appearing around 286Hz. ‘Plucking’ the end of the fingerboard with your thumb yields a smaller peak above or below the air resonance, assuming they don’t already coincide. Many simple diagnostics can be performed in this manner. For example, it became clear from a few taps and thunks that a slow-rising, rather annoying resonance on the open G of a certain violin was a tailpiece resonance (see figures 1 and 2), which was then lowered to unobtrusiveness by the installation of a heavier fine tuner on the E string.

An instrument’s wolf note is most often caused by the main-corpus resonance – the so-called B1 mode appearing around 500–550Hz for violins, 170–190Hz for cello (see figure 3). The bass-bar region is the most sensitive area for this resonance and tapping here will yield its exact frequency and also gives us an idea of the effect of our adjustments to the soundpost, fingerboard or tailpiece.

We have seen how some general features of violin frequency response affect both projection and tonal balance. Old Italian violins, in particular, tend to concentrate their energy in two distinct frequency regions and this sets them apart from other violins, at least on a statistical basis. In the light of this, the ability to measure frequency response in the workshop takes on a real value. Instruments can be compared in terms of overall power or by using ‘quality criteria’, such as those discussed in the October 2003 issue, or in



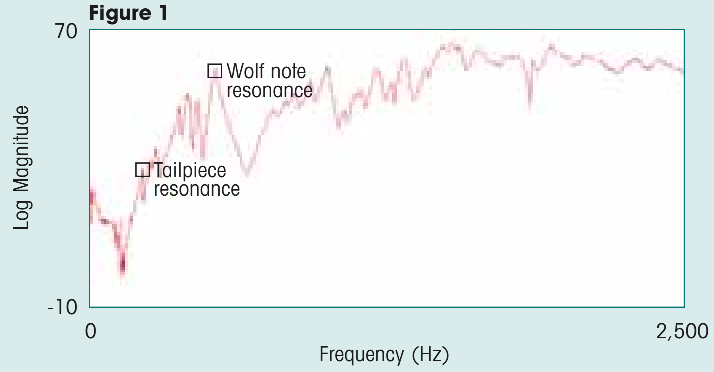
ABOVE hitting the side of the bridge with a small hammer is a simple way to excite the violin across a broad frequency range

countless other ways. At another level, the coordination of the objective data with the subjective experience of playing and listening provides a kind of ear training, enabling you to listen to violin sound in a more analytic fashion. Plotting frequency response using computer-generated coloured maps lends an additional, visual sensation to the experience of listening to violin sound and this helps sharpen what is surely a maker's most important tool – tonal intuition.

To measure frequency response, we need to do at least four things: excite the violin across its frequency range; pick up the resulting sounds; compare the excitation forces with the sound output; and deal with the acoustics of the room in which the measurements were made. Each of these can be addressed in a variety of ways; indeed, researchers often build equipment and write software specifically suited to an individual experiment. Here we will consider only equipment and software that is commercially available, reasonably priced and suitable for a variety of uses.

When a violin is played, the vibration of the bowed string drives the bridge in a predominantly side-to-side motion. Scientific experiments require a repeatable and consistent means of excitation, but players rarely play a bow stroke exactly the same way twice, so the bridge is normally driven artificially – by everything from bowing machines to record-cutters. Ideally, the driver should be able to excite measurable amounts of sound over the violin's entire frequency range, without coupling significant amounts of mass to the bridge, which would effectively mute the instrument and skew the results. The driver is typically fed with a computer-generated signal, which can take the form of a sine wave, swept across the frequency range in a kind of continuous glissando. Alternatively, a mixture of all frequencies, such as white noise, can be used. ▸

Figure 1



All photos and diagrams: Martin Schleske

A third approach, known as impulse excitation, is to deliver all frequencies at once in the form of a sudden blow. Imagine a small hammer, the handle made of six inches of soundpost stock, the head from a piece of hardwood dowel weighing several grams. If the head of the hammer were infinitely hard, the energy of its blow would be equally distributed across all frequencies; in practice, the relative hardness of the head and the surface it is striking limit high-frequency excitation. This is easily demonstrated by tapping a table top, first with your fingertip and then with a house key. The brighter click is due to the greater excitation of the table's high-frequency modes and is made by the key.

If we tap the side of the violin bridge with our wooden hammer, the resulting sound – a kind of resonant thud – will contain contributions from all of the instruments' resonances, or at least those which radiate sound, can be excited by a side-to-side motion of the bridge and are within the hammer's frequency range.

