The Violin (as I understand it)

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Introduction

The violin is, arguably, the most important musical instrument. Apart from its wider use, the violin (i.e. the bowed strings) forms the base of all orchestras. It differs from other chordophones by using a bow to excite the strings and from wind instruments by having a greater content of harmonics in the sound created. The original statement requires some qualification. What is it about a simple instrument based on drawing a bow across a taught string that makes it a challenge to play but with an outstanding reward? Why is the behaviour of a stretched string the source of such enjoyment? How is it that a combination of wooden parts put together in such a fashion brings out the sound contained in the vibrating string? The opinions expressed in what follows are based on the experimental findings on a violin made by the author. The principles discovered for the violin can be transferred to the viola and the violoncello with due regard to the change of scale which will affect the position and nature of the resonances. It is hoped that some answers to these and other questions are contained in what follows.

The most important sound producing function of the violin is the monopole action. This has been variously described as a breathing action or in reference to a "simple source", that is, a pulsating sphere. This is why the main air resonance is so effective leading to the belief that the sound came from inside the violin. All resonances below 1 kHz make a contribution to the monopole action in their vicinity and have no other effect. Violins with a large monopole component over the range to 1 kHz will be preferred by top violinists. Vibrato will add a changing colour to the sound as the harmonics move back and forth over the resonant peaks and troughs. The amplitude of the top is about ten times that of the back and will vary inversely with its thickness. The amplitude of the breathing action will be large the closer nodal lines are to the margins. The bassbar restores the longitudinal stiffness of the top lost when the soundholes are cut. The soundpost placed outside the treble foot of the bridge raises the output of the three lower strings and controls the position of the nodal line on that side of the violin, for the main body modes. The violin, in the evolution of bowed string instruments that all relied on the vibration of the top plate for sound production, has included the back to take advantage of, and maximise the monopole action to come close to a simple source.

It is no wonder that early makers intuitively hit on the fundamental function of the body. Much research in recent times has concentrated on the fine detailed performance of the individual parts without recognising the big picture.

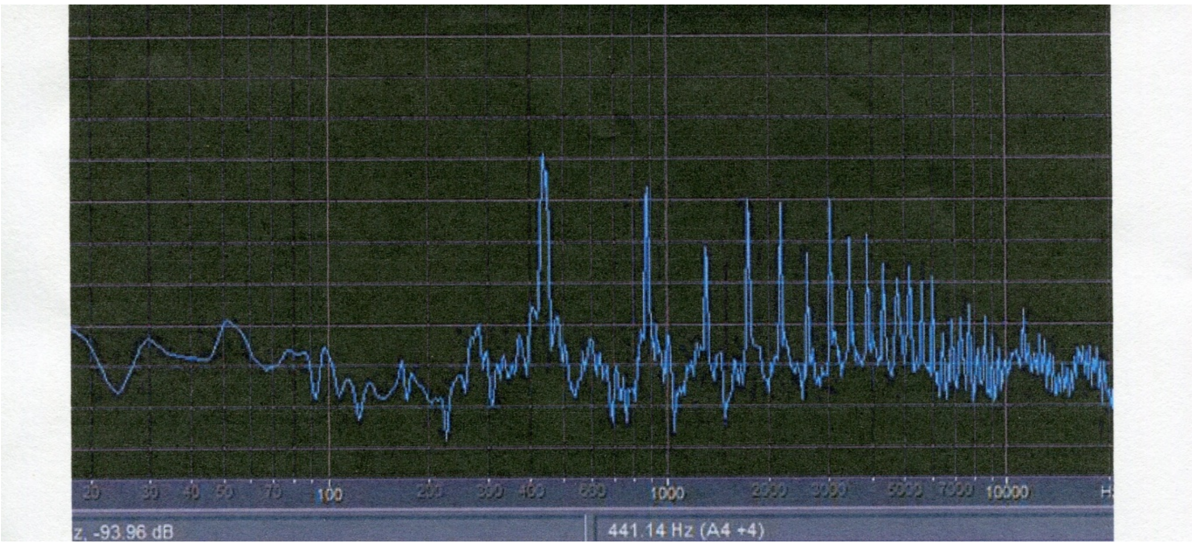
The parts of a violin will be discussed in turn and their behaviour explained, hopefully, in terms that are readily understood.

Strings

A string stretched between two points, when displaced laterally by bowing, will vibrate forming loops which are anchored at each end, the number limited only by the bending stiffness of the string. Each loop decreases in size as the reciprocal of the number of the loop on the string e.g. if the first single loop has an amplitude of one, two loops will have an amplitude of one half, three with one third and so on. The loops exist all at the same time making the shape of the string complicated. The sound from such a vibrating string is very faint. Something is needed to raise the level of the sound if a vibrating string is to be used to make a musical instrument; this is the acoustical gain of the body.

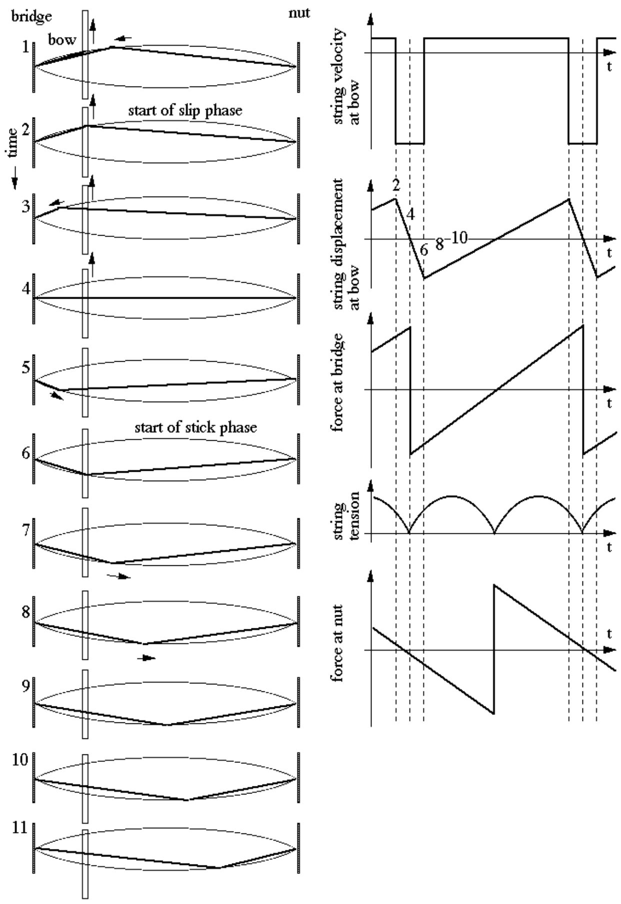
Strings were traditionally made from sheep's intestines by removing everything from the fresh gut leaving the collagen base. Several of the guts were chosen depending on the thickness required and twisting them while stretched; the greater the number of twists the greater the flexibility of the string at the cost of limiting tension. The strings after drying were polished. Strings selected were tested to ensure they gave true vibrations. By nature, these strings were extremely variable both in tension, diameter and mass per unit length. A silver winding was introduced in the 17th century, on the G string to produce a thinner string as the unwound gut was too thick to allow a quick response.

