A Look at Un-Electronic Musical Instruments

A little later in the course we will be looking at the problem of how to construct an electrical model, or analog, of an acoustical musical instrument. To prepare for this, we need to consider how such instruments work.

All acoustical instruments are built around some kind of RESONATOR. A structure is resonant if it responds to an energy impulse by vibrating for a noticeable length of time. The frequency of vibration is determined by the size and material of the resonator, and the pattern of vibration may be simple harmonic motion or some more complex action. If the vibration dies away quickly, the resonator is said to be DAMPED. A repeating series of impulses will sustain the vibrations if the frequency of the pulses matches to some degree the natural frequencies of the resonator. If the resonator responds to a wide range of input frequency, it is BROADLY TUNED. If the input frequency has to match the frequency of the resonator pretty closely before resonance occurs, the resonator is NARROWLY TUNED.

Acoustic instruments also require some sort of DRIVER, a mechanism that applies energy to the resonator in the appropriate form. The driver may be as simple as a stick (or bare hand), or it may be an elaborate resonant structure itself. If the driver supplies the energy all at once, it is an IMPULSE driver; if the energy is applied as a repeated stream of pushes, the driver is often called a SOUND GENERATOR.

Fig.1 A simple instrument

Most instruments also possess some kind of pitch control mechanism. Pitch is controlled at two levels, tuning and performance. The tuning of an instrument determines the pitch possibilities that the artist may exploit during the performance. An instrument's tuning is largely in the manufacturing process, although there is often some provision made for adjustments. Pitch controllers may modify the operation of the resonator, the driver, or both. Some instruments provide pitch selection by duplication of tuned structures, trading flexibility of intonation for the possibility of polyphonic performance.

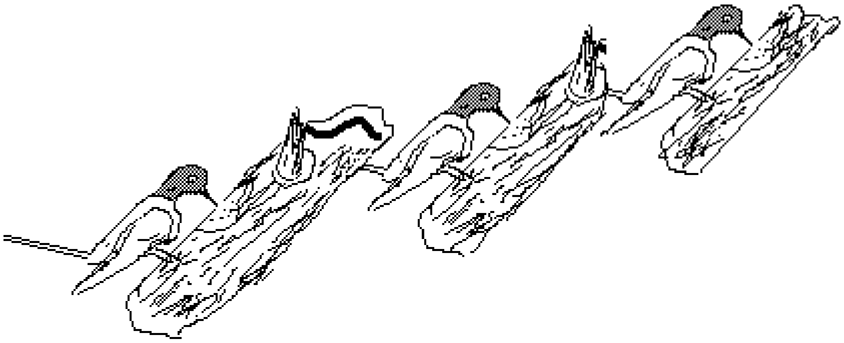

Fig. 2 A polyphonic instrument

It is difficult to organize a general discussion of operating principles of instruments because there are so many varieties, but for engineering purposes we can divide instruments into three classes based on the style of driver; the familiar strings, winds, and percussion instruments.

STRING INSTRUMENTS

The driver or sound generation device of the string instrument is a tightly stretched string. When the string is excited, which may be done by a hammerblow, a pluck, or a continuous scrape, it is set into motion at a rate determined by its length, mass, and tension. The motion is complex and contains energy at many (almost) harmonically related frequencies. This motion is transmitted to the resonator via the bridge, a light piece of wood supporting one end of the string.

The resonator of a string instrument is commonly an oddly shaped box or a wide thin board. The resonator is not sharply tuned; it responds to broad bands of frequencies and radiates sound at those frequencies from its entire surface area. The response of the body or soundboard is not flat within these bands, however, so some frequencies are transmitted more efficiently than others. These response peaks are called FORMANTS, and play a very important part in establishing the timbral identity of an instrument.

Since the tuning of the resonator is very broad, the string frequency is the controlling factor in the pitch of the instrument. (The string itself is a narrowly tuned resonator.) String frequency is controlled by adjusting tension for tuning and by manipulating length for performance. The formant frequencies do not change, so the waveform produced varies somewhat from one pitch to another.