The difficulty with this approach lies in achieving the same result twice. Hitting the bridge a little harder or in a slightly different place, or from a slightly different angle, will excite a somewhat different response. This consistency can be increased by building a jig to hold the instrument and another to hold the hammer. The hammer can be suspended, for example, in the manner of a pendulum, then lifted to touch a reference bar of fixed height before being released to strike the bridge. The blow needs to be strong enough to produce sounds that are well above the level of ambient noise, yielding a good signal-to-noise ratio, but not so strong as to knock the bridge out of position. In practice, a blow with roughly the energy of a robust pizzicato note is quite sufficient. Provided the jigs are used in consistent ways, much can be learned from these kind of relative measurements. If, however, you want to compare your results with those of professional researchers or colleagues using different equipment, it may be worth investing in an impact hammer.

Impact hammers come in a variety of sizes and are widely used for vibration testing – in everything from car parts to aeroplane wings and suspension bridges. A piezo crystal embedded in the hammer head creates an electrical signal relative to the rapidly changing force at the tip of the hammer during impact. This signal allows the computer to subtract the frequency characteristics of the hammer-blow from the total acoustic measurement. Commercial impact hammers are calibrated – that is, a given force at the tip will create a signal of specified magnitude. In this way, measurements made by different hammers, or indeed by other calibrated excitation methods, can be meaningfully compared. The following page shows a PCB Piezotronics impact hammer suitable for violin testing. At roughly €1,000, it is not cheap. Still, it is a ▸

Figure 2

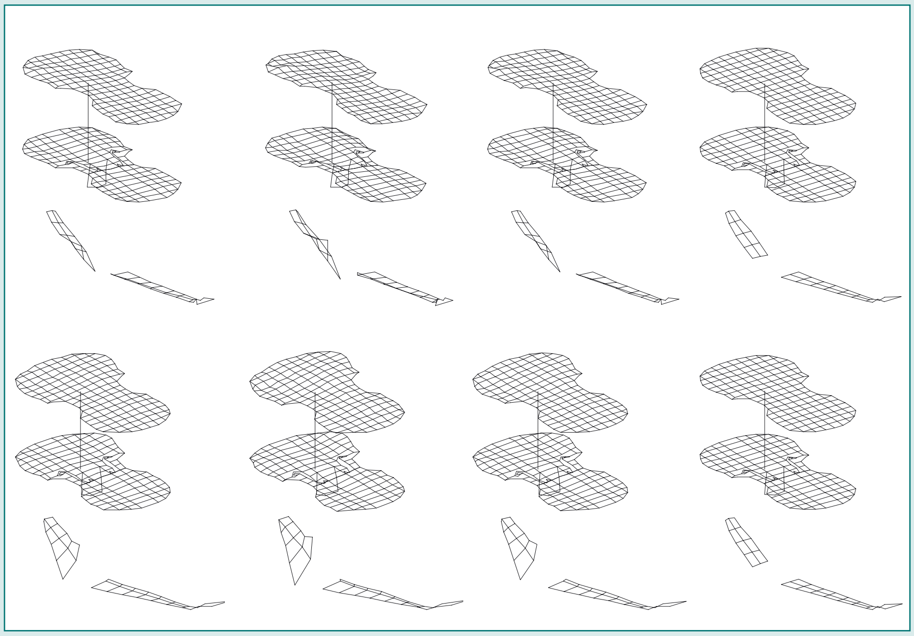
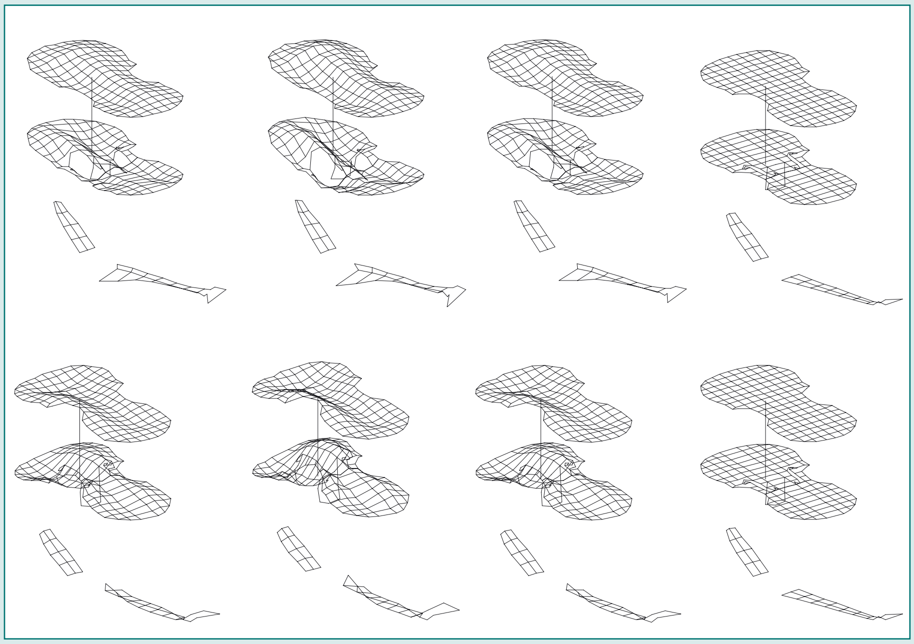