Today, strings generally have a core which is wound with a metal cover, usually aluminium. The core can be nylon or a bundle of synthetic fibres, a steel wire or a steel cable. The multitude of string makers and "flavours" adds to the precept that the string has a significant part in the production and quality of the sound. The vast difference in price ($5 to $100s/set) asked for modern strings reflect the variability and range of qualities.



This figure shows the harmonic content of the open A string bowed 25 mm from the bridge with a force of 1.7 N. The height of the harmonics is influenced by the body response and will not show the progressive decrease in height mentioned above.

For my experiments "Chorda" gut strings were used for the Baroque setup and "Thomastik Infeld" Dominant for the modern setup.



The Bow

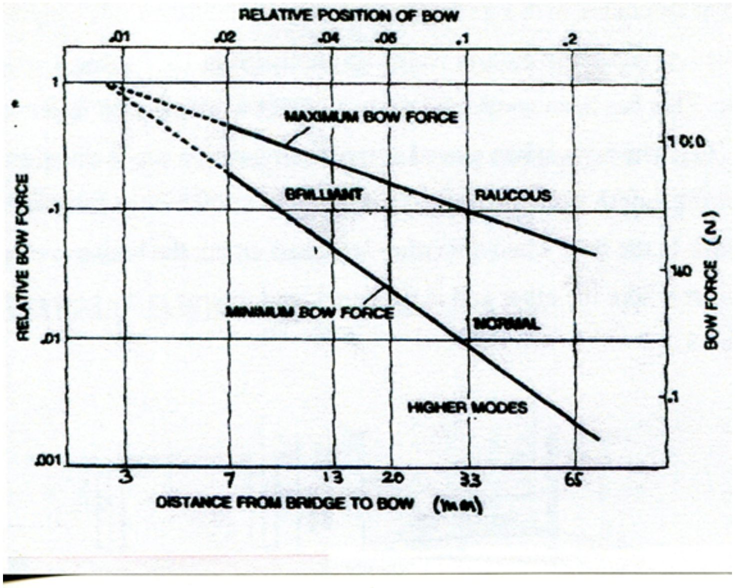
The strings on a violin are excited by a bow drawn across them. The bow is best made of Pernambuco, a South American wood that has a high stiffness, fitted with a ribbon of horse hair which is coated with rosin to increase the friction between the hair and the string. Uncoated hair does not grip the string. Early bows were relatively straight with a pikes head and fixed frog, the tension in the hair ribbon being varied by applying a force from the thumb of the right hand. The modern bow has a hatchet head and frog by which the tension in the hair ribbon is adjusted with a screw. The bow stick is tapered and has a reverse camber which allows a uniform force to be applied along the full length of the bow stroke. This was not possible with earlier bows. A bow has resonances that have to be allowed for by the player.

The Action of the Bow

At the beginning of a stroke the bow pulls the string to one side forming a kink which on release sends two kinks one travelling to the bridge (the other travelling to the nut); the slowly built up force at the string notch is suddenly released applying a reversed sideways force to the bridge top. The kink then returns to the bow which picks up the string again (the other kink takes longer to be reflected back to the bow where it is probably absorbed in the bow stroke), the first kink travels on to the nut and back to the bow to repeat the cycle. The cycle continues at the frequency of the fundamental of the note being played. The release occurs because the bow can no longer hold the string. The gradual increase in force at the bridge while the bow holds the string and the sudden release when the kink reaches the bridge constitutes a “saw tooth” signal. This conveys to the bridge top a force at frequencies equal to that of the fundamental and a number of harmonics related to the sharpness of the kink which depends on the bending stiffness of the string. When the bow stroke is reversed the kink travels in the other direction. This is a simple description of a Helmholtz action. Control of the force of the bow on the string and its velocity is what the violin student has to master to generate a pleasing sound. The behaviour of the bow hair/string is more involved than this simple outline and is the subject of much study.

This figure shows; on the left, the motion of the kink that moves to the bridge, for the bowing direction shown. On the right, as a function of time, (from the top) the string velocity at the bow, the displacement at the bow, the force at the string notch on the bridge, the string tension and the force at the nut. This simplified illustration is for an ideal string with a sharp kink and bow hair with no width. In reality this does not happen, the bow hair is of varying width depending on the player's intention and the kink is never sharp.

The question is; how will knowledge of the behaviour of an ideal string help the player? Playing is a whole body exercise. As the note played moves up the string so the bow moves nearer the bridge. Players are concerned with how quickly the string speaks and how tolerant the string is to the attack of the bow. Because the action of the bow on a real string is complicated, the width of bow hair presented to the string and the bow speed and force have to be carefully applied for the player to get the sound they want. In the end all this becomes intuitive. Generally the player wants to approach a true Helmholtz motion as possible as it is rich in harmonics. Bowing nearer the bridge increases the harmonic content but requires a greater bow force. Loudness is governed by the speed of the bow.

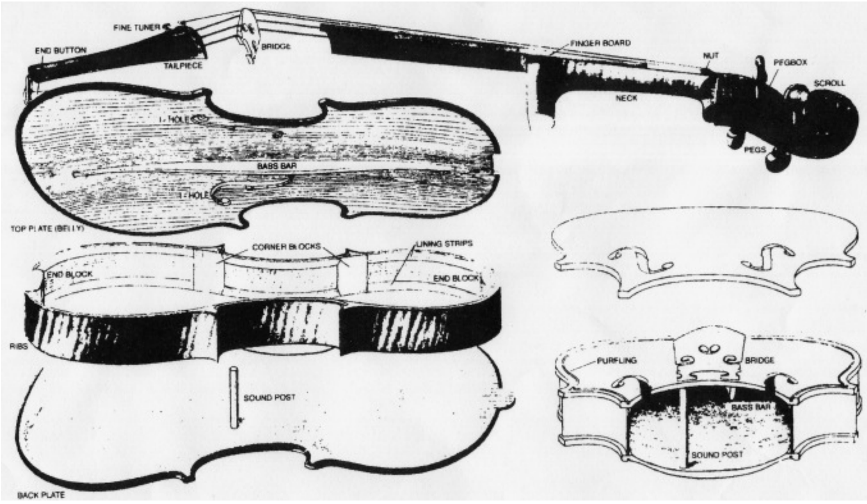


This figure shows the approximate bowing parameter limits for a violin. Brilliance is related to the increase in the number of harmonics in the sound. The latitude near the bridge is lower than near the fingerboard.

The Violin Body

The string is stretched between the nut at the end of the neck, and pegbox, which is rigid and the tailpiece attached to the violin at the tailpin by a loop of tailgut. Between them it passes over a bridge (a slender sycamore construction with four string notches at the top edge and two feet that sit on the top plate of the violin at about the middle of its length. The top plate is the most active part of the violin, about 10x that of the back. The body does not amplify the sound of the string, but is an independent sound source. It vibrates in response to the rocking action of the bridge and radiates sound in all directions at the frequency of the fundamental of the note being played. The harmonics on the other hand, radiate more directionally and move with the motion of the player sweeping over the listeners and reflecting off the surroundings. The result is a subtle change in the quality of the sound being heard.