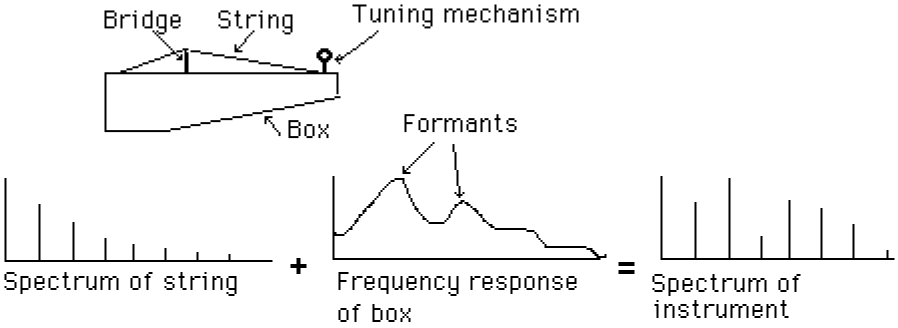

Fig. 3 A string instrument

WIND INSTRUMENTS

With wind instruments, the resonator is usually in the shape of a pipe and the energy is supplied as a stream of air into the pipe. The driving mechanism is some kind of valve that periodically interrupts or modulates the air flow. The reed of some woodwinds and the lips of the brass player are examples of modulating valves. These respond to back pressure from the resonator, so the resonator has almost total control of the frequency of the instrument. The resonant frequency of a pipe is determined by its length but the system will respond at harmonics of that frequency with a little encouragement from the driver. (The actual mechanism of resonance is a standing wave.) Notewise pitch control in the winds is usually done by adjusting the length of the resonator. Slight changes to the driver cause slight changes in pitch, whereas major changes in the driver will cause the pipe to shift modes of vibration and produce a large jump in pitch.

The spectral content of pipe resonators follows the harmonic series closely but the upper components usually deviate somewhat from the predicted frequencies. The amplitudes of the various partials are determined by the shape of the pipe, particularly by the configuration at the ends.

In the WOODWINDS the pipe length is changed by opening or closing holes along the side of the instrument. The part of the instrument that extends beyond the open holes acts as a second resonator, modifying the sound produced by the primary resonator in a manner that changes somewhat from note to note. Woodwinds typically only use the three lowest vibratory modes of the pipe, so enough holes have to be provided to fill in notes for an octave or more.

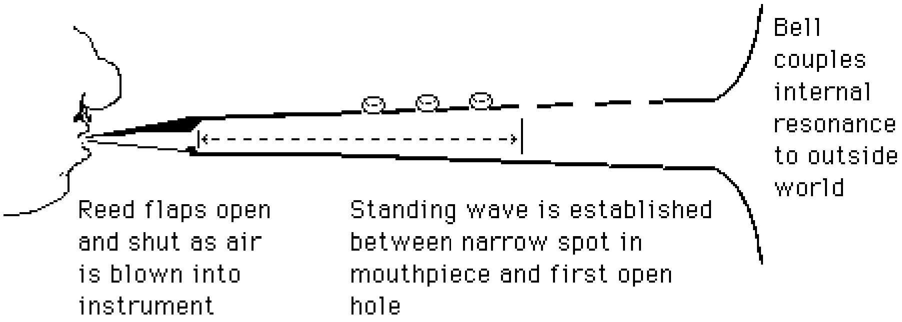

Fig. 4 A wind instrument.

In the BRASS instruments the pipe length is manipulated directly, adding sections by the use of valves or pulling slides in or out. Since the air modulating valve is part of the player's body (the lips) it is very responsive, allowing use of many high pipe modes. In fact, the fundamental mode of vibration is not used at all (except for special effects), so only enough valves or slide positions are required to fill in the space between the second and third modes, an interval of a fifth. Much of the brass timbre is attributable to the bell, which is frequency selective in the way it transmits sound power into the open air. The sound is drastically changed if the shape of the bell flare is modified by the addition of a mute.

There are non-pipe wind instruments:

The ocarina is a Helmholtz resonator that is tuned by opening holes in no particular order. The more holes open, the lower the pitch because the holes add to the vibrating mass.

The harmonica and accordion have reeds that sound into a rudimentary resonator. The resonator provides a weak formant, but no pitch control.

In the voice, the resonant structures are an assortment of body cavities, including the mouth. The volume of these cavities can be changed, producing tunable formants. The major driving mechanism of the voice is the larynx, containing two loosely stretched flaps of muscle that can modulate the air flow from the lungs. The frequency produced is controlled by muscular tension, with no effective feedback from the resonators. The result is an instrument with independently controlled pitch and timbre. The timbral range is extended by an alternate driving mechanism, the tongue, which can provide a variety of noise and impulse inputs to the system.

PERCUSSION INSTRUMENTS

Loosely speaking, a percussion instrument is anything you can hit. If we must make a generalization, we might say that percussion instruments usually lack a complex driving mechanism that could be separated from the resonator. The unifying principle is that impulse energy is applied directly to the resonator, which responds with vibrations for a short period of time. You can see that almost any instrument can be played in a percussive mode.

The resonator may be an air chamber of the Helmholtz or pipe variety, or may simply be a particularly resonant chunk of metal or wood. The air resonators have spectra that fit the harmonic model to some degree, giving a fairly definite pitch, but the solid body resonators vibrate in extremely complex ways, with spectra that are non-harmonic clusters of components or even broad band noise. Pitch on these instruments is usually not very discernable beyond a general highness or lowness.

SUMMARY

You can see from this discussion that there are (at least) three common relationships between drivers and resonators. We might call these driver controlled, feedback controlled, and resonator controlled. In the strings and non-pipe winds the frequencies of the resonator do not strongly affect the frequency of the driver or the pitch of the instrument; pitch control is a function of the driver. In the pipe winds, the resonator and the driver affect each other, producing a pitch suitable to both. In the percussion instruments pitch is entirely up to the resonator, since the driving energy is applied as an impulse.

Source: http://www.co-bw.com/Audio_Acoustic_Instruments.htm