Figure 3



TOP the movement of a resonating tailpiece

ABOVE the main-corpus or B1-mode resonance, which occurs at around 500–550Hz in violins. Tapping the region above the bass-bar will yield its exact frequency professional tool suited to a wide variety of tests and will last a lifetime (see the contacts box for other suppliers).

A microphone is the obvious way to pick up sound, and surprisingly clean, relative readings can be made with inexpensive ones; the bumps in their frequency response tend to be smooth and relatively small compared with those of a violin. Most professional sound recording and measurement is done with electret or 'condenser' microphones, which require phantom power, a 48 volt DC supply usually provided by the pre-amplifier. Computer soundcards don't typically provide phantom power, but external devices that do – including sound card / pre-amp combinations – are widely available. Some microphones are designed to make particular voices or instruments sound good, claiming to add 'warmth' or any number of other intangibles. For measurement purposes, however, we want a neutral microphone with a frequency response that is as flat as possible. Fortunately, calibrated microphones are available at reasonable prices (several hundred Euros and up). These come with their own frequency-response chart, which can be put into a microphone compensation file in the software, allowing measurements of absolute, rather than relative, sound pressure. Microphones are also sensitive to sound direction: omnidirectional ones pick up sound from all directions with about equal sensitivity; whereas cardioid microphones, by contrast, mainly detect sound from a single direction. This can be useful when measuring in normal listening environments as some of the reflected sound is ignored by the microphone. The directionality comes at the expense of bumpier frequency response and the microphone has to be calibrated before it can be used for measurement purposes.


ABOVE the PCB Piezotronics impact hammer has a sensor in the tip which can be calibrated to allow accurate measurements

Once we have managed to excite the instrument's resonances with an impact hammer, even a highly trained ear would have difficulty identifying more than a few of these resonances. Fortunately, in 1822 Jean Baptiste Joseph Fourier, a French mathematician and former classmate of Napoleon, developed a mathematical tool that today's engineers use probably more frequently than any other. The Fourier Transform yields analysis of any wave form in terms of its constituent sine waves, the basic units of sound analysis. The Fast Fourier Transform (FFT), a version specially adapted for computers, is the core of most acoustical software.

Separating the acoustics of a violin from the acoustics of the room in which it is tested is a significant challenge. Many researchers use anechoic chambers, whose lack of reverberation allows for clean measurements. A small shop-built anechoic chamber is not unfeasible, but, lacking this, the reflected sound can be reduced by building an absorbent shell that partially encloses the test violin. Another shell could be built around the microphone, or a directional microphone can be used. Large, acoustically dead rooms are more suited to acoustic measurement than small, live ones. Another approach is to average out the room's acoustics by taking readings in a number of different positions around the room. We will examine this and the practicalities of a custom anechoic chamber in the next article.

Acoustic research is a fascinating undertaking, but also a demanding and often frustrating one. If you watch an acoustics experiment in progress, you will probably conclude that researchers spend most of their time finding the right cables, trouble-shooting equipment and fixing software glitches. Computers, originally designed as willing drones, turn out to be temperamental creatures, ill at ease with the tasks we assign them. Violin makers new to the field are likely to make as many mistakes as acousticians building their first violins – everything from runaway purfling to leaky varnish. A relationship with a professional researcher is therefore invaluable and organisations such as the Catgut Acoustical Society, now part of the Violin Society of America (VSA), were founded to bring makers and researchers together. The VSA-Oberlin Acoustics Symposium is a week-long summer workshop that provides both theoretical and practical support for violin makers. S

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