Below is an exploded view of a violin showing the various parts. Note in particular the sides, or ribs, and the position of the blocks to which the sides are glued. The blocks stabilise the structure and provide a firm anchor point for the neck mortice and tailpin. Classical violins had the neck butted to the ribs and nailed through the top block. The location of the bassbar inside the top plate and in the sectional view, the position of the bridge, soundpost and bassbar are seen.



Construction of the Violin

The sides, or ribs of Maple about 1 mm thick, are the only part of the violin that is bent to shape; and that, after damping the wood, and using a hot bending iron. The sides are glued to blocks, in my case of willow (glued temporarily to an internal mould that sets the shape of the violin) at the upper and lower ends of the body and at the corners of the inner bouts. Since the sides are only 1 mm thick, linings are added to the edges that will be glued to the plates to

increase the gluing width to about 3 mm. The blocks and linings are eventually trimmed to reduce the total mass. The top is of Spruce and the back and neck, pegbox are of Maple.

All the parts, other than the sides, are carved from solid billets; the top from Spruce that has been quarter cut (or preferably split to check for runout which is to be avoided) and the outer edges of the tree joined with a “book joint” to give mirror image halves. The reason for this is mainly to ensure clear wood with no defects. The Amatis, for example, turned one half end for end thus giving the appearance for the flame to be that of a slab back rather than the “herring bone” on so many violins. This may have had something to do with ease of carving especially for the inside of the plate. In carving the plates, one has to balance the mass with the desired stiffness. This is done by a combination of plate thickness and arching type. For the top, the thickness is generally uniform, at about 3 mm, with slightly thinner margins and at the centre bouts, the arch extending to the edge to give a “tube effect”. For the back, the thickness may be greater in the central region, about 4 mm going to about 2.5 mm at the margins.

Plate stiffness is affected by the arching. The cross arching raises the longitudinal stiffness, the degree depends on the vertical component of the arch profile. Therefore in the centre bout region the arch profile should be taken well out to the edge. The "tube effect" enhances the effect of the arching. The longitudinal arch profile affects the cross plate stiffness. Since it is more gradual its effect is not great. This is not detrimental as the shape of the violin plates allows a signal from the bridge foot to reach the plate margins at the same time because the speed of sound is greater along the grain than across it.

Spruce has a low density and high stiffness along the grain and low stiffness across the grain. In the top these stiffnesses are altered by the arching as already mentioned. The Maple used for the back is not as anisotropic as Spruce and will behave differently. Since the top is about 10 times more active than the back this does not cause a problem.

Elastic Properties of the Spruce and Maple used in a violin made by the author.

		Spruce	Maple
Density (kg/m^3)		414	650
Elastic Modulus	E_L (GPa)	12.7	9.8
	E_R (GPa)	1.1	0.8
Shear Modulus	G_{LR} (GPa)	0.65	1.5
	G_{LT} (GPa)	0.5	1.2

The density was determined by weighing an accurately machined test block. The cross grain elastic modulus, E_R, was about one tenth of the longitudinal elastic modulus, E_L. Spruce is a soft wood with medullary rays while Maple is a hard wood which has numerous pores. The grain in Spruce is very prominent due to the rapid spring growth rate and the slower late summer growth rate, but not in Maple. Cut near the base of the tree, Maple has an attractive figure which is highly prized.

The parts are glued together with hot water gelatine glue made by boiling animal skins or bones containing collagen to produce a solution of gelatine. The solid gelatine subsequently obtained is used as the glue. It has the advantage that parts can be reglued onto the old glue surface. When dried the glue is rigid and does not creep.

Plate Tuning

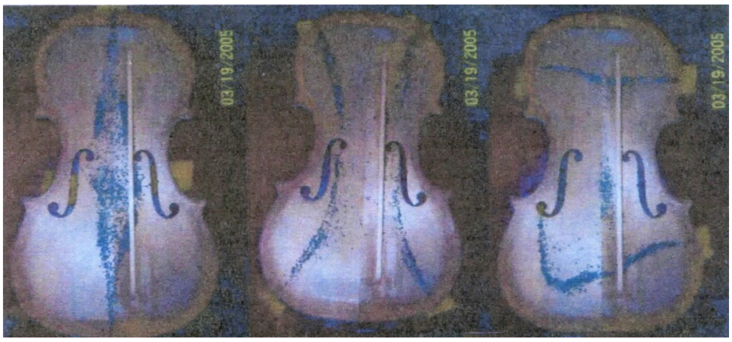
Violin plates are thin so that they will be flexible and allow well formed resonance modes to be obtained. There is no obvious endpoint to guide the maker so the plates are flexed and bent to ascertain their stiffness. They have to be thick enough to withstand the stress when the violin is setup. From the study of classical violin plates and other research free plate vibration modes have been found that guide the maker. The mass of the plates and the mode frequencies are used as an indication of the final thickness desired.

Initial mode frequencies of the Top and Back plates (freely suspended).

Plate	mass (g)	mode frequencies f(exp) (Hz) and Q values.					
		#1	Q	#2	Q	#5	Q
Top	77	92	-	176	48	365	52
Top (f-holes cut)	75	87	-	162	54	309	62
Back	117	120	-	178	59	392	56

This table shows the three prominent free plate vibration mode frequencies and plate mass for a top and back. The bassbar will be tuned to bring the mode frequencies back to those without the soundholes. Note #2 frequency matching and #1 kept at 92 Hz in the top plate.

Top plate Chladni patterns for free plate modes #1, #2 and #5 without bassbar.



Top plate Chladni patterns for free plate modes #1, #2 and #5 with bassbar tuned to original frequencies without soundnoles.

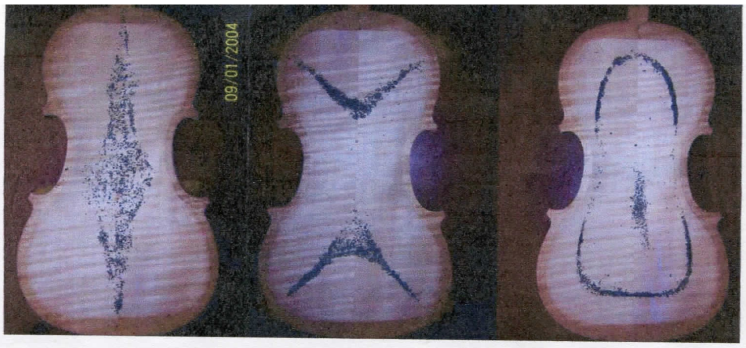
Top plate mode frequencies (freely suspended) with bassbar fitted.

Plate	mass (g)	mode frequencies (Hz) Q values ( )		
		#1	#2	#5
Top (bassbar tuned)	81.3	88 (31)	176 (45)	362 (53)

This table shows the frequencies with the bassbar tuned to return the mode frequencies to the original values without the soundholes as given in the table above.

Plate tuning supplements the testing of plate flexibility and stiffness by hand manipulation with a quantitative evaluation. The Chladni patterns should have thin nodal lines to ensure optimum active areas. The frequencies of the three modes in the top have an octave relation. In most classical violins #5 frequency for the top plate lies between 300 and 350 Hz. The thicknesses are slightly less than 3 mm. The density of the Spruce used lies below 400 kg/m^3.

The relationship between free plate frequencies and the frequencies of the main body modes in the assembled violin has been difficult to determine. It appears higher plate modes result in higher body modes and vice versa. The shifts are not great. There may be an influence on the playability; those violins with lower mode frequencies may be more responsive.



Back plate Chladni patterns of modes #1 #2 and #5

Back plate Chladni patterns for free plate modes #1. #2 and #5.

Air Resonances

The resonances of the violin exploit both air and wood behaviour. The main air resonance, A0, is important in that it is the lowest frequency resonance and supports the fourth, or lowest, string. It is excited by the action of the string on the body and its frequency is determined by the volume of air in the body, which act as a spring, and the mass of air in the soundholes which vibrates. It occurs at a frequency of about 280 Hz (i.e. $C_4^{\#}$ on the G string) in the violin. This is known as a Helmholtz resonance, the sound comes from the vibrating air mass in the soundholes. There are higher air modes, the most important one, A1, occurs at about 480 Hz the air oscillating between the upper and lower bouts. Some players are attracted to the feel of matching A0 with the fingerboard resonance, B0; the violin feels alive.

The acoustic parameters of A0 on the Baroque violin fitted with gut strings at A415 and a Renaissance bridge at the soundholes

Resonance Peak	f(expl) (Hz)	df/dm (MHz/kg)	m (mg)	s (N/m)	Z (kg/s)	Q	R (kg/s)
A0 (no s/post)	264	11.3	12	32	0.62	9	0.07
A0 (s/post 7/15)	281	4.25	34	108	1.92	8	0.24

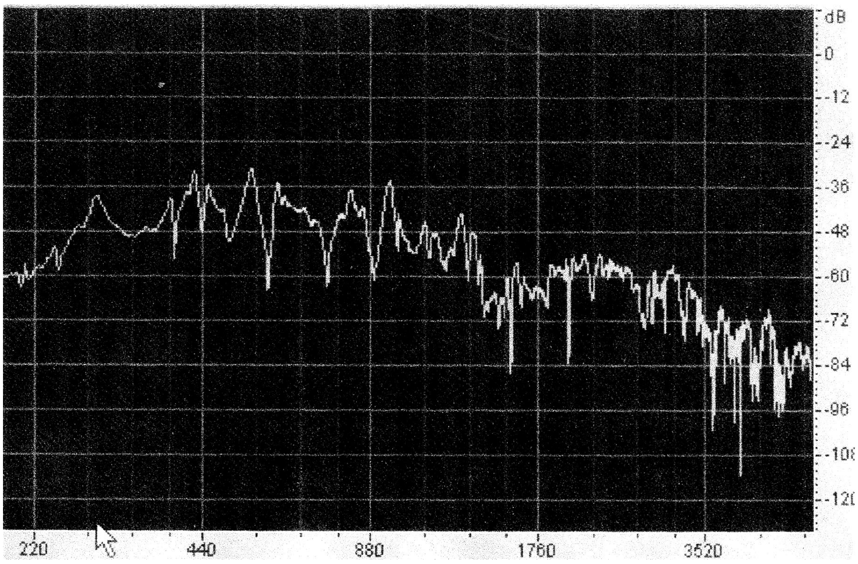
This table shows the effect of the soundpost in stiffening the violin body by its effect on the effective mass, m, stiffness, s, impedance, Z, and the radiation resistance, R for the main air resonance, A0. Since the body is the same for this resonance in both forms, Baroque and Romantic, these results would be the same for both.

The Vibration Behaviour of the Body of the Violin

The violin has four strings stretched between a tailpiece and a fixed "nut" at the end of the fingerboard. The strings pass over the bridge, set in the waist of the violin, which transfers the force from the string to the top of the violin with a rocking motion. The body of the violin vibrates as a whole in a series of modes that are determined by its mass and the stiffness of its parts. The body has a series of resonances from an air resonance at low frequency and a series of body resonances at medium frequencies to plate resonances at high frequencies. These resonances provide a response that lifts the sound output up to about 90 dB. (the pain threshold is 120 dB, Rock bands are about 110 dB; the lower discernible limit is about 20 dB)

The "saw tooth" that the bridge transmits to the body contains the harmonics generated in the string by the bow, of which the strength is modified by the bridge resonance (a broad peak centred around 2500 Hz) and lifts the response which would otherwise fall off at 12 dB per octave at high frequencies.

All structures that have stiffness and mass have resonances of vibration e.g. bridges, cars and rail carriages etc, which are usually in the feeling range. A resonance is a vibration of large amplitude and occurs at a frequency determined by the square root of the ratio of stiffness to mass. A high stiffness and low mass gives a high frequency; a large mass a low frequency. The violin body has resonances in the frequency range of musical pitch and can be used to enhance the vibrations, in this case, of a string. Structural bodies vibrate as a whole with different mode shapes depending on the frequency and the physical nature of the body. In the case of the violin there are about six body resonances below 1 kHz that contribute to the sound and influenced by the arching, plate thicknesses, soundpost and bassbar as well as the plate resonances. The result is a "spiky" response.



This figure illustrates the tap response of a modern violin showing the resonance peaks with the lowest peak being the main air resonance. The other peaks are body resonances. Between resonances of the same polarity there is a sharp trough. Resonances that have opposite polarity have a shallow trough e.g. the main air resonance and the next higher resonance.

The bowed string through the bridge, presents a saw tooth signal to the body, as mentioned above, that contains a high content of harmonics. The body which is a collection of resonances reacts to these harmonics, the coincidence of the resonance peaks and the harmonics is variable, and gives an ever changing sound that to the ear appears uniform because of this complex mixture. Vibrato adds to the variation in harmonic content of the note as they move back and forth over the resonances present.

A feature of each body resonance (including the air resonance) is its vibration mode and the monopole content. This latter is the "breathing action" of the mode where the body behaves like a sphere expanding and contracting and is called a "simple source". The main air resonance (there are higher air resonances) acts only as a monopole, while body resonances vary in monopole content depending on the shape of the mode. The soundpost, a slender piece of Spruce fitted between the top and the back near the treble foot of the bridge, serves to maximise the monopole component of the body resonances. Resonances appear on the response as peaks that have height and width. These features are determined by the level of damping, or to use an inverse, a Q value, which for the air resonance is about 10 and for the body resonances about 50. Body peaks should not be too high. High resonances are hard to control with the bow and lead to an unpleasant sounding "wolf"note. With a very strong resonance, the bow may be unable to supply enough energy to maintain it. 'When the resonance decays, the bow excites it again. This instability gives an unpleasant sound.

The response is therefore not smooth but "spiky"; it begins to rise at about 200 Hz (the lowest note on the violin is G_3 at 196 Hz) and drops off at about 5 kHz. The output at frequencies above 2 kHz is boosted above the natural fall-off expected with frequency of 12 dB per octave, by a bridge resonance. This resonance which is the rocking motion of the upper part of the bridge, occurs at about 3 kHz.

Between the peaks there are minima that may be deep or shallow. The form of the minima is determined by the polarity of the resonances. Resonance polarity is defined such that if the bridge is moving to the right, as viewed by the player, and accompanied by an increase in body volume the polarity is positive but if there is a decrease in volume the polarity is negative. Two adjacent peaks of positive polarity (or negative polarity) will have a deep trough between them due to cancellation. The two main body resonances at about 500 Hz show this feature. The bridge can move by either rocking about the treble foot or moving vertically. The latter is not as important as the rocking motion. The volume change is governed by the plate area of the body mode that is out of phase with the area in contact and moving with the bass foot of the bridge. A large net volume change will mean a large monopole component and therefore good all round radiation.

The main air resonance, although not a body resonance, acts with different polarity since there is no deep trough between it and the adjacent higher body resonance. For the main air resonance, the radiation resistance is about 0.1 kg/s (a tentative value for the resistance with no soundpost is 1×10^{-6}). The compliance of the body adds about 130 cc to the effective volume of the violin which is about 2 litres. A rigid body would increase the resonance frequency by 10 Hz.

A0 285 Hz   C2 385 Hz   B1- 422 Hz   B1+ 528 Hz   C4 600 Hz   ? 852 Hz

This figure shows the Chladni patterns on the top and back of a modern violin. The nodal lines have to be closed and cannot end abruptly, they may have to cross the sides to be continuous from front to back. The plates are moving in opposite directions across a nodal line. The resonance frequencies are shown. Except for C2 the nodal lines should be nearer the margins to give a maximum monopole component to the body mode. A0 is a complete monopole and has the lowest radiation resistance of about 0.1 kg/s. The other resonances have a radiation resistance of about 5-15 kg/s which could be lowered by a smaller plate mass and control of the plate arching.

Looking at the nodal lines in the resonance modes above in the light of the table following, most of the modes are good radiators with low radiation resistances of about 5 except B1-, which has a much higher resistance. Cancellation will occur in the top resulting in a lower monopole component and poor radiation. All the other modes must have a high monopole component. Perhaps increasing the activity of the back (by thinning) would raise the strength of the monopole component and the output of the violin.

C2 with its central nodal line in both the top and back must be of positive polarity to be a good radiator. Modes with longitudinal nodal lines in the back if near the margins would also contribute to the monopole component.

Summary of measured vibration parameters for resonances of the modern violin showing effective mass, m, and stiffness, s, the total resistance to bridge motion, R

Mode	f(0) (Hz)	df/dm (Hz/kg)	m (kg)	s (MN/m)	Z (kg/s)	Q	R (kg/s)	f(calc)
A0	286	4.25×10^6	0.034	108 N/m	1.92	14	0.14	--
C2	386	2943	0.066	0.39	160	77	2	387
B1--	423	2571	0.082	0.58	218	47	5	423
B1-- (2)	420	2229	0.094	0.66	249	47	5	422
B1-	450	554	0.41	3.27	1158	56	21	450
B1- (2)	447	514	0.44	3.43	1229	45	35	446
B1+ (2)	528	3543	0.074	0.82	196	38	5	530
B1++	540	4143	0.065	0.75	221	49	5	541
C4?	586	2771	0.106	1.43	289	84	5	585
?	878	1229	0.36	10.9	1978	37	54	875
?	944	19457	0.024	0.85	139	79	2	947

From this table it can be seen that B1- type resonances at 450 Hz have a higher radiation resistance than B1+ resonances and therefore not expected to be good radiators. Not all the body resonances shown appear together in a violin.

The air and body resonances, because of the good monopole content and low radiation resistance, radiate sound uniformly in all directions. Radiation resistance is the impedance divided be the Q value, expressed as kg/s, and ideally is as low as possible. A high monopole component coincides with a low radiation resistance. Body modes also radiate directionally related to their mode shape. Most fundamentals occur at frequencies below 1 kHz. At high frequencies, above 1 kHz, where plate resonances are prominent, sound radiation is more directional and reflections in an auditorium together with the movement of the player, become important for them to reach the listener. These are the frequencies of the harmonics in the sound. The sound of the violin is therefore ever changing and is never monotonous.

It can be argued from the results given in the tables above that an elevated effective stiffness (and mass) is linked with a high radiation resistance. Like every feature in the violin a compromise has to be reached between ability to vibrate and the strength to withstand the stress imposed on the structure by the string tension.

The Main Air Resonance, A0.

The construction of the violin evolved to place the main air resonance, A0, low in the range of the violin. This gave the body a volume of about 2 litres and a soundhole area of about 1400 mm^2 which placed the resonance frequency at about 280 Hz ($C4^{\#}$) on the G string. The air resonance is an example of the Helmholtz resonance which requires a volume with an opening; the mass of air in the opening oscillates against the spring of the air in the container. Sound emanates from the opening so long as the mass of air is excited. This resonance is described by the oscillation of the classical mass/spring system of physics. There is damping provided by the friction in the walls containing the vibrating mass of air. Because the walls of the violin are compliant, the frequency of the air resonance is lower by about 10 Hz than the true Helmholtz frequency. This is equivalent to an increase in volume of about 150 cc and depends on the stiffness of the body. The soundpost stiffens the body and without it the air resonance frequency is about 250 Hz. A0 has a Q value of from 5 to 15 compared with 50 for body modes. A 10 % increase in volume lowers the air resonance by about a semitone. An increase in soundhole area of 20% raises the resonance by about the same amount.

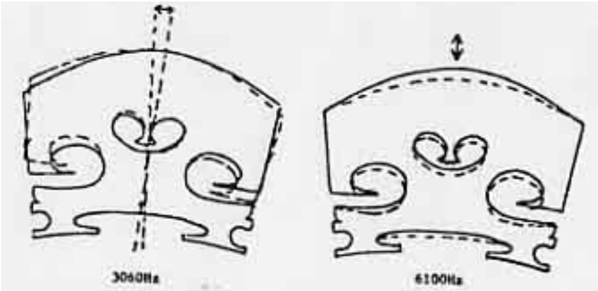
There are higher air modes in the violin as air oscillates inside the instrument. They are not connected with the Helmholtz resonance. The lowest of these occurs at about 475 Hz as air oscillates between the upper and lower bouts. It is not a strong resonance and has little effect on the sound of the instrument.

The violin is constructed to act as a "simple source" i.e. an oscillating sphere. This action ensures there is no cancelation and radiation occurs equally in all directions. Since the top plate amplitude is about 10 times that of the back, radiation will be stronger from the top. The sound radiation is of two kinds (1) below 1 kHz where most of the fundamentals occur, the body mode radiation is by a simple source or breathing action called a monopole mode, and (2) above about 1kHz plate modes radiate sound directionally. Most harmonics lie above 1 kHz. To maximise the monopole radiation of the body resonances the nodal lines need to be close to the margins as possible. Any cancellation is kept to a minimum and areas of the plates that contribute to the breathing action are maximised. The presence of the soundpost ensures the nodal lines are close to the margins.

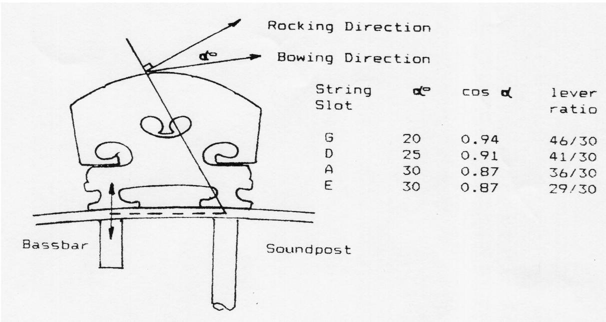
Attempts to increase the sound output of the violin without a redesign, would be to optimise the nodal pattern of the body modes by arching design and soundpost position.

The Bridge

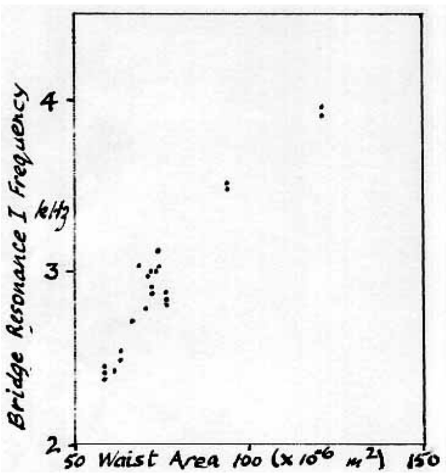
The bridge has two roles; to support the strings (high enough for the bow to be applied to each string) and to convey the impulse of the vibrating string to the top plate. The bridge as a whole rocks about the treble foot moving the bass foot which sits over the bassbar and thus exciting the violin body. The sound output of the violin falls off as the frequency rises; the bridge has a resonance at about 3 kHz where the top rocks in plane about the waist. This resonance lifts the response over a range of frequencies in this region.



This figure illustrates the in-plane motion of two resonances of the violin bridge. On the left, the rocking motion of the upper part above the waist at 3 kHz, on the right, a vertical motion at 6 kHz.



This figure shows the geometry of rocking about the treble foot for bowing on the D string.



This figure shows the change in rocking frequency with change in the area of the waist region of the bridge. A narrow waist with reduced stiffness lowers the frequency; a wide waist raises the frequency. A resonance frequency of 3 kHz corresponds to a waist area of about 70 x 10^{-6} m^2.

The Bridge Hill

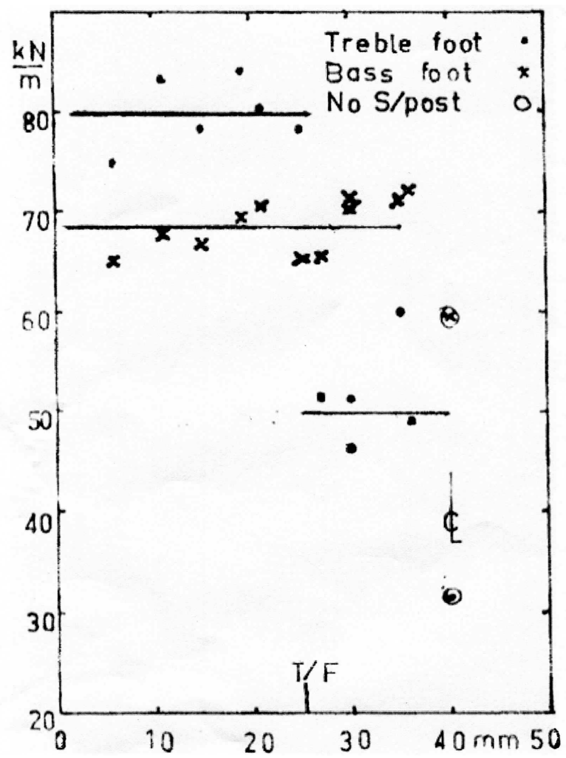
The in-plane rocking of the bridge at 3 kHz has raised interest in the effect it might have on the quality of sound from the violin. This frequency coincides with a very sensitive region in human hearing. (telephone receivers are tuned to peak at this frequency)

It would seem that only a few violins have been found to have a broad resonance in the 2.5 - 3 kHz region of their response. It is expected that the response which otherwise would fall off at about 6 dB/octave at high frequencies, would be raised over this range even if a bridge hill is not evident since the action at the bridge top is transmitted to the bridge foot.

It is still not clear if it is a combined bridge/body effect and if the f-holes have an input.

The Soundpost

Once the body has been made and the body modes have been established, the soundpost "voices" the instrument. It adjusts the loudness balance across all four strings and maximises the all round radiation field.



The soundpost fits between the top and the back behind the treble foot of the bridge but is not glued in place. It is a 6 mm diameter rod of Spruce cut along the grain, which means it will be light and stiff. It is best placed behind and outboard of the treble foot of the bridge. It raises the output of the lower three strings to that of the first string. It has to fit closely the inner surfaces of the two plates and its end grain has to be at right angles to that of the top plate to prevent it being embedded in the top. The soundpost maximises the monopole or breathing action of the violin body modes. The nodal line pattern of these modes should be adjusted to give a maximum plate area that is in a breathing action.

The figure above shows the stiffness at the position of the bridge feet, by direct loading, as a function of the position of the soundpost. The vertical axis gives the stiffness in kN/m and the horizontal axis the distance from the inner edge of the treble soundhole. No soundpost gave the two values on the right namely 60 kN/m at the bass foot that sits over the bassbar and 30 kN/m at the treble foot of the bridge. The violin body was therefore "soft"; the soundpost stiffens the violin. With the soundpost in place the stiffness over the bassbar is unchanged at about 70 kN/m. However, at the treble foot the stiffness is different if the soundpost is outside the foot at 80 kN/m and inside the foot at 50 kN/m. At the position of the treble foot the stiffness is uncertain and very sensitive to the soundpost position. These experimental results are for a particular violin and may be different for other instruments. Direct loading at the position of the bridge feet might be a measure of the stiffness of the body with the possibility of a lower practical limit. The implication is that under the action of the bow, the bridge foot with the lowest resistance will move with a possible difference between the up and down bow stroke.

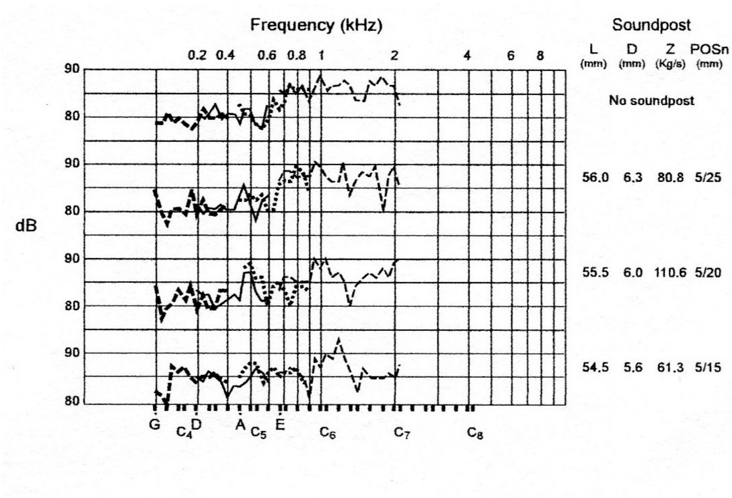


Figure 1. Saunders Loudness Curves for violin No 1 with soundposts located in the positions shown.

This figure shows the effect of the soundpost and its position on the loudness of notes on each string. The standard position, 5/20, shown does not give uniform loudness across the range as does position 5/15 which is outside the line of the treble foot of the bridge. These results are obtained by a Saunders Loudness Test. Each note (for an octave on each string) is bowed without vibrato as firmly as possible without breaking and the strength of the note in dB recorded 1m from the treble side and in the plane of the violin. The loudness of each down bow stroke is measured and the consistent value recorded. Consistent bowing is aimed at throughout.

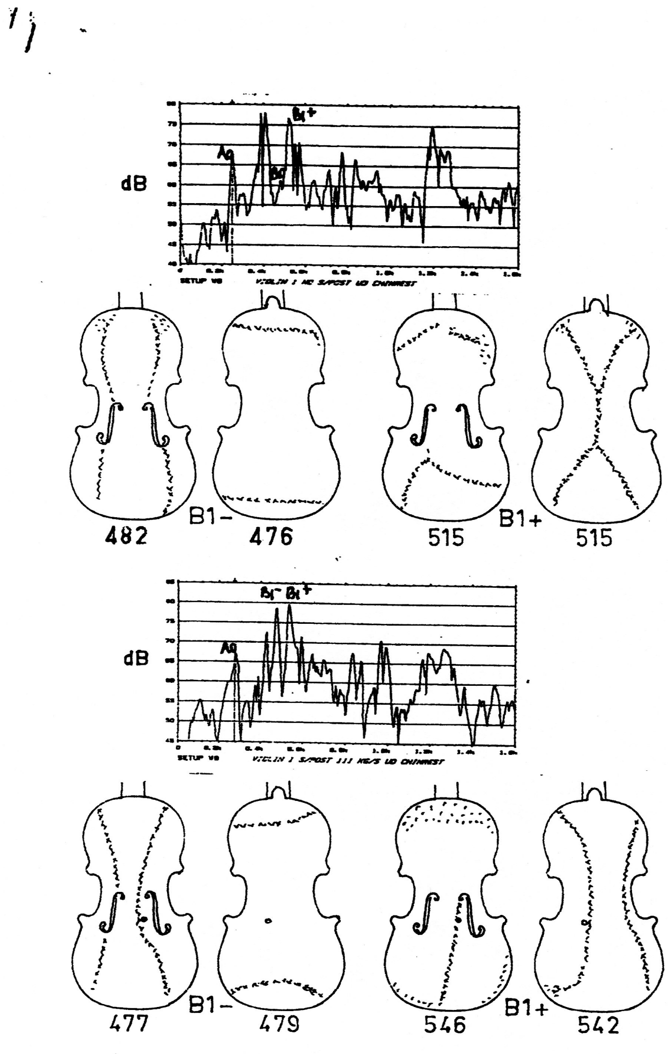


Figure 1. Tap response and mode shapes for:
(top) with NO SOUNDPOST
(bottom) with SOUNDPOST

This figure shows an example of the effect on the mode shape with and without the soundpost for the two body resonances near 500 Hz. The tap response with no soundpost shows a small peak for B1- which may be in error. The repositioning of nodal lines is quite evident. It is interesting that from the tables above, the radiation for B1- (15 kg/s) is greater than that for B1+ (5 kg/s) which makes the latter a better radiator.

The Bassbar

The bassbar, of Spruce, with the grain lying in the vertical plane of the bar, tapered towards the ends and glued inside the top, just inside the upper eye of the bass soundhole and under the bass foot of the bridge, vertically to the plane of the instrument. It connects the upper and lower bouts of the top plate and moves with the rocking motion of the bridge. The bassbar is used to return the top plate to the longitudinal stiffness it had before the soundholes were cut.

The Soundholes

The soundholes in bowed string instruments have been of varying shapes. In the forerunner to the violin they evolved into inward or outward facing “C” shapes placed in the central waist region. In the violin the soundholes have become “f” shaped and delineate a central area with “free” edges on which the bridge is placed and which has associated with it a bassbar and a soundpost. This may partly explain the greater activity of the top plate which is about 10 times that of the back. The built in flexibility of this region brings the whole violin into vibration. The total area of the soundholes determines the vibrating mass of air at the main air resonance. A 20% change in area moves the air resonance frequency by a semitone; larger up a semitone, smaller down a semitone. A 10% change in air volume will move the frequency a semitone; smaller upward and larger down.

The soundholes do not have sharp corners but have rounded curves. This is to limit the possibility of cracks along the grain. Slightly thicker edges will assist in this regard. The spacing between the soundholes at the top is about 42 mm and a little wider than the width of the bridge feet. The inner nicks at the centre of the soundhole length are placed at the “stop length” which fixes the string length. The rear face of the bridge is placed on the line between these nicks and set vertically to the plane of the top plate.

The Purfling

The purfling round the edge of the violin has the visual effect of “framing” the instrument. It has a more practical purpose in protecting the top from cracks along the grain that may start at the edge of the plate. It consists of three strips of wood, often two of ebony separated with one of pear wood or other exotic timber. The purfling is let into a groove about 1/2 to 2/3 of the plate edge thickness. The purfling plays no part in the vibration of the instrument. The edges of the plates are glued rigidly to the sides so that any flexing must occur inside the edge and may include the sides.

Varnish

There has been a lot of speculation about the classical varnish. It is thought that makers bought their varnish and were influenced by the practice of the artists of the day. The varnish had to be kept from soaking into the wood as this would alter the resonant behaviour. A sealant was first applied to the wood surface. A mineral ground was thought to have been used but another possibility is “cera colla”, a mixture of a water emulsion of bee’s wax and glue. The glue is necessary for the varnish layer to adhere. This mixture is colourless.

The varnish is a resin dissolved in a drying oil such as linseed. The purpose of varnish is to keep the violin clean and add colour. The difficulty has been to add enough colour to the varnish and to add something to hasten the drying. Recourse has been to apply separate colour layers, called glazing. In this way sufficient depth of colour can be achieved as against multiple varnish layers. Clear varnish is used to separate colour layers and finally to protect the whole process. The reed of the top plate can be highlighted by the application of the colour with the fingers, as the scraper finish results in the late wood being depressed; the late wood is cut while the early wood is depressed while it is being cut.

It is thought that a golden layer, such as alizarin (made yellow with a weak acid like tartaric) was applied to the first varnish layer put on the sealer. The main colour layer depended on the choice of resin. Colour layers were generally applied by hand with the fingers. The red component was alizarin which was obtained initially from the madder root which produced "Turkey red" used in military uniforms. Other resins give different shades of brown allowing variation in the final result. This combination of layers is thought to provide the golden hue that comes through the top colour in a certain light.

This procedure is thought to have been used, because when the varnish is worn off, the violin remains clean and there is no change to the quality of sound from the instrument.

Playing the Violin

The violin which is a working instrument suffers some robust handling during its life. Varnish is necessary as a protection against handling and the humid atmosphere in the vicinity of the player. It also enhances the beauty of the woods used. The varnish usually adds about 10 g to the mass of the violin, contributing a little damping. There is a well known adage that varnish be "not too hard, not too soft and not too much". The stresses in the violin create a useful level of damping. The neck is French polished and not varnished because varnish cannot be relied on to remain hard and not soften under the hand.

The violin is under considerable compression along its length tending to fold it up and placing the back in tension. The strings when tuned to pitch impose a longitudinal tension of about 22 kg wt (220 N). There is a downbearing at the bridge, of about 9 kg wt (90 N) divided between the two feet, which is resisted by the arching of the top, as well as the soundpost (which is not glued) and the bassbar inside the top under the bass foot of the bridge. Any increase in tension e.g. by adding another string, has the effect of decreasing the aoutput, hence the compromise in having four strings to give a reasonable compass for the register. By contrast, the force exerted by the bow is about one hundredth (2 N) of the force due to the strings. It would appear that expertly made modern violins are equally as good as the classical violins made 300 years ago.

In summary, the violin, of mass about 400 g is a wooden box of exquisite shape with parts carved from the solid, the top Spruce and the back, sides, neck and head of Maple, the whole held together with hot water gelatine glue. Four strings, tuned in fifths, are fitted over a bridge of sycamore giving a range of three and a half octaves. The ebony fingerboard has no frets allowing the player great freedom of expression. To quote one writer; "It was a small instrument, containing no more wood than necessary and that judiciously distributed; and the stresses so well balanced that it awoke at the touch of a bow."

The violin in the hands of violinists in the past was not as inviolate as it appears today. Players in the 17th and 18th centuries were quite innovative; for example, the bridge was placed below the soundholes as shown in early paintings, perhaps to increase the output since a longer string at the same tuning would be at a higher tension. Intentional mistuning, called “scordatura”, has been used to achieve special effects e.g. to take advantage of the resonances of the violin, to make fingering easier, to allow chords to be played that would otherwise be impossible. Heinrich Ignaz Franz von Biber (1644-1704) employed this innovation in his Mystery Sonatas. Tuning an instrument differently to the accepted practice, as Mozart did in 1779, by tuning the viola up a tone for more brilliance in his Sinfonia Concertante in E_b for violin and viola, K364 is another example. There is an interest in Historically Informed Performance Practice involving the study of original scores. As there is little difference in sound quality between the Baroque and Modern setup of the violin, early performance practice has to be centred on playing techniques as discussed in full by Leopold Mozart in a treatise entitled “A Treatise on the Fundamental Principles of Violin Playing” translated by Editha Knocker, OUP 1948.

The conversion from the Baroque setup to the Romantic setup became possible on the introduction of the chinrest by Louis Spohr in 1820. Most of the conversions were carried out in Paris by J.B.Vuillaume (many others must have been involved; but he was the principal one and who collaborated with Felix Savart who studied Stradivari plates and also the soundpost in 1824). Wear of the varnish occurs on both sides of he tailpiece of old violins, the chinrest seems to have been placed on the left of the tailpiece. The violin had been held by the left hand while stopping notes, the Baroque neck/fingerboard being wedge shaped made this possible and also allowed the left hand to move along the neck and still hold the instrument. The chinrest freed the hand and allowed greater virtuosity.

The reference to “original instruments” may be a misnomer since most conversions only involved a smaller bassbar which would lower the stiffness of the top plate a little, and a thinner soundpost. The conversion of the modern neck to the shorter and wedge shaped Baroque neck would certainly require a re-education to early playing practice. This major change is most unlikely. The use of lighter bows would certainly be much easier to adopt.

Tuning pitch throughout Europe varied with the pitch of organs in different cities and was not much different to what is used today. String tensions would certainly be lower with the shorter string length hence the practice of placing the bridge below the soundholes to allow a greater tension for the same tuning and therefore a louder output.

The player is the single most important element that makes the violin so important. The player controls the quality of sound, its volume and its nuances. It is often said that the left hand makes the notes, the right hand makes the music. The violin is an instrument for communicating the most subtle of emotions. The player has at his disposal many techniques including vibrato, double stops, left hand pizzicato, artificial harmonics and many bow strokes from legato to martele. Vibrato deserves special mention in that it was applied sparingly and on long sustained notes in earlier times. In more recent times it was applied continuously, mostly by Fritz Kriesler, and became frowned upon. The judicial application of vibrato to a note adds an emotional strength as the harmonics sweep over the peaks and troughs of the response curve, varying the timbre continually during its duration. Rocking the finger that is stopping the note can alter the frequency and therefore the sound between a narrow to a wide vibrato.

There is the story of an owner who asked his accomplished friend to play a violin he had acquired of which he was very proud. His friend not knowing the circumstances replied “how do you want me to play it; for buying of selling?”.

A Little History

Before 1500 Renaissance bowed string instruments varied widely in shape, some had a waist but no corners in the central bout, others were oval in shape. Bows were very crude and appeared heavy. The number of strings was probably three or four. They were mostly played at the shoulder. The soundholes were C shaped and faced either inward or outward. The turning in of the upper half of an outward facing C soundhole to make the f-shape of the modern soundhole probably occurred at the same time as the bassbar and soundpost became established early in the sixteenth century. Andrea Amati (1511-1580) is regarded as fixing the design of the violin that we know today. In the middle of the century he made violins, violas and cellos (basses) for Charles IX of France. His sons and grandson, Nicolo (1596-1684) who trained Antonio Stradivari (1644-1737) as well as Andrea Guarneri (1626-1698) established Cremona in Northern Italy as the centre of violin making for 200 years. The latter’s grandson Giuseppe Guarneri (del Gesu) (1698-1744) ranks with Stradivari as the greatest violin makers. Renowned violin makers worked in other Italian cities, Milan, Rome, Naples and Bologna for example. Isabella d’Este (d.1539), the wife of the 4th Marquess of Mantua (1466-1519) encouraged music making and the making of viols, etc. Viols which had a fretted fingerboard, a flat back and a possible soundpost were played at the knee developed alongside violins but were “out shouted” by the violin and have not survived.

The art of bow making peaked in Paris with Francois Tourte (1747-1835) who perfected the reverse camber of the stick, about 1787, making modern playing possible. Paris became the centre for bow making in the 19th century.

Violin playing technique and virtuosity developed slowly from simply accompanying voice parts to music composed particularly for the instrument. Most virtuoso players up to the end of the 20th century could trace their teachers back to Giovanni Viotti (1755-1824) who founded the French violin playing school which is connected with later teaching. A notable offshoot was the Russian school with Leopold Auer who influenced the teaching of Menuhin and Heifetz. Fritz Kreisler’s link to Viotti was through a separate line via Massart and Kreutzer. Treatise have been written on violin technique, the most notable by Leopold Mozart in 1756. Since the introduction of the chinrest in 1820 playing technique began as a stiff disciplined approach but has become a more relaxed and free form.

More material can be found at: www.phys.unsw.edu.au/music/people/mclennan